AGRICULTURE, FOOD AND NUTRITION NEXUS IN RURAL SETTINGS: CASE STUDIES FROM NORTHWEST ETHIOPIA

Fentahun Tesafa Mohammed

A Dissertation Submitted to

Center for Food Security Studies
College of Development Studies
Addis Ababa University

Presented in Fulfillment of the Requirements for the Degree of Doctor of Philosophy in Food Security and Development

Principal supervisor: Messay Mulugeta (Ph.D., Asso. Prof.)

Co-supervisor: Solomon Tsehay (Ph.D., Asst. Prof.)

Addis Ababa, Ethiopia

June 2023

Declaration

I, the undersigned, declare to Addis Ababa University School of Graduate Studies that this dissertation is a product of my original research work, and it has not been submitted to any other university for any academic degree. Materials and information other than my own are dually acknowledged.

Fentahun Tesafa Mohammed		30/06/2023
Name	**Signature**	**Date**

Approval sheet

As principal supervisor/co-supervisor, I certify that I have read and evaluated the dissertation prepared by **Fentahun Tesafa** entitled **'Agriculture, Food and Nutrition Nexus in Rural Settings: Case Studies from Northwest Ethiopia'** and recommend for Defense as fulfilling the requirement for **Ph.D. Degree** in Food Security and Development.

Messay Mulugeta (Ph.D., Asso. Prof.)		
Principal supervisor	**Signature**	**Date**
Solomon Tsehay (Ph.D., Asst. Prof.)		
Co-supervisor	**Signature**	**Date**

As members of Examining Board of Dissertation Defense, I hereby certify I have read and evaluated the report prepared by **Fentahun Tesafa** entitled **'Agriculture, Food and Nutrition Nexus in Rural Settings: Case Studies from Northwest Ethiopia'** and recommend it is acceptable as a report for **Ph.D. Degree** in Food Security and Development.

Belay Semaneh (Ph.D., Professor)		
Internal examiner	**Signature**	**Date**
Arega Shumetie (Ph.D., Asso. Prof.)		
External examiner	**Signature**	**Date**
Desalegn Yayeh (Ph.D., Asso. Prof.)		
Chairman	**Signature**	**Date**

Acknowledgements

I would like to thank the Almighty of God for enabling me to pursue my PhD with safe and healthy life. My sincere gratitude goes to my principal supervisor Dr. Messay Mulugeta for his insightful and constructive guidance from inception of the proposal development to end of the overall research project. His critical comments and suggestions on the structure and contents of the thesis have considerably helped own its present state. Working with him, I also learnt how committed follow up, accessing updated information regularly, and acting timely for mails and assignments can make one successful, which would be of great help for my endeavor in future career. I am also indebted to my co-supervisor Dr. Solomon Tsehay for his tireless and unreserved scholarly advice on econometric methods and his genuine encouragements. Dr. Solomon, I really thank you so much for the countless discussions we had and for your unreserved comments to improve the quality of the research work. My gratitude also goes to the Board of Examiners: Dr. Dessalegn Yayeh (chair person), Prof. Belay Semaneh (internal examiner) and Dr. Arega Shumetie (external examiner).

I would like to say thank you all the people that supported and encouraged me in one way or the other to the successful completion of this thesis. Particularly, I would like to thank farmers and agricultural officials in the study districts for their voluntarily participation in this research during field work. I am also grateful to Mr. Ahmed Hamid for his technical support in processing maps of the study locations, and my sister Momu Tesafa and my brother Abdulaziz Tesafa for their moral support and endeavor for addressing the accommodation problem I had encountered during my stay at Addis Ababa.

Special thanks to my darling wife Hawa Hussein for her dependable encouragement in all day-to-day activities of my PhD student career through material and financial supports, besides her responsibilities in looking after our children. Above all, her moral support and encouragement throughout my study period become an energy and incentive for me to successfully completed the assignment.

Fentahun Tesafa

June 2023

Table of Contents

List of Tables

List of Figures

Abbreviations

AC	Agricultural Commercialization
AD	Agricultural Diversification
AFN	Agriculture, Food and Nutrition
AHM	Agricultural Household Model
CCO	Crop Commercialization Orientation
CSA	Central Statistical Agency of Ethiopia
COHE	Cost of Hunger Ethiopia
DD	Dietary Diversity
FAO	Food and Agriculture Organization of the United States
FCS	Food Consumption Score
FCO	Full Commercialization Orientation in Crop & Livestock Farms
FD	Farm (Production) Diversity
FNS	Food and Nutrition Security
FS	Food Security
GDP	Gross Domestic Product
GSEM	Generalized Structural Equation Modeling
HDDS	Household Dietary Diversity Score
HFS	Household Food Security
IPs	Impact Pathways
LCO	Livestock Commercialization Orientation
MD	Market Diversity
MDD	Minimum Dietary Diversity
MDD-W	Minimum Dietary Diversity for Women
OFI	Off-Farm Income
SDGs	Sustainable Development Goals
SFA	Stochastic Frontier Analysis
SPO	Subsistence Production Orientation
WB	World Bank
WEA	Women Empowerment in Agriculture
WEAI	Women Empowerment in Agriculture Index
WHO	World Health Organization of the United States
WoA	Woreda Office of Agriculture

AGRICULTURE, FOOD AND NUTRITION NEXUS IN RURAL SETTINGS: CASE STUDIES FROM NORTHWEST ETHIOPIA

Fentahun Tesafa Mohammed

In Fulfillment of the Requirements for the Degree of Doctor of Philosophy in Food Security and Development, Addis Ababa University, 2023

Executive Summary

Food insecurity is a critical challenge in developing countries like Ethiopia, where agriculture is the primary livelihood base for majority of people. Market-oriented policies currently promote measures to reduce food insecurity in the country. This seems a paradox that seeks evidence-based research to come up with effective and sustainable solutions. Majority of these vulnerable people being smallholder farmers predominantly managed agriculture ignited the desire to conduct this research with perspective of suggesting viable solutions to mitigate their food insecurity through empirical research to target. Evidence on agriculture-food-nutrition (AFN) nexus is also weak and winding. This thesis aims at investigating how agriculture influences household food security (HFS) and individual nutrition status from pathways perspectives that most studies often confined to determine the size and direction of impacts, rather than channels by which these impacts occur. Cross-sectional data were collected from 545 households, 245 women, 231 men and 80 children under five years randomly selected in northwest Ethiopia for evaluating impacts of key pathways of agriculture (subsistence, income and empowerment) to FS of households, women and children.

Findings from bivariate Tobit regression revealed that both crop and livestock commercialization improved HFS, but in quite different ways. The income from crop sales was instrumental in allowing households to buy additional foods while livestock sales fostered crop diversity for self-consumption by allowing them to purchase non-food items. Livestock commercialization was more important than crop commercialization for better HFS due to its strong net positive effect. The dose-response analyses affirmed that diversifying crops in rainy season up to certain level of intensity (0.3) and specialization in dry season increased HFS. This highlighted the relevance of income generated from diverse farming and specialization in the respective season. Additionally, livestock diversity could expand HFS mainly from diverse food groups (0.6), which may suggest livestock husbandry is more nutrition sensitive than cropping.

Among 224 dual households with primary female and male adults, 224 women and 75 children in Libokemkem district used for assessing empowerment *pathways, 33% of households, 44% of women and 28% of children are food insecure while 64% of women are empowered with efficiency in crop farm at 0.652. Crop production can be increased by 35% even with existing inputs as farmers enabled to perform optimally. The generalized structural equation modeling also depicted that empowering women in agriculture improved dietary diversity and ensured food security for women, children and households in Libokemkem. The interaction pathways helped enhance food diversification and better market orientation of farm production encouraged these outcomes to ascend among all aforementioned groups. However, the adverse implication of efficiency interaction proved to be stronger in magnitude than its direct positive effect, the efficiency interaction pathway implied net reduction of these outcomes across all groups. Heavy workload and lack of voice in production decisions are the two major domains contributed to 48 and 22% of women disempowerment respectively. This suggests interventions specifically targeting these dimensions of disempowerment to increase empowerment to affect AFN nexus positively. Some even suggest gender has a disconnecting/adverse effect on such linkages.*

AFN linkages may not require production systems to be subsistent. Supporting investments in improving road infrastructure to function all weathers, better access to institutional services (credit & off-farm employment) and enhanced awareness of extension towards promoting commercialization and diversified food consumption seem to be more promising. This research concludes commercialization is crucial not just for FS, but also for smallholder agriculture in providing additional nutrition. Also it recommends households focus on cash crops production to increase income during dry season, and promoting diversification up to certain level in rainy season to expand FS through subsistence and income pathways. Women empowerment further heightened the role of these pathways in improving FS. Off-farm employment is also suggested as a means of enhancing household resilience to withstand shocks and improve agricultural productivity.

Keywords: *Agriculture diversification, commercialization, empowerment, food security*

CHAPTER ONE

GENERAL INTRODUCTION

1.1. Background

Food insecurity and malnutrition are colossal and universal problems in many parts of the developing world. Food and nutrition security (FNS) can play a strategic role globally in that its improvement lays a foundation for achieving many of Sustainable Development Goals (SDGs). Despite progresses in recent decades, a significant number of the global population remain chronically hungry. Between 702 and 828 million people are unable to meet their minimum dietary energy needs. The number has grown by about 150 million since the outbreak of COVID-19 pandemic. Around 2.3 billion people were moderately or severely food insecure in 2021 and 34.4% of children under five suffer from stunted growth, wasting or are overweight. One in three women of reproductive age were still affected by anemia in 2019 with no progress since 2012 (FAO *et al.*, 2022), and nearly 45% of children died due to poor nutrition in 2011 (Black *et al.*, 2013). The overall economic costs of malnutrition are significantly large, about USD 3.5 trillion per annum, which is 5% of the global GDP (FAO, 2013). Such economic costs are remarkably high in several developing countries. For example, in Ethiopia the annual costs associated with child undernutrition reached 16.5% of its GDP in 2009 (COHE, 2012).

The challenges to ending hunger, food insecurity (FI) and all forms of malnutrition keep growing globally. As seen in the State of Food Security and Nutrition report (FAO *et al.*, 2022), the prevalence of COVID-19 pandemic, Ukraine war and climate extremes are making world hunger and severe FI more critical. A global economic slowdown or a downturn in one or more important players in the world economy can further damage developing economies, which can, in turn, influence food security (FS) adversely. Recent evidence suggests that the number of people unable to afford a healthy diet around the globe rose by 112 million to almost 3.1 billion in 2020, reflecting the impact of inflation on consumer food prices during the pandemic. The ongoing war in Ukraine is also disrupting supply chains and further boosting prices of grain, fertilizer and energy. FAO *et al.* (2022) highlight without intensified efforts even the gains that have been made in reducing the prevalence of child stunting by one-third in the previous two decades are now under treat by the triple crises of climate, conflict and COVID-19.

A large proportion of these FI population are smallholder farmers in developing countries that depend on agriculture as source of their livelihood. In such a predominantly agrarian economy, a wide array of challenges in the agricultural production system itself and the complexity of production and consumption decisions at household level have a large impact on FNS of smallholders (Ehui & Pender, 2005; Wenhold *et al.*, 2007). Improving agricultural productivity and the linkage of agriculture with FS has been a central issue of development policies in Sub-Saharan Africa (Allen, 2003; Haddad, 2000). This stems from the role that the agriculture sector can play as primary source of livelihood including food and nutrition in majority of the developing world (Ehui & Pender, 2005; Hawkes & Ruel, 2006). The concept of nutrition-sensitive agriculture presumes that agricultural production practices have the potential to positively affect the underlying determinants of nutrition (Ruel *et al.,* 2018). Despite this assumption, it has been difficult to empirically support, as causal pathways hypothesized to run among agricultural diversification (AD), agricultural commercialization (AC) and FS are long and winding. A number of recent review papers also confirmed the limited evidence on agriculture, food and nutrition (AFN) nexus.

Theoretically, it is assumed appropriate levels of diversification are a question of scale in which AD does not necessarily imply every single farm has to be extremely diverse. AD may promote diverse food consumption in farm household, e.g., in Sub-Saharan Africa, where smallholder farmers are often subsistence-oriented (FAO, 2014). Typical farms in Africa are already quite diverse. Further diversification might prevent gains from specialization that could, in turn, lead to income losses potentially impacting HFS adversely (Hirvonen *et al.*, 2016; Sibhatu *et al.*, 2015). Some authors point to market access is better than AD for improved HFS (Sibhatu & Qaim, 2018; Bellon *et al.*, 2016). Others argue AD as more relevant (Berry *et al.*, 2015; Jones *et al.*, 2014). This is essentially true in the context of developing world with smallholders significantly large, poor market infrastructure and incomes unequally distributed. The findings on these linkages are mixed and vary through time and space even in case of smallholders. This calls for continuous and extensive geographically specific studies mainly in Africa. While agriculture is the primary livelihood base for most Africans and market-oriented policies currently promoted region-wide, FI remains widespread in the region seems a paradox that seeks evidence-based research for effective and sustainable solutions. All this suggests the need to focus on vulnerable populations (smallholder farmers) for surging a FS panorama in empirical analysis.

This is certainly the case in Ethiopia where agriculture remains the mainstay of its economy. It contributes to 34% of the GDP, 82% of export earnings and employs 67% of the total population of the country in 2019 (FAO, 2021; Ketema & Diriba, 2021).

Smallholder farmers managed more than 95% of the agricultural land in the country (CSA, 2014), which is greater than 70% in the entire Africa (Onyutha, 2018). Intertwined with average landholding quite small as 0.8 ha (FAO, 2018), heavy reliance on low input and rain-fed production highly exposed the agriculture sector to risks of environmental shocks. Moreover, the recent food prices driven by the triple crises of conflicts, COVID-19 pandemic and climate change have adversely impacted farm production, trade, income and FS of the country. The ongoing war in Ukraine and the internal conflict in Ethiopia further heightened the proportion of people suffering from FI. According to the Global Food Security Index 2021 report that assessed the FS situations across 113 countries, Ethiopia is ranked 108th with a score of 37.6 out of 100 and has experienced reduction in net FS score of 0.6 between 2020 and 2021 (EIU, 2020, 2021), which is much lower than Ireland the most FS by 46.4 percentage points.

Poverty and food insecurity (FI) are quite pervasive in rural Ethiopia, where the rate of poverty among smallholder farmers is nearly 67% (FAO, 2018) and FI remains quite large as 57.8% over 2014-2020 (FAO, 2021). This claims that promoting diversification of household income into off-farm income (OFI) may be a new way out of household from poverty and FI (Chang & Mishra, 2008) by ameliorating food shortage risks in case of yield shocks (Qureshi *et al.*, 2015). Cognizant to this, the Ethiopian development paths have given prime attention to reduce poverty and FI by introducing various initiatives. The Agricultural Development Industrialization Road Map (2013), the two successive Five Years Growth and Transformation Plans (2010-2020), and the recently endorsed Ten Years Development Indicative Plan for the period 2020-2030 (PDC, 2020) have clearly set out AD and off-farm & non-farm activities should be promoted alongside with transition of agriculture from subsistence to commercially-oriented production to reduce risks of rural areas to poverty and FI. Yet, reducing FI and malnutrition in Ethiopia as part of the developing world continues to be a key policy challenge and development problem. Around 65% of children under five were stunted, underweight or wasted in 2019 (FAO, 2018) and anemia was also pervasive among women of reproductive age (24%) and children (57%) in 2016 in Ethiopia (EDHS, 2016).

This thesis therefore attempted to understand how agricultural development strategies of improving agricultural productivity, AD, AC & OFI are linked to FNS of smallholder farmers by considering the potential pathways in AFN nexus. With these development challenges, this research is relevant at least in four ways, which generally inquires "How can the smallholder agriculture work to better FNS of rural households and vulnerable individuals in the context of northwest Ethiopia?"as the central question to answer. First, it helps understand the extent to which diversity of crop and livestock species the rural households grow/collect (farm diversity), variety of foods they purchase (market diversity), and commercialization of agriculture are associated with their dietary diversity (DD). Second, it adds value to a growing literature on AFN nexus by providing empirical evidence taking Ethiopia as a case, where, to the best of my knowledge, there is yet limited/no studies conducted. Correcting shortfalls in a number of potential pathways of agriculture to FNS in this research. Third, it contributes methodologically using a rigorous mixed methods design that brings together quantitative & qualitative approaches for evaluating the impacts of the key pathways of agriculture to FNS providing a generalizable data that can more effectively support advocacy for development of policies and programs to strengthen FNS.

Finally, the findings may be relevant to Ethiopia's policy and strategy of facilitating the smallholder agriculture to become nutrition sensitive and enhancing the role of women empowerment in agriculture (WEA) to better FNS by examining multiple factors that affect the link among FD, MD and DD. Understanding AFN nexus is also essential to shed light on the ongoing debate as to whether state-led efforts promoting AC or on-farm diversification practices of smallholder farmers in view of food sovereignty will help reduce FI in the rural settings.

1.2. Problem Statements

Food insecurity and malnutrition are still widespread problems in several developing countries as discussed above. Addressing the question of how to make agriculture and food systems more nutrition-sensitive is of high relevance for research and policy mainly in African countries, where smallholder farmers play a principal role in the agriculture sector and many of them are FI and malnourished. Studies in the literature on AFN nexus have widely recognized the need to understand what and how agriculture contributes to FNS of rural households globally and specifically in the developing world. The concept of nutrition-sensitive agriculture emanates from this perspective the fact that agricultural production practices have the potential to positively affect underlying determinants of nutrition (Ruel *et al.*, 2018). Though this assumption is intuitively sensible, it has proven difficult to be supported empirically as causal pathways hypothesized to run from agriculture to FNS are long and winding. Granting agricultural advances have been impressive in the recent decades, progress in improving FNS of rural households in the developing world has not yet found suitable. As such, understanding the capacity of farming systems to contribute to FNS is gaining ground as an objective among economists and development professionals (Carletto *et al.*, 2015).

Gomez *et al.* (2013) suggested that influencing the AFN nexus positively can lead to improvements for rural populations and to better pathways for transformation of local food systems. Frelat *et al.* (2016) and Pinstrup-Andersen (2007) pointed out nutrition is closely linked to agriculture not only because it produces food, but many of the undernourished people globally are also smallholder farmers. This implies that a focus of attention shall be given to vulnerable populations (smallholder farmers) when mounting the FS and nutrition perspectives in empirical analysis. However, the main agricultural policy response to undernutrition was to strengthen staple food production through price incentives and promoting improved farm technologies, focusing primarily on a narrow range of cereal crops such as wheat, rice and maize (Pingali, 2015). While this strategy has clearly helped reduce hunger, it has led to lower levels of crop diversity (Khoury *et al.*, 2014). This informed that the global food supplies become more homogeneous may have decreased DD (Frison *et al.*, 2006; Graham *et al.* 2007), which is associated with higher rates of micronutrient deficiencies, child stunting & deaths, and other negative health consequences (M'Kaibi *et al.*, 2015).

Scholars suggest more diversified agriculture and food systems may help improve dietary quality and nutrition (Berry *et al.*, 2015; Herforth, 2015; Pingali, 2015), but empirical evidence on the effects of diversification strategies on dietary improvement of smallholder farmers is limited (Sibhatu & Qaim, 2018; Webb & Kennedy, 2014). Appropriate levels of diversification are a question of scale. Moreover, food systems diversity does not necessarily imply that every single farm has to be extremely diverse.

On the one hand, diverse farm production may promote diverse food consumption in the farm household. This holds particularly true in Sub-Saharan Africa, where smallholder farms are often subsistence-oriented (FAO, 2014). Typical farms in Africa on the other hand are already quite diverse. Further diversification might prevent gains from specialization that potentially influencing nutrition adversely (Hirvonen *et al.*, 2016; Sibhatu *et al.*, 2015). Despite subsistence orientation, smallholders are engaged in market transactions to acquire cash income for purchasing basic necessity goods and services (Neway, 2006), and hence the market plays a substantial share of the food they consumed (Frelat *et al.*, 2016; Hirvonen *et al.*, 2016). Some scholars point to market access as more important than AD in improving HFS (Bellon *et al.*, 2016; Sibhatu & Qaim, 2018) and others tend to AD is more relevant (Berry *et al.*, 2015; Jones *et al.*, 2014).

Off-farm income (OFI) is the other variable that may affect linkages between AFN. The extant literature has given due attention to growth and poverty implications of OFI in developing countries, yet little is known about its impact on FS (Duong *et al.*, 2020; Rahman & Mishra, 2020). The key evidence also discloses little policy efforts have been made to promote the off-farm sector in a pro-poor approach that can overcome potential constraints specifically in Sub-Saharan Africa, where production on smallholder farms is critical to FS of the rural poor (Herrero *et al.*, 2010).

The empirical evidence in AFN nexus is mixed and varies through time and space, which calls for continuous and geographically specific studies. As Ruel and colleagues reported that a number of reviews published in the past two decades also affirmed the evidence on what and how agriculture contributes to nutrition is extremely scanty (Ruel *et al.*, 2018). The AFN linkages are therefore contextual and examining them is more relevant in the context of African countries like Ethiopia. While agriculture is a primary livelihood base for majority of the people and market-oriented policies currently promoted in the country, FI and malnutrition remain widespread. This seems to show a paradox that seeks evidence-based research to come up with effective and sustainable solutions. Majority of these vulnerable people being smallholder farmers predominantly managed agriculture escalated the motive to conduct this research with a perspective of suggesting viable solutions to mitigate their FI through empirical research to target. All these demonstrate that understanding the capacity of the farming systems, agricultural commercialization, the role of gender in agriculture and off-farm employment to meet food and nutrition needs of rural households is overriding.

The current research has therefore tried to look at the links between AFN from these pathways perspectives by which agriculture can influence FNS of smallholder farmers in the context of Ethiopia, a low-income country in East Africa with a higher share of rural population (80%). Among which, about 21% of households are undernourished and persistent chronic malnutrition affects 38.4% of children under five years (FAO, 2018). Poverty and FI is quite pervasive in rural Ethiopia, where the rate of poverty is nearly 67% among smallholder farmers (FAO, 2018) and FI remains quite large as 57.8% over 2014-2020 (FAO, 2021).

From the aforementioned, the central question is “How can the smallholder agriculture work to better FNS of rural households and vulnerable individuals in northwest Ethiopia?”Addressing such inquiry helps understand the extent to which diversity of crop and livestock species the rural households grow/collect (farm diversity), variety of foods they purchase (market diversity), commercialization orientation of agriculture and women empowerment are associated with their DD and FS situations. Households' decisions about the mix of agricultural products to produce, consume and market (sell and purchase) have important implications on AFN nexus for better FNS. This sequence of events represents the theoretical underpinning of this research that seeks to inquire the following research questions to answer empirically: (1) To what extent do varying levels of AD and off-farm employment influence HFS? (2) How do commercialization orientation practices of smallholder farmers affect HFS? (3) Which commercialization practices (crop/livestock) does it induce better HFS? (4) To what extent does women empowerment in agriculture (WEA) and production efficiency of smallholder farmers influence DD of women and their children)? (4) Does WEA produce a gender-biased effect on DD of children aged 6-60 months?

1.3. Objectives of the Research

The general objective of this research was to investigate the key pathways by which agriculture can influence FNS of households/individuals in rural settings so as to draw conclusions and policy implications that inform understandings of FNS issues in northwest Ethiopia. The analysis was carried out based on the following key pathways of agriculture: as source of food, income and women's role in agriculture. The specific objectives were to:

1. evaluate whether commercialization orientation of smallholder farmers in agriculture production improves household food security (HFS) in northwest Ethiopia;
2. assess HFS impacts of agricultural diversification intensities among smallholder farmers in those areas;

3. analyze effects of off-farm employment intensities on food security of households in those areas;
4. examine the role of women empowerment and production efficiency in agriculture on dietary diversity and food security of women, children, and
5. evaluate the role of production efficiency in agriculture on dietary diversity and food security of women, children and households in northwest Ethiopia

1.4. Theoretical Foundations

There are several pathways mentioned in the literature by which agriculture can contribute to FNS. Theoretically it is possible to have positive, neutral or even negative associations between AD and DD of rural households. This association may, however, be influenced by the nature of agricultural production practices of smallholder farmers (being subsistence or market-oriented) and the role of women in agriculture. This section synthesizes first the available literature on these relationships into four strands of thinking summarized based on the four key pathways linking AFN and it then presents the theoretical foundation of the current research.

Scholars in the first strand of subsistence pathway view that agriculture through increased AD directly translates into greater food availability, the subsistence production practices have the potential to improve FS in terms of dietary diversity and quantity available to the household year-round. Here it can be hypothesized that if households practice subsistence production without engagement in market transactions, then the link between agriculture (AD) and FS (DD) will be positive. This may be simple in highly autarkic households in which their decisions in production and consumption are not separable (Taylor & Adelman, 2003). Advocates in this stance also reveal that in rural areas of the developing world, where markets often function poorly with high transaction costs limits market participation while fostering own-consumption (Barrett, 2008; Chamberlin & Jayne, 2013; Hazell *et al.*, 2010).

In line with market (or income) pathway, the second strand claims that such a subsistence relationship between AFN can be quite complex under increasing opportunities for market participation, where households have more opportunities to trade, generate income and purchase different types of foods (Jones, 2017; Sibhatu & Qaim, 2018). Consequently households will tend to practice commercialization of agriculture through specialization in production of crops/livestock that have comparative advantages, due to more opportunities to sell their farm produces while purchasing the foods they consume (Baratt, 2008), as markets provide more diverse foods than any individual household can produce. Hence, if markets function well with no transaction costs in buying and selling foods, then there will be little reason to expect an association between what a farm household produces and what it consumes. This implies that with improved market access household's decision on production and consumption will be separable.

Proponents in this strand, however, argue in two different ways. On the one hand, scholars view that with improved access to markets, the subsistence (own-consumption) pathway could weaken to the extent market diversity (MD) can substitute for AD. Hence, specialization in most profitable farm produces may cause the link between AD and DD disappears while only between MD and DD (i.e. income pathway) remains relevant. This is because increasing farm productivity through specialization and improved market access will maximize household's profit with which could purchase diverse and quality foods (Dillon *et al.*, 2015; Sibhatu *et al.*, 2015; Hirvonen & Hoddinott, 2014), and households become more market oriented. This view refers to the link when agriculture generates income is translated into expenditure on nutrition-enhancing commodities such as food, health, education and social services. Other scholars argue that MD complements AD rather than replacing each other in their contribution to DD. Some evidence points to markets can offer opportunities for households to benefit from growing diversified foods enables to exploit seasonality and fill particular market niches (Bellon *et al.,* 2016; Keleman *et al.,* 2013; Muhanji *et al.*, 2011).

In this regard, the literature shows mixed results on which the current research is expected to provide empirical evidence taking the rural Ethiopia as a case is chosen. Treating the food consumption score (FCS) that is calculated using all the foods the household consumed decomposed into FCS of self-produced and FCS of purchased foods is the novelty of this research; as this helps capture the scope of contribution of AC to HFS that can be achieved through enhancing investments of increased income (obtained in the process of AC) in agricultural production practices and technologies increased agricultural productivity, and through investments in basic needs (such as foods, education and health) improved food availability to households. In doing so, the study can highlight the role of agricultural and development policies and programs in supporting HFS among smallholder farmers in the rural Ethiopia.

The third stance in view of food price pathway claims that even the role of AC depends on the food price shock that would have on HFS through affecting their income and purchasing power, despite varying among net buyers and net sellers of foods

(Holmes *et al.*, 2008; Kalkul *et al.*, 2013). There may be five types of farm households in rural areas as Sharma (2016) identified in case of India: (1) exclusive sellers- who only sell and do not buy-back; (2) exclusive buyers- who buy and do not sell at all; (3) net sellers- whose sales are higher than their purchases; (4) net buyers- whose purchases are higher than their sales; and (5) non-participants- who neither sell nor buy. Accordingly the rise in food prices is expected to influence HFS positively for farmers in categories 1 & 3, adversely for those in categories 2 & 4, and has no effect for farmers under category 5. Practically, it is rare for farmers to get under categories 1, 2 & 5 in the context of Ethiopia. Consequently the current study restructured these categories of farming households into two operational groups: net sellers and net buyers. It is operationally defined a household is net seller if the value of food sold (s_i) is greater than the value of food it bought (b_i), and it is net buyer if $s_i < b_i$. More formally, let p_i is a relative food price that represents a ratio of values of foods sold (s_i) to foods purchased (b_i) by household i, the household is net seller if p_i >1, net buyer if p_i <1, neither net seller nor net buyer for p_i =1, and self-sufficient/autarkic if $s_i = b_i = 0$. Farmers under categories 1 & 3 above are now treated as net sellers and those under categories 2 & 4 are net buyers.

Evidence in this strand of thinking points to a food price rise causes a shift of consumption patterns from a variety of high micronutrient foods to high carbohydrate staple foods for net buyers (Meerman & Aphane, 2012), for most staple foods are much cheaper than fruits, vegetables and animal source foods. On the other hand, by enabling greater access to food and essential nutrients for net buyers, reduced food prices can improve health and productivity of the general workforce while also freeing additional household resources from food to other expenditures, including productive investments.

However, proponents suggest other factors may impede the adverse effect of the rise in food price on FS of net buyers including: government policy (e.g. PSNP, free food, food for work, cash for work), community and individual level coping mechanisms (e.g. saving, transfers, credit), and household income (like off-farm income opportunities).

With this presumption, this research also tried to look at how change in relative food price influences HFS in terms of DD among net buyers and net sellers. Here is hypothesized that food price has positive implication on HFS for net sellers, negative implication for net buyers, and is neutral for neither net buyers nor net sellers. This also suggests the effect of AC on HFS vary among these three groups of farming households. It can be hypothesized that AC enhances HFS of net sellers, while it may be deterrent for net buyers and has no effect (or neutral) for neither net buyers nor net sellers. The latter, however, does not mean AC does not have any implication on HFS, as $P_i = 1$ implies that AC contributed to maintain HFS and to keep better in consumption smoothing. This on the other hand reflects a part that AC can play for the HFS is resilient to relative food price shocks in the food market. Among sample households of this study (n=295), only one household was neither net seller nor net buyer while around 46% were net buyers and the remaining 54% were net sellers. Addressing this issue the present study may also contribute in suggesting policy implications that help design targeted interventions on how vulnerable individuals/households can ensure access to food when the food price shock causes market distortions.

The last strand focusing on empowerment (or gender) pathway views that what matters for better FS of households/individuals are the agriculture-gender linkages identifies women empowerment in agriculture (WEA) as an important aspect to consider.

This has been clearly articulated across different reviews and research initiatives in AFN (Malapit *et al.,* 2014; Ruel *et al.,* 2018). Women represent a large portion of agriculture sector yet are often subject to barriers such as limited decision making and mobility autonomy that constrain their agricultural choices. As the primary caregivers, these limitations make it a challenge for women to provide sufficient and adequately nutritious foods to both themselves and their children (Kjeldsberg *et al.,* 2018). Three pathways identified in the literature through which gender mediates the relationship between AFN: (1) agricultural production can itself be a way of empowering women farmers, (2) agricultural time requirements and labor can have trade-offs with childcare and feeding practices, and (3) risks associated with women's agricultural labor could contribute to intra-generational malnutrition.

Advocates argue that although agriculture has been recognized as a key sector to leverage for improved nutrition outcomes, the evidence on agriculture-gender linkages to nutrition is relatively weak and sizeable knowledge gaps remain (Kadiyala *et al.*, 2014). One study on a relationship among livestock, women and child nutrition outcomes in India found that acquisition of livestock assets by illiterate women increases their intra-household bargaining power and results in greater investments in child nutrition (Jumrani & Birthal, 2016). Others point out negative implications production interventions can have on DD and nutrition status due to women's stress in time and energy leading to reductions in care giving practices and risks for women's own health (Gillespie *et al.*, 2019; Ruel *et al.,* 2018).

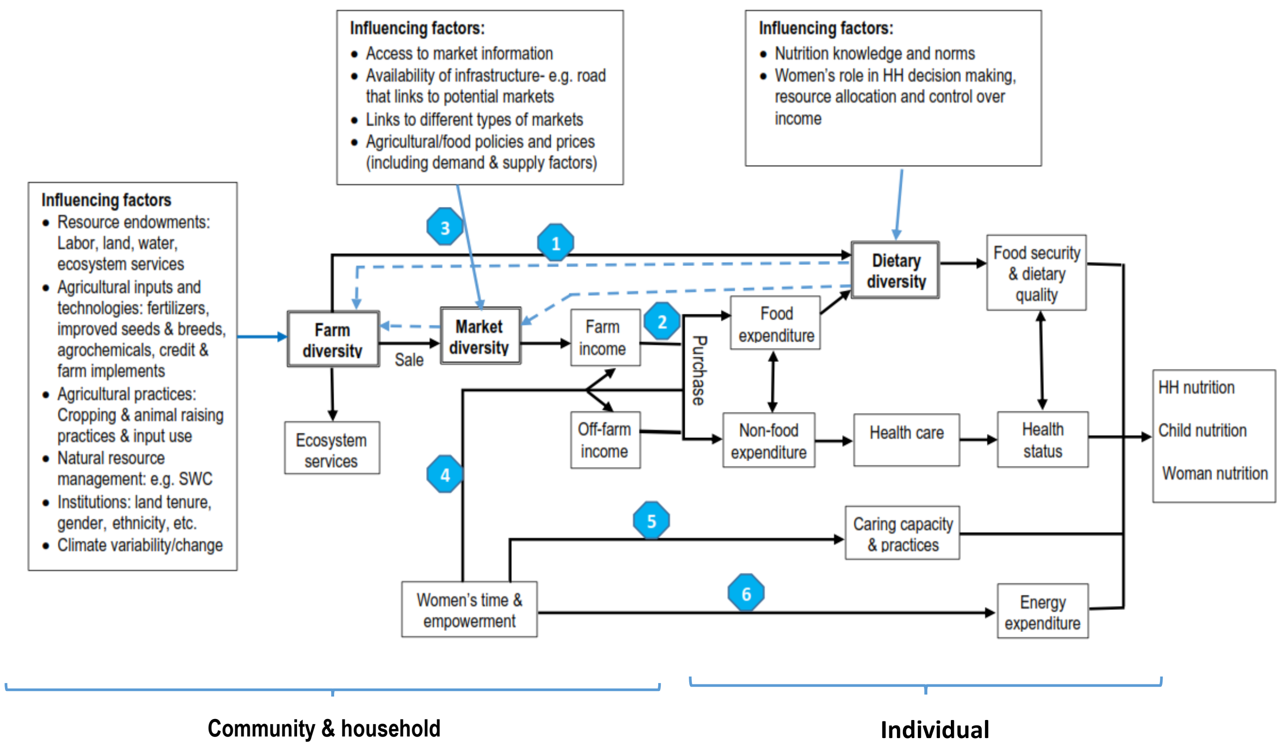
A recent review of quantitative studies to explore the ways women empowerment is quantitatively measured shows that a significant absence of indicators of time resource allocation, reproductive decision making and men's engagement in childcare and nutrition (Santoso *et al.,* 2019). In exploring the effect of WEA on DD, some authors included gender of household head interacted with AD variable in their models linking agriculture to FS (e.g. Sibhatu *et al.,* 2015). Others construct WEA index (WEAI) as a proxy variable for WEA interacted with gender of children to see whether it has a differential impact on DD between boys and girls (Gebremeskel & Abidoye, 2020). There is also an emerging evidence that shows WEA has important implications on how AD relates to their own and children diets (Malapit *et al.,* 2015). No or very few studies use WEAI interacted with AD to analyze its effect on the association between AD and DD of households/individuals.

In this regard, the present research contributes to the literature by exploring: whether WEA can influence this relationship positively or not in the one hand, and its effect on intra-gender DD of children on the other hand by incorporating WEAI interacted with AD as well as with gender of children aged 6-60 months into the systems of equations. Here it is assumed that the allocation decision of foods by households can be influenced by unobserved individual specific characters such as child gender preference (estimated through including a proxy variable representing a ratio of male to female number of children within a household in the model) and community variables (e.g. culture, religion, ethnicity). It is thus attempted to investigate whether an empowered woman can influence household decisions towards better FS as well as to identify which empowerment domain has a larger impact on intra-gender DD of children through estimating the effect of the five domains of empowerment (5DE) separately on child DD.

Several scholars suggest the need for more robust quantitative methods to establish causal relationships within the pathways (Gillespie *et al.*, 2019; Kjeldsberg *et al.*, 2018). Webb & Kennedy (2014) ratify the need for more research on impact pathways (IPs) as they found many existing studies have focused on determining the size and direction of impacts, rather than the channels by which impact occurs. With this backdrop, this thesis identifies investigating the clear link among AFN is really a critical challenge/gap that is expected to address the issue considering the various potential pathways through which agriculture can influence FNS of households/individuals in the context of rural Ethiopia.

To this end, to the best of my knowledge, there is lack of studies that have been conducted so far incorporating all these IPs, rather than most of few studies focus their investigations only on one or two pathways at a time, implying that their findings are confined only to these pathways without controlling for others. Bellon and his colleagues also disclosed that even these few studies have examined the link between AD and DD using simple correlation or regression analyses that reveal a positive association between these two variables, after correcting for other potential covariates such as education, farm size, family size, gender and wealth (Carletto *et al.*, 2015; Dillon *et al.*, 2015; Hirvonen & Hoddinott, 2014; Jones *et al.*, 2014; Luckett *et al.*, 2015; Malapit *et al.*, 2015; M'Kaibi *et al.*, 2015; Oyarzun *et al.*, 2013; Sibhatu *et al.*, 2015 cited in Bellon *et al.* 2016). Results are also context specific and can be controversial (Berti, 2015; Luckett *et al.*, 2015). This thesis was initiated to fill such knowledge gaps trying to examine the influence of the potential pathways of agriculture to FNS of households/individuals.

Once identifying the six impact pathways from previous literature as analyzed in detail above, the conceptual framework as a guide to our empirical analysis was developed extended mainly from Bellon *et al.* (2016) modeling the relationships between the three types of diversity to represent the complexity as in Figure 1.1 comprising the food prices and WEA dimensions into consideration: (1) diversity of crops and livestock produced/ gathered (farm diversity [FD]), (2) diversity of foods consumed in diets (dietary diversity [DD]), and (3) diversity of foods purchased in markets (market diversity [MD]), (4) change in relative price of foods sold to purchased, and (5) the implications of WEA on linkages among the three diversities. The framework highlights the six pathways in AFN nexus as the circumscribed numbers shown in Figure 1.1.



Source: Adapted from Bellon *et al.* (2016) and Kadiyala *et al.* (2014).

Figure 1.1. The conceptual framework for analyzing AFN nexus and pathways

As shown in Figure 1.1 the physical flows connect FD and DD through subsistence pathway (PW_1), while FD and MD through sale, and MD and DD through purchase via income pathway (PW_2). These flows, however, span three different scales from the community to the household and to the individual. The information flows (represented by broken arrows) create feedback loops (via demand, supply, prices, preferences, knowledge and tradition) across time and scales. Individuals, households or communities generate outcomes associated with each type of diversity that are important for them and for the society such as FS, DD, income and ecosystem services. However, each type of diversity can be influenced by a set of exogenous factors like resource endowments, availability of infrastructure, links to various markets, population pressure, land quality, land tenure, climate variability, gender relationships, ethnicity, etc. Some of these factors may influence all the three types of diversity, while others may be specific to a subset. This analytical framework hypothesizes the linkages among the three diversities are endogenous and thus difficult to ascertain causality among them.

As also Figure 1.1 shows that our conceptual model captures issues of how food price shock influences FS of vulnerable individuals among net buyers and net sellers through the food price pathway (PW_3). The role of agriculture-gender linkages on women and children diets can also be addressed through the three pathways that conceptualized from women's time and empowerment perspectives. This dimension is more critical to consider in the context of many low income countries like Ethiopia, wherein majority of the populations are vulnerable to malnutrition and women's engagement in most agricultural and reproductive activities are indisputably large. This suggests women's work time is an essential input for FNS outcomes.

Given the potential trade-offs pertaining to time in productive versus reproductive activities, its implications for women and children FNS are described via empowerment, childcare and energy expenditure pathways. As seen in Figure 1.1, the empowerment pathway (PW_4) refers to a link when the agricultural labor conditions can influence empowerment of women's control over nutrition-relevant resources and decision making. Childcare pathway (PW_5) relates to the pressures that heavy and prolonged women workloads in agriculture placed on childcare and feeding. Energy expenditure pathway (PW_6) represents effect of energy expenditure (due to energy-intensive nature of agricultural labor) and health hazards (e.g. due to exposure to pathogens via waste water irrigation and/or livestock in homestead) on women and their children nutrition and health status. These pathways carry special significance for household nutrition outcomes, mainly for children's health and nutrition with the assumption that women have consistently been found to be more likely than men to invest in their children's health and well-being, and the income and resources that women control wield disproportionately strong effects on health and nutrition outcomes.

From this conceptual framework one can understand that households' decisions about the mix of agricultural products to produce, consume and market (sell and purchase) have important implications on AFN nexus for better FNS, despite great complexity to entail. This sequence of events represents the theoretical underpinning of this research that hinged on production and consumption theories of rural households, who are both sellers and buyers of agricultural produces, adopted from Singh *et al.* (1986) and Straus (1983).

Agriculture being an important source of income in most developing countries and majority of the households in these areas are both producers and consumers of their own produces may complicate the traditional microeconomic theory. The inputs they use partly originate from the market and partly from their own production exacerbates the complexity. Efforts to predict the consequences of agricultural policies are often confounded by such complex, behavioral interactions characteristics of semi-commercialized rural economies (Singh *et al.*, 1986). This suggests that any change in agricultural policy may affect not only production but also consumption and labor supply (Coase, 1960). Depending on the market situations that prevail, there are two basic types of theoretical models that often used to explore the link between production and consumption decisions in the world of rural household economy. These are: separable (or complete markets) agricultural household model and non-separable (missing markets) agricultural household model (AHM). AHMs generally show that which factors determine the level of household production, consumption, demand for inputs and supply of labor, and their relationships under these circumstances.

Since markets are imperfect in many cases specifically in the developing world, scholars argue that local prices are determined endogenously (De Janvry & Sadoulet, 2006; Seng, 2016) by market prices and factors influencing transaction costs (Alene *et al.*, 2008); and transaction costs are heterogeneous across locations and households (Barrett, 2008; Olwande *et al.*, 2015). As markets are distant or hard to reach, the higher transaction costs by households will be an incentive to stay self-sufficient/autarkic. This implies that household-specific factors (like household assets and human capital endowments) will also determine the prices that can influence the decision making process (Mason & Smale, 2013). For instance, a household that has a motorbike will face lower transaction costs than a household that does not, as the former will require less time to reach the market, and hence can spend more hours on income generating activities. Such situations with imperfect markets and heterogeneous transaction costs can best be understood through the non-separable AHM. In this underpinning, it is generally assumed that there will be recursive relationships (or simultaneity) between production and consumption decisions of farm households.

Unlike non-separable, the separable AHM views that there is only a one-way (non-recursive) relationship between production & consumption decisions with the assumption that perfect markets to prevail. Mason and Smale (2013) suggest that this scenario seems difficult to apply in the context of the developing world. Advocates, however, opined that the non-separable situation can be quite complex under increasing opportunities for market participation, where households have more opportunities to trade, generate income and purchase different types of foods in the current globalization context (Ickowitz *et al.,* 2019; Koppmair *et al.,* 2016; Ogutu *et al.,* 2019). This shows that production activities of the household can be analyzed separately from consumption activities, and being split into profit maximizing and utility maximizing components, makes the model separable (Otekunrin *et al.,* 2019). This splitting property facilitates our empirical analysis much more dutiful. Accordingly the household maximizes its profit independently of its decisions regarding consumption and labor supply, but the decisions on consumption and labor supply cannot be made independently from production decisions (Singh *et al.,*1986). The households' production decisions therefore determine their income, which can then be used to spend on produced goods, purchased goods and leisure. In this underpinning, households are considered to be price-takers and optimal consumption can be determined depending on prices of each of the above goods.

This also determines how much of the produced good is consumed, and how much is marketed. If prices of the produced good were high, the household might demand less of it, as it can achieve higher utility if it sells it. Prices in a separable scenario are assumed to be exogenously determined which allow separability of households' decisions of production from consumption. This model solves the production decisions first regardless of consumption preferences and it then solves for consumption decisions based on optimal production decisions. Consequently the household behaves as if its production decisions are made first and then the generated full income through farm profits is allocated between consumption of goods and leisure. Hence, consumption (FS) depends on production decisions and household demographic characteristics, but not vice-versa (Feleke *et al.*, 2005; Kirimi *et al.,* 2013). The theoretical framework of this research was built mainly in this context with the view that there is a one-way causation between production and consumption decisions among smallholder farmers.

As the conventional microeconomic theory postulates households derive utility from the consumption of foods through the satisfaction found in a set of taste characteristics as well as the health effects of the nutrients consumed. Among the various indicators that used to measure FS derived from the consumption of foods, this thesis has used the food group DD indices. The fact that the DD is universally recognized as a key component of healthy diets strongly associated with nutrient adequacy (Torheim, 2004; Ruel, 2003), and indices of DD are also good, simple and reliable indicators of dietary quality and adequacy (Arimond *et al.,* 2010; Savy *et al.,* 2005; Torheim, 2004). Key evidence in Sub-Saharan Africa and elsewhere in the developing world highlights smallholder farmers rely heavily on their farm production to satisfy consumption requirements of households (Dillon & Barrett, 2014; Hoddinott *et al.,* 2014) and purchase only some food items from the market. Herrador *et al.* (2015) claim that it is often unlikely for farm households to consume their produces of high value crops, rather selling them and purchase cheap food items to meet the calorie requirements of their members. This requires a joint food consumption model to use that combines food production and purchases.

For the simplicity of demonstrating the model, let's consider only two farm-produced and one market-purchased foods. A utility function of rural households can be specified as of Equation 1.1.

$$U = U(F_1, F_2, F_m, \bar{l}, X) \tag{1.1}$$

where U is a utility function assumed to be well behaved (twice differentiable, increasing in its arguments and strictly quasi-concave). F_1 and F_2 are quantities of farm produced foods 1 and 2 consumed by the household; F_m is quantity of a market-purchased food consumed by the household; $\bar{l}$ is leisure; and X is the vector of household demographic characteristics (e.g. age, gender, education level of household head, family size) and contextual/community characteristics (e.g. location dummies). As both producer and consumer, the household is assumed to maximize its utility (Equation 1.1) from the consumption of these foods subject to constraints of farm production (Equation 1.2), income (Equation 1.3), and time (Equation 1.4) as follows:

$$Y(Q_1, Q_2, L_d, A, L^0, K^0) = 0 \tag{1.2}$$

$$P_1(Q_1 - F_1) + P_2(Q_2 - F_2) - P_m F_m - w(L_d - L_f) + N = 0 \tag{1.3}$$

$$T = L_f + \bar{l} \tag{1.4}$$

where Y(.) is the implicit production function assumed to be well-behaved (twice differentiable, increasing in outputs, decreasing in inputs and strictly convex); Q_1 and Q_2 are quantities of foods 1 and 2 produced on-farm; L_d is total labor demanded for on-farm use; A is farm technology; L^0 is the household's fixed quantity of land; K^0 is the fixed stock of capital; P_1 is price of food 1; P_2 is the price of food 2; P_m is the price of market-purchased food; $(Q_1 - F_1)$ and $(Q_2 - F_2)$ are marketed surplus of food 1 and 2, respectively; w is the wage rate; L_f is the family labor supply to on-farm use; $(L_d - L_f)$ is the hired labor (L_h) for on-farm use; N is non-farm income that adjusts to ensure that Equation 1.3 is zero; and T is total time available to the household to allocate between work (L_f) and leisure $(\bar{l})$.

With the separability scenario as detailed above, the production can be solved first. The first order conditions for input demand (L_d^*) and output supply (Q^*) in terms of all prices, wage, technology, fixed land, and fixed capital are represented in Equation 1.5 and Equation 1.6 respectively as follows,

$$L_d^* = L_d^*(P_1, P_2, w, A, L^0, K^0) \tag{1.5}$$

$$Q^* = Q^*(P_1, P_2, w, A, L^0, K^0) \tag{1.6}$$

Incorporating the time constraint (Equation 1.4) into the income constraint (Equation 1.3) and rearranging it, we can get Equation 1.7.

$$P_1Q_1 + P_2Q_2 + w(T - L_d) + N = P_1F_1 + P_2F_2 + P_mF_m + wl \tag{1.7}$$

These solutions involve the decision rules for the quantities of labor input used and output produced (production-side). Once the optimum level of labor is chosen, the value of full income when profits have been maximized can be obtained by substituting L_d^* and Q^* into the left hand side of the income constraint (Equation 1.7) as follows:

$$Y^* = P_1Q_1^* + P_2Q_2^* + wT - wL_d^* + N \tag{1.8}$$

$$Y^* = wT + N + \pi^*(P_1, P_2, w, A, L^0, K^0) \tag{1.9}$$

where Y^* is the full income under the assumption of maximized profit π^*. Now the first order conditions for consumption demand can be solved in terms of prices, wage and income. Incorporating socio-demographic factors (X) into the model, Equation 1.10 shows the demand for food.

$$F_i = F_i[P_1, P_2, P_m, w, Y^*(w, P_1, P_2, A, L^0, K^0, N), X] \quad \text{where } i = 1, 2, m. \quad (1.10)$$

1.5. Definitions of Terminologies

This section briefly defines and explains some of the umbrella concepts/terminologies that have been commonly used throughout this thesis, for details refer the respective sections in Chapters 2, 3 & 4.

Agricultural commercialization: A proportion of total agricultural outputs sold at farm level in a given year. A household is commercially oriented in crop production if it sold at least 50% of the total amount of crop outputs produced last year. A household is livestock commercial oriented if it sold at least 10% of the total amount of livestock raised in Tropical Livestock Units in the previous year prior to the survey. The relative crop commercialization orientation is also defined in this research as a rate of crop income to total annual income from sale of crops, livestock and all agricultural byproducts in the last one year prior to the survey. As this definition captures a trade-off between crop and livestock commercialization, this would mean that households better in crop commercialization would also be less/not commercially-oriented in livestock.

Agricultural diversification: A count of all crops and livestock species produced on household farm in the last one year prior to the survey. Crop diversification is a simple count of crop species cultivated by the household in the previous year prior to the survey. Livestock diversity refers to the number of livestock species reared by the household last year.

Agricultural diversification intensity: An agricultural diversity Simpson index that is operationally measured based on the relative share of area coverage of each crop species from total cultivated crops by the household or the number share of each livestock species from the total number of livestock species raised by the household in the previous year prior to the survey.

Food security: A situation that exists when all people at all times have physical, economic and social access to sufficient, safe and nutritious food to meet their dietary needs and food preferences for an active and healthy life (FAO, 2002). It is operationally conceptualized at household level in terms of food consumption score (FCS) as the weighted sum of food groups that any member of a household had consumed for the last 7 days prior to the survey. A household is defined as food insecure if its FCS is above 42 and food insecure, otherwise.

Efficiency: The concepts of efficiency can be seen into two: technical efficiency (output-oriented) and allocative efficiency (input-oriented). Allocative efficiency (AE) refers to the ability of a farm to use inputs in optimal proportions given their prices and technology (i.e. obtaining optimal profits with least cost of production). Technical efficiency relates to the ability of a farm unit to produce maximum level of output with given level of inputs and technology. Economic efficiency is the combination of technical and allocative efficiency. This study deals with TE in the context of Ethiopia, as part of a developing country, the main concern may be output shortfall rather than input over usage. Lack of price data also implies the nuisance to address AE. Thus, the output-oriented approach is preferred. A technically efficient production unit is operationally defined in this thesis as the one that attained maximum level of output in crop farm using available inputs and technology, and those that produced below this level are considered technically inefficient.

Empowerment: A process that enables individuals to exercise choice (Kabeer, 1999). Empowerment implies increased capabilities and agency for women and their family members as women have better access and possession of material, human and social resources. This research adopts women empowerment in agriculture index (WEAI) from Alkire *et al.* (2013) to directly assess women empowerment across five domains in agriculture: production, resource, income, leadership and time use.

Nutrition sensitive agriculture: A food-based approach to agricultural development that seeks to maximize agriculture's contribution to human health and nutrition. It puts nutritionally rich foods and dietary diversity at the heart of overcoming the triple burden of malnutrition (undernutrition, overnutrition and micronutrient deficiencies). Being nutrition sensitive means incorporating nutrition objectives, concerns and considerations to enable communities to achieve food and nutrition security. NSA could comprise a focus on diversifying crops to include more nutrient-dense foods.

Nutrition status: The nutrition status of women and children derived from minimum dietary diversity for women (MDD-W) in reproductive age and minimum dietary diversity (MDD) for children under five years modules. A woman in a reproductive age group has adequate nutrition status had she consumed at least 5 out 10 food groups defined in MDD-W module in the last 24 hours prior to the survey, and poor nutrition status otherwise. A nutritionally adequate child has consumed at least 4 out of 7 food groups defined in MDD module in previous 24 hour, and poor nutrition status otherwise.

Profitability: A profitability of a farm is measured in this study as the net return obtained from each unit of Ethiopian Birr invested either in crop or livestock farm.

Specialization: A situation that exists when a household produced crop or livestock species that have comparative advantages due to market opportunities and market access. Accordingly the lower the agricultural diversification the higher will be the level of specialization.

1.6. Study Area Description

Amhara region is located in the northwestern part of Ethiopia. With a population of 21.1 million in 2017, Amhara is the second most populous region next to Oromia. Its economy mainly depends on agriculture sector, which is dominated by smallholder farmers. It is the major source of food, export earnings and raw materials for local industries. The region is large in terms of area and endowed with a diverse agro-ecology, giving it a huge potential for production of a variety of agricultural products both for domestic consumption and exports. The water resources from Lake Tana and the rivers found in the region provide immense potential for irrigation development. Apart from a small percentage of the population engaged in the services and industry sectors, nearly 84% of the population of Amhara region resides in rural areas and is engaged in agriculture. Poverty is pervasive in the region with around 26.1% of the population living below the national poverty line compared to 23.5% for the entire country in 2016. Amhara region had a child poverty rate of 34% in 2011 (UNICEF, 2018).

The study was conducted in Bahirdar Zuria, Bure, Dangila and Libokemekem districts in Amhara region (Figure 1.2). They are found in West Gojjam, Awi and South Gondar zones in the region. Bahirdar Zuria has a total surface area of 128,290 ha. Among which annual crops cover 37.9%, permanent crops (9.5%), grazing land (21.5%), forest land (7.3%), herbs and shrubs (5.1%), water bodies (4.4%), land covered by buildings (8.8%) and land not yet used for any purpose (4.4%). It comprises 32 rural kebeles with no urban kebele. The altitude of the district ranges 1750-2300 m a.s.l. with annual rainfall intensity of 1200-1800 mm and temperature ranging 10-32 ^{O}C. Its agro-ecology is completely characterized by middle altitude (Woynadega), where nitosols (red) is the dominant soil type comprising 56%, followed by cambisols (grey) and vertisols (black) accounting for 34 and 10% in order. Males accounted for 48.8% of the population of 202,960 people and the female headed households comprised only 14% of the total 34,304 households. Among surveyed households in the district (n=70), 41.4% were subsistence oriented in both their crop and livestock production, whilst those commercially oriented in crop production recorded 28.6%, in livestock husbandry 17.1%, and in both crop and livestock farms 12.9%. Around 14.3% of the households were food insecure while the remaining 85.7% were food secure in the year 2020/21.

Dangila district has a total surface area of 77,430 ha. Among which annual crops cover 51.9%; permanent crops 0.3%, grazing land 15.8%; land covered by forest, herbs and shrubs 20.3%, water bodies 0.2%; and buildings and land not yet used for any purpose accounted for 4.3%. It comprises 27 rural and 6 urban kebeles. Its altitude is 1840 m a.s.l. with annual rainfall intensity of 700-1400 mm and temperature ranging 18-25^{O}C. Its agro-ecology is completely characterized by middle altitude (Woynadega) with soil types of grey 80% and black 20%. Males accounted for 48.9% of the population of 149,119 people and the female headed accounted only for 15.4% of the total 21,567 households. About 53.4% of surveyed households in Dangila (n=150) were subsistence oriented in both crop and livestock production, whereas livestock, crop, and both crop & livestock commercially oriented households registered 25.3, 12.7 and 10.7% in the year 2020/21 respectively. The food insecurity situation of households in this district was significantly highest (36%) compared to Bahirdar Zuria and Bure districts in the year 2020/21.

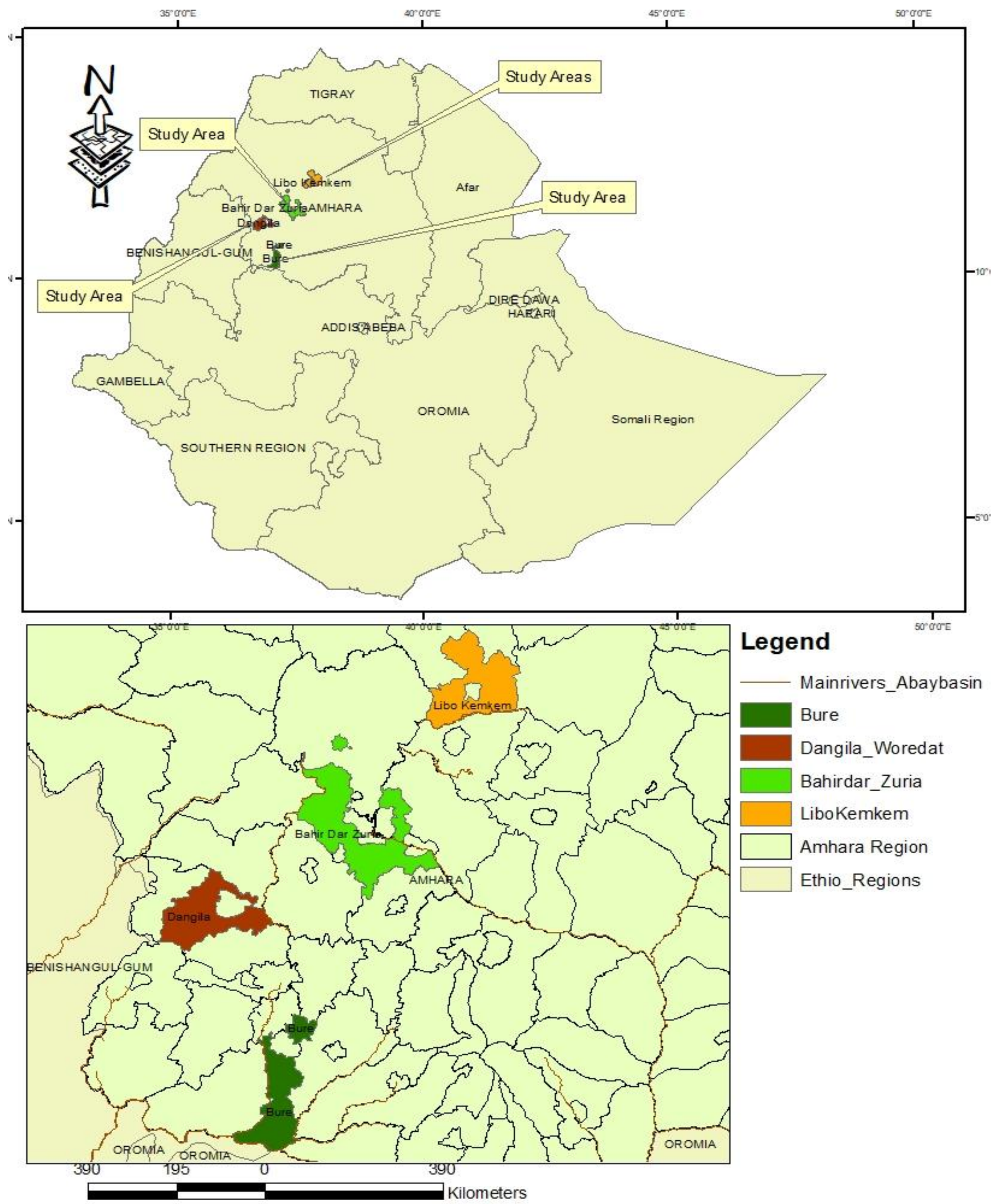
Bure district registers a total surface area of 58,795 ha, to which annual crops cover 50.4%, permanent crops 1.8%; grazing land 5.2%; forestland, herbs and shrubs 31.2%, water bodies 0.3%; and land covered by buildings and not yet used for any purpose records 11.1%. The district is composed of 19 rural and one urban kebeles. Its altitude ranges from 700 to 1350 m a.s.l. with rainfall intensity of 1200 mm and temperature ranging 18-27 ^{O}C. The agro-ecology is classified as woynadega (77.23%), qola (21.77%) and dega only 1%, with the soil type characterized by red 63%, grey 20% and black 17%. Males registered 49.5% of a population of 116,076 people and the female headed comprised only 15.1% of the total 16,567 households. While 30.7% of surveyed households in the woreda (n=75) were found to be subsistence oriented in agriculture production, those who were commercially oriented in cropping 54.7%, in livestock husbandry 6.7%, and in both crop and livestock farms recorded 8.0%. Bure has demonstrated the lowest rate of food insecurity accounting for 6.7% of surveyed households relative to the aforesaid districts.

Disaggregating households by districts, households in Bure were more likely to be commercial oriented, whereas subsistence production was the dominant orientation of households in Bahirdar Zuria and Dangila districts. The comparative analysis however depicted that Dangila observed to be at the top position in livestock commercialization (25.3%), followed by Bahirdar Zuria (17.1%) and Bure (6.7%). Whereas in crop commercialization practices, Bure took the first stage recording about 54.7% next to Bahirdar Zuria 28.6% and Dangila 12.7%. Bahirdar zuria was found in a better position in terms of commercialization in both crop and livestock farms (13%) relative to Dangila (11%) and Bure (8%). Livestock diversification index that calculated simply counting the livestock species reared by the household averaged to be 4.12 over the three districts whilst Dangila scored largest 5.42 followed by Bahirdar Zuria 4.88 and Bure 3.95. In crop production diversity that computed by counting the crop species grown by households in the year 2020/21, Bahirdar Zuria recorded highest 5.59 relative to Bure 4.65 and Dangila 4.17. Whereas in the overall agricultural diversification combining crop and livestock production, Bahirdar Zuria, Dangila and Bure registered on average 10.46, 9.58 and 8.59 in the order mentioned.

The other location is Libokemkem, which is among the food insecurity vulnerable districts in the region. With an area of 1082 sq.km the district is composed of 33 kebeles, among which 26 are yet safety net kebeles vulnerable to food insecurity. The rural areas covers around 91% and females about 49% of its total population 233,311 people

(Libokemekem WoA report, 2020). Among the total 48,261 households in the district, the rural households were more than 87% while the female headed households recorded 19.3%. Its altitude ranges 1800-2850 m a.s.l. with annual rainfall of 900-1200 mm and temperature of 11.1-27.9 ^{O}C. Its agro-ecology is composed of Woynadega 77% , Dega 16% and qolla 7%; where brown soil is the dominant soil type accounted for 60%, followed by red 22%, black 15%, and grey 3%. Among surveyed households (n=250), women in reproductive age (n=245) and children under five years (n=80) in Libokemkem district, about 33, 44 and 28% of households, women and children were food insecure respectively. While 64% of the households have adequate level of women empowerment, their efficiency in production of crop farms found to be 65.2% in this district.

Mixed crop and livestock is the dominant farming system across the entire study districts that characterized by rain-fed production mainly of cereal crops, and they have an emerging experience in irrigation production on vegetables. All surveyed households in these districts engaged in crop farming while about 97% also raised livestock.



Source: Own GPS arc map.

Figure 1.2. Study districts in their national and regional settings

1.7. Methodological Philosophy and Approaches

This section summarizes the philosophical assumption this research brings into inquiry to better understand what and how agriculture contributes to FNS of households/individuals in the context of rural Ethiopia. Here it is assumed that the relationships between AFN are situations that prevail in the world of rural economies independent of the mind that this research aims to explore through a pragmatic and mixed methods research design with an emphasis given to quantitative research approaches, instead of assuming this nexus as an objective reality socially constructed through interaction of one another for which individuals will develop subjective meanings of their experiences. As the current study assumes households' decisions about the mix of agricultural products to produce, consume and market have important implications for AFN nexus brings about better FNS, these relationships can be explored based on production and consumption theories of rural households who are both sellers and buyers of agricultural produces. Two types of theoretical models identified in literature used to understand links between production and consumption decisions characterized by the market situations that prevail in rural household economies namely separable and non-separable AHMs as explained above.

The literature in research, however, reveals quantitative, qualitative and mixed methods are the three research approaches commonly mentioned. The differences between qualitative and quantitative researches can be viewed from the philosophical assumptions the researcher brings to the study, the research designs (or strategies) used in the study and the specific methods employed to practice these strategies (Creswell, 2014). Despite ongoing debate about what philosophical underpinnings researchers bring to inquiry, post-positivism, constructivism, transformative and pragmatism are widely discussed in the literature (Creswell, 2014; Degefa, 2005). Some scholars call these philosophical stances as worldviews (Creswell, 2014; Guba, 1990), others call them paradigms (Degefa, 2005; Scotland, 2012), and yet others said epistemologies and ontologies (Getaneh, 2017; Crotty, 1998) or broadly perceived research methodologies (Neuman, 2000). Different authors have used various terms to represent the philosophical stances they bring to their studies. This thesis, however, uses the term worldview and paradigm interchangeably as meaning “a basic set of beliefs that guide action” adopted from Guba (1990).

Post-positivism is the traditional form of research that views phenomena have an independent existence of an objective reality which can be discovered via research, and hence it is the aim of the researcher to obtain this meaning (Scotland, 2012). As non-measurable world data are invalid according to positivism, the research underpinned this stance does not give room to accommodate methods from qualitative approach (Degefa, 2005). In contrast, constructivism (or interpretivism) claims that the objective reality is socially constructed through the interaction of one another. That is, individuals seek understanding of the world in which they live and work, and develop subjective meanings of their experiences. It is typically seen as an approach to qualitative research (Lincoln & Guba, 1985). This stance holds the view that observations cannot be pure in the sense of altogether excluding interests and values of individuals (Degefa, 2005).

Transformative paradigm focuses on the needs of groups and individuals in the society that may be marginalized. It argues the post-positivist assumptions imposed structural laws and theories that did not fit marginalized individuals in our society or issues of power and social justice, discrimination and oppression that needed to be addressed and even the constructivism did not go far for an action agenda to help marginalized people (Creswell, 2014). The theoretical perspectives may be interpreted with the philosophical assumptions that construct a picture of the issues being examined, the people to be studied, and the changes that are needed, like feminist perspectives, critical theory, or disability theory.

Pragmatism on the other hand arises out of actions, situations and consequences, unlike antecedent conditions in post-positivism. Pragmatists believe that truth is what works at the time, but not based on a duality between reality independent of the mind or within the mind. It is concerned with applications (what works) and solutions to problems, and hence instead of methods, it emphasizes on the research problem and uses all approaches available to understand the problem (Patton, 2002; Rossman & Wilson, 1985). Others suggest pragmatism is more appropriate to apply for mixed methods researches (Morgan, 2007; Tashakkori & Creswell, 2007) like FNS studies that seek to use a mix of qualitative and quantitative approaches (Degefa, 2005). The present study adopts pragmatism as its philosophical underpinning the fact that neither quantitative nor qualitative approach alone is sufficient to better understand what and how agriculture contributes to FNS of households/individuals in the context of rural Ethiopia. Thus, this thesis frames all the research procedures in the next section based on this pragmatic perspective.

1.8. Research Procedures

1.8.1. Research Design and Approaches

As has been discussed above the impacts of agriculture to FS of households, women and children would be evaluated using quantitative and qualitative data generated through pragmatic approaches, this research has therefore employed a mixed-methods research design that tends to focus on quantitative approaches.

The complexity and multidimensional aspects of FS become a critical challenge to address FS issues. Social, political, environmental, cultural and economic forces combine to add layers of complexity to FS. As detailed in the conceptual framework, analyzing AFN nexus from multiple IPs perspectives increases the complexity, so do the research problems faced by FS researchers. To adequately address such complexities, researchers are challenged to find ways of investigating that embrace multidimensionality of FS. This challenge has been major driver for substantial growth in interest around mixed methods research in recent years in fields of social science, education and health (Bowers *et al.*, 2013; Glogowska, 2011). Mixed methods research offers an alternative methodology for FS researchers to use to capture the complex issues in a more comprehensive manner than could be achieved by either quantitative or qualitative research (Andrew & Halcomb, 2012; Simons & Lathlean, 2010).

The nature of the research question is another important dimension that drives the choice of research designs. When we see the first research question of this thesis, it seeks to describe the FS situations of households/individuals based on descriptive analysis of quantitative data using DD indices. The remaining research questions seek to understand causal relationships among variables; thus, they could be addressed based on inferential statistical tests using various econometric models and statistical software. With this quantitative approach, the thesis attempts to identify the important factors that influence FS, the association between AD and DD, and analyze impacts of each potential pathway of agriculture to FS of households/individuals. Addressing all these research questions seek to apply both quantitative and qualitative approaches, and hence a mixed methods research deign is the appropriate approach for this study.

1.8.2. Sampling Techniques and Sample Size Determination

Mixed methods sampling practice usually recognizes the underlying research problems that are embedded in a given set of assumptions about the nature of the social world. One study suggests that the ideal sample size should emanate from the specific research problem (Collins *et al.,* 2006). Another author argues that the size of a sample for quantitative researches depends on the type of analysis (Onwuegbuzie & Collins, 2007), noting that different size samples are needed for different analytical procedures in order to run statistical tests to ascertain significance of findings. The most common type of mixed methods sampling design in the literature of mixed methods studies comprised a sequential design using multilevel samples. As detailed in the research design subsection, this study uses a two-stage mixed methods research framework for which a sequential mixed methods sampling design is appropriate, using rural households for the larger quantitative sample; and key informants (officials of stakeholder organizations) and focus group discussants (representatives of communities) for the second smaller qualitative samples that used for adaptation of the data collection instruments customized with the local contexts of northwest Ethiopia. The sampling techniques and sample size determination for quantitative and qualitative samples are briefly discussed hereunder.

Dangila, Bure, Bahirdar Zuria and Libokemkem districts are the target areas purposively selected from Amhara region in northwest Ethiopia the fact that these districts are intervention areas of Bahir Dar University that I have been working for and specifically the last district is also due to the one among food insecurity vulnerable districts in the region. Libokemkem woreda was thus found the appropriate location for this study to thoroughly examine the role of WEA to FS of vulnerable individuals in the household (women & children) at closer distance. Once these districts were chosen purposively, the study adopted a two-stage stratified sampling procedure to select study locations (kebeles) and households randomly from Dega, Woynadega and Qolla agro-ecologies in those target districts.

First, clustering the total kebeles in each district into these agro-ecologies at least one kebele would be chosen from each cluster for the sample to cover variability of the population in it. At this stage a total of 17 kebeles were chosen randomly from those agro-ecologies available in the four districts. Then, the final sampling units (households) in those 17 selected kebeles were subdivided into two strata based on gender (male & female headships) as factor of stratification, for it has important implication on most outcome variables of this study. Finally, a total of 545 households were drawn from 17 kebeles randomly, among which 295 households were from 12 kebeles chosen in the first three districts (9% comprised female heads) that used to deal with impacts of the first two pathways (AD & AC) of agriculture to HFS, while the other 250 households were from five kebeles in Libokemkem district assessed for evaluating the role of WEA and TE on FS of households and vulnerable individuals (women and children). Purposive sampling is the other sampling method used to select stakeholders to participate in KII and FGD for adaptation of various FS modules in the local context.

As suggested by Onwuegbuzie and Collins (2007) the minimum sample size for causal-comparative analysis needs to be 51 participants per group for one-tailed hypotheses and 64 participants for two-tailed hypotheses. Accordingly the study is expected to take a minimum sample size of 192 households from the three agro-ecologies in the study districts and hence using a sample of 295 and 250 households in the two cases. Moreover, the study covered a sample of primary women (245) and primary men (231) from these 250 households for data used to estimate WEAI and GPI within the household between women and their spouses, as well as of their children aged 5-60 months (80) to gather quantitative data to determine the impact of agriculture on FS of women and their children. In sum, a total sample of 545 households, 245 women, 231 men and 80 children were assessed in this study.

1.8.3. Data Collection Techniques

Structured household survey: Primary data were gathered from household cross-sectional surveys through an interviewer-administered structured questionnaire onto various aspects of the rural economy. Since farmers as respondents of this research are unable to fill the questionnaire by themselves, such data collection was administered by well-trained data collectors. The questionnaire captured a wide array of information including household demographic and socioeconomic characteristics, various FS modules, food production, food and nonfood expenditures, prices, asset ownership, employment, access to institutional services and infrastructure facilities, biophysical factors, among others.

Key informant interviews and focus group discussions are the qualitative approaches applied for collecting data on background/historical information about the communities and for adaptation of FS modules (HDDS, FCS, MDD, MDD-W, HFIAS & MAHFP) to the local context.

Secondary sources: Secondary data were gathered through reviewing various relevant research reports/books, browsing internationally recognized databases as well as national databases (CSA, MoFED, NBE, MoA) and gathering reports directly from relevant Bureaus/Woreda Offices (BoA, WoA, BoDRMFS).

1.8.4. Data Entry and Analysis

The study has used descriptive analyses (various indices) and inferential analyses (econometric models and statistical tests) to examine the quantitative research issues, and the qualitative data were used to improve the content of the data collection instruments. STATA version 13.1 was the statistical software applied to analyze the data collected through quantitative methods.

1.8.5. Ethical Issues

The study was approved by thesis examining/advisory committee in the Center of Food Security Studies at College of Development Studies, Addis Ababa University, Ethiopia. The advisory committee also checked each significant contribution to and quotation in this work I have obtained from other people's published works or unpublished materials, has been attributed, and has been cited and fully referenced. This material has not been published elsewhere in any form. The subjects, as well as heads of selected households and local authorities, were informed of the purpose and procedures of the study. All participants signed an informed consent form and were enrolled in the study on a voluntary basis.

1.9. Limitations and Scope

The study was conducted only in four districts in Amhara region for the purpose to generate information that can be generalized to the context of Amhara region may not be enough to assess the important issues that need to be addressed well related to food and nutrition insecurity situations of the region in general. Moreover, it gathered cross-sectional data generated through household survey, considering only Meher (rainy) and dry (irrigation) seasons of a specific year may be its delimitation, with this data alone may be difficult to see the effect of seasonal variations on FNS of households and individuals in the rural settings. Budget, labor and time are among the constraints for this research delineated only to the four districts and cross-sectional data. The other delimitation is focusing on the rural settings irrespective of urban households. This is the fact that the main interest of the current study is to examine AFN linkages, considering farm production diversification as one of the key factors limited this study to disregard the urban settings. Because the farm diversification aspect is almost lacking in case of urban households in Ethiopia, particularly in Amhara region.

However, this research has attempted to address all these limitations through use of various FS indicators, for example, Monthly Adequate Household Food Provisioning (MAHFP) helps address the effect of seasonal variations on outcome variables of the study. Moreover, anticipating neither quantitative nor qualitative research approaches are sufficient to address FS issues, the study adopts mixed research approaches, including the qualitative research approaches (FGDs and KIIs) helped fill the gaps that cannot be addressed well with quantitative approaches alone using household surveys with structured questionnaires.

1.10. Outline of the Dissertation

The thesis is composed of five chapters. This is the first chapter of the dissertation that introduces the background of the research and summarizes the available literature in AFN nexus into four strands of thinking helps build the conceptual framework to use and the research gaps to address in this thesis. In addition, it highlights the philosophical underpinnings, the theoretical perspectives, research designs, and the specific research methods of data collection, analysis and interpretation adopted in this research. Each of the subsequent three chapters has been developed as a separate article that emanated from the three key pathways of agriculture to FS linkages in the rural settings, which in line with the objectives of the research, and hence the chapters are interrelated. Chapter 2 demonstrates HFS impacts of crop and livestock commercialization orientation of smallholder farmers while correcting for other potential covariates. It also discusses the important factors that influence commercialization orientation of smallholder farmers in their crop and livestock production. Chapter 3 focuses on the implications of agricultural diversification and off-farm employment strategies on HFS of smallholders in northwest Ethiopia. The effect of seasonal variation in crop production diversification as well as sectoral variation in crop and livestock production on HFS are presented. Chapter 4 examines the role of women empowerment and production efficiency in agriculture on FS of women, children and households in the context of rural Ethiopia. Chapter five gives a synthesis of the thesis and concludes with a discussion of important findings and implications in methodological, theoretical and future research perspectives.

References

Alene, A.D., Manyong, V.M., Omanya, G., Mignouna, H.D., Bokanga, M. & Odhiambo, G. (2008). Smallholder market participation under transactions costs: Maize supply and fertilizer demand in Kenya. *Food Policy,* 33:318–328.

Allen, L.H. (2003). Interventions for micronutrient deficiency control in developing countries: Past, present and future. *J. Nutr.,* 133:3875S–3878S.

Andrew, S. & Halcomb, E. J. (2012). Mixed Method Research. In Borbasi, S. & Jackson, D. (Eds.) Navigating the Maze of Research: Enhancing Nursing & Midwifery Practice. 3rd ed. Marrickville, New South Wales, Elsevier.

Arimond, M., Hawkes, C., Ruel, M.T., et al. (2010). Agricultural interventions and nutrition: lessons from the past and new evidence. In: Thompson, B., Amoroso, L. (Eds.), Combating Micronutrient Deficiencies: Food-Based Approaches. FAO and CAB, Rome, pp. 41-75.

Barrett, C.B. (2008). Smallholder market participation: Concepts and evidence from eastern and southern Africa. *Food Policy,* 33:299–317.

Bellon, M.R., Ntandou-Bouzitou, G.D. & Caracciolo, F. (2016). On-farm diversity and market participation are positively associated with dietary diversity of rural mothers in Southern Benin, West Africa. PLoS ONE, 11(9):e0162535.

Berry, E.M., Dernini, S., Burlingame, B., Meybeck, A. & Conforti, P. (2015). Food security and sustainability: Can one exist without the other? *Public Health Nutr.,* 18:2293–2302.

Berti, P.R. (2015). Relationship between production diversity and dietary diversity depends on how number of foods is counted. *Proc Natl Acad Sci USA.,* 112 (42):E5657.

Black, R.E., Victora, C.G., Walker, S.P., Bhutta, Z.A., *et al.* (2013). Maternal and child undernutrition and overweight in low-income and middle-income countries. *Lancet*, *382:*427–451.

Bowers, B., Cohen, L.W., Elliot, A.E., Grabowski, D.C., *et al.* (2013). Creating and supporting a mixed methods health services research team. *Health Services Research,* 48:2157–2180.

Coase, R.H. (1960). The problem of social cost. Journal of Law and Economics, 3:1–44.

Carletto, C., Ruel, M., Winters, P. & Zezza, A. (2015). Farm-level pathways to improved nutritional status: Introduction to the special issue. *Journal of Dev. Studies,* 51(8):945-957.

Chamberlin, J, & Jayne, T.S. (2013). Unpacking the meaning of 'market access': evidence from rural Kenya. *World Dev.,* 14:245–264.

Chang, H.H. & Mishra, A. (2008). Impact of off-farm labor supply on food expenditures of the farm household. *Food Policy,* 33(6):657–664.

COHE (2012). The cost of hunger in Ethiopia: Implications in the Growth and Transformation Plan. In The Social and Economic Impact of Child Undernutrition in Ethiopia Summary Report; Central Printing Press: Addis Ababa, Ethiopia.

Collins, K.M., Onwuegbuzie, A.J. & Jiao, Q.G. (2006). Prevalence of mixed methods sampling designs in social science research. *Evaluation and Research in Education,* 19(2): 83–101.

Creswell, J.W. (2014). *Research design: qualitative, quantitative, and mixed methods approaches*. 4th ed., SAGE Publications, Inc.

Crotty, M. (1998). The foundations of social research. London: Sage.

CSA (2014). *Land Utilization: Private Peasant Holdings, Meher Season: Agricultural Sample Survey 2014/2015*; Central Statistical Agency (CSA): Addis Ababa, Ethiopia, Vol. IV.

Degefa, T. (2005). Rural livelihoods, poverty and food insecurity in Ethiopia: A case study at Erenssa and Garbi communities in Oromiya Zone, Amhara National Regional State. PhD Thesis at Norwegian University of Science and Technology, NTNU Trondheim.

De Janvry, A. & Sadoulet, E.(2006). Progress in the modeling of rural households' behavior under market failures. In Poverty, Inequality and Development; Springer: Berlin/Heidelberg, Germany, pp.155–181.

Dillon, B. & Barrett, C. B. (2014). Agricultural Factor Markets in Sub-Saharan Africa: an Updated View with Formal Tests for Market Failure. Washington, DC: World Bank Group.

Dillon, A, McGee, K. & Gbemisola, O. (2015). Agricultural production, dietary diversity and climate variability. *J Dev Stu.*, 51:976–995.

Duong, P, Thanh, P. & Ancev, T. (2020). Impacts of off-farm employment on welfare, food security and poverty: Evidence from rural Vietnam. *International Journal of Social Welfare*, 30:84–96.

EDHS (2016). Ethiopia demographic and health survey 2016.

Ehui, S. & Pender, J. (2005). Resource degradation, low agricultural productivity and poverty in sub-Saharan Africa: Pathways out of the Spiral. *Agric. Econ.*, 32:225–242.

EIU (2020). Global Food Security Index 2020: Addressing structural inequalities to build strong and sustainable food systems. New York: The Economist Intelligence Unit Limited.

EIU (2021). Global Food Security Index 2021: The 10-year anniversary. New York: The Economist Intelligence Unit Limited.

FAO (2013). *State of Food and Agriculture 2013: Food Systems for Better Nutrition*; FAO: Rome, Italy.

FAO (2014). The State of Food and Agriculture 2014: Innovation in Family Farming; FAO: Rome, Italy,

FAO (2018). Country factsheet on small family farms-Ethiopia 2018.

FAO (2021). World Food and Agriculture- Statistical Yearbook 2021.

FAO, IFAD, UNICEF, WFP & WHO (2022). *The State of Food Security and Nutrition in the World 2022. Repurposing Food and Agricultural Policies to Make Healthy Diets More Affordable*; FAO: Rome, Italy.

Feleke, S.T., Kilmer, R.L. & Gladwin, C.H. (2005). Determinants of food security in Southern Ethiopia at the household level. *Agric. Econ.*, 33:351–363.

Frelat R, Lopez-Ridaurab S, Gillerc, K.E., Herrerod, M., *et al.* (2016). Drivers of household food availability in sub-Saharan Africa based on big data from small farms. *Proc Natl Acad Sci USA*., 113(2):458–463.

Frison, E.A., Smith, I.F., Johns, T., et al. (2006). Agricultural biodiversity, nutrition and health: making a difference to hunger and nutrition in the developing world. *Food Nutr Bull*., 27:167–179.

Gebremeskel Berhane & Abidoye, B.O. (2020). Women empowerment in agriculture and child nutrition: Evidence from Ethiopia. AERC Working Paper GMBF-004. African Economic Consortium, Nairobi.

Getaneh Mossu (2017). Households poverty and livelihoods nexus in small towns of East Gojjam, Amhara Region, Ethiopia. PhD dissertation, Addis Ababa University, Ethiopia.

Gillespie, S., Poole, N., van den Bold, M., *et al.* (2019). Leveraging agriculture for nutrition in South Asia: What do we know and what have we learned? *Food Policy,* 82:3–12.

Glogowska, M. (2011) Paradigms, pragmatism and possibilities: Mixed-methods research in speech and language therapy. *International Journal of Language & Communication Disorders*, 46:251–260.

Gómez, M.I., Barrett, C.B., Raney, T., Pinstrup-Andersen, P., *et al.* (2013). Post-Green Revolution food systems and the triple burden of malnutrition. ESA Working Paper No. 13-02, August.

Graham, R.D., Welch, R.M., Saunders, D.A., et al. (2007). Nutritious subsistence food systems. In Advances in Agronomy, 92, 1-72 [DL Sparks, editor]. New York: Academic Press.

Guba, E. G. (1990). The alternative paradigm dialog. In E. G. Guba (Ed.), The paradigm dialog (pp. 17–30). Newbury Park, CA: Sage.

Haddad, L. (2000). A conceptual framework for assessing agriculture-nutrition linkages. *Food Nutr. Bull.*, 21:367–373.

Hawkes, C. & Ruel, M. (2006). The links between agriculture and health: An intersectoral opportunity to improve the health and livelihoods of the poor. *Bull. WHO,* 84:984–990.

Hazell, P., Poulton, C., Wiggins, S. & Dorward, A. (2010). The future of small farms: trajectories and policy priorities. *World Dev.;* 38:1349–1361.

Herforth, A. (2015). Access to adequate nutritious food: New indicators to track progress and inform action. In The Fight against Hunger and Malnutrition: The Role of Food, Agriculture and Targeted Policies, p. 139-162 [D Sahn, ed.]. Oxford University Press.

Herrador, Z., Perez-Formigo, J., Sordo, L., Gadisa, E., et al. (2015). Low Dietary Diversity and Intake of Animal Source Foods among School Aged Children in Libo Kemkem and Fogera Districts, Ethiopia. *PLOS ONE,* 10(7).

Herrero, M., Thornton, P.K., Notenbaert, A.M., Wood, S., *et al.* (2010). Smart investments in sustainable food production: Revisiting mixed crop-livestock systems. *Science,* 327(5967):822–825.

Hirvonen, K. & Hoddinott, J. (2014). Agricultural production and children's diets: evidence from rural Ethiopia. ESSP Working Paper no. 69. Washington, DC: IFPRI.

Hirvonen, K., Taffesse, A.S. & Hassen, I.W. (2016). Seasonality and household diets in Ethiopia. *Public Health Nutr.,* 19:1723–1730.

Hoddinott, J., Headey, D. & Dereje, M. (2014). Cows, Missing Milk Markets and Nutrition in Rural Ethiopia. International Food Policy Research Institute (IFPRI) and Ethiopian Development Research Institute (EDRI).

Holmes, R., Jones , N. & Wiggins, W. (2008). Understanding the impact of food prices on children. Report of the Overseas Development Institute.

Ickowitz, A., Powell, B., Rowland, D. Jones, A. & Sunderland, T.C. (2019). Agricultural intensification, dietary diversity, and markets in the global food security narrative. *Glob. Food Secur.,* 20:9–16.

Jones, A.D. (2017). Critical review of the emerging research evidence on agricultural biodiversity, diet diversity, and nutritional status in low- and middle-income countries. *Nutrition Reviews*, 75(10):769–782.

Jones, A.D., Shrinivas, A. & Bezner-Kerr, R. (2014). Farm production diversity is associated with greater household dietary diversity in Malawi: Findings from nationally representative data. *Food Policy,* 46:1–12.

Jumrani, J. & Birthal, P.S. (2016). Livestock, women and child nutrition in rural India. *Agricultural Economics Research Review,* 28(2): 223.

Kadiyala, S., Harris, J., Headey, D., *et al.* (2014). Agriculture and nutrition in India: Mapping evidence to pathways. *Annals of the New York Academy of Sciences*, 1331(1):43–56.

Kalkuhl M., Kornher, L., Kozicka, M., Boulanger, P. & Torero, M. (2013). Conceptual framework on price volatility and its impact on food and nutrition security in the short term. Food Secure Working paper no.15.

Keleman, A., Hellin, J. & Flores, D. (2013). Diverse varieties and diverse markets: scale-related maize "profitability crossover" in the Central Mexican Highlands. *Hum Ecol Interdiscip J.,* 41:683–705.

Khoury, C.K., Bjorkman, A.D., Dempewolf, H., *et al.* (2014). Increasing homogeneity in global food supplies and the implications for food security. *Proc Natl Acad Sci USA,* 111:4001–4006.

Kirimi, L., Gitau, R. & Olunga, M. (2013). Household food security and commercialization among smallholder farmers in Kenya. In Proceedings of the Fourth International Conference of African Association of Agricultural Economists (AAAE), Hammamet, Tunisia, 22–25 September 2013. doi.org/10.22004/ag.econ.161445.

Kjeldsberg, C., Shrestha, N., Patel, M., Davis, D., Mundy, G. & Cunningham, K. (2018). Nutrition-sensitive agricultural interventions and gender dynamics: A qualitative study in Nepal. *Maternal and Child Nutrition*, 14(3):1–9.

Koppmair, S., Kassie, M. & Qaim, M. (2016). Farm production, market access and dietary diversity in Malawi. *Public Health Nutr.,* 20:325–335.

Libokemekem WoA (2020). Libokemekem Woreda Office of Agriculture report 2019/20. Unpublished.

Lincoln, Y. S. & Guba, E.G. (1985). Naturalistic inquiry. Beverly Hills, CA: Sage.

Luckett, B.G., DeClerck. F.A.J, Fanzo, J., Mundorf, A.R. & Rose, D. (2015). Application of the nutritional functional diversity indicator to assess food systems contribution to dietary diversity and sustainable diets of Malawian households. *Public Health Nutr.,* 18:2479–2487.

Malapit, H.J., Sproule, K., Kovarik, C., *et al.* (2014). Measuring progress toward empowerment: Women's empowerment in agriculture index: Baseline report. IFPRI Books .

Mason, N.M. & Smale, M. (2013). Impacts of subsidized hybrid seed on indicators of economic well-being among smallholder maize growers in Zambia. *Agric. Econ.,* 44:659–670.

Meerman, J. & Aphane, J. (2012). Impact of high food prices on nutrition. FAO Expert Consultation on Policy Responses to High and Volatile Food Prices. FAO.

M'Kaibi, F.K., Steyn, N.P., Ochola, S., *et al.* (2015). Effects of agricultural biodiversity and seasonal rain on dietary adequacy and household food security in rural areas of Kenya. *BMC Public Health,* 15:422.

Morgan, D. (2007). Paradigms lost and pragmatism regained: Methodological implications of combining qualitative and quantitative methods. *Journal of Mixed Methods Research,* 1(1):48–76.

Muhanji, G., Roothaert, R.L., Webo, C. & Stanley, M. (2011). African indigenous vegetable enterprises & market access for small-scale farmers in East Africa. *Int J Agri Sust.,* 9:194–202.

Neuman, W.L. (2000). *Social research methods: Qualitative and quantitative approaches* (4th ed.). Boston: Allyn & Bacon.

Neway Gebreab (2006). Commercialization of smallholder agriculture in Ethiopia. In *Ethiopian Development Research Institute, Notes and Papers Series No.3;* Ethiopian Development Research Institute: Ethiopian; pp. 1–20.

Ogutu, S.O., Godecke, T. & Qaim, M. (2019). Agricultural commercialisation and nutrition in smallholder farm households. *Journal of Agricultural Economics,* 71:534–555.

Olwande, J., Smale, M., Mathenge, M.K., Place, F. & Mith€ofer, D. (2015). Agricultural marketing by smallholders in Kenya: A comparison of maize, kale and dairy. *Food Policy,* 52:22–32.

Onwuegbuzie, A.J. & Collins, K.M.T. (2007). A typology of mixed methods sampling designs in social science research. *The Qualitative Report,* 12(2):281–316.

Onyutha, C. (2018). African crop production trends are insufficient to guarantee food security in sub-Saharan region by 2050 owing to persistent poverty. *Food Secur.*, 10:1203–1219.

Otekunrin, O.A., Momoh, S. & Ayinde, I.A. (2019). Smallholder farmers' market participation: Concepts and methodological approaches from Sub-Saharan Africa. Current Agriculture Research Journal, 7(2):139-157.

Patton, M. Q. (2002). *Qualitative evaluation and research methods* (2nd ed.). Thousand Oaks, CA: Sage.

PDC (2020). Ten-year Perspective Economic and Development Plan (2020-2030). The FDRE Planning and Development Commission. Addis Ababa, Ethiopia.

Pingali, P. (2015). Agricultural policy and nutrition outcomes-getting beyond the preoccupation with staple grains. Food Sec., 7:583–591.

Pinstrup-Andersen, P., ed. (2015). Food Price Policy in an Era of Market Instability: A Political Economy Analysis. New York: Oxford University Press.

Qureshi, M.E., Dixon, J. & Wood, M. (2015). Public policies for improving food and nutrition security at different scales. *Food Security,* 7(2):393–403.

Rahman, A. & Mishra, S. (2020). Does non-farm income affect food security? Evidence from India. *J. Dev. Stud.*, 56:1190–1209.

Rossman, G.B. & Wilson, B.L. (1985). Numbers and words: Combining quantitative and qualitative methods in a single large-scale evaluation study. *Evaluation Review, 9*(5):627–643.

Ruel, M.T. (2003). Operationalizing dietary diversity: a review of measurement issues and research priorities. *Journal of Nutrition,* 133:3911S–3926S.

Ruel, M.T., Quisumbing, A.R. & Balagamwala, M. (2018). Nutrition-sensitive agriculture: What have we learned so far? *Global Food Security,* 17:128–153.

Santoso, M.V., Kerr, R.B., Hoddinott, J., Garigipati, P., Olmos, S. & Young, S.L. (2019). Role of women's empowerment in child nutrition outcomes: *A systematic review,* 1–14.

Savy, M., Martin-Prevel, Y., Sawadogo, P., Kameli, Y. & Delpeuch F. (2005). Use of variety/diversity scores for diet quality measurement: relation with nutrition status of women in a rural area in Burkina Faso. *Eur J Clin Nutr.,* 58:703–716.

Scotland, J. (2012). Exploring the philosophical underpinnings of research: Relating ontology and epistemology to the methodology and methods of the scientific, interpretive, and critical research paradigms. *English Language Teaching,* 5(9).

Seng, K. (2016). The Effects of Market Participation on Farm Households' Food Security in Cambodia: An Endogenous Switching Approach. MPRA Paper No.69669, 19 Mar 2016.

Sharma, V.P. (2016). Marketable and marketed surplus of rice and wheat in India: Distribution and determinants. *Int. Jn. of Agri. Econ.*, 71(2):137–159.

Sibhatu K., Krishna, V.V. & Qaim, M. (2015). Farm Production Diversity and Dietary Diversity in Developing Countries. *Proc. Natl. Acad. Sci. USA*, 112:10657–10662.

Sibhatu K. & Qaim, M. (2018). Review: Meta-analysis of the association between production diversity, diets, and nutrition in smallholder farm households. *Food Policy,* 77:1–18.

Simons, L. & Lathlean, J. (2010). *Mixed methods*. In Gerrish, K. & Lacey, A. (Eds.) The Research Process in Nursing. 6th ed. London, Wiley-Blackwell.

Singh, L., Squire, L. & Strauss, J. (1986). Agricultural household models. Baltimore: Johns Hopkins University Press.

Strauss J. (1983). Socioeconomic determinants of food consumption and production in rural Sierra Leone: Application of an agricultural household model with several commodities. MSU International Development Papers. Michigan State University, East Lansing, Michigan.

Tashakkori, A. & Creswell, J. W. (2007). Exploring the nature of research questions in mixed methods research. Editorial. *Journal of Mixed Methods Research, 1*(3):207–211.

Taylor, J.E. & Adelman, I. (2003). Agricultural household models: genesis, evolution and extensions. *Rev Econ Househ.,*1:33–58.

Torheim, L.E., Ouattara, F., Diarra, M.M., Thiam, F.D., et al. (2004). Nutrient adequacy and dietary diversity in rural Mali: Association and determinants. *Eur. J. Clin. Nutr.,* 58:594–604.

UNICEF (2018). Amhara Regional State 2007/08-2015/16 Budget Brief. UNICEF, Ethiopia.

Von Braun, J. (1995). Agricultural commercialization: Impacts on income and nutrition and implications for policy. *Food Policy,* 20:187–202

Webb, P. & Kennedy, E. (2014). Impacts of agriculture on nutrition: nature of the evidence and research gaps. *Food Nutrition Bulletin* 35:126–132.

Wenhold, F., Faber, M., Van Averbeke, W., Oelofse, A., et al. (2007). Linking smallholder agriculture and water to household food security and nutrition. *Water SA*, *33:*327–336.

CHAPTER TWO

COMMERCIALIZATION ORIENTATION AND FOOD SECURITY NEXUS AMONG SMALLHOLDER FARMERS IN NORTHWEST ETHIOPIA: A BIVARIATE TOBIT APPROACH

Accepted for publication in Journal of Sustainability

2.1. Abstract

Food insecurity remains a critical challenge in developing countries like Ethiopia, where the majority of the population derive their livelihood from agriculture characterized by mixed farming systems. Smallholder farmers, the principal actors of agriculture, are facing rapidly increasing population and urbanization and have been unable to be self-sufficient in food. This paper aims to examine the role of commercialization on food security and its determinants in rural settings. We used cross-sectional data from 295 households randomly selected in northwest Ethiopia. Results from bivariate Tobit regression revealed both crop and livestock commercialization improved household food security, but in quite different ways. The income from crop sales was instrumental in allowing households to buy additional foods while livestock sales fostered crop diversity for personal consumption, by allowing farmers to purchase non-food items. We also found livestock commercialization was more important than crop commercialization in improving food security due to its strong net positive effect. Thus, agriculture-food security nexus may not require the production systems to be subsistent. Supporting investments in improving road infrastructure to function all weathers, better access to institutional services (credit and off-farm employment), and enhanced awareness of extension towards promoting commercialization and diversified food consumption seem to be more promising. The research paper concludes that commercialization is vital not just for economic growth and food security, but also for smallholder agriculture in providing additional nutrition.

Keywords: *commercialization; market participation; food security; smallholders; Ethiopia*

2.2. Introduction

Food insecurity and malnutrition are among the key challenges in many developing countries. Food and nutrition security can play a strategic role globally in that its improvement lays a foundation for achieving many of Sustainable Development Goals (SDGs). Despite progresses in recent decades, a significant number of the global population remain chronically hungry. Between 702 and 828 million people are unable to meet their minimum dietary energy needs. The number has grown by about 150 million since the outbreak of the COVID-19 pandemic. Around 2.3 billion people were moderately or severely food insecure in 2021 and 34.4% of children under five years suffer from stunted growth, wasting or are overweight. One in three women of reproductive age were still affected by anemia in 2019 with no progress since 2012 [1], and nearly 45% of children died due to poor nutrition in 2011 [2]. The overall economic costs of malnutrition are significantly large, about USD 3.5 trillion per annum, 5% of the global GDP [3]. Such economic costs are remarkably high in several developing countries, for example, in Ethiopia the annual costs associated with child undernutrition reached 16.5% of its GDP in 2009 [4].

The challenges to ending hunger, food insecurity and all forms of malnutrition keep growing globally. As indicated in the State of Food Security and Nutrition report [1], the prevalence of the COVID-19 pandemic, the Ukraine war and extreme climate events are making world hunger and severe food insecurity more critical. A global economic slowdown or a downturn in one or more important players in the world economy can further damage developing economies, which can, in turn, influence food security adversely. Recent evidence suggests that the number of people unable to afford a healthy diet around the globe rose by 112 million to almost 3.1 billion in 2020, reflecting the impact of inflation on consumer food prices during the pandemic. The ongoing war in Ukraine, on the other hand, is disrupting supply chains and further boosting prices of grain, fertilizer and energy. The report [1] highlights that without intensified efforts even the gains that have been made in reducing the prevalence of child stunting by one-third in the previous two decades are now under treat by the triple crises of climate, conflict and COVID-19.

A large proportion of these food insecure people are smallholder farmers in less developed countries that depend on agriculture as their livelihood. In such a predominantly agrarian economy, a wide array of challenges in the agricultural production system itself, and the complexity of production and consumption decisions at household level, have a large impact on the food security of smallholder farmers [5,6]. Improving agricultural productivity and the linkage of agriculture with food security has been a central issue of development policies in sub-Saharan Africa [7,8]. This stems from the role the agriculture sector can play as a primary source of livelihood, including food and nutrition in the majority of the developing world and mainly in sub-Saharan Africa [5,9]. The concept of nutrition-sensitive agriculture presumes agricultural production practices have the potential to positively affect the underlying determinants of nutrition [10]. Despite this assumption, it has been difficult to empirically support, as the causal pathways hypothesized to run among agricultural commercialization (AC), diversification (AD) and food security (FS) are long and winding. A number of recent review papers also confirmed the limited evidence on how AC contributes to FS.

Theoretically, it is assumed that appropriate levels of diversification are a question of scale in which AD does not necessarily imply every single farm has to be extremely diverse. AD may promote diverse food consumption in the farm household, e.g., in sub-Saharan Africa, where smallholder farmers are often subsistence-oriented [11]. Typical farms in Africa are already quite diverse. Further diversification might prevent gains from specialization that could, in turn, lead to income losses potentially impacting HFS adversely [12,13]. Some authors point to market access being more important than AD for improved HFS [13,14]. Others argue that AD is more relevant [15,16]. This is essentially true in the context of developing countries, where smallholder farmers are significantly large in number, market infrastructure is poor and incomes unequally distributed. Even the findings of such linkages in the case of smallholders are mixed and vary through time and space. This requires continuous and extensive geographically specific studies. The geographical context of such issues is more relevant in Africa. While agriculture is the primary livelihood base for most Africans and market-oriented policies are currently promoted region-wide, food insecurity remains widespread in the region, which seems a paradox that seeks evidence-based research for effective and sustainable solutions. All these suggest the need to focus on vulnerable populations (smallholder farmers) for mounting a food security perspective in empirical analysis.

This is certainly the case in Ethiopia where agriculture has continued to be a source of livelihood for more than 66% of the population in the last two decades (2000–2019) [17]. Smallholder farmers managed 96% of agricultural land in the country [18], greater than 70% of the average in Africa [19]. Despite improvements in the sector, including a robust growth of 4.53% annually from 2014–2019, the prevalence of moderate or severe food insecurity remains on average 57.8% in the country over the same period [17]. This problem is of utmost concern in this era of SDGs in which achieving the goals by 2030 is imperative. The sector is widely recognized not only for reducing food insecurity but also to offer the required growth at various levels of the Ethiopian economy. This would, however, require transition of agriculture from subsistence to commercially-oriented production. This view was well articulated in the following series of development policies and strategies of the country [20]: the long-term strategy of Agriculture Development-Led Industrialization since the early 1990s, Sustainable Development and Poverty Reduction Program (2003-2005); Plan for Accelerated and Sustained Development to End Poverty (2006-2010); and the subsequent Growth and Transformation Plans I (2011-2015) and II (2016-2020).

To better understand the extent and the role of AC on HFS, the following are the central questions to address: (i) Are commercialization practices of smallholder farmers associated with better HFS? If yes, which commercialization practice (crop/livestock) induces better HFS and how? (ii) Does commercialization imply trade-off/synergy between consumption of own-produced and purchased foods? (iii) What are the factors influencing commercialization of agriculture among smallholder farmers? The purpose of this study is to evaluate whether commercialization orientation in agricultural production helps improve food security in terms of food consumption patterns and dietary diversity of households among smallholder farmers in northwest Ethiopia.

This paper adds to the literature in four ways. First, we analyze effects of AC strategy on HFS operationally measured in terms of food consumption and dietary diversity. Second, differentiating HFS resulting from purchased and own-produced foods helps understand transmission channels of AC to HFS. Third, using the bivariate Tobit model, capable of jointly estimating all relevant parameters, provides evidence of jointness in decision making process. Finally, understanding AC-FS nexus is essential to shed light on the ongoing debate as to whether state-led efforts promoting AC or on-farm diversification practices of smallholder farmers in view of food sovereignty will help reduce food insecurity in the rural settings.

2.3. Materials and Methods

2.3.1. Study Settings

The study uses cross-sectional data from a household survey implemented during June and July 2020 using structured questionnaires. The survey covered a sample of 295 rural households and 12 villages randomly selected from Dangla, Bure and Bahirdar Zuria districts (Woredas) in northwest Ethiopia. The household selection was based on a two-stage stratified sampling. The survey team was composed of 12 experienced enumerators of agricultural experts. An intensive two days of training was given to the survey team to create understanding of the contents of the questionnaire and of the approaches and procedures of how to conduct face-to-face interviews with farmers using local language (Amharic) and how to probe answers to the difficult questions through examples and farmers' wordings. Pilot-testing of the survey instruments and fieldwork procedures were conducted prior to the main survey. The data quality was checked through close supervision of the enumerators by supervisors via checking the collected data every night, and giving them feedback every other morning by asking them further explanations for abbreviated/vague data (if any), and to recollect the data that was sought.

2.3.2. Measuring Household Food Security

Food insecurity continues to be a major development problem worldwide, undermining health, productivity and survival of the people. Efforts to overcome the development challenges posed by food insecurity necessarily begin with accurate measurement of key indicators at household level. Although the concept of FS is evolving, the widely accepted definition of FS is a situation that exists "when all people at all times have physical, economic and social access to sufficient, safe and nutritious food to meet their dietary needs and food preferences for an active and healthy life" [21]. This suggests FS is a multidimensional and dynamic phenomenon that comprises four pillars: availability, accessibility, utilization and stability. The literatures seem to agree that identification of household behaviors related to food access serves as a critical building block for the development of policies and programs helping for vulnerable populations, effective targeting of aid and impact evaluation.

This study therefore tried to measure FS at household level operationally conceptualized in dietary-based food consumption. Despite a variety of approaches available, the simple food count and food group diversity are commonly mentioned in literature. The simple food count index is a simple count of all food items consumed by the household, while household dietary diversity score (HDDS) and food consumption score (FCS) measure the count of food groups the household consumed in a certain recall period. Since the first approach fails to capture whether the household gets different micronutrients [13,22], we tend to focus the latter mainly on FCS for the reasons detailed therein.

HFS is conceptualized in terms of FCS as the weighted sum of food groups that any member of a household had consumed for the last 7 days prior to the survey. The food security status of households was determined based on the food consumption data gathered using the standard FCS module of [23]. We applied a list-based recall of food consumption data based on eight food groups: (1) starchy staples, (2) pulses, (3) vegetables, (4) fruits, (5) meats, fish and eggs, (6) milk, (7) sugars, and (8) fat and oils, within which were listed the food items customized in the local context. Once the data on food items were combined into food groups, the maximum value for any food group was capped at seven. Households were presented with the calculated FCS, based on possible frequency of number of days (ranging 0–7) and internationally standardized weights (0.5–4) assigned for the food groups the household consumed in the last 7 days. A weight of 0.5 corresponded to the food group with lowest nutritional contribution, and 4 for the one contributing the highest. A specific weight was assigned to each food group, to reflect not only its nutritional importance, but also to help assess whether the production systems of smallholder agriculture were nutrition sensitive or not.

Using a 7 day recall period also seemed better to capture consumption habits of households than the 24 h recall that was used in HDDS. This was supported by [22] that disclosed that dietary diversity score of a 7 d recall data is highly correlated with nutrient adequacy more than when based on a 1d recall. Information about the main source of foods has its own implication in understanding how far the food consumption of households is vulnerable to the risks of food purchases. Additionally, the FCS data can be analyzed to construct the other three indicators of HFS, which were more important in the context of this study: FCS of purchased foods, FCS of own-produced foods and FS category. Equation (2.1) is the formula used to calculate FCS:

$$FCS_i = \sum_{j=1}^{8} W_j F_j \tag{2.1}$$

where FCS_i represents food consumption score of household i; W_j is the weight of food group j consumed by household i; and F_j is the frequency of number of days household i had eaten food group j in the previous week prior to the survey.

FCS is a composite and continuous score with a possible range of 0–112. FCS in general represents dietary diversity of foods consumed by households, irrespective of where they were sourced. FCS of own-produced foods refers to the calculated dietary diversity based only on own-produced foods the household consumed. FCS of purchased foods is the dietary diversity of foods the household consumed from purchases. The simplicity of gathering food consumption data by means of this qualitative approach is noteworthy and why it is preferred to the quantitative approach, which tries to measure the quantity of foods the household consumed daily, becoming technology and knowledge intensive besides being more expensive. All these imply that FCS is the appropriate approach to conceptualize and evaluate AC in the context of HFS.

Households can further be classified into food consumption groups to categorically determine the food insecurity prevalence. In formulating this categorical variable, most studies have used standardized thresholds of 21 and 35 among poor, borderline and acceptable consumption [23]. These thresholds are based on a minimum consumption of 7 d starch with 7 d vegetables as the first threshold (21), and the addition of 7 d of pulses to this gives the second threshold (35). However, there may be a situation where the thresholds may increase from 21/35 to 28/42, primarily in cases where households have a very high frequency of sugar and oil consumption. This is the fact in areas where even the poorer consumption food patterns include frequent oil and sugar consumption, such as in Ethiopia. A diet of starch and vegetables accompanied by only the addition of oil and sugar should yet be considered poor. This suggests the thresholds to be adjusted into FCS are ≤ 28, 28.5–42 and >42 in order, as poor, borderline and acceptable food consumption levels. As such, we used the latter thresholds (28/42) to assess the FS status of households in the context of rural Ethiopia. Accordingly, the FS status of households can be formulated in terms of FCS as in Equation (2):

$$\mathrm{FS_i} = \begin{cases} 1 & \text{if } \mathrm{FCS_i} > 42 \\ 0 & \text{if } \mathrm{FCS_i} \leq 42 \end{cases} \tag{2.2}$$

where $\mathrm{FS_i}$ is a binary variable that has a value of 1 if household i is food secure and 0 if is food insecure.

2.3.3. Measuring Commercialization Orientation

Similar to food security, commercialization is a multidimensional concept and any single indicator cannot capture all its facets. The literature applies different methods to measure the commercialization orientation of households. Several studies conceptualized commercialization orientation focusing on market participation of farm households from the output side, using the commonly cited definition of AC as a "proportion of total agricultural output sold at farm level" [24–26]. This index captures the trade-offs the households makes at any level of market engagement between production and consumption along a subsistence–commercial continuum from zero to unity. Berhanu and Moti [27] operationalize AC concepts from methodological and analytical perspectives as a combination of market orientation and participation. They explained market orientation as a situation that prevails when production decisions are based on market signals, while market participation is simply the farm produce offered for sale and use of purchased inputs. As such, it seems market orientation tends toward profit maximization, whilst market participation appears to be about utility maximization. Yet others define AC as total annual income from sale of crops, livestock and all agricultural byproducts [28].

The fact that there would always be some amount of output that even a subsistence household would sell at a lower end, to acquire cash income for purchasing basic necessity goods and services, does not alter as the ratio of marketed output up to a certain minimum level cannot be taken as a measure of commercialization. Recognizance of this suggests that 20% marketable surplus can be used as a cut-off point in the Ethiopian context to define commercialization orientation at farm level [29]. Others have used one third of the value of total crop output sold (i.e., 33%) in the case of Nigeria [30] and half of total crop output sold (i.e., 50%) in case of Ethiopia [24] as a threshold to define whether a household is commercially oriented in crop production. Adopting the latter threshold, we defined crop commercially oriented households as those that sold at least 50% of the total amount of crops they produced last year, while subsistence-oriented were those having lower or no sales.

As the process of commercialization varied in nature between livestock and crops, and a smaller unit of participation in livestock marketing would enable farmers to reap better income relatively with little/no transaction costs, a lower threshold (10%) was used for defining commercialization orientation in livestock production in the context of Ethiopia. Livestock commercially oriented households were those that sold at least 10% of total amount of livestock output (in tropical livestock units) raised in the previous year, and those with lower or no sales were subsistence-oriented in livestock production. Constructing indices to measure participation of farm households in crop and livestock output markets using Equations (2.3) and (2.4), commercialization orientation in their crop and livestock production was determined based on the thresholds of these indices used, as in Equations (2.5) and (2.6), respectively, as follows:

$$\mathrm{COMPI_i} = \frac{\sum_j^k \mathrm{CS_j}}{\sum_j^k \mathrm{CP_j}} \tag{2.3}$$

$$\mathrm{LOMPI_i} = \frac{\sum_m^q \mathrm{LS_m}}{\sum_m^q \mathrm{LP_m}} \tag{2.4}$$

$$\mathrm{CCO_i} = \begin{cases} 1 & \text{if } \mathrm{COMPI_i} \geq 0.5 \\ 0 & \text{if } \mathrm{COMPI_i} < 0.5 \end{cases} \tag{2.5}$$

$$\mathrm{LCO_i} = \begin{cases} 1 & \text{if } \mathrm{LOMPI_i} > 0.1 \\ 0 & \text{if } \mathrm{LOMPI_i} \leq 0.1 \end{cases} \tag{2.6}$$

where $\mathrm{COMPI_i}$ and $\mathrm{LOMPI_i}$ represent crop output market participation index and livestock output market participation index of household i; $\mathrm{CS_j}$ and $\mathrm{CP_j}$ denote total amount of crop j sold and produced in kilograms by household i (j = 1,2,…, k crops); $\mathrm{LS_m}$ and $\mathrm{LP_m}$ were the total amount of livestock m sold and produced in TLUs by household i (m = 1,2,…, q livestock) in the last year prior to the survey. To better understand the relative importance of crop and livestock commercialization on HFS, we extended the Coates and Galante [28] simple definition of AC as "total agricultural income…", and used a term "relative crop commercialization orientation", operationally defined as a "proportion of crop income to total agricultural income the household earned from crops, livestock and all agricultural byproducts sold in the previous year". As this definition captures a trade-off between crop and livestock commercialization, this would mean that households better in crop commercialization would also be less/not commercially-oriented in livestock production. The relative crop commercialization orientation index (RCCI) was formulated as in Equation (2.7):

$$\mathrm{RCCI_i} = \frac{\sum_{j}^{k} \mathrm{CI_j}}{\sum_{j}^{k} \mathrm{CI_j} + \sum_{m}^{q} \mathrm{LI_m}} \tag{2.7}$$

where CI_j and $\mathrm{LI_m}$ were the income received by household i from (by)products of crop j and livestock m sold in the previous year, respectively. The denominator terms after equality sign of Equation (2.7) represents the total agricultural income as the sum of income the household earned from all crops and livestock (by)products sold in the year.

2.3.4. Empirical Model and Estimation Strategy

Several studies on agriculture and food security nexus have used a farm household model designed to capture key features of agriculture in the developing countries, such as non-separability of production and consumption decisions due to market imperfections, interconnection between transaction costs and market participation decisions, interaction among farm households for factor markets and seasonality of resource use. In this underpinning, scholars argue that local (or decision) prices are determined endogenously [31,32] by market prices and factors influencing transaction costs [33]; and transaction costs are heterogeneous across locations and households [34,35]. As markets are distant or hard to reach, the higher transaction costs are an incentive for households to stay self-sufficient, and hence food production and consumption decisions are non-separable. Studies in Tanzania [36] and in Cambodia [32] also framed their empirical models of market participation based on the non-separability assumption.

However, this situation can be quite complex under increasing opportunities for market participation, where households have more opportunities to trade, generate income and purchase different types of foods [26,37,38]. With improved market access and opportunities, households' decisions on production and consumption are separable. Accordingly, the household behaves as though its production decisions are made first and then the generated full income is allocated between consumption of goods and leisure. Hence, consumption (FS) depends on production decisions and household demographic characteristics, but not vice-versa [25,39]. As production decisions contribute to income through farm profits, factors influencing production can affect income and, hence, household consumption decisions. This study was built in this context with the view that commercialization can play an important role for the well-being of households who are both sellers and buyers of foods and other agricultural commodities. With this separability assumption, we hypothesize that there is a one-way causation between commercialization and food consumption among smallholder farmers.

To guide the empirical analysis, a bivariate Tobit framework was adopted from [24,40] for joint evaluation of HFS impacts of AC, whether it would be through a trade-off or synergy effect between consumption of own-produced foods and purchased foods. We postulate that farmers follow sequential decisions in consumption of any particular food. First, whether to choose to consume a particular (produced/purchased) food. Second, to what extent is the intensity of consumption conditional on choice? In such a case, it is appropriate to use the bivariate Tobit model developed at household level using FCS of own-produced foods and FCS of purchased foods as dependent variables for joint determination of how commercialization orientation affects HFS, so as to better understand to what extent purchased foods are substituted for, or supplementary to, own-produced foods, after correcting for other covariates. The outcome function for choosing consumption of a particular foods group (measured in terms of FCS, as an indicator of HFS level) is given by Equation (2.8):

$$Y^{*} = \alpha C_i + \beta X_i + \varepsilon_i \tag{2.8}$$

where Y^{*} is a latent variable representing HFS in terms of FCS of a particular foods group the household consumed; C_i is the level of relative crop commercialization orientation of household i, a key explanatory variable of this study; X_i is the vector of other regressors that may affect HFS; α is a scalar parameter of interest and β is the vector of parameters to be estimated; and ε_i is the error term distributed normally with zero mean and variance σ^2.

For households choosing consumption of own-produced foods group, Y_i^{*} equals the actual level of consumption (Y_i). For those who did not choose own-produced foods group, Y_i^{*} is an index reflecting potential consumption as in Equation (2.9):

$$Y_i = \begin{cases} Y^{*} \text{ if } \alpha C_i + \beta X_i + \varepsilon_i > 0 \\ 0 \quad \text{if } \alpha C_i + \beta X_i + \varepsilon_i \leq 0 \end{cases} \tag{2.9}$$

Before turning to the details of our estimation procedure, let us see first the brief description of the univariate Tobit model. As seen in Equation (2.9), a Tobit approach can also capture the decision to choose as well as the resulting outcome (intensity), while others, such as the probit or logit model, provide information on the decision to choose only. This suggests the Tobit model can be framed conceptually to evaluate the relationship of one or more independent variables with a dependent variable having continuous observations but censored to either left, right or both. In our case, the dependent variable comprised nonnegative values, and was left-censored. If this relationship were estimated using OLS regression without censoring, the resulting estimators would be inconsistent and yield downward-biased slope coefficients and an upward-biased intercept [41]. Maximum likelihood estimator (MLE) would, therefore, be consistent in the Tobit model. The fact that a significant share of households consumed a mix of purchased and produced foods over a 7 d recall period (see Table 2.1), meant we used a bivariate Tobit framework to capture censorship and the tradeoff/synergy effects of commercialization between these two consumption outcomes in the structural form of the model specified in Equations (2.10-2.14) as follows:

$$Y_{1i}^{*} = \alpha C_{1i} + \beta X_{1i} + \varepsilon_{1i} \quad (2.10)$$

$$Y_{1i} = \text{Maximum}\ (Y_{1i}^{*}, 0) \quad (2.11)$$

$$Y_{2i}^{*} = \alpha C_{2i} + \beta X_{2i} + \varepsilon_{2i} \quad (2.12)$$

$$Y_{2i} = \text{Maximum}\ (Y_{2i}^{*}, 0) \quad (2.13)$$

$$\varepsilon_{1i},\ \varepsilon_{2i}\ \approx N[0,0,\delta_1^2,\delta_2^2,\rho_{12}] \quad (2.14)$$

where Y_{1i}^{*} denotes FCS of purchased foods consumed by household i; Y_{2i}^{*} represents FCS of own-produced foods consumed by household i; ρ_{12} is the correlation between the error terms ε_{1i} and ε_{2i}. The distributions are independent if the covariance between these two errors (i.e., $\rho_{12} = 0$). A positive significant value of ρ_{12} implies commercialization has a synergy effect on consumption between purchased and produced foods, and a negative value shows presence of trade-off.

Table 2.1. Extent of commercialization orientation, food source diversity and profitability (n=295)

HH categories by commercial orientation & food sources	% of total HHs	Profitability of investment (ETB)	
		Crop farm	Livestock farm
Only livestock commercial oriented (CCO=0, LCO=1)	18.64	2.16	34.78
Only crop commercial oriented (CCO=1, LCO=0)	27.12	7.53	6.82
Crop & livestock commercial oriented (CCO=1, LCO=1)	10.51	4.63	39.21
Subsistence production oriented (CCO=0, LCO=0)	43.73	2.31	4.15
Consume only purchased foods (PF=1; OF=0)	1.02	1.68	11.51
Consume only own-produced foods (PF=0; OF=1)	2.37	2.76	5.42
Consume purchased & own-produced foods (PF=1; OF=1)	96.61	4.00	14.51

Source: Own survey data 2020. HHs=households, CCO=crop commercial oriented, LCO=livestock commercial oriented, PF=purchased foods, OF=own-produced foods.

The role of commercialization orientation of smallholder farmers on HFS was, therefore, evaluated not only based on analyzing its total effect in FCS of all foods consumed by the household using a conventional Tobit approach, but also assessed decomposing the FCS from purchased and own-produced foods as dependent variables to identify transmission channels of AC to HFS, as well as controlling for the potential endogeneity problem. Addressing the latter aspect calls for use of a bivariate Tobit, capable of jointly estimating all the parameters of interest, besides providing evidence whether trade-off/synergy effect AC has occurred between consumption of purchased and produced foods. To enhance robustness of the results, we also used HDDS as an additional HFS indicator, measured in terms of counts of food groups the household consumed in the last 24 h, for which a Poisson model was adopted to analyze impact of AC on HDDS.

As has been discussed, share of crop income to agricultural income (C_i in Equation 2.1) was an indicator used to measure commercialization in a way to grip the relative importance of crop and livestock commercialization to HFS that most studies were limited in addressing. C_i represented level of crop commercialization relative to AC (so-called relative crop commercialization, henceforth), so an increase in this level would also mean a decrease in livestock commercialization relative to AC (so-called relative livestock commercialization). While analyzing the effect of C_i on HFS, we also tested whether it was an endogenous explanatory variable or not. Attempting to check such endogeneity through a control function approach, we followed the two-stage method adopted from [24,26,42] by introducing the generalized residual and expectation of relative commercialization index ($\widehat{C_i}$) into Equations (2.10-2.14). We found the generalized residual was statistically insignificant, verifying that there was no endogeneity bias (despite this result not being shown in this paper), and, hence, a direct estimation of the original model of bivariate tobit specified in Equations (2.10-2.14) would yield consistent estimates.

Like food consumption, commercialization orientation is an outcome of a two-step decision process, as Bellemare and Barrett [43] revealed regarding rural households in developing countries making market participation and volume decisions sequentially. First, the farmer decides whether to choose to sell part of any agricultural (crop/livestock) output. Then, the intensity of market participation conditional on such choice must be assessed. The rate of market participation is the percentage of households that actually sell any of their agricultural output, while the intensity of market participation is the level of output sold by the household who participated in the market. As detailed above, this paper measured market participation levels of households with two indices: crop output market participation index (COMPI) and livestock output market participation index (LOMPI). Thus, as justified above, at least 50% of total amount of crop output sold (COMPI $\geq$ 0.5) and 10% or more of the total amount of their livestock output sold (LOMPI $\geq$ 0.1) were the thresholds for market participation level used to define commercialization orientation of households in their crop and livestock production conditional on positive values. Application of a censored simultaneous-equations framework was preferred for joint analysis of factors influencing crop and livestock commercialization of smallholders. However, we needed to replace the commercialization outcomes instead of the consumption outcomes as dependent variables, and exclude the C_i variable in the system of equations in this case.

2.3.5. Definition and Measurement of Independent Variables

Table 2.2 presents definition and measurement of independent variables used in the econometric analyses and expected signs of their relationships with outcomes.

Table 2.2. Definition, measurement and expected sign of variables used in econometric analyses

			Expected effect		
Variables	**Descriptions**	**Measurements**	**CCO**	**LCO**	**HFS**
rcci	Relative crop commercialization index	Continuous (ranging 0 to 1)			+/−
profcrop	Profitability of crop farm	Net return per input cost	+		
proflvst	Profitability of livestock farm	Net return per input cost		+	
cdim	Crop diversity index in Meher season	Count	−		+
cdir	Crop diversity index in irrigation season	Count	−		+
ldi	Livestock diversity index	Count		−	+
aghd	Age of household head	Years	+/−	+/−	+
aghdsq	Age of household head squared	Continuous	+/−	+/−	+/−
edhdy	Education of household head	Years of schooling	+	+	+
edmoy	Education of mother	Years of schooling	+	+	+
dmalhd	Male headed household	Binary (1 if male headed)	+/−	+/−	−
hszn	Family size	Persons per HH (num.)	−	−	−
owculha	Own cultivated land size	Hectares	+	+/−	+
ldri	Land rented-in index (tenancy)	Continuous (ranging 0 to 1)	+/−	+/−	+/−
crac	Access to credit services	Binary (1=yes, 0=no)	+	+	+/−
ofia	Access to off-farm income	Binary (1=yes, 0=no)	+	+	+/−
mtd	Travel distance to nearest town market	Walking hours	−	−	−
plm	Presence of food market in the village	Binary (1=yes, 0=no)	+	+	+
rodac	Access to all weather road	Binary (1=yes, 0=no)	+	+	+
extac	Access to agri-extension services	Binary (1=yes, 0=no)	+	+	+
irac	Access to irrigation water	Binary (1=user,0=nonuser)	+	+/−	+

Source: Literature review and authors ‘understanding and experiences.

2.4. Results and Discussion

2.4.1. Descriptive Results

All sample households had cultivated crops and 97% of them also raised livestock during the 12 months period covered by the survey, indicating that mixed farming systems characterized the agricultural production in the study areas. Almost 99% produced staple crops, 31% pulses, 48% vegetables, 16% fruits and 28% cash crops. Among which the proportion of households commercially oriented in production of staple crops recorded 32%, pulses 37%, vegetables 76%, fruits 75% and cash crops 92%; this was by definition of a household as being commercially oriented in crop production if it sold at least 50% of the total volume it produced in a year. While 99% of our sample sold some part of their farm produce, around 56% of the crop output and 86% of livestock output were kept for home consumption and other purposes. This suggested that commercialization was limited in terms of the volume of marketed surplus. The average household sold 42.5% of its farm output in our case in northwest Ethiopia, which was similar to a study in western Kenya [26], which reported the typical household sold 44% of its farm output.

If we sub-divided our sample into commercialization quartiles to compare the 25% most commercialized with the 25% least commercialized households, this share ranged between 26% for the least commercialized and 59% for the most commercialized households. Overall, around 40% of households sold more than half of the total farm output they produced, despite the share of output sold varying by type of crops grown. More than 28% of our sample cultivated at least one type of cash crop. The cash crop production accounted for 3.2% of the total volume and 9.4% of the total area coverage of crop production and for 16% of total crop income. This meant that the sales of food crops generated larger total cash income than the sales of cash crops.

The sample farms were highly diversified and produced about 34 different crop species and 12 livestock species in the study communities. They produced a number of varied food crops, such as maize, millet, teff, wheat, barley, beans and peas. Many also kept chicken, sheep, goats, cattle and sometimes beekeeping. In terms of cash crops, the crops grown included kchat, coffee, hops, sugarcane, and fruit and vegetables (such as avocado, mango, papaya, potato, onion and potato). Despite high agricultural diversification in the study areas, a large proportion of households (23.4%) were food insecure, among which 19% were moderately FI and 4.4% were severely FI. This suggested not just self-production in the context of AD for own consumption could address FI, as commercialization of agriculture could also play a critical role in the link between agriculture and FS. More than 56% of households were commercially oriented in their agricultural production.

We used a one-way parametric ANOVA and Pearson's chi-squared test statistics to assess differences in household characteristics observed in quantitative and qualitative terms, respectively, across commercialization orientation and food security categories.

2.4.1.1 Commercialization orientation, food source diversity and profitability

Assessing commercialization orientation of households is essential for understanding the relative importance of commercially-oriented and subsistence production to HFS. To facilitate comparisons by commercialization orientation in descriptive analysis, households were disaggregated into four groups, based on crop and livestock output market participation levels: subsistence production oriented (SPO), crop commercial oriented (CCO), livestock commercial oriented (LCO), and full commercial oriented (FCO). As detailed above, these groups were constructed based on the thresholds of the two indices (COMPI and LOMPI). SPO households were those with values of COMPI $<$ 0.5 and LOMPI $<$ 0.1. LCO households were those with COMPI $<$ 0.5 and LOMPI $\geq$ 0.1 and CCO were those with COMPI $\geq$ 0.5 and LOMPI $<$ 0.1. Those with COMPI $\geq$ 0.5 and LOMPI $\geq$ 0.1 were FCO i.e., commercially oriented both in crop and livestock production.

Table 2.1 presents the extent of households and profitability of crop and livestock farm investments across commercialization orientations and food source diversity. A total of four combinations of commercialization orientations and three combinations of food source diversity were observed. Among the sample households (n=295), around 19% were LCO only, 27% CCO only, more than 10% were commercially oriented in both crop and livestock production (FCO), and a significantly higher share (44%) were subsistence-oriented (SPO) in their agricultural production. Overall, households commercially oriented in livestock, crop, and either in crop or livestock production comprised 29.15, 37.63 and 56.27%, respectively. More than 56% of the households were commercially-oriented in their agricultural production. The majority (96.6%) consumed both purchased and own-produced foods, whilst few, about 1%, consumed only purchased foods and 2.4% only own-produced foods.

Regarding profitability, for each ETB invested in a crop farm it was the CCO group that received the highest return (7.53 ETB), followed by FCO (4.64 ETB) and more than 2.31 ETB was earned by the SPO group. Whereas each ETB invested in livestock production would significantly imply higher returns in commercially oriented groups over their counterparts, more importantly in FCO and LCO groups. Households that consumed both purchased and produced foods were those who received the highest return from crop and livestock farm investments (see Table 2.1 at the bottom). This suggested that profitability of the farm investment might have positive implications on a household's decision to move towards commercialization of agriculture as expected.

2.4.1.2 Demographic and socioeconomic characteristics

Characteristics of households across commercialization orientation and food security status are presented in Table 2.3. Majority of the households comprised male headed families, around 91%. No significant difference was observed in sex of heads across AC and FS strata. The mean age of household heads was about 47 years. The younger the household head the higher would be the propensity of the household to be commercially oriented. However, they seemed similar in their ages across FS and FI groups. In terms of education, household heads completed on average 2.52 years of schooling. All the commercially oriented groups were found to be better in formal education (between 2.6 and 4.1 years) than their counterparts (1.6 years) at 1% significant level. The education level of heads might enhance the likelihood of households becoming commercially oriented, and, hence, food secure.

Family size was the other variable expected to play a crucial role in agricultural decision making. The mean family size among sample households was 6.27 persons per household, ranging from 1-14. While FCO and LCO groups implied a significantly larger family size, both in terms of numbers and adult equivalents, than the SPO group, lower size of family was observed by the CCO group at $p = 0.029$ and $p = 0.04$, respectively. The family size was higher in the FI group than its counterpart at $p = 0.03$, as expected.

Dependency ratio averaged to be 33.3% among sample households, despite not varying significantly across commercialization and FS strata. The larger the family size the more likely the family was to engage in agricultural commercialization, and, hence, attract larger families. This suggested the larger the family size the higher would be the likelihood of households to be engaged in commercialization, both in crop and livestock production. Households reporting crop farming as their main livelihood were more likely to be CCO (71%) and, hence, FS (63%) more than SPO (51%). Whilst those whose main livelihood were mixed (crop and livestock) farming would tend to be LCO (62%), which, on the contrary comprised a larger share of FI (48%) than FS (35%). Livestock ownership might also swell the propensity of the household to be commercially oriented, both in crop and livestock production.

Table 2.3. Household characteristics by commercialization orientation and FS status

Characteristics	Commercialization orientation					FS status	
	SPO	LCO	CCO	FCO	*p*-Value	FI	FS
Sex of HH head (1 = male)	88.37	96.36	91.25	93.55	0.345	91.30	91.15
Age of HH head (years)	48.37	46.96	44.11	44.65	0.027 **	46.91	46.46
Education of HH head (years)	1.58	2.64	3.34	4.06	0.000 ***	1.83	2.73 **
Family size (persons)	6.38	6.62	5.69	6.68	0.029 **	6.75	6.12 **
Family size (AEU)	4.93	5.10	4.36	5.23	0.040 **	5.13	4.74
Dependency ratio (%)	32.16	35.04	31.78	38.73	0.268	32.79	33.44
Crop farming as main livelihood (%)	65.12	36.36	71.25	54.84	0.000 ***	50.72	63.27 *
Mixed farming as main livelihood (%)	33.33	61.82	26.25	41.94	0.000 ***	47.82	34.51 **
Others as main livelihood (%)	1.55	1.82	2.5	3.23	0.926	1.45	2.21
Total cultivated land (ha)	1.45	1.64	1.57	1.80	0.058 *	1.44	1.59
Own cultivated land (ha)	1.33	1.20	1.48	1.55	0.028 **	1.09	1.45 ***
Rented-in to cultivated land (% ha)	6.83	24.10	5.34	10.05	0.000 ***	16.87	7.88 ***
Livestock owned (TLU)	5.47	5.88	4.67	6.59	0.005 ***	5.08	5.56
Distance to nearest town market (hrs)	2.28	2.97	1.99	2.10	0.000 ***	3.17	2.04 ***
Presence of local food market (1=yes)	77.52	81.82	97.50	96.77	0.000 ***	59.42	93.81 ***
Access to all weather road (1=yes)	42.64	41.82	58.75	74.19	0.003 ***	52.17	49.56
Access to credit service (1=yes)	48.84	76.36	63.75	83.87	0.000 ***	44.93	66.81 ***
Access to off-farm income (1=yes)	27.13	29.09	52.50	67.74	0.000 ***	15.94	45.58 ***
Access to extension service (1=yes)	87.60	87.27	92.50	93.55	0.557	89.86	89.38
Access to irrigation water (1=yes)	72.09	52.73	55.00	58.06	0.023 **	72.46	59.29 **
Bahidar Zuria district (1=yes)	41.43	17.14	28.57	12.86	0.000 ***	14.29	85.71 ***
Dangla district (1=yes)	51.33	25.33	12.67	10.67	0.000 ***	36.00	64.00 ***
Bure district (1=yes)	30.67	6.67	54.67	8.00	0.000 ***	6.67	93.33 ***
Number of observations	129	55	80	31		69	226

Source: Survey data 2020. AEU=Adult equivalent unit; TLU=Tropical livestock unit. *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$.

Households with a larger farm size were expected to produce better marketable surplus over what was needed for own consumption, and were more likely to be CCO and, hence, FS. The mean area of land cultivated by the household was estimated to be 1.56 ha, ranging 0.25 to 4 ha. Among which own land comprised 90% (1.37 ha) and rented-in land 10% (0.19 ha). The size of land cultivated by all the commercially oriented groups was significantly larger than their counterpart. The FCO group recorded the largest (1.8 ha), LCO (1.64 ha) and CCO (1.57 ha) and more than 1.45 ha was cultivated by the SPO group, despite not varying significantly across FS status.

Access to land market (proxied by intensity of rented-in land), labor market (proxied by access to off-farm employment), and access to credit were among factor market participation indicators expected to affect both commercialization orientation and food security of households positively. Assessing the role of land transactions among farm households is indispensable for most African countries, particularly in Ethiopia, where land reform has almost been absent for a number of decades. Participation in the land market (so-called intensity of tenancy) was defined in this study as a proportion of rented-in (or shared-in) land to total area of cultivated land by the household. The intensity of tenancy was significantly highest in LCO (24%), followed by FCO (10%), SPO (6.83%) and CCO (5.34%). This might imply the larger the size of own farmland with secure rights increased the propensity of households to be commercially oriented (FCO or CCO) and FS was more than offset by the expanded land market in cultivated land with a rented-in approach, which was so expensive. On the other hand, participation in the land market seemed to enhance the likelihood of households to be LCO. This might be because households sold their livestock in need of income to share the burden of tenancy.

Similarly, the intensity of tenancy was significantly higher in the FI group (17%) than its counterpart (8%), by more than two folds. This might also suggest households with larger cultivated land (1.64 ha) but comprising smaller own farmland (1.2 ha) with a larger share of rented-in land (24%) would tend to be LCO (Table 2.3), which, in turn, might increase the affinity of this household FI from 23 to 42% (Table 2.4). Put differently smaller landownership may not be offset to the extent the FI household becomes FS by expanding the land to be cultivated by 18.4% (0.35 ha) due to land transactions.

Table 2.4. FS, expenditure and income related indicators by commercialization and FS status

Characteristics	Commercialization Orientation					FS Status	
	SPO	LCO	CCO	FCO	*p*-Value	FI	FS
Food consumption score (FCS)	55.5	52.1	55.9	61.6	0.119	33.8	62.3 ***
Household FS status (1 = FS, 0 = FI)	76.7	58.2	85.0	87.1	0.001 ***		76.6
Contribution of purchased foods (% FCS)	54.0	53.2	59.9	47.8	0.053 *	57.3	54.1
FCS of purchased foods	29.9	25.7	32.8	28.4	0.029 **	19.6	32.9 ***
FCS of own-produced foods	25.6	26.3	23.1	33.2	0.031 **	14.2	29.4 ***
Total HH expenditure ('000 ETB/y)	54.2	68.0	47.0	65.7	0.000 ***	64.0	53.5 **
Share of food exp. to total exp. (%)	29.9	22.23	23.2	25.6	0.655	21.0	23.9 *
Share of nonfood exp. to total exp. (%)	53.7	58.82	51.1	50.7	0.031 **	60.2	51.6 ***
Total HH income ('000 ETB/y)	23.0	56.0	88.7	143.5	0.000 ***	45.7	67.8
Share of agri-income to total income (%)	95.0	96.4	93.3	92.6	0.478	99.0	93.2 ***
Household income PAE (ETB/y)	6912	13192	24919	30686	0.000 ***	10815	16888
Crop output market participation index	0.27	0.31	0.67	0.64	0.000 ***	0.37	0.44 **
Livestock output market participation index	0.01	0.25	0.01	0.22	0.000 ***	0.11	0.07 *
Agricultural income ('000 ETB/y)	27.7	52.9	84.1	80.5	0.000 ***	45.0	55.7
Share of crop income to agri-income (%)	76.6	43.5	88.4	64.6	0.000 ***	63.3	75.1 ***
Number of observations	129	55	80	31	295	69	226

Source: Survey data 2020. Note: Average exchange rate in 2020: 1 USD = 34.9505 ETB; PAE = Per adult equivalent; FS = food secure, FI = food insecure. *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$.

Regarding other factors, around 62 and 39% of households reported they had better access to credit and off-farm employment, respectively. All commercially oriented groups showed better position in access to both credit and off-farm employment than the SPO group. This might imply that better access to credit increased the propensity of households to be commercially oriented to 84% from 49% being subsistence oriented in their farm production, which might, in turn, enhance the likelihood of the household FS (67%) more than it would be FI (45%) (Table 2.3). Better access to off-farm employment, on the other hand, raised the affinity of households to being commercially oriented from 27 to 68% and might also imply the FS households growth from 16 to 46%. This suggested access to factor markets (such as credit and labor) might have positive implications for household to be commercially oriented and FS.

Liquidity constraint or limited access to output markets was the other aspect that had to be assessed, as it can play a part in whether a household remained SPO and FI. Access to output markets was measured in this study using three indicators: distance to the district town market, quality of the road infrastructure connecting the village to the main road and presence of a local food market in the village. Whereas participation of households in output markets was measured with two indices: COMPI and LOMPI. The longer travel distance from market, the lower road quality and absence of local food market were hypothesized to affect commercialization adversely, which, in turn, would have negative implications on HFS. CCO and FCO groups reported lower walking hours required to reach the nearest town market in order 1.99 and 2.1 than the 2.28 h reported by their counterparts, despite longer hours by the LCO group (2.97).

Similarly, a significantly higher share of households in FCO (74%) and CCO (59%) groups reported better access to quality roads (functioning in all dry and wet weathers) than their counterparts (43%), yet a lower rate was observed in the LCO group (42%). Regarding the presence of a local food market, a larger proportion of households from CCO and FCO groups (97% each) reported the existence of a local food market, followed by LCO group (82%), with more than 77% reported by the SPO. This suggested the presence of a local food market increased the likelihood of the household being commercially oriented (CCO or FCO) from 78 to 98% and, hence, FS from 59 to 84%, whilst access to quality roads improved the propensity of the household to be commercially oriented from 43 to 74%. However, all the groups seemed similar regarding access to extension services, while the SPO group showed better access to irrigation (72%) than their counterparts (53–58%), a pattern that needs more study to understand it better. Disaggregating households by districts, households in Bure were more likely to be crop commercial oriented, whereas subsistence production was the dominant orientation of households in Bahirdar Zuria and Dangla districts.

Additionally, households characterized in terms of FS, expenditure and income related measures by commercialization orientation and FS strata are presented in Table 2.4. The mean FCS of the sample households was estimated to be 56, ranging between 22–100.5. Although a higher mean implied better FS and a lower mean less FS, the mean value of FCS could not reflect the FI prevalence in absolute terms. This required derivation of a qualitative indicator (so-called FS status) from FCS to categorize households so as to generate information making it simple to understand the FI prevalence qualitatively. As indicated in Equation (2) FS status is a binary variable with a value of 1 if a household is FS (i.e., FCS > 42) and 0 if it is FI (FCS ≤ 42). We found 76.6% of households were FS while the FI recorded 23.4%, among which about 19% were moderately FI and 4.4% were severely FI. The propensity of fully or crop commercial oriented households to be FS increased from 77% to 85–87%, despite reducing to 58% for households commercially oriented in livestock production (Table 2.4).

To differentiate HFS impacts of commercialization orientation as to whether it had been through increased consumption of purchased foods with or without replacing own-produced foods, as well as to identify which commercialization orientation was more important for better HFS, the overall FCS of households was disaggregated into FCS from own-produced foods and purchased foods. Assessing such an issue in absolute terms implied that the FCS derived from both purchased and own-produced foods consumed by the household in the FS group were 33 and 29, which were significantly higher than 20 and 14 in the FI group.

The contribution of purchased foods to household FCS averaged at 55%; this figure was significantly higher among CCO households (60%) and lower in LCO (53%) and FCO (48%) and 54% among SPO households. This suggested crop commercialization might affect HFS positively through nurturing consumption of purchased foods, whereas livestock commercialization might improve HFS by enhancing consumption of own-produced food crops. The lower share of purchased foods to FCS of LCO and FCO groups would also mean better share of FCS from own-produced foods. Such results were also confirmed by a higher rate of food expenditure to total expenditure by CCO (23.2%) and FCO (25.6%) groups and a lower rate by LCO group (22.2%) than 23% by their counterpart. On the other hand, the LCO group spent a significantly larger share of non-food expenditure (59%) whilst the CCO and FCO groups spent a lower rate (51% each) than the 54% that was incurred by the SPO group, moving a step forward the view that LCO fosters own food crops consumption by allowing households to finance non-food expenditure.

The annual total expenditure of households in the year 2020 averaged at 55,986 ETB (1602 USD). Food and non-food expenditure shared around 23.2 and 53.6%, respectively. While the mean annual income a typical household earned in the study areas was estimated to be 62,658 ETB (1793 USD), of which agricultural income was responsible for 94.5%. The contribution of agriculture to total annual income of the household was significantly higher in the FI group (99%) than its counterpart (93%). Characterizing households into FS and FI, in terms of their expenditure and income, implied that the share of food expenditure to total expenditure was significantly larger in FS group (24%) than in FI (21%) at 10% level. By contrast, the non-food expenditure shared about 60% of total expenditure in FI group overweighed the 52% that was in FS group significantly at 1% level. AC improved not just overall annual income of households but also enhanced the income per adult equivalent by more than two folds of its counterpart.

Regarding market participation indicators, we found all commercially oriented groups recorded better COMPI than their counterparts, even by more than two folds in the cases of CCO and FCO groups. LOMPI also showed a similar pattern of a significantly higher value in LCO and FCO groups than their counterparts. While the former participation implied a positive effect on HFS, the latter might affect HFS adversely. This did not necessarily suggest participation in crop output markets could significantly improve HFS while participation in livestock markets significantly affected HFS adversely, due to issues of heterogeneity in unobserved and other observed factors and censorship, which is addressed well in the econometric results section later using a bivariate Tobit model. The income the households earned annually from farming activities was significantly higher among all commercially oriented groups than their counterparts, and AC increased household income. The relative importance of each commercialization on HFS could be captured using a relative crop commercialization index (i.e., share of crop income to agricultural income) as an indicator. An increase in crop income relative to agricultural income implied the propensity of the household to be FS (75%) and was significantly higher than 63% that would have been FI.

2.4.2. Econometric Results

This subsection presents and discusses the results of econometric models applied in the current study to evaluate the link between commercialization orientation and food security of households, as well as to identify joint determinants of commercialization orientation of households in their crop and livestock production.

2.4.2.1 Commercialization and food security nexus

Estimation results of Tobit and Poisson regression models are presented in Table 2.5. Ceteris paribus, when relative crop commercialization level was larger by one unit, the FCS of purchased foods (FCS_{PF}) was also larger by 3.58 units, significantly lower in magnitude than it lowered the FCS of own-produced foods (FCS_{OF}) by 9.46 units, which ultimately implied the net reduction of FCS by 6.42 units. This, on the other hand, meant that commercialization orientation in livestock production was more important than in crop production for better HFS. As the converse reflected relative livestock commercialization, a unit rise in its level reduced the FCS_{PF} by 3.58 units, while improving the FCS_{OF} by 9.46 units resulting in a net increment of HFS by 6.42 units in FCS. Despite not being significant in magnitude, the Poisson result also showed the same direction of implication that confirmed LCO potentially improved HDDS whilst CCO was against it. Overall, this suggested CCO impacted HFS positively via increased consumption of purchased foods, whereas LCO improved HFS with better consumption of own-produced food crops.

Despite most studies evaluating commercialization focusing mainly on either crop or livestock production, the works in Kenya [26], Cambodia [32], Tanzania [36] and the Great Lakes of Central Africa [44] confirmed participation of smallholder farmers in crop output markets improved HFS and dietary quality through increased consumption of purchased foods. It also seems consistent with [26] claiming commercialization does not reduce consumption of nutrition from own-produced foods, which, in our case, was exhibited in commercialization in livestock production helping sustain consumption of diversified food crops from own production. This suggested that the higher the level of CCO the more market oriented the crop farm towards selling majority of its produce, exceeding the pace of earned income translating into purchases of diversified foods for consumption, ultimately implying CCO impacts HFS adversely. This may work as [45] revealed in Zambia, in areas with less everyday access to a range of food items, where capital accumulation alone may not help avoid deficiencies in HFS.

In livestock farming as well, the higher the level of LCO the more market oriented in selling more of its produce; enhancing consumption of own-produced food crops, this being significantly higher than the rate it could hamper consumption of purchased foods potentially made through crop sales, as the household becomes commercially oriented in livestock production, which would eventually result in better HFS.

Table 2.5. Estimation results of Tobit, bivariate Tobit and Poisson regression models

Variables	Tobit	Bivariate Tobit		Poisson
	FCS	FCS_{PF}	FCS_{OF}	HDDS
rcci	−6.42 (3.80) *	3.58 (3.13)	−9.46 (3.45) ***	−0.007 (0.054)
cdim	1.41 (0.87) *	−1.60 (0.78) **	2.90 (0.85) ***	0.066 (0.013) ***
cdir	−2.80 (0.61) ***	−1.69 (0.68) **	−1.20 (0.75) *	−0.014 (0.012)
ldi	2.15 (0.53) ***	−0.05 (0.44)	2.23 (0.48) ***	0.011 (0.007)
aghd	−1.76 (0.72) **	−0.57 (0.59)	−1.17 (0.65) *	−0.024 (0.01) **
aghdsq	0.02 (0.007) **	0.005 (0.006)	0.013 (0.007) **	0.0002 (0.0001) **
edhdy	−0.03 (0.34)	−0.43 (0.29)	0.43 (0.31)	0.008 (0.005)
edmoy	0.78 (0.43) *	0.17 (0.36)	0.57 (0.40)	0.003 (0.007)
dmalhd	1.00 (2.83)	1.88 (2.89)	−1.12 (3.19)	−0.019 (0.06)
hszn	0.29 (0.54)	0.20 (0.45)	0.11 (0.49)	0.005 (0.006)
owculha	2.79 (1.99)	3.92 (1.78) **	−0.98 (1.96)	0.015 (0.03) ***
ldri	−0.97 (6.42)	2.10 (4.69)	−2.84 (5.16)	−0.14 (0.083) *
crac	0.63 (2.16)	1.33 (1.74)	−0.83 (1.92)	0.007 (0.03)
ofia	−1.69 (2.07)	3.05 (1.77) *	−4.71 (1.94) **	−0.009 (0.03)
plm	10.23 (3.27) ***	6.92 (2.71) **	3.08 (3.02)	−0.013 (0.04)
mtd	−3.89 (0.75) ***	−1.08 (0.72)	−2.92 (0.79) ***	0.023 (0.01) *
rodac	0.20 (1.92)	0.64 (1.66)	−0.35 (1.83)	0.016 (0.03)
extac	−5.33 (3.02) *	−1.16 (2.84)	−4.87 (3.12)	0.058 (0.03)
irac	6.24 (2.75) **	−1.58 (2.49)	7.82 (2.74) ***	−0.068 (0.04) *
_cons	82.68 (17.85) ***	38.33 (14.56) ***	44.06 (16.01) ***	2.17 (0.25) ***
σ_1			12.64 (0.53) ***	
σ_2			13.92 (0.58) ***	
ρ_{12}			−0.71 (0.12) ***	

Source: Survey data 2020. Wald $chi^2(19) = 68.15$; Prob > $chi^2 = 0.000$; robust standard errors are in parentheses; FCS=food consumption score; FCS_{PF} =FCS of purchased foods; FCS_{OF} =FCS of own-produced foods. *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$.

In order to capture issues of seasonality and the role of irrigation on HFS, the current paper tried to look at agricultural production (i.e., agricultural diversification) variables decomposed into crop diversity (further disaggregated into Meher and irrigation seasons) and livestock diversity. As Table 2.5 shows a one unit increase in Meher (rainy) season crop diversity implied a net increment of HFS by 1.4 units in FCS, as the positive effect of rising FCS_{OF} by 2.9 units overweighed in magnitude its adverse effect on crop commercialization being reduced FCS_{PF} by 1.6 units, controlling for confounding factors.

The Poisson result also confirmed diversification of crop production in Meher season had positive implication on HDDS. Nevertheless, crop diversification in irrigation (dry) season affected HFS negatively, as this index increased by one-unit HFS reduced FCS by

2.8 units. On the other hand, livestock diversity improved HFS, directly enhancing consumption of own-produced foods. Here can be understood diversification of crops to a certain level would have positive implication on HFS if it were during Meher season, but crop specialization in the dry season improved HFS, because diversification in the latter season impacted both purchased and produced foods consumption adversely. A slightly similar result was revealed in Mali [37] where diversification of farm production after a certain level may not be an effective strategy to improve dietary diversity of smallholder farmers, and rather better access to markets, productivity-enhancing inputs and technologies were more important.

The bivariate Tobit results also demonstrated that other determinants of HFS, with varying level of influence, included education of mothers, size of own farmland, presence of local food market in the village and access to irrigation, which affected HFS positively as expected, while age of household head, distance to the nearest road/town market and access to extension influenced HFS adversely. The latter variable implied a pattern that would require more study to understand. However, other covariates, such as sex of household head, family size, access to credit and quality of the road infrastructure, would not have significant influence on HFS.

As age of household head increased HFS decreased even at the increasing rate at older ages. This was due to reducing consumption of own-produced foods. The descriptive analysis above also confirmed that families with younger heads were more likely to be commercially oriented as they might be more productive and, hence, would be better in HFS than those headed by elders. Similar results in Pakistan [46] and Nigeria [47] revealed that as the household head advances in age the propensity of the household to become food insecure rises.

Regarding education, formal education level of mothers significantly improved HFS by enhancing consumption of both own produced and purchased foods. It was also consistent with FAO *et al.* [1] that argue children in rural settings and poor households, whose mother received no formal education, were more vulnerable to stunting and wasting. By contrast the head's education level seemed to improve subsistence consumption and discouraged consumption of purchased foods, despite not being significant in magnitude.

Size of own farmland had positive implications on HFS in terms of increased consumption of purchased foods by encouraging crop commercialization, whereas land transactions seemed to influence HFS negatively in terms of HDDS. The descriptive result confirmed that land area owned with secure rights could improve HFS and had been more than offset by expanding the land to be cultivated through a rented-in approach being so expensive. The previous work in Cambodia [32] was consistent with this finding, implying that size of land owned instead of the overall cultivated land has important implication as the latter has more potential for endogeneity.

The positive effect of off-farm employment on HFS enhancing consumption of purchased foods and its negative effect on HFS reducing consumption of own-produced foods being strong seemed to yield a net reduction of HFS in overall FCS and HDDS. In line with other studies in Ethiopia [27,48] and in India [49], our finding seemed to reflect the context of the farming systems in most developing countries for the fact that the majority of households engaged in off-farm activities were those which were less food secure and resource deficit. They used off-farm activities as a coping strategy for food insecurity. On the other hand, this suggested off-farm employment could improve HFS through making smallholder agriculture commercially oriented instead of being subsistent.

Similarly, presence of a local food market in the village enhanced HFS, mainly due to increased consumption of purchased foods resulting from improved commercialization of agriculture. The other indicator of access to markets was the travel distance (in waking hours) required to reach the nearest main road or town market revealed. A travel distance larger by one hour in HFS was lowered by 4 units of FCS. The longer the distance the farmer resided from the nearest main road or town market the less market integration and the higher would be the transaction costs influencing HFS adversely, mainly due to limited commercialization. However, this was mainly due to reduced consumption of own produced foods, which is a pattern that also needs further study to understand.

Access to irrigation, on the other hand, enhanced HFS as expected mainly through increased consumption of own produced foods. Furthermore, a statistically significant and positive sign on the constant underscores would be unobserved factors that tended to influence HFS positively. Table 2.5 shows at the bottom, $(\rho_{12} = -0.71)$, that as commercialization orientation of farmers improved there would be trade-off between consumption of purchased and own-produced foods statistically significant at 1% level. This showed evidence on the relevance of bivariate Tobit to capture such a non-recursive interdependence between consumption of purchased and own-produced foods resulting from commercialization.

2.4.2.2 Factors influencing commercialization orientation

We employed a bivariate Tobit model again for joint determination of factors influencing crop and livestock commercialization orientation among smallholder farmers. Table 2.6 in column 2 presents profitability of crop farm, irrigation season crop diversification, education level of household head, size of own farmland, access to credit, access to off-farm employment, presence of local food market in the village and quality of the road infrastructure as factors identified to enhance transition of smallholder farmers from subsistence to commercial oriented crop production. In contrast, we found Meher season crop diversification, rented-in land and access to irrigation were among the factors impacting CCO adversely, the latter two showing a pattern that would require more study to understand.

Table 2.6. Joint determination of factors influencing CCO and LCO: A bivariate Tobit model

Variables	CCO			LCO		
	Coef.	**Std. Err.**	***p*-Value**	**Coef.**	**Std. Err.**	***p*-Value**
profcrop	0.018 ***	0.004	0.000			
proflvst				0.006 ***	0.0009	0.000
cdim	−0.049 **	0.025	0.050			
cdir	0.049 **	0.022	0.027			
ldi				0.108 ***	0.022	0.000
agehd	0.017	0.018	0.348	0.043	0.031	0.161
aghdsq	−0.0003	0.0002	0.177	−0.0005	0.0003	0.146
edhdy	0.019 **	0.009	0.032	0.004	0.014	0.778
edmoy	−0.009	0.011	0.454	0.011	0.018	0.519
dmalhd	0.045	0.091	0.619	0.032	0.154	0.835
hszn	−0.018	0.014	0.190	0.010	0.022	0.658
owculha	0.108 *	0.056	0.052	−0.067	0.077	0.384
ldri	−0.265 *	0.147	0.071	0.367 *	0.219	0.093
crac	0.100 *	0.055	0.067	0.151 *	0.086	0.080
ofia	0.129 **	0.057	0.023	−0.014	0.087	0.871
plm	0.258 ***	0.087	0.003	−0.237 *	0.133	0.075
mtd	−0.0007	0.022	0.976	0.087 ***	0.031	0.005
rodac	0.157 ***	0.052	0.003	0.127	0.080	0.113
extac	−0.013	0.089	0.886	0.173	0.147	0.237
irac	−0.167 **	0.079	0.035	0.047	0.088	0.597
_cons	−0.225	0.453	0.620	−1.896 **	0.749	0.011
σ_1	0.401 ***	0.017	0.000			
σ_2	0.553 ***	0.032	0.000			
ρ_{12}	0.036	0.106	0.735			

Source: Survey data 2020. *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$. Wald $chi^2(18) = 146.6$; Prob > $chi^2 = 0.000$.

Table 2.6 in column 5 presents estimates of variables expected to affect LCO of smallholders. Profitability of livestock farm, livestock diversification, rented-in land, access to credit and distance to district town market influenced LCO positively. Presence of local food market in the village was the only factor observed to affect LCO negatively. AS significantly negative sign on a constant implied there would be unobserved factors that tended to affect LCO adversely. As also seen in Table 2.6 at the bottom, there was no statistically significant interdependence between CCO and LCO.

The profitability of crop farm and livestock farm investment would have positive implication on commercialization behavior of households in crop and livestock production, respectively. This was consistent with the descriptive analysis showing households commercially oriented in crop and livestock production received more than three and eight folds of the returns their counterparts earned from each ETB invested in crop and livestock farm, respectively (Table 2.1).

Assessing the effect of seasonal variation in production on crop commercialization orientation of smallholder farmers, we found diversification of crop production would have negative (positive) implication on crop commercialization if it were during rainy (irrigation) season, respectively. As diversification of crop production was larger in rainy season by one unit the level of crop commercialization lowered by 0.05 unit (Table 2.5), which, in turn, implies HFS reduced by 1.6 units of FCS from purchased foods (Table 2.6). By contrast, a one unit increase in diversification of crop production in dry season would improve crop commercialization level by 0.05 unit, which might then reduce HFS by 1.2 units of FCS from subsistence production. Access to irrigation was the other dimension that significantly influenced crop commercialization adversely, as also seen in

Table 2.5, and might imply it encouraged subsistence production, which seems a pattern that would need more study to understand.

Livestock diversification, on the other hand, had a direct implication on livestock commercialization; as livestock diversification rose by one unit commercialization of livestock improved by 0.1 units, which might, in turn, improve HFS by 2.2 units of FCS from self-produced food crops, by allowing households to finance their nonfood expenditures, as also supported by the descriptive analysis.

Education level of household head significantly affected crop commercialization positively but it did not significantly influence commercialization in livestock production. As land area owned by a household increased by 1 ha, level of crop commercialization improved by 0.1 units that consequently boosted HFS by 4 units of FCS from purchased foods. On the other hand, land transactions among farmers with a rented-in approach had negative implication on crop commercialization while it affected livestock commercialization positively. This might be due to the fact that farmers sold part of their livestock to share the burden of such tenancy in crop farm as the descriptive results also confirmed. Access to credit was the other factor that had a significantly positive effect on commercialization orientation of households in both crop and livestock production. Whereas access to off-farm employment positively affected crop commercialization, it did not significantly impact livestock commercialization.

While both availability of a local food market in the village and quality of the road infrastructure significantly improved crop commercialization, the former influenced livestock commercialization adversely but did not significantly affect the latter. Distance to district town market significantly influenced livestock commercialization positively, which seems a pattern that also seeks further study to understand. Education level of mothers, sex of heads, family size and access to extension were among the covariates considered that did not significantly affect the transition of agriculture from subsistence to commercially oriented production.

2.5. Conclusions and Implications

Estimates of econometric models on a relative crop commercialization index identified that livestock commercialization was more important than crop commercialization for achieving better HFS. Although CCO improved HFS through increased consumption of purchased foods, its adverse effect on subsistence consumption was significantly higher in magnitude, so ultimately it yielded a net reduction in HFS. By contrast, commercialization orientation in livestock production resulted in a net increment in HFS, as its synergy effect on crop diversification for own consumption strongly overweighed in magnitude its adverse effect in reducing consumption of purchased foods. This has crucial policy implications in food security and nutrition transition and further contributes to extant literature on agriculture–nutrition pathways.

Supporting investments in improving road infrastructure, both in terms of access and quality to function all weather conditions, establishing better access to institutional services (credit, extension, off-farm employment and land markets) and awareness creation for enhanced diversified food consumption are viable intervention areas to improve the role of AC to HFS for vulnerable households. Further increasing AD may not be the most effective strategy to improve HFS, as [12,13,37] confirmed, as diversification after a certain level might prevent gains from specialization that could, in turn, lead to income losses potentially affecting HFS adversely. Transformation of agriculture from subsistence to commercially oriented production seems to be more promising, similar to the findings of [13,14] who identified market access as more important than farm diversification for food security to improve. All these suggest AC is vital, not only for economic growth and improved wellbeing of households, but also because it plays a crucial role for the smallholder agriculture to be more nutrition sensitive.

While several tests confirmed robustness of our findings, a few limitations remain. The analysis was based on cross-sectional data limited to capture seasonal differences and identification strategy, and, as argued by [25], a household's FS position is dynamic with the possibility that a household that is FS today may not be so tomorrow and vice-versa. Using bivariate Tobit is limited to address the interaction effects between variables. Future studies with panel data considering changes in the level of AC and food security position of households over time and adopting the approach that can capture interaction effects, besides controlling for the complex relationship between variables in an integrative system, will enhance the robustness of the findings in AC–FS linkages. Additionally, some variables were found to be different from expected and when compared to other studies and need to be further researched.

Acknowledgments: The authors are grateful to all farmers and agricultural officials in the study districts for their dedicated participation in the study.

Conflicts of interest: The authors declare no conflict of interest.

References

1. FAO; IFAD; UNICEF; WFP; WHO. *The State of Food Security and Nutrition in the World 2022. Repurposing Food and Agricultural Policies to Make Healthy Diets More Affordable*; FAO: Rome, Italy. https://doi.org/10.4060/cc0639en.
2. Black, R.E.; Victora, C.G.; Walker, S.P.; Bhutta, Z.A.; Christian, P.; de Onis, M.; Ezzati, M.; Grantham-McGregor, S.; Katz, J.; Martorell, R.; et al. Maternal and child undernutrition and overweight in low-income and middle-income countries. *Lancet* **2013**, *382*, 427–451. https://doi.org/10.1016/S0140-6736(13)60937-X.
3. FAO. *State of Food and Agriculture 2013: Food Systems for Better Nutrition*; FAO: Rome, Italy, 2013.
4. COHE. The cost of hunger in Ethiopia: Implications in the Growth and Transformation Plan. In *The Social and Economic Impact of Child Undernutrition in Ethiopia Summary Report*; Central Printing Press: Addis Ababa, Ethiopia, 2012.
5. Ehui, S.; Pender, J. Resource degradation, low agricultural productivity and poverty in sub-Saharan Africa: Pathways out of the Spiral. *Agric. Econ.* **2005**, *32*, 225–242.
6. Wenhold, F.; Faber, M.; Van Averbeke, W.; Oelofse, A.; van Jaarsveld, P.; van RensburG, W.S.J.; van Heerden, I.; Slabbert, R. Linking smallholder agriculture and water to household food security and nutrition. *Water SA* **2007**, *33*, 327–336.
7. Allen, L.H. Interventions for micronutrient deficiency control in developing countries: Past, present and future. *J. Nutr.* **2003**, *133*, 3875S–3878S.
8. Haddad, L. A conceptual framework for assessing agriculture—Nutrition linkages. *Food Nutr. Bull*. **2000**, *21*, 367–373.
9. Hawkes, C.; Ruel, M. The links between agriculture and health: An intersectoral opportunity to improve the health and livelihoods of the poor. *Bull. WHO* **2006**, *84*, 984–990.
10. Ruel, M.T.; Quisumbing, A.R.; Balagamwala, M. Nutrition-sensitive agriculture: What have we learned so far? *Glob. Food Secur.* **2018**, *17*, 128–153.
11. FAO. *The State of Food and Agriculture 2014: Innovation in Family Farming*; FAO: Rome, Italy, 2014. Available online: http://www.fao.org/3/a-i4040e.pdf (accessed on 12 April 2022).
12. Hirvonen, K.; Taffesse, A.S.; Hassen, I.W. Seasonality and household diets in Ethiopia. *Public Health Nutr*. **2016**, *19*, 1723–1730.
13. Sibhatu, K.T.; Krishna, V.V.; Qaim, M. Farm Production Diversity and Dietary Diversity in Developing Countries. *Proc. Natl. Acad. Sci. USA* **2015**, *112*, 10657–10662.
14. Bellon, M.R.; Ntandou-Bouzitou, G.D.; Caracciolo, F. On-farm diversity and market participation are positively associated with dietary diversity of rural mothers in Southern Benin, West Africa. *PLoS ONE* **2016**, *11*, e0162535.
15. Berry, E.M.; Dernini, S.; Burlingame, B.; Meybeck, A.; Conforti, P. Food security and sustainability: Can one exist without the other? *Public Health Nutr*. **2015**, *18*, 2293–2302.
16. Hoddinott, J. Agriculture, health and nutrition: Towards conceptualizing the linkages. In *Reshaping Agriculture for Nutrition and Health*; Fan, S., Pandya-Lorch, R., Eds.; IFPRI: Washington, DC, USA, 2012.
17. FAO. *World Food and Agriculture-Statistical Yearbook*; FAO: Rome, Italy, 2021.
18. CSA (Central Statistical Agency of Ethiopia). *Land Utilization: Private Peasant Holdings, Meher Season: Agricultural Sample Survey 2014/2015*; CSA (Central Statistical Agency of Ethiopia): Addis Ababa, Ethiopia, 2014; Volume IV.

19. Onyutha, C. African crop production trends are insufficient to guarantee food security in sub-Saharan region by 2050 owing to persistent poverty. *Food Secur.* **2018**, *10*, 1203–1219.
20. Solomon, W.; Fentahun, T.; Admasu, F.; Melkamu, M. Study of Agro-Food Processing Industries in Ethiopia: Policy and Strategy Options for Its Development (2015–2025). IPSRD and BiT, 2017. Available online: https://psi.gov.et/index.php/policy-briefs/file/96 (accessed on 5 August 2021).
21. FAO. *The State of Food Insecurity in the World 2009: Economic Crisis, Impacts and Lessons*; FAO: Rome, Italy, 2009.
22. Swindale, A.; Bilinsky, P. *Household Dietary Diversity Score for Measurement of Household Food Access: Indicator Guide (V.2)*; FHI 360/FANTA III Project: Washington, DC, USA, 2006.
23. WFP. *Food Consumption Analysis, Calculation and Use of the Food Consumption Score in Food Security Analysis, Vulnerability Analysis and Mapping Branch*; WFP: Rome, Italy, 2008.
24. Bekele, A.; Kassa, B.; Legesse, B.; Lemma, T. Effects of crop commercial orientation on productivity of smallholder farmers in drought-prone areas of the Central Rift Valley of Ethiopia. Ethiop. *J. Agric. Sci*. **2010**, *20*, 16–34.
25. Kirimi, L.; Gitau, R.; Olunga, M. Household food security and commercialization among smallholder farmers in Kenya. In Proceedings of the Fourth International Conference of African Association of Agricultural Economists (AAAE), Hammamet, Tunisia, 22–25 September 2013. https://doi.org/10.22004/ag.econ.161445.
26. Ogutu, S.O.; Godecke, T.; Qaim, M. Agricultural commercialisation and nutrition in smallholder farm households. *J. Agric. Econ.* **2019**, *71*, 534–555.
27. Berhanu, G.; Moti, J. Commercialization of smallholders: Does market orientation translate into market participation? In *Improving Productivity and Market Success (IPMS) of Ethiopian Farmers Project Working Paper 22*; ILRI: Nairobi, Kenya, 2010.
28. Coates, J.; Galante, T. *Agricultural Commercialization, Production Diversity and Consumption Diversity among Smallholders in Ethiopia: Results from a 2012 National Integrated Agriculture and Rural Socioeconomic Survey*; Friedman School of Nutrition Science and Policy: Boston, MA, USA.; Tufts University: Medford, MA, USA, 2014.
29. Gebreab, N. Commercialization of smallholder agriculture in Ethiopia. In *Ethiopian Development Research Institute, Notes and Papers Series No.3*; Ethiopian Development Research Institute: Ethiopian, 2006; pp. 1–20.
30. Benson, T.; Amare, M.; Ogunniyi, A.B. The relative commercial orientation of smallholder farmers in Nigeria: Household and crop value-chain analyses. In *Strategy Support Program, Working Paper 66*; Strategy Support Program: 2020.
31. De Janvry, A.; Sadoulet, E. Progress in the modeling of rural households' behavior under market failures. In *Poverty, Inequality and Development*; Springer: Berlin/Heidelberg, Germany, 2006; pp. 155–181.
32. Seng, K. The Effects of Market Participation on Farm Households' Food Security in Cambodia: An Endogenous Switching Approach. MPRA Paper No.69669, 19 Mar 2016. Available online: https://mpra.ub.uni-muenchen.de/69669/ (accessed on 18 June 2022).
33. Alene, A.D.; Manyong, V.M.; Omanya, G.; Mignouna, H.D.; Bokanga, M.; Odhiambo, G. Smallholder market participation under transactions costs: Maize supply and fertilizer demand in Kenya. *Food Policy* **2008**, *33*, 318–328.
34. Barrett, C.B. Smallholder market participation: Concepts and evidence from eastern and southern Africa. *Food Policy* **2008**, *33*, 299–317.

35. Olwande, J.; Smale, M.; Mathenge, M.K.; Place, F.; Mith€ofer, D. Agricultural marketing by smallholders in Kenya: A comparison of maize, kale and dairy. *Food Policy* **2015**, *52*, 22–32.
36. Manda, J.; Azzarri, C.; Feleke, S.; Kotu, B.; Claessens, L.; Bekunda, M. Welfare impacts of smallholder farmers' participation in multiple output markets: Empirical evidence from Tanzania. *PLoS ONE* **2021**, *16*, e0250848. https://doi.org/10.1371/journal.pone.0250848.
37. Koppmair, S.; Kassie, M.; Qaim, M. Farm production, market access and dietary diversity in Malawi. *Public Health Nutr*. **2016**, *20*, 325–335.
38. Ickowitz, A.; Powell, B.; Rowland, D., Jones, A.; Sunderland, T.C.H. Agricultural intensification, dietary diversity, and markets in the global food security narrative. *Glob. Food Secur.* **2019**, *20*, 9–16.
39. Feleke, S.T.; Kilmer, R.L.; Gladwin, C.H. Determinants of food security in Southern Ethiopia at the household level. *Agric. Econ.* **2005**, *33*, 351–363.
40. Rahman, S.; Chima, C.D. Determinants of food crop diversity and profitability in Southeastern Nigeria: A multivariate Tobit approach. *Agriculture* **2016**, *6*, 14. https://doi.org/10.3390/agriculture6020014.
41. Amore, M.D.; Murtinu, S. Tobit models in strategy research: Critical issues and applications. *Glob. Strategy J.* **2021**, *11*, 331–355. https://doi.org/10.1002/gsj.1363.
42. Wooldridge, J.M. Control function methods in applied econometrics. *J. Hum. Resour.* **2015**, *50*, 420–445.
43. Bellemare, M.F.; Christopher, B.; Barrett, C.B. *An Ordered Tobit Model of Market Participation: Evidence from Kenya and Ethiopia*; WP 2005-10; Cornell University: Ithaca, NY, USA, 2005.
44. Justus, O.; Knerr, B.; Owuor, G.; Ouma, E. Agricultural commercialization and household food security: The case of smallholders in Great Lakes Region of Central Africa. In Proceedings of the 2015 Conference of International Association of Agricultural Economists (IAAE), Milan, Italy, 9–14 August 2015. https://doi.org/10.22004/ag.econ.212588.
45. Mofya-Mukuka, R.; Kuhlgatz, C. Impact of agricultural diversification and commercialization on child nutrition in Zambia: A dose response analysis. *J. Agric. Sci.* **2016**, *8*, 60–75. https://doi.org/10.5539/jas.v8n4p60.
46. Abdullah, Z.D.; Shah, T.; Ali, S.; Ahmad, W.; Ud Din, I.; Ilyas, A. Factors affecting household food security in rural northern hinterland of Pakistan. *J. Saudi Soc. Agric. Sci.* **2019**, *18*, 201–210.
47. Funmilola, F.A.; Patricia, O.A. Determinants of food security among low-income households in Maiduguri Metropolis of Borno State, Nigeria, Asian. *J. Soc. Sci. Humanit*. **2014**, *3*, 74–86.
48. Goshu, D.; Kassa, B.; Ketema, M. Measuring diet quantity and quality dimensions of food security in rural Ethiopia. *J. Dev. Agric. Econ*. **2013**, *5*, 74–185. https://doi.org/10.5897/JDAE12.141.
49. Rahman, A.; Mishra, S. Does non-farm income affect food security? Evidence from India. *J. Dev. Stud.* **2020**, *56*, 1190–1209. https://doi.org/10.1080/00220388.2019.1640871.

CHAPTER THREE

IMPACT OF AGRICULTURE DIVERSIFICATION AND OFF-FARM INCOME ON RUAL HOUSEHOLD FOOD SECURITY IN NORTHWEST ETHIOPIA: A DOSE RESPONSE APPROACH

Accepted for publication in Ethiopian Journal of Development Research

3.1. Abstract

Food insecurity is a colossal and universal problem in developing countries like Ethiopia, more than half of its population are food insecure. The situation is critical in rural areas where agriculture diversification and off-farm employment remain important for household food security to improve. Previous studies exploring this relationship provide mixed results and yet, the effect may vary according to the extent of the two interventions. The purpose of this study is to investigate impact of farm diversification and off-farm employment intensities on food security. Cross-sectional data were generated from 295 households randomly chosen in rural Ethiopia. We used generalized linear model for estimating dose-response functions adjusted for generalized propensity score as treatments are continuous and not necessarily normally distributed. The findings revealed crop diversification in rainy season production up to certain level of intensity (0.3) and specialization in dry season enhanced food consumption and dietary diversity. This demonstrated the farm income effect of diverse farming in rainy season and specialization in dry season is more crucial than accentuating on self-consumption. Livestock diversity also improved food security, but it seems more from diverse food groups (0.6). This indicated livestock husbandry is more nutrition sensitive than cropping. The paper recommends households focus on cash crops production to increase income during dry season, and promoting diversification up to certain level during rainy season to increase food security through subsistence and income pathways. Off-farm employment is the other aspect suggested for household resilience to withstand shocks and improve agricultural productivity.

Keywords: *Agricultural diversification; Dose-response; Food security; Off-farm income, Ethiopia*

3.2. Introduction

Agriculture is the main stay of Ethiopian economy, which contributes to 34% of the GDP, 82% of export earnings and employs 67% of the total population of the country in 2019 (FAO, 2021; EEA, 2021). The sector is dominated by smallholder farmers who managed more than 95% of the agriculture land. Intertwined with average landholding being small as low as 0.8 ha (FAO, 2018a), heavy reliance on rain-fed production highly exposed the sector to risks of environmental shocks. Moreover, the recent food prices driven by the triple crises of conflicts, COVID-19 pandemic and climate change have adversely impacted agriculture production, trade, income and food security (FS) globally mainly low-income countries. The ongoing conflict in Ukraine and civil war in Ethiopia further heightened the proportion of people suffering from food insecurity. According to the Global Food Security Index 2021 report that assessed FS situations across 113 countries, Ethiopia is ranked 108th with a score of 37.6 out of 100 and has experienced reduction in net FS score of 0.6 between 2020 and 2021 (EIU, 2020, 2021), which is much lower than Ireland the most FS by 46.4 percentage points.

Poverty and food insecurity (FI) is quite pervasive in rural Ethiopia, where the rate of poverty among smallholder farmers is nearly 67% (FAO, 2018a) and the FI remains larger as high as 57.8% over 2014-2020 (FAO, 2021). This claims promoting diversification of household income into off-farm income may be a new way out of household from poverty and FI (Chang & Mishra, 2008; Mohammed & Fentahun, 2020) by smoothing food consumption overtime and ameliorating food shortage risks in case of yield shocks (Qureshi *et al.*, 2015). Cognizant to this, the Ethiopian development paths have given prime attention to reduce poverty and FI by introducing various initiatives.

The agricultural development industrialization road map (2013), the two successive five years growth and transformation plans (2010-2020) and the recently endorsed ten years development plan for the period 2020-2030 (PDC, 2020) have clearly set out agricultural diversification and off-farm activities should be promoted along side with agricultural transformation to reduce risks of rural areas to poverty and FI. Yet, reducing FI and malnutrition in Ethiopia continues to be a key policy challenge and development problem. Around 65% of children under five were stunted, underweight or wasted in 2019 (FAO, 2018a) and anemia was pervasive among women of reproductive age (24%) and children (57%) in 2016 in Ethiopia (EDHS, 2016).

Researchers have widely recognized the need to study the causal link between agriculture, food and nutrition worldwide. However, studies exploring this relationship have provided mixed results. Some scholars showed agriculture diversification (AD) significantly improves FS in terms of dietary diversity (Jones *et al.*, 2014; Mulat *et al.*, 2017; Habtamu *et al.*, 2017). A similar finding by Herrero et al. (2010) identified the synergies between crop and livestock production can secure food availability and access for households by increasing income and self-consumption while maintaining environmental services. Frelat *et al.* (2016) pointed at nutrition is closely linked to agriculture not just it produces food, but many of the undernourished people globally are also smallholder farmers. However, Ruel *et al.* (2018) cited a number of review papers published in the past two decades claimed that evidence on what and how agriculture contributes to nutrition is extremely scant.

Another authors systematically reviewed studies reporting findings from several countries also noted little evidence to support the assumption of increasing AD is an effective strategy to improve diets and nutrition of smallholders (Sibhatu & Qaim, 2018) and lack of robust evidence on nutrition impacts of agriculture (Webb & Kennedy, 2014; Bhavani & Rampal, 2018). They emphasized the need for proper research design, use of appropriate metrics and strengthening the evidence base can help better inform policy. Some others claimed market access is essential to improve FS in rural areas (Bellon *et al.*, 2016; Jones, 2017). All this suggests agriculture-food-nutrition nexus are contextual and examining them is really vital in situations of developing countries with majority of rural population, heavy reliance on subsistence production and high prevalence of malnutrition. Gómez *et al.* (2013) agreed influencing such nexus positively can lead to improvements for rural populations and to better pathways for transformation of local food systems.

The extant literature has also given due attention on growth and poverty implications of off-farm income (OFI) in developing countries, yet little is known about its impact on FS and nutrition (Duong et al., 2020; Rahman & Mishra, 2020). Moreover, the key evidence disclosed little policy efforts have been made to promote the off-farm sector in a pro-poor approach that can overcome potential constraints mainly in sub-Saharan Africa, where production on smallholder farms is critical to FS of the rural poor (Herrero *et al.*, 2010). Understanding the capacity of farming systems and off-farm employment opportunities to meet food and nutrition needs of rural households is overriding. In the face of a growing evidence demonstrating HFS impacts of AD and OFI, there is a tendency to treat these two interventions as binary decision variables seems an oversimplification. The fact that farmers produce at different intensity levels of diversification may have different effects on HFS operationally measured in food consumption and dietary diversity.

The current paper extended this conventional econometric setup to accommodate issue of continuous treatments (AD & OFI intensities) and evaluated their impact on HFS. This is the novelty of this paper that adds a new dimension to the discourse on AD, OFI & FS linkages by analyzing the varying levels using dose-response functions (DRFs) and generalized propensity score (GPS) approach. To help evaluate AD and OFI as critical strategies for improving HFS in case of rural Ethiopia, the following are the key questions raised to answer: (1) What is the status of AD among smallholder farmers and how far does it affect HFS? (2) How does participation in off-farm employment influence HFS?

3.3. Materials and Methods

3.3.1. Study Areas

The study generally aims to evaluate impacts of AD and off-farm employment intensities on HFS of smallholder farmers in northwest Ethiopia in Amhara region. With a population of 22.5 million in 2019, Amhara is the second most populous region next to Oromia (UNICEF, 2021). Its economy remains highly agrarian primarily managed by smallholders, and nearly 84% of the population engaged in agriculture (UNICEF, 2018). The region is large in terms of area and endowed with diverse agro-ecologies giving it a huge potential for production of a variety of agricultural outputs for domestic consumption and exports. Yet, poverty is pervasive in the region with 26.1% of the population living below the national poverty line compared to 23.5% in the entire country in 2016; it is more rampant in rural 28.8% than in urban areas 11.6% (NPC, 2017). Childhood stunting in the region is among the highest in the country, about 46% more than 38% in the country (EDHS, 2016).

The cross-sectional survey data on quantitative and qualitative variables were collected between July and August 2020 from 295 households randomly selected in Bahirdar Zuria, Dangila and Bure districts of Amhara region. The household selection was based on a two-stage stratified sampling. The survey team comprises 12 experienced agricultural experts. An intensive two-days training was given to them to create understanding on contents of questionnaire and how to manage face-to-face interviews with farmers using local language and probing the difficult questions through examples and farmers' wordings. Pilot-testing of the survey instruments and fieldwork procedures were conducted prior to main survey. The data quality was checked through close supervision of enumerators and encoders during data collection and entry, respectively.

3.3.2. Conceptual Framework and Empirical Model

The impact evaluation framework of this study was developed from counterfactual perspective that allows to make causal claims in case of observational data and continuous treatments adopted from (Austin, 2019; Wu et al., 2021). In experimental research, as study units are randomized to receive different treatment levels, the units assigned to different levels of treatment will have similar distributions of pre-treatment covariates (Wu *et al.*, 2021). When the treatment is binary, like the standard propensity score matching presumed, by pairing treatment group with control group that has nearly identical values of covariates, the two groups are theoretically interchangeable. In observational studies, as one group received a treatment prior to the survey, the two groups would not be the same on pre-exposure covariates. In this case, we cannot observe the counterfactuals and the groups are not interchangeable. As units in observational studies are not randomized to different treatment levels, the imbalance in pre-treatment covariates may lead to confounding bias (Antonakis *et al.*, 2010). To obtain consistent estimates, this selection bias to treatment or control group has to be modeled.

In most FS studies, confounding adjustment is traditionally made by fitting a multivariate regression model with FS outcome as dependent variable, AD, for example, as a key independent variable and many potential confounders are additional independent variables (Adjimoti & Kwadzo, 2018; Muthini *et al.*, 2020; Sekabira & Nalunga, 2020; Lemlem *et al.*, 2021; Sinyolo *et al.*, 2021; Kabir *et al.*, 2022). It has been well documented in the literature traditional regression methods do not allow for clear distinction between the design and analysis stages (Wu *et al.*, 2021), are susceptible to model misspecification and often their results cannot be interpreted as causal effects (Bellon *et al.*, 2016). In reply to this, some others have used the standard PSM method (Abebaw *et al.*, 2010; Justus *et al.*, 2015), but this approach is limited to capture continuous treatments. Many researchers have advocated for the development and implementation of methods for causal inference to inform FS and nutrition policy (e.g. Mofya-Mukuka & Kuhlgatz, 2016; Ogutu *et al.*, 2019). When the treatments are continuous, like AD & OFI intensities in our case, there is no explicit way to distinguish units as exposed and unexposed, which calls for a different procedure. In such conditions, the GPS specification is more appropriate than the standard PSM for estimating DRFs. We developed the impact evaluation framework at household level with a generalized linear model (GLM) for estimating the DRFs at each treatment level using GPS for adjusting confounders.

To quantify the impact of AD and OFI one can employ the typical impact evaluation framework considering AD (or OFI) as treatment and HFS is the observed outcome. This section details the econometric approaches used in this study focusing on AD as treatment, but all details also hold OFI. For simplicity of demonstrating the estimation strategy; first, we use a simplified model of the conventional impact assessment scenario where D is a binary exposure representing household's decision to choose whether to diversify its farm production $(D = 1)$ or not to diversify $(D = 0)$. Later, we will see GLM, a flexible approach of interest that can address issues of continuous and the different distribution functions of the treatment. We sought to quantify the expected treatment effect on treated as specified in Equation (3.1):

$$\tau|_{D=1} = E(\tau|D = 1) = E(Y_1|D = 1) - E(Y_0|D = 1) \tag{3.1}$$

where τ is the average treatment effect on treated (ATT), D is a dummy variable for AD decision, Y_1 denotes the outcome when the household diversified its production and Y_0 shows the outcome in case the household did not diversify its production.

The estimation problem arises as it cannot be observed how a diversified household would have performed had in fact not diversified its production-i.e. $E(Y_0|D = 1)$ cannot be observed. Although the difference $[\tau^e = E(Y_1|D = 1) - E(Y_0|D = 0)]$ could be estimated, it would potentially be a biased estimator of ATT, as the groups compared are likely to be different in their characteristics. This is because of self-selection of households, which is likely to occur when farm characteristics affect the utility that a farm derives from AD or OFI. In formulating the effect of farm characteristics on treatment variable, we assume the relationship between utility (U) and farm characteristics (Z) of household i can be expressed as Equation (3.2):

$$U = \beta' Z_i + \epsilon_i \tag{3.2}$$

where ϵ_i shows the residual. Given the farmer maximizes utility by choosing whether to or not to diversify, the probability of employing diversification strategy is shown by Equation (3.3):

$$P(D_i = 1) = P(U_1 > U_0) = P\left(\epsilon_i > -\beta' Z_i\right) = 1 - \Phi\left(-\beta' Z_i\right) \tag{3.3}$$

where U_1 is the maximum utility gained from choosing the treatment; U_0 is the maximum utility derived from being in the control group; Φ shows the distribution of the residual, which is logistic in case of Logit model that can be applied for analysis as one considered AD as a binary variable. Results of outcome comparisons between groups are biased even if farm characteristics are controlled for as one uses an OLS regression. To show this, consider a reduced-form relationship between technology choice and outcome variables specified in Equation (3.4) as follows:

$$Y_i = \beta_0 + \beta_1 D_i + \beta_2 Z_i + u_i \tag{3.4}$$

where Y_i represents a vector of outcome variables for household i such as demand for foods; D_i denotes a binary choice variable of diversification as defined above; Z_i represents farm level and household characteristics; and u_i is an error term with $u_i \sim N(0, \delta)$. The issue of selection bias arises if the error term of technology choice ϵ_i in Equation (2) and the error term of outcome specification u_i in Equation (3.4) are influenced by similar variables in Z_i. This leads to a non-zero correlation between the two error terms, which would in turn imply biased regression estimates if Equation (3.4) were estimated using OLS approach. Specifically β_1 would not be a valid estimator of ATT.

Several econometric approaches are available in the literature on impact evaluation to re-establish a randomized setting in case of self-selection bias. Difference-in-differences is the one that is not applicable in our study, as this requires panel data over certain periods. The instrumental variables method is the other one that relies on parametric assumptions regarding functional form of relationship between outcomes and predictors as well as on exogeneity of instruments used. As this method is also quite sensitive to violation of these restrictive assumptions, we adopt the nonparametric, matching approach in which households of the group of diversified farmers are matched to those households in the control group, who are similar in their observable characteristics. Moreover, it is common in the impact evaluation literature to treat diversification as a binary decision variable in which most studies have employed PSM to address the selection bias as discussed above. Yet, PSM is an oversimplification in situations when farmers produce at different intensity levels of diversification may have different effects on HFS.

The current paper tries to extend this econometric setup to handle household's exposure to different levels of diversification, and measure its impact on HFS. So the GPS method was adopted from Hirano and Imbens (2004) to balance differences among farms of different intensity levels conditional on their observable characteristics. This approach has been used in observational studies since its formulation by Bia and Mattei (2008) addresses exposure to continuous treatments. Even Bia & Mattei have used the maximum likelihood estimator that does not allow for distribution assumptions other than normal density. Instead, the present paper used a flexible GLM following Guardabascio and Ventura (2014) for estimation of DRFs adjusted for GPS captures issues of both continuous and different distribution functions of a treatment. This means that adjusting for GPS removes all biases associated with differences in covariates. The unbiased impact of different intensities among farms of diversification on HFS can then be demonstrated with DRFs.

The GPS approach involves three stages. First, the GPS are generated based on observed covariates. Second, the conditional expected values of the outcome variables (FS indicators) are estimated as a function of treatment exposure (AD intensity) and the GPS. Third, the average DRF is estimated. The DRF depicts for every treatment exposure level the direction and magnitude of the relationship between AD and HFS, after correcting for observed covariate bias (Hirano & Imbens, 2004). Following Guardabascio and Ventura (2014), the GPS was specified as Equation (3.5):

$$\widehat{R_\imath} = r(T, X) = c\left(T, \widehat{\Phi}\right) \exp\left\{\frac{T\hat{\theta} - a\left(\hat{\theta}\right)}{\widehat{\Phi}}\right\} \qquad (3.5)$$

where $\widehat{R_\imath}$ is the GPS generated for household i; $\hat{\theta}$ and $\widehat{\Phi}$ are the estimate parameters of θ and Φ of the selected conditional distribution of the treatment given the covariates.

The GPS was estimated using Bernoulli quasimaximum estimator, called GLM, with covariates X_i and fractional logit specification with Bernoulli distribution and logit link function, which takes into account both treatments (AD & OFI) range between 0 and 1. Like the conditional independence assumption (CIA) in PSM setting for dichotomous treatment, we presume weak confoundedness. This assumption essentially postulates that once all observable characteristics are corrected for, there is no systematic selection into specific levels of AD intensity left that is based on unobservable characteristics (Flores &

Flores-Lagunes, 2009). The GPS is a balancing score suggested to derive unbiased estimates of the DRFs (Hirano & Imbens, 2004). Given T_i & R_i, the conditional expectation for outcome Y_i is modeled as a flexible function of the two arguments expressed in Equation (3.6) as,

$$\varphi\{E(Y_i/T_i, R_i)\} = \lambda(R_i, T_i; \alpha) = \alpha_0 + \alpha_1 T_i + \alpha_2 T_i^2 + \alpha_3 R_i + \alpha_4 R_i^2 + \alpha_5 T_i R_i \quad (3.6)$$

where T_i & R_i are the treatment level measured as diversification index and GPS for household i respectively; α's are parameters to be estimated. Finally, we estimate the DRFs by averaging the expected FS outcome of Equation (3.6) at each level of treatments (AD or OFI) as in Equation (3.7).

$$E\{\hat{Y}(t)\} = \frac{1}{N}\sum_{i=1}^{n} \hat{\gamma}\{t, r(t, X)\} = \frac{1}{N}\sum_{i=1}^{n} \varphi^{-1}\left[\hat{\lambda}\{t, \hat{r}(t, X_i); \hat{\alpha}\}\right] \quad (3.7)$$

where N is number of observations, t is each treatment level, $\hat{r}(t, X_i)$ is expected value of conditional density of treatment at varying levels of AD & $\hat{\alpha}$ are parameters estimated at second stage.

We tested the balancing property of the estimated GPS by employing the approach proposed by Guardabascio & Ventura (2014). The conditional expectation of the outcome for each farm was estimated using a flexible polynomial function, with quadratic approximations of the treatment and GPS as in Equation (3.6). The specification for continuous outcomes was estimated using OLS regression. Then the DRF in Equation (3.7) was evaluated at 5 evenly distributed levels of treatments. The set of the potential treatment values was divided into three intervals and the values GPS evaluated at the representative point of each treatment interval were divided into five intervals. Confidence bounds at 95% level were estimated using bootstrapping procedure with 100 replications. Results of the DRFs are presented graphically. We used Stata 13.1 statistical software for data analysis.

3.3.3. Descriptions and Measurement of Variables

3.3.3.1. Measuring household food security

Household FS is the key outcome variable of interest operationally conceptualized as the sum of unique foodstuffs consumed by household in a specified period. Food consumption can be better estimated using expenditure data collected over 7 day recall, rather than 24 hour time frame, as a longer recall period might capture a variety of foods consumed by household despite adding some level of noise reduces its accuracy (Jones *et al.*, 2014; Mulat *et al.*, 2017). The study adopted not just a 7 d recall food frequency module from WFP (2008) for measuring HFS in terms of food consumption, it also applied a standardized 24 h recall dietary diversity module of Swindale & Bilinsky (2006) to compare and enhance robustness of results obtained via food consumption score (FCS) and household dietary diversity score (HDDS).

3.3.3.2. Measuring agricultural diversification

A wide variety of approaches have been employed in empirical literature to measure AD to examine the association between AD, FS and nutrition. Several studies have used household biodiversity index (HBI) as an indicator of AD (e.g. Herforth, 2010; Jones *et al.*, 2014; Sekabira & Nalunga, 2020) with some iteration of a count of specific crop species cultivated and livestock species raised. Biodiversity index is conceptualized as a simple count of all crops and livestock species produced on household farm usually in one production year as a measure of AD. Some others have used production diversity score (Koppmair *et al.*, 2016), aggregated production diversity index (Habtamu *et al.*,

2017) and agriculture enterprise score (Mulat *et al.*, 2017) which only counted food groups produced by household to measure AD with the assumption that HBI (i.e. agricultural diversification index-ADI in our case) does not necessarily reflect diversity from dietary point of view. We developed aggregated production diversity metric- so called agricultural diversification score (ADS) operationally defined as the number of food groups produced by household per year. The ADS was constructed based on the food groups formulated similar to those used in FCS module customized with local contexts in northwest Ethiopia.

However, both ADI and ADS do not address differences in distribution of diversification, as all items/groups are equally weighted regardless of quantity produced. Arimond and Ruel (2004) suggested ADI/ADS can be more or less meaningful depending on the relative share of each food produced. We adopt the Simpson index (Simpson, 1949) to capture the relative intensity of each food item/group produced by the household. This relative index was estimated using area share of each crop species (group) from total crops cultivated, and number share of each livestock species (group) among total livestock raised by household as in Equation (3.8).

$$\mathrm{SI} = 1 - \sum_{i}^{K} W_i^2 \qquad (3.8)$$

where SI is the Simpson index, W_i is the area (number) share of crop (livestock) species/group i respectively. SI ranges between 0 & 1; a value of 0 implies only one food species/group is produced while a value closer to 1 reflects more even distribution of area (number) by crop (livestock) type.

Using Equation (3.8) we constructed six Simpson indices via simple and group count approaches to address seasonal variations in crop production during Meher (rainy) and irrigation (dry) seasons: (1) Meher season crop diversity Simpson index (mCDSI) and (2) irrigation season crop diversity Simpson index (iCDSI) that calculated based on relative share of crop species produced; (3) Meher season crop diversity Simpson score (mCDSS) and (4) irrigation season crop diversity Simpson score (iCDSS) based on relative share of crop groups produced; (5) both seasons crop diversity Simpson index (bCDSI) represents diversification of crop species produced in both seasons; (6) both seasons crop diversity Simpson score (bCDSS) reflects diversification of crop groups produced in both seasons; and (7) livestock diversity Simpson index (LDSI) and (8) livestock diversity Simpson score (LDSS) are the two indices for measuring intensity of livestock species and groups diversification reared last year, respectively. The other two, (9) agriculture diversity Simpson index (ADSI) as the average value of bCDSI and LDSI and (10) agriculture diversity Simpson score (ADSS) is the average value of bCDSS and LDSS, are composite indices of crop and livestock species and groups produced by household to measure the overall AD.

Overall, we used 10 measures of AD to assess its effect on HFS not only to differentiate the role of intensity in terms of species and groups of crops and livestock produced, but also to determine the implication of seasonal variations in diversification of production on FCS and HDDS.

3.3.3.3. Off-farm income

Off-farm income is the other key explanatory variable that can influence HFS. Rural off-farm employment as an income stream may affect dietary diversity of households comprises: (a) wage employment, (b) annual private transfer income (remittances) and (c) non-farm self-business. The value of this off-farm variable could be measured as if a household received income from all the three sources scored 3; those who received income from none of these sources scored 0. While counting the number of income sources can capture income diversification, it does not automatically imply households with more off-farm income sources have higher income levels relative to families engaged in fewer off-farm activities. As such, we measured off-farm employment level (intensity) operationally defined as a proportion of off-farm income to total income of household last year prior to the survey.

3.3.3.4. Confounding factors

Other covariates were identified based on existing theory regarding determinants of HFS and potential confounding factors of the relationship between AD (OFI) and HFS from extant literature. Factors that may have confounded the association between AD and HFS were corrected for sex, age and education level of household head, household size, cultivated farm size, farm income, access to off-farm income, and location dummies. Moreover, access to extension & credit, presence of local food market, travel distance from nearest town market, road quality and access to irrigation were considered to control for effects of institutional services and market infrastructure on AD, OFI & FS linkages.

3.4. Results and Discussion

3.4.1. Household Characteristics

Socioeconomic characteristics of households that used as balancing variables for estimating GPS are presented in Table 3.1. A typical household in the study areas comprised around 6 persons almost similar to the national average of 5 persons and is a predominantly male headed, only 9% were feminized relatively lower than 21% of the average in Ethiopia (FAO, 2018a). The average education level of household head was 2.5 years with 47 years old. More than 55% were illiterate with no formal education, and those attending primary education comprised 30% and secondary & above about 15%. The size of cultivated land averaged to be 1.6 ha in the study areas seems a bit larger than 1.4 ha in the entire country (FAO, 2018a). An average family farm in the study areas generated a gross annual income of 1793 USD (62660 ETB) was also higher relative to 1246 USD in the entire country (FAO, 2018a). Agriculture remains the main occupation of household contributing to 85% of its annual gross income in the study areas more than 79% in the entire country (FAO, 2018a).

Add to economic indicators, access to basic infrastructure has been visualized in this study. A household walked on average 2.31 hours to reach the market in nearest town from home. While 86% have access to local food markets in their villages, half of them reported better access to road connecting their villages to nearest town that functions in both dry and wet seasons. Households that mentioned have access to irrigation and credit each recorded 62% and those accessed to extension services registered 89%.

Table 3.1. Descriptive statistics of household characteristics used as balancing variables

Balancing variables	Measurement	Mean	Std.Dev.	Min.	Max.
Sex of household head	Binary (1=male, 0=female)	0.91	0.28	0	1
Age of household head	Continuous (years)	46.56	10.61	20	72
Education level of household head	Continuous (years)	2.52	3.32	0	12
Household size	Continuous (number)	6.27	2.13	1	14
Cultivated land size	Continuous (ha)	1.56	0.7	0.25	4
Annual gross farm income	Continuous ('000 ETB) [a]	53.22	61.13	0	562.25
Annual gross total income	Continuous ('000 ETB)	62.66	132.77	0.30	2072.61
Distance to nearest town market	Continuous (walking hours)	2.31	1.27	0	7
Presence of food market in village	Binary (1=yes, 0=no)	0.86	0.35	0	1
Access to all weather road	Binary (1=yes, 0=no)	0.50	0.50	0	1
Access to irrigation	Binary (1=yes, 0=no)	0.62	0.49	0	1
Access to credit	Binary (1=yes, 0=no)	0.62	0.49	0	1
Access to extension	Binary (1=yes, 0=no)	0.89	0.31	0	1

Source: Own survey data (2020). [a] The official exchange rate of money in survey period was 1 USD=35 ETB.

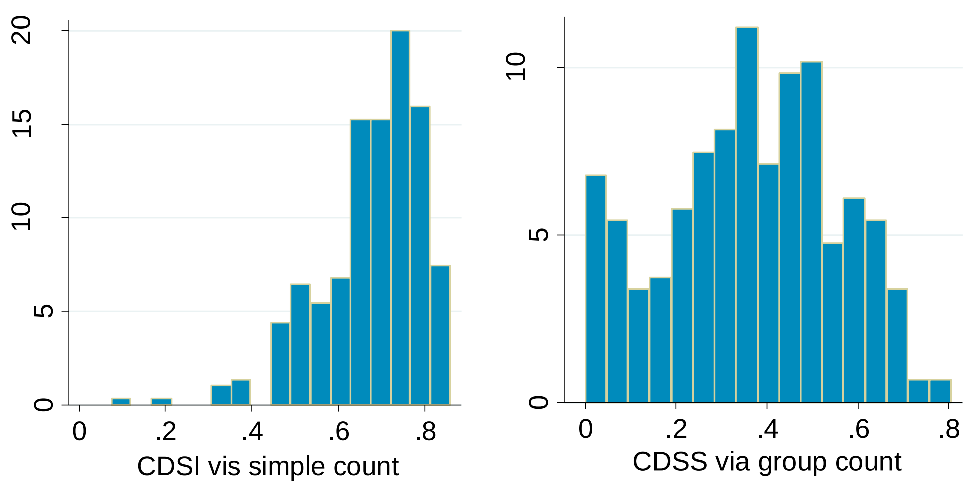
Table 3.2 summarizes the outcome and treatment variables of the current paper. The average FCS and HDDS were 55.6 and 7 respectively. The three diversities of crop, livestock and agriculture production measured in simple count reached 0.68, 0.64 & 0.66 Simpson index respectively, whilst the corresponding figures via group count averaged to be 0.37, 0.64 & 0.49. This illustrated households have better diversification in livestock than crop farming. Around 39% have access to off-farm employment with diversification intensity of 0.04 Simpson index and off-farm income contributed to 5% of annual gross income of the household (Table 3.2).

Table 3.2. Summary statistics of outcome and treatment variables

Variables	Descriptions	Mean	Std.Dev.	Min.	Max.
Outcome variables:					
FCS	Food consumption score of household	55.61	17.61	22	100.5
HDDS	Household dietary diversity score	7.04	1.82	1	12
Treatment variables:					
CDSI	Crop diversity Simpson index	0.68	0.12	0.07	0.86
LDSI	Livestock diversity Simpson index	0.64	0.21	0	0.86
ADSI	Agriculture diversity Simpson index	0.66	0.13	0.16	0.84
CDSS	Crop diversity Simpson score	0.37	0.19	0	0.81
LDSS	Livestock diversity Simpson score	0.64	0.17	0	0.84
ADSS	Agriculture diversity Simpson score	0.49	0.12	0.09	0.78
SOFI	Share of off-farm income to total income	0.05	0.13	0	1
AOFI	Access to off-farm employment (1=yes, 0=no)	0.39	0.49	0	1
OFIDSI	Off-farm income diversity Simpson index	0.04	0.12	0	0.5

Source: Own survey data (2020).

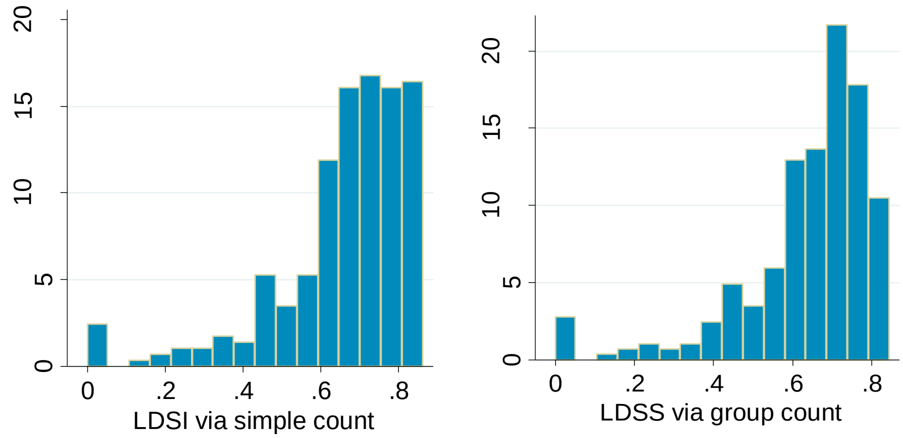
Figure 3.1 presents the distributions of crops produced by households to better understand whether diversification of crops stems from specific or diverse food groups. Majority of households have crop diversification intensities 0.65 to 0.8 Simpson Index (CDSI) measured by counting simply the crop species irrespective of its food group (Figure 3.1a). As implied by group count approach (Figure 3.1b) estimating diversification intensities in terms of food groups the crop species be from, larger share of households have crop diversification intensities between 0.25 to 0.5 Simpson score (CDSS) seems lower compared to CDSI of the former approach. Further, a comparative analysis of panels (a) & (b) of Figure 3.1 suggested larger segment of households more specialized in crop groups while more diversified in crop species only from very few food groups. This implies that majority of crop diversifications stem from same food group, may be starch staples as almost all households produced at least one crop species in this food group.



(a) **(b)**

Figure 3.1. Distribution of crop diversification intensities by households

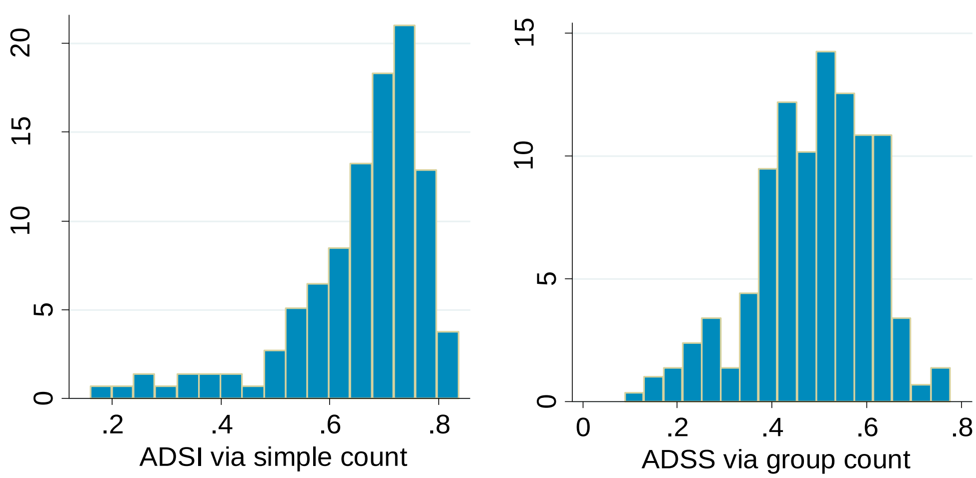
The livestock diversification intensity estimated using simple count (Figure 3.2a) and group count (Figure 3.2b) approaches informed majority of households have diversification levels of 0.6 to 0.8. This entailed households have better livestock diversity in both individual and group of livestock species they raised, suggesting livestock diversification is more from diverse food groups.



(a) **(b)**

Figure 3.2. Distribution of livestock diversification intensities by households

Figure 3.3 displays the overall AD intensity combining crop & livestock productions by household. The majority have AD levels of 0.6 to 0.8 Simpson index (ADSI) using simple count (Figure 3.3a) and between 0.4 & 0.65 Simpson score (ADSS) via group count (Figure 3.3b). The results implied better AD intensities by majority of the households.



(a) **(b)**

Figure 3.3. Distribution of agricultural diversification intensities by households

3.4.2. Food Security Impacts of Crop, Livestock & Agriculture Diversifications

This section discusses the results of continuous treatment effects of production diversification and off-farm employment intensities on HFS estimated using GPS matching. Covariate balancing tests compared three different groups varying in levels of each diversification indicators (CDSI, LDSI, ADSI, CDSS, LDSS & ADSS) as dependent variables of different models analyzed each separately. Before matching, most of the covariates for these three treatment groups differ significantly across all the six models. After matching, most of the differences turn insignificant. This implied the variables used for balancing fairly balance the differences in household and farm characteristics, which in turn verified GPS is an appropriate approach for analyzing continuous treatment effects (Albeit this result not shown in this paper). The subsequent subsections present DRFs estimated at each level of crop, livestock and AD and off-farm employment intensities graphically.

3.4.2.1. Effects of crop diversification on food security

Figure 3.4 presents the role of crop diversification intensities in Meher (rainy) and irrigation (dry) seasons production on food consumption (FC) and dietary diversity (DD) of households evaluated through DRF & GPS framework. The horizontal axes in panels (a), (c) & (e) of Figure 3.4 represent crop diversification intensity in Meher, irrigation and both seasons production in Simpson index such as Meher season CDSI, irrigation season CDSI and both seasons CDSI respectively; and the vertical axis measures the expected effects on food consumption score (FCS) and dietary diversity score (HDDS) of households at a given level of diversification.

Rainy and dry season crop diversification intensity based on simple count. Controlling for confounding factors, the results have shown evidence in favor of crop diversification in rainy season improved HFS through better FC and DD as an increasing trend seen in panels (a) & (b) of Figure 3.4. This finding corroborates the works in Malawi (Jones *et al.*, 2014), Kenya (Mulat *et al.*, 2017) and in Ethiopia & Tanzania (Habtamu *et al.*, 2017) that revealed farm diversification can improve household DD. It was crop specialization in irrigation season favored HFS to increase by enhancing FCS & HDDS (panels c & d of Figure 3.4); the latter, however, implied diversification in dry season might have positive implication on DD had it also been above certain level of intensity (0.4). This slightly agrees with the finding of another study in Ethiopia (Babatunde & Qaim, 2010) suggested more diversity in farm production can adversely impact child height-for-age in the context of poor rainfall. The overall crop diversification intensity combining rainy and dry seasons' production also demonstrated the relevance of crop diversity for better HFS as an upward trend of FCS and HDDS seen in panels (e) and (f) of Figure 3.4.

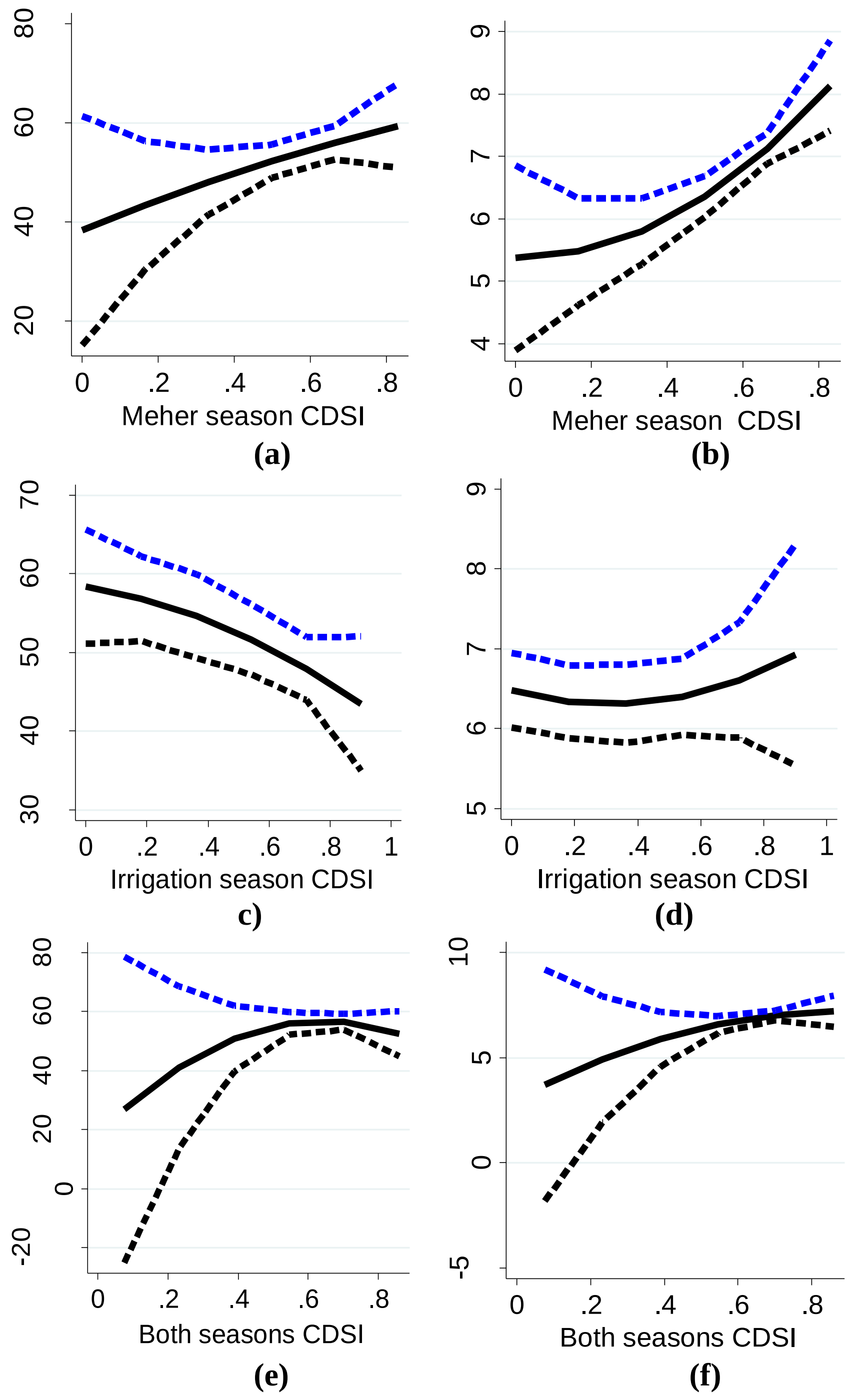


Figure 3.4. DRFs of seasonal crop diversification effects on FCS and HDDS (simple count)

Note: Solid lines are DRFs & dashed lines show 95% confidence intervals obtained through bootstrapping.

Rainy and dry season crop diversification intensity via group count. Figure 3.5 depicts HFS impacts of diversification intensity in crop groups to evaluate whether diversity in production crops from different food groups or specific group enhances HFS. Both the

FC and DD indicators demonstrated that HFS effects of crop diversification from diverse food groups tend to be positive at low diversification levels (i.e. high specialization). The DRFs in panels (a) and (b) of Figure 3.5 have a maximum at roughly 0.3, and become lower at high levels of diversification in rainy season production. This non-linear relationship on the one hand might reflect specialization in production of crops from very few food groups results in less diverse diets with rising adverse consequences on HFS. The extremely high diversification levels on the other hand slow down HFS as less efficient production structure prevents gains from specialization (i.e. less diversified farms). Thus, crop diversification in Meher season at 0.3 implied for most farmers moderately increased diversification in crop production would be beneficial for improved FC and DD. A comparative analysis of same panels (a) and (b) of Figure 3.4 with those in Figure 3.5 implied diversification in production of crops from very few food groups in rainy season would have positive implication on HFS.

The DRFs for the effect of diversification in dry season production of crop groups on FC and DD of households are similar (see panels c & d of Figure 3.5), but show a very different shape relative to rainy season production. Both panels reveal a negative relationship of dry season crop diversification with FCS & HDDS. Comparing panels (c) & (d) of Figure 3.4 with those panels (c) & (d) in Figure 3.5 revealed all have similar patterns that implied it is entirely specialization in production of crop from specific food group in dry season improved HFS. It has to be kept in mind, however, that very few farms have actually reached diversification levels of crop production above 0.5 Simpson score in irrigation season as shown in the histogram. In these high intensities of dry season diversification the estimation of the DRFs on HDDS are, therefore, based on few treatment units and should therefore be interpreted with caution. This is also seen by the spread of confidence interval at that point of intensity in all graphs of interest.

Whereas when comparing same panels (e) and (f) of Figure 3.4 with those in Figure 3.5, the DRFs for the effect of overall crop diversification intensities on FCS & HDDS disclosed diversification in production of diverse crop species would yield better HFS had it been from limited food groups than from diverse food groups. This suggested yet there is scope for improving crop production systems of smallholder farmers a bit more nutrition sensitive; may be through strengthening and supporting the extension system to promote diversification of crop production to be from diverse food groups instead of being from specific group- for example starchy staples as most households produced in the study areas. This, meanwhile, encourages smallholder farmers to adopt sustainable production system in crop farming similar to the findings identifying crop diversification as part of sustainable production practices (FAO, 2018b; Getachew Teferi *et al.*, 2018) can improve dietary quality while protecting household food production and income from weather shocks as different crops have different sensitivity to climate variability (Babatunde & Qaim, 2010). Herrero *et al.* (2010) also confirmed the synergy between cropping and livestock husbandry can increase FS and income of the people while maintaining environmental services.

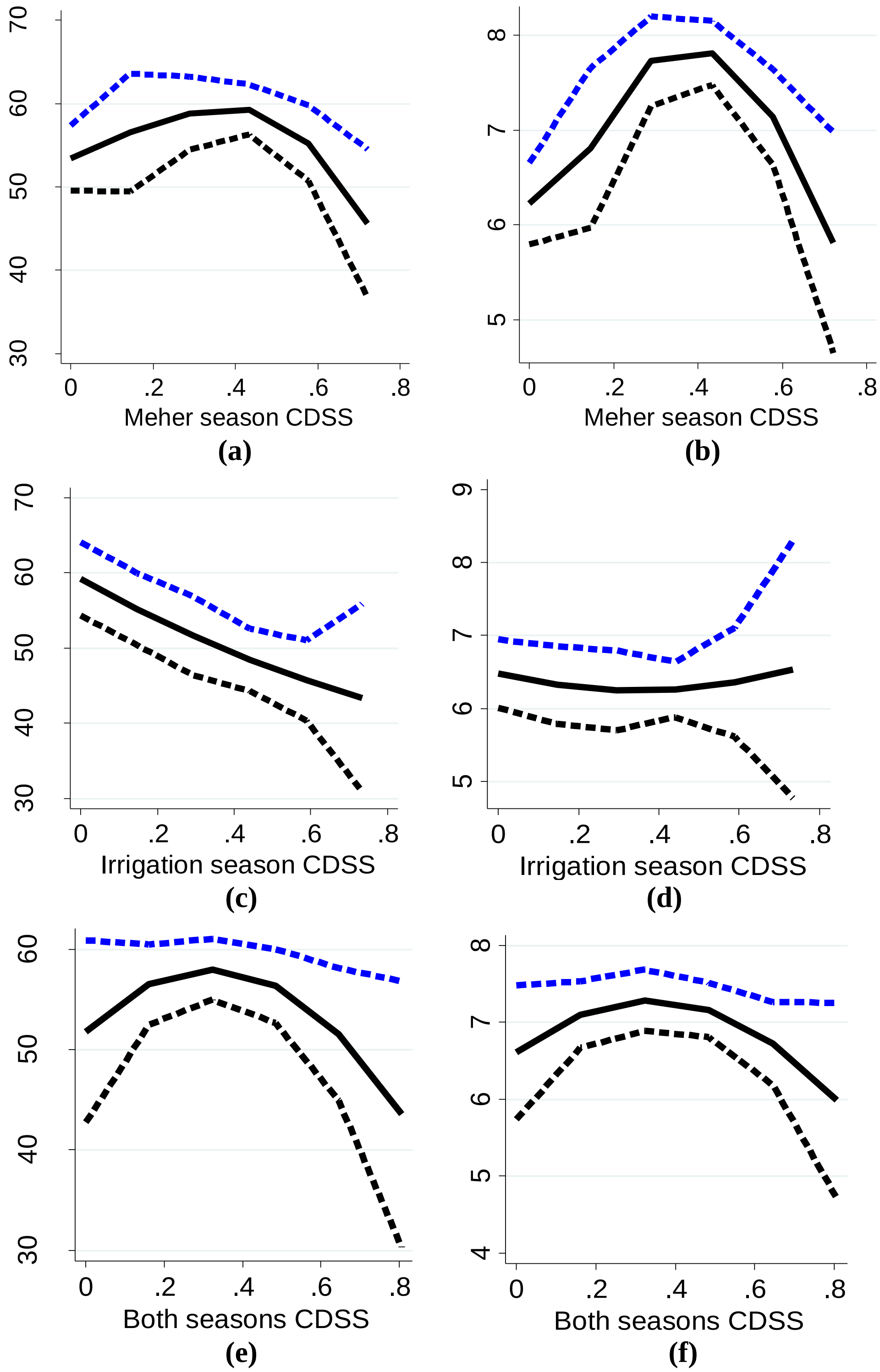


Figure 3.5. DRFs of seasonal crop diversification effects on FCS and HDDS (group count)

Note: Solid lines are DRFs and dashed lines show 95% confidence intervals obtained through bootstrapping.

3.4.2.2. Effects of livestock diversification on food security

Another important aspect of smallholder agriculture is livestock husbandry that has generally shown positive implication on HFS. As seen in Figure 3.6 both simple count (panels a & b) and group count (panels c & d) approaches demonstrated livestock diversification has positive effect on HFS. This implied a more diverse portfolio of livestock raised has been driven more from diverse food groups than from unique food group. It also informed livestock production is more nutrition sensitive than crop farming slightly similar to the results in Kenya (Muthini *et al.*, 2020) revealed the count of animal species has highest magnitude of association with DD of households & women.

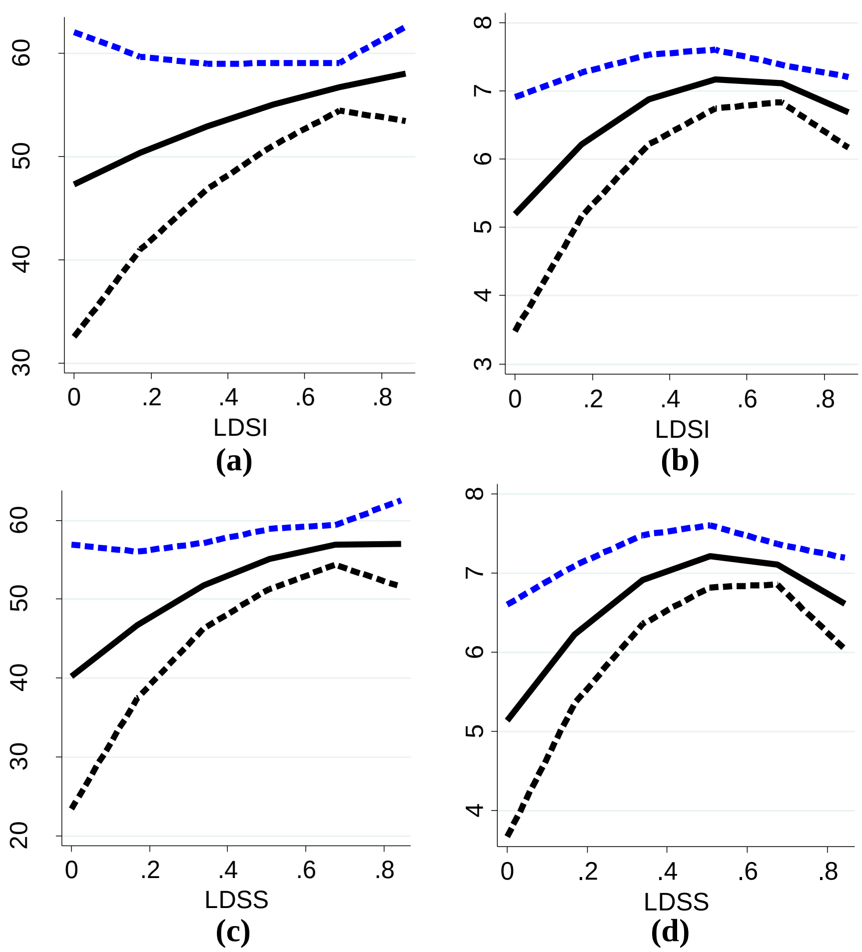


Figure 3.6. DRFs of livestock production diversification effects on FCS and HDDS

Note: Solid lines are DRFs and dashed lines show 95% confidence intervals obtained through bootstrapping.

3.4.2.3. Effects of agricultural diversification on food security

As AD comprising overall crop and livestock production presented in Figure 3.7 shows that the DRFs reached maximum roughly at 0.5 Simpson score and then declines along the way (panels c & d in Figure 3.7). This suggests an increase in AD up to certain levels can improve HFS in both FC and DD that reached maximum at 0.5, and then tend to decline at high levels of diversification. Moreover, diversification in farm production would have positive implication on HFS if it were up to this maximum level, beyond which diversification within same food group may enhance HFS as supported by an increasing trend of panels (a) & (b) seen in Figure 3.7.

3.4.2.4. Effects of off-farm employment on food security

Figure 3.8 presents the effect of off-farm employment on HFS in terms of FCS (Figure 3.8a) and HDDS (Figure 3.8b). The off-farm employment at lower level (up to 0.2) and higher level (beyond 0.6) seem to have positive implication on FCS and HDDS. This suggested as the level of employment intensity becomes higher not only there exists few treatment units but there would also be over dispersion, and hence it is up to intensity level of 0.2 Simpson index increased HFS in both FCS and HDDS. Off-farm employment has an adverse effect on HFS at moderate levels between 0.2 and 0.6.

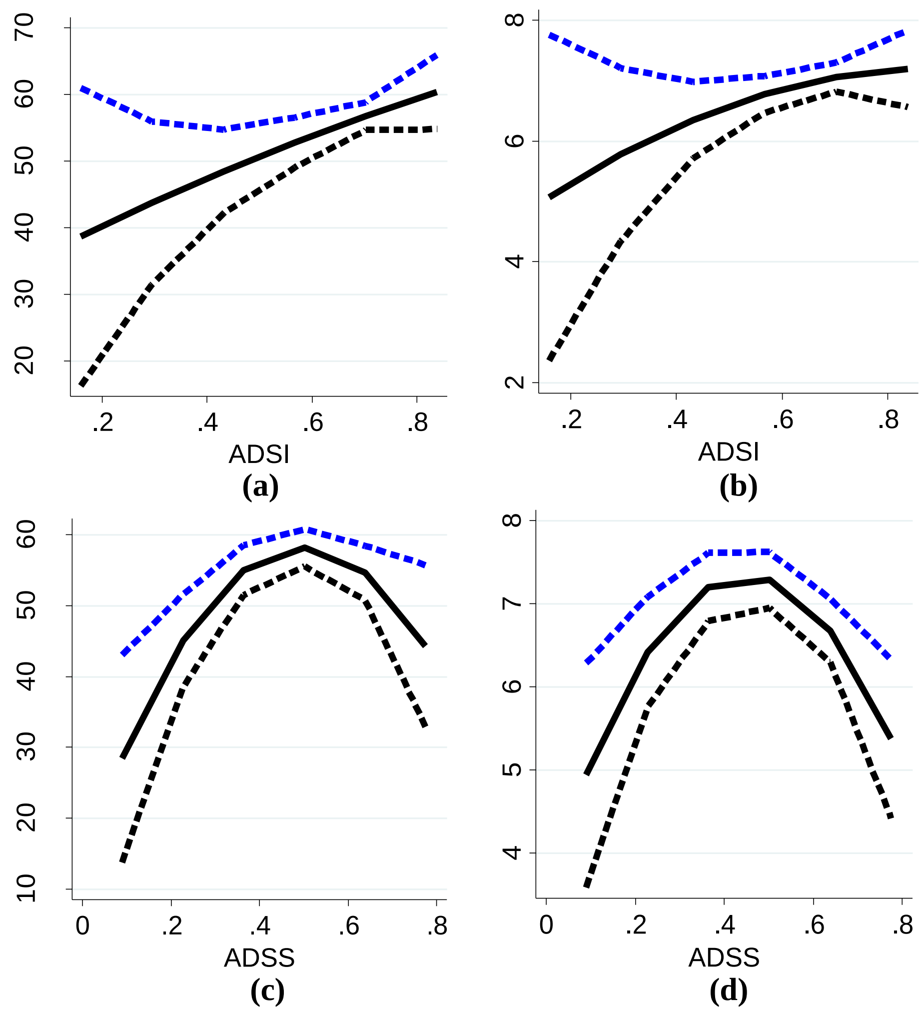


Figure 3.7. DRFs of overall agricultural diversification effects on FCS and HDDS

Note: Solid lines are DRFs and dashed lines show 95% confidence intervals obtained through bootstrapping.

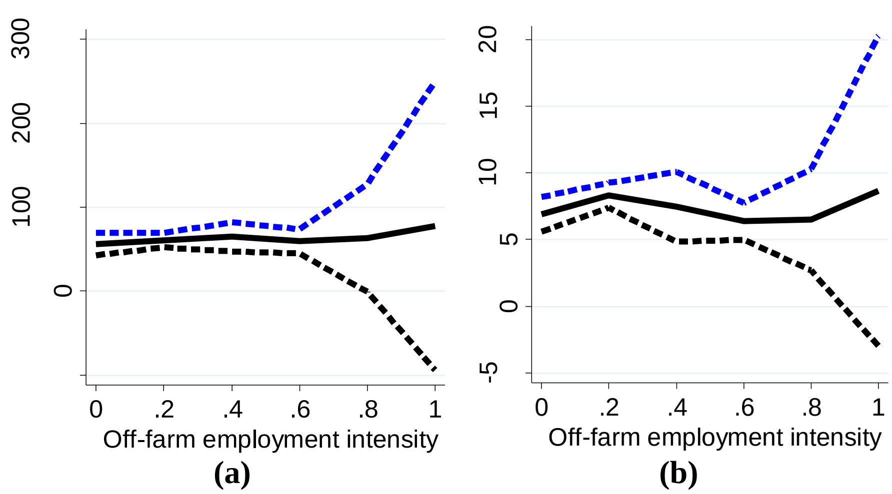


Figure 3. 8. DRFs of off-farm employment intensity effects on FCS and HDDS

Note: Solid lines are DRFs and dashed lines show 95% confidence intervals obtained through bootstrapping.

3.5. Conclusion and Policy Implications

The study investigated the role of AD and off-farm employment intensities in ensuring HFS in northwest Ethiopia. Aiming to differentiate effects of seasonal and sectoral variation in production, we analyzed the role of crop diversification in rainy and dry seasons and livestock diversification separately. Crop diversification would have positive implication on HFS had it been in rainy season production whilst specialization in dry season could improve HFS in both FC and DD.

As estimates of DRFs show that crop diversification intensity reached maximum at 0.3 Simpson score in rainy season may mean for most farmers a moderately increased diversification of crops from very limited food groups would be more beneficial in their FS situation. This suggests capitalizing diverse crop production practices of smallholder farmers being from same food group (i.e. cereals) to be from different food groups may enhance the crop farming system to be more nutrition sensitive, it might even without compromising benefits of specialization in an environmentally friendly way. But, it was entirely specialization in dry season helps improve HFS. Specialization in cash crops production may be vital for farmers not only because more efficient to use the water resource, which is so scarce, during dry season, they are also more attractive economically. This demonstrated that the farm income effect of diverse farming system in rainy season and specialization in dry season is so crucial, slightly similar to the finding of Sibhatu et al. (2015) suggests the farm income effect of diverse farming system is more pronounced than ensuring subsistence consumption.

Diversification in livestock production would also have positive implication on HFS. But, the diversification seems more from diverse food groups than specific one. This informed that livestock production is more nutrition sensitive than crop farming. Analyzing effects of AD combining crop and livestock production on HFS, the DRFs reached maximum at roughly 0.5 Simpson score and become lower at highest levels. This suggests diversification in production of different food groups being from crop and livestock farms further heightened its positive effects on HFS, which corroborates Herrero et al. (2010) that claimed the synergy between cropping and livestock husbandry can increase FS and income of the people. Finally, it concludes that not simply higher diversification level has positive implication on HFS but the diversification should also be from diverse food groups and up to certain level. Off-farm employment is the other variable suggested for building HFS resilience to withstand shocks, diverse incomes and improve agricultural productivity, similar to the work of Mofya-Mukuka & Kuhlgatz (2016) in Zambia suggested off-farm income sources as resilience to yield shocks.

Acknowledgements: Authors are grateful for all individuals involved in the study from district to kebele levels in Amhara region.

Competing interests: Authors declare no competing interests.

References

Abebaw, D., Fentie, Y. & Belay, K. (2010). The impact of a food security program on household food consumption in Northwestern Ethiopia: A matching estimator approach. *Food Policy* 35:286–293.

Adjimoti, G.O. & Kwadzo, G.T. (2018). Crop diversification and household food security status: evidence from rural Benin. *Agriculture and Food Security* 7(82):1-12.

Antonakis, J., Bendahan, S., Jacquart, P. & Lalive, R. (2010). On making causal claims: A review and recommendations. *The Leadership Quarterly* 21:1086-1120.

Arimond, M. & Ruel, M.T. (2004). Dietary diversity is associated with child nutritional status: evidence from 11 demographic and health surveys. *Journal of Nutrition* 134(10):2579-85.

Austin, P.C. (2019). Assessing covariate balance when using the generalized propensity score with quantitative or continuous exposures. *Statistical Methods in Medical Research* 28(5):1365–1377.

Bakhtsiyarava, M. & Grace, K. (2021). Agricultural production diversity and child nutrition in Ethiopia. *Food Security* 13:1407–1422.

Bellon, M.R., Ntandou-Bouzitou, G.D. & Caracciolo, F. (2016). On-farm diversity and market participation are positively associated with dietary diversity of rural mothers in Southern Benin, West Africa. PLoS ONE. 11(9): e0162535.

Bhavani, R.V. & Rampal, P. (2018). Review of agriculture-nutrition linkages in South Asia. *CAB Reviews* 13:046.

Bia, M. & Mattei, A.A. (2008). Stata package for the estimation of the dose-response function through adjustment for the generalized propensity score. *The Stata Journal* 8(3):354–73.

Chang, H.H. & Mishra, A. (2008). Impact of off-farm labor supply on food expenditures of the farm household. *Food Policy* 33(6):657–664.

Duong, P, Thanh, P. & Ancev, T. (2021). Impacts of off-farm employment on welfare, food security and poverty: Evidence from rural Vietnam. *International Journal of Social Welfare* 30:84–96.

EDHS (2016). Ethiopia demographic and health survey 2016.

EEA (2021). State of the Ethiopian Economy 2020/21. In: Economic Development, Population Dynamics, and Welfare, pp.1–325 (Mengistu Ketema & Getachew Diriba, eds.). Ethiopian Economics Association, Addis Ababa, Ethiopia.

EIU (2020). Global Food Security Index 2020: Addressing structural inequalities to build strong and sustainable food systems. New York: The Economist Intelligence Unit Limited.

EIU (2021). Global Food Security Index 2021: The 10-year anniversary. New York: The Economist Intelligence Unit Limited.

FAO (2018a). Country factsheet on small family farms-Ethiopia 2018.

FAO (2018b). The state of food security and nutrition in the world 2018. Building climate resilience for food security and nutrition. Rome, FAO.

FAO (2021). World Food and Agriculture- Statistical Yearbook 2021.

Flores, C.A. & Flores-Lagunes, A. (2009). Identification and estimation of causal mechanisms and net effects of a treatment under unconfoundedness. IZA Discussion Paper No. 4237. Bonn, Germany: Institute for the Study of Labor.

Frelat R, Lopez-Ridaurab S, Gillerc, K.E., Herrerod, M., *et al.* (2016). Drivers of household food availability in sub-Saharan Africa based on big data from small farms. *Proc Natl Acad Sci USA*. 113(2):458-463.

Getachew, T. Degefa, T. & Nigussie, S. (2018). Food insecurity of rural households in Boset district of Ethiopia: A suite of indicators analysis. *Agriculture and Food Security* 7 (65).

Gómez, M.I., Barrett, C.B., Raney, T., Pinstrup-Andersen, P., *et al.* (2013). Post-Green Revolution food systems and the triple burden of malnutrition. ESA Working Paper No. 13-02, August.

Guardabascio, B. & Ventura, M. (2014). Estimating the dose-response function through a generalized linear model approach. *The Stata Journal* 14(1):141–158.

Habtamu Yesigat, Sibhatu Biadgilign, Schickramm, L., Sauer, J. & Getachew Abate (2017). Production diversification, dietary diversity and food poverty: Empirical evidence from Ethiopia and Tanzania.

Herforth, A. (2010). Nutrition and the Environment: Fundamental to Food Security in Africa. In: The African Food System and Its Interaction with Human Health and Nutrition, pp.1–384 (Pinstrup-Andersen P, ed.). Ithaca, NY, US: Cornell University Press in cooperation with the United Nations University.

Herrero, M., Thornton, P.K., Notenbaert, A.M., Wood, S., *et al.* (2010). Smart investments in sustainable food production: Revisiting mixed crop-livestock systems. *Science* 327(5967):822–825.

Hirano, K. & Imbens, G.W. (2004). The propensity score with continuous treatments. In: Applied Bayesian Modeling and Causal Inference from Incomplete-Data Perspectives, pp.73–84 (Gelman, A. & Meng, X.L., eds.). West Sussex, England: Wiley InterScience.

Jones, A.D. (2017). Critical review of the emerging research evidence on agricultural biodiversity, diet diversity, and nutritional status in low- and middle-income countries. *Nutrition Reviews* 75(10):769–782.

Jones, A.D., Shrinivas, A. & Bezner-Kerr, R. (2014). Farm production diversity is associated with greater household dietary diversity in Malawi: Findings from nationally representative data. *Food Policy* 46:1-12.

Justus, O., Knerr, B., Owuor, G. & Ouma, E. (2015). Agricultural commercialization and household food security: The case of smallholders in Great Lakes Region of Central Africa. In: Proceedings of the 2015 Conference of International Association of Agricultural Economists, pp.1–25. Milan, Italy.

Kabir, R., Halima, O., Rahman, N., Ghosh, S., Islam, S. & Rahman, H. (2022). Linking farm production diversity to household dietary diversity controlling market access and agricultural technology usage: Evidence from Noakhali district, Bangladesh. *Heliyon* 8, e08755.

Koppmair, S., Minale Kassie & Qaim, M. (2016). Farm production, market access and dietary diversity in Malawi. *Public Health Nutrition* 20(2):325–35.

Lemlem Teklegiorgis, L.T., Gornott, C., Hoffmann, H., & Sieber, S. (2021). Farm production diversity and household dietary diversity: Panel data evidence from rural households in Tanzania. *Frontiers in Sustainable Food Systems* 5:612341.

Mofya-Mukuka, R. & Kuhlgatz, C. (2016). Impact of agricultural diversification and commercialization on child nutrition in Zambia: A dose response analysis. *Journal of Agricultural Science* 8(4):60–75.

Mohammed Adem & Fentahun Tesafa (2020). Intensity of income diversification among small-holder farmers in Asayita Woreda, Afar Region, Ethiopia. *Cogent Economics and Finance* 8:1759394.

Mulat Demeke, Meerman, J., Scognamillo, A., Romeo, A. & Solomon Asfaw (2017). Linking farm diversification to household diet diversification: Evidence from a sample of Kenyan ultra-poor farmers. ESA Working Paper No.17-01. Rome, FAO.

Muthini, D., Nzuma, J. & Nyikal, R. (2020). Farm production diversity and its association with dietary diversity in Kenya. *Food Security* 1107–1120.

NPC (National Planning Commission) (2017). Ethiopia's progress towards eradicating poverty: An interim report on 2015/16 Poverty Analysis Study, September 2017.

Ogutu, S.O., Godecke, T. & Qaim, M. (2019). Agricultural commercialisation and nutrition in smallholder farm households. *Journal of Agricultural Economics* 71:534–555.

PDC (2020). Ten-year Perspective Economic and Development Plan (2020-2030). The FDRE Planning and Development Commission. Addis Ababa, Ethiopia.

Qureshi, M.E., Dixon, J. & Wood, M. (2015). Public policies for improving food and nutrition security at different scales. *Food Security* 7(2):393–403.

Rahman, A. & Mishra, S. (2020). Does non-farm income affect food security? Evidence from India. *Journal of Development Studies* 56(6):1190–1209.

Ruel, M.T., Quisumbing, A.R. & Balagamwala, M. (2018). Nutrition-sensitive agriculture: What have we learned so far? *Global Food Security* 17:128–153.

Sekabira, H. & Nalunga, S. (2020). Farm production diversity: Is it important for dietary diversity? Panel data evidence from Uganda. *Sustainability* 12(1028):1–20.

Sibhatu Kibrom, Krishna, V. & Qaim, M. (2015). Farm production diversity and dietary diversity in developing countries. Proceeding of the National Academy of Sciences USA, pp.10657–10662 (Turner, B. L., ed.). Arizona State University, Tempe, AZ.

Sibhatu, K. & Qaim, M. (2018). Review: Meta-analysis of the association between production diversity, diets and nutrition in smallholder farm households. *Food Policy,* 77:1–18.

Simpson, E.H. (1949). Measurement of diversity. Nature, 163:688. Macmillan Publishers Ltd.

Sinyolo, S., Murendo, C., Nyamwanza, A.M., Sinyolo, S.A., Ndinda, C. & Nwosu, C.O. (2021). Farm production diversification and dietary diversity among subsistence farming households: Panel data evidence from South Africa. *Sustainability* 13:10325.

Swindale, A. & Bilinsky, P (2006). Household Dietary Diversity Score for Measurement of Household Food Access: Indicator Guide (V.2); FHI 360/FANTA III Project: Washington, DC, USA.

UNICEF (2018). Amhara Regional State 2007/08-2015/16 Budget Brief. UNICEF, Ethiopia.

UNICEF (2021). Amhara Regional State: Regional Health and Education Expenditure Analysis 2014/15-2018/19. Budget Brief 2020/21. UNICEF, Ethiopia.

Webb, P. & Kennedy, E. (2014). Impacts of agriculture on nutrition: nature of the evidence and research gaps. *Food Nutrition Bulletin* 35:126–132.

WFP (2008). Food Consumption Analysis, Calculation and Use of the Food Consumption Score in Food Security Analysis, Vulnerability Analysis and Mapping Branch; WFP: Rome, Italy.

Wu, X., Mealli, F., Kioumourtzoglou, M., Dominici, F. & Braun, D. (2021). Matching on generalized propensity scores with continuous exposures. doi.org/10.48550/arXiv.1812.06575.

CHAPTER FOUR

WOMEN EMPOWERMENT, EFFICIENCY AND FOOD SECURITY NEXUS IN RURAL ETHIOPIA: A GENERALIZED STRUCTURAL EQUATION MODELING

A manuscript submitted to Heliyon Journal

4.1. Abstract

The paper investigates impact of women empowerment and production efficiency in agriculture with particular emphasis on food security for women, children & households, using cross-sectional data gathered from samples of 245 women, 80 children and 250 households surveyed in Libokemem district in Amhara Region in South Gondar Zone. We applied stochastic frontier model to determine the level and determinants of efficiency and generalized structural equation modeling to examine the relationships between these variables. The results illustrated that 33% of households, 44% of women and 28% of children in Libokemkem woreda are food insecure while 64% of the households have adequate level of women empowerment and efficiency in crop farm reached 0.652. This suggests that crop production can be increased by 35% with given inputs by simply enhancing efficiency to achieve optimum outputs. Women are disempowered in two major domains including heavy workload and lack of voice on decision making in production. This contributed to a marked level of disempowerment calculated at 48 and 22% respectively. About 1 in 2 women have high workload above time poverty line 10.5 h/d. The findings also revealed that women empowerment improved dietary diversity and ensured food security among women, children and households in the woreda. The interaction pathways helped enhance food diversification and better market orientation of farm production encouraged these outcomes to increase among all aforementioned groups. However, while the adverse implication of efficiency interaction proved to be stronger in magnitude than its direct positive effect, the efficiency interaction pathway ultimately implied net reduction of these outcomes across all groups. This suggests that interventions specifically targeting these dimensions of disempowerment are needed to increase empowerment by strengthening agriculture-food-nutrition nexus positively. Some even suggest that gender has a disconnecting/ adverse effect on these linkages.

Keyword: *Empowerment, Efficiency, Food security, Generalized structural equation modeling, Ethiopia*

4.2. Introduction

Although there are marked variation among countries, women contributed about 50% of the agricultural labor force in Asia and Africa (FAO, 2011). The fact that women represent a large segment of the workforce in the agriculture sector, they are often subjected to barriers such as limited decision making power and lack of freedom of mobility in their choices of agricultural practices. Their lower level of access to productive resources (such as land & livestock), inputs (fertilizers & improved seeds), and services (credit & extension) for agriculture reflects a gender gap which is most often rooted in disempowering social norms that are spatially specific on geography and dominant cultural values (Gupta *et al.,* 2017). As the primary caregivers, such limitations pose a challenge for women to provide sufficient and adequately nutritious foods both for themselves and their children (Kjeldsberg *et al.,* 2018).

Agriculture has been recognized as a key sector to leverage for improved food security and nutrition outcomes. Yet, the evidence on agriculture-gender linkages to nutrition is relatively weak and sizeable knowledge gaps remain (Kadiyala *et al.,* 2014). The emerging literature on the relationships between agriculture and nutrition, however, highlights the important role of gender in agriculture, food and nutrition (Malapit *et al.*, 2014; Ruel *et al.,* 2018). A study in India reveals that acquisition of livestock assets by illiterate women increases their intra-household bargaining power which results in greater investment in child nutrition (Jumrani & Birthal, 2016). Others point out the adverse implications that production interventions can have on diet diversity and nutritional status due to women's stress in time and energy leading to reductions in their care giving practices and risks for women's own health (Gillespie *et al.,* 2019; Ruel *et al.,* 2018).

Women's time constraints not only are a burden on women themselves but can also hamper the care and welfare of children and other family members. This suggests that agricultural innovations that greatly boost labor burdens may have an adverse implication even if income increases. Labor-saving technologies may benefit women even if neither production nor income is improved. Labor-augmenting technologies that reduce the time women need to spend on domestic works may also give them more freedom to choose among activities that are empowering especially if these options have not been available in the past. This study generally aims at investigating relationships between empowerment, efficiency and food security at household and individual levels focusing on the three key pathways identified in the literature through which gender mediates agriculture-food-nutrition (AFN) nexus: (1) agricultural production can itself be a way of empowering women farmers, (2) agricultural time requirements and labor can have trade-offs with childcare and feeding practices, and (3) risks associated with women's agricultural labor could contribute to intra-generational malnutrition and poor health.

A recent systematic review of a number of quantitative studies aiming to explore the ways in which women empowerment is quantitatively measured identifies a significant absence of indicators of time allocation, reproductive decision making and men's engagement in childcare and nutrition (Santoso *et al.,* 2019). The authors indicate that while these studies provide important insight into gender as mediator between AFN nexus, more qualitative studies are needed to explore the complex and context-specific interplays between gender dynamics and AFN pathways. Other scholars suggest more robust quantitative methods required to establish causal relationships within the pathways (Gillespie *et al.,* 2019; Kjeldsberg *et al.,* 2018). Webb and Kennedy (2014) ratify the need for more research on impact pathways. Many studies have focused on determining the size and direction of impacts rather than the channels by which impact occurs. Gupta *et al.* (2017) also affirm that there is lack of research that systematically examines the link between farming practices and the level of women empowerment in relation to men in the agricultural sector.

Although a great deal of research exists on gender and agriculture, few studies investigate the implications of reduced gender inequalities within households for production efficiency in agriculture. Seymour (2017) tries to look at the role of women empowerment in agriculture (WEA) on technical efficiency (TE) of crop farm in Bangladesh and he identified that reduced gender disparities within households are associated with higher levels of TE. Another study conducted in Bangladesh also examined crop productivity and efficiency effects of WEA and indicated that both WEA and a reduction in gender-gap in empowerment (GGE) significantly enhance production efficiency (Anik & Rahman, 2020). The authors suggest on the importance of issuing policies specifically targeting women to enhance their empowerment in agriculture and reduce GGE.

Rahman and Salim (2013) revealed that despite the fact that labor is a critical factor in agricultural production, due to gender differences and skills, there exists heterogeneity in labor. There is also a widespread discourse on gender gap in agricultural productivity and efficiency. Some authors suggest productivity of men and women in agriculture is the same (Croppenstedt *et al.,* 2013; Quisumbing, 1996). Others point out gender based differences in productivity due to unequal access to resources and other constraints specific to women including low returns from resources they generally possess vividly standout (Aguilar *et al.,* 2015; Kilic *et al.,* 2015). This implies that explaining gender differences in productivity only through unequal access to resources may provide a misleading information, as gender gap also exists in differences of returns derived from resources possessed by women.

The literature on GGE and TE in agriculture is scant and the available evidences are also mixed (Anik & Rahman, 2020). Udry (1995) reported differences in resource allocation in agriculture between men and women in Burkina Faso and others noted female labor input (Rahman, 2010) and a reduction in gender-gap in empowerment reciprocate each other (Anik & Rahman, 2020; Seymour, 2017). This significantly improves efficiency in agriculture in Bangladesh. Some others have studied WEA with respect to nutritional outcomes in Nepal (Malapit *et al.*, 2015; Cunningham *et al.*, 2015), food security outcomes in Bangladesh (Sraboni *et al.*, 2014) and market orientation of farm production in India (Gupta *et al.,* 2017). Although these studies considered production diversity, area of cultivable land and market orientation aspects respectively, very limited research has systematically examined the link between efficiency of farming systems and women's status in empowerment relative to men in agriculture sector. This study tries to bridge the gap by focusing on linkages between production efficiency of farm households and women empowerment in agriculture in Libokemkem woreda of South Gondar Zone in northwest Ethiopia.

The primary objective of this paper is to measure the level and gender-gap in the distribution of WEA and thereby investigate its impact on production efficiency of crop farmers and food security for women, children and households. Women's education level and share of female labor input as TE shifters, among other covariates, are considered.

We also assess intra-household empowerment gap between women and men within households to identify the key derivers of disempowerment and gender gap in empowerment (GGE). We employed a trans log stochastic production frontier (SPF) and generalized structural equation modeling (GSEM) framework to analyze the cross-sectional data on 245 women, 80 children and 250 households surveyed in Libokemkem woreda in northwest Ethiopia during July and August 2021.

This study contributes to the literature on women's role in agriculture as follows. First, it provides a detailed disaggregated analysis of WEAI, GGE and TE by terciles to examine the level of inequality of these indicators within and among rural households. Second, it presents a robust analysis on the drivers of WEA and TE. Finally, it offers empirical evidence on the role of WEA on DD and FS of women, children and households through examining its direct and indirect pathways. This contribution is expected to add value to the knowledge gap around issues of WEA and TE related to FS of households and vulnerable Ethiopians.

4.3. Conceptual Framework

Despite consistent gains in agricultural productivity in the last half century, lack of food security persists in many regions of the world. Addressing this issue is really pertinent in low income countries like Ethiopia, where most people are at risk of food insecurity and malnutrition. Women's engagement in agricultural and domestic tasks is remarkably high. Evidence suggests women's work time is an essential input for FS and nutrition outcomes. Given the potential trade-offs pertaining to time in productive and reproductive activities, its implications for FS and DD of households and vulnerable individuals (women and children) are operationally conceptualized based on the three pathways (PW) identified in the literature through which gender mediates associations between AFN: empowerment, child care and energy expenditure.

Figure 4.1 presents the conceptual model developed to guide our analysis of linkages between WEA, TE and FS in rural settings that is framed in generalized structural equation modeling (GSEM), where boxes depict observed (manifest) variables and oval shapes show latent (unobserved) variables. The conceptual groups that map to reflect the three major pathways onto five domains of empowerment are abstract constructs best modeled using 10 indicators that are conceptually relevant and inter-correlated. The first PW is empowerment that refers to a link when the agricultural labor conditions can influence empowerment of women in having control over nutrition-relevant resources and decision making outlined through different interrelated channels, such as women's role in food production and use of income, women's control over household resources and other decisions, and women's employment as source of income (Hereforth & Harris, 2014).

Moving from left to right in the path diagram in Figure 4.1, our hypothesized model shows that the empowerment PW is operationally measured with the three latent domains (production domain [PD], resource domain [RD] and income domain [ID]) constructed using the first six indicators (input in productive decisions [IPR]; relative autonomy in production decisions [RAI], asset ownership [AO], asset buying, selling and transfer rights [BST], credit access & use [CU] and income control over [ICO]) that enclosed by boxes at the top left corner. The second is childcare PW relates to the pressures that heavy and prolonged women workloads in agriculture has placed on childcare and feeding. This PW can be addressed through the latent time-use domain (TD) constructed using the last two observed indicators (workload [WL] and leisure time available for primary woman/man [LS]). The third PW is energy expenditure that reflects the risks of energy expenditure and health hazards on women could contribute to intra-generational malnutrition and poor health that the current paper lacks to capture. Instead, we considered interaction PWs of empowerment with technical efficiency (TE), market orientation (MO) and diversification of agricultural production (AD) as shown by arrows pointing from these variables to the path linking WEAI to FS outcomes in Figure 4.1.

These pathways may have special significance for household nutrition outcomes, mainly for children's nutrition and health with the assumption that women have consistently been found to be more likely than men to invest in their children's health and well-being, and the income and resources that women control wield disproportionately strong effects on health and nutrition outcomes not just for themselves and their children but also for other family members.

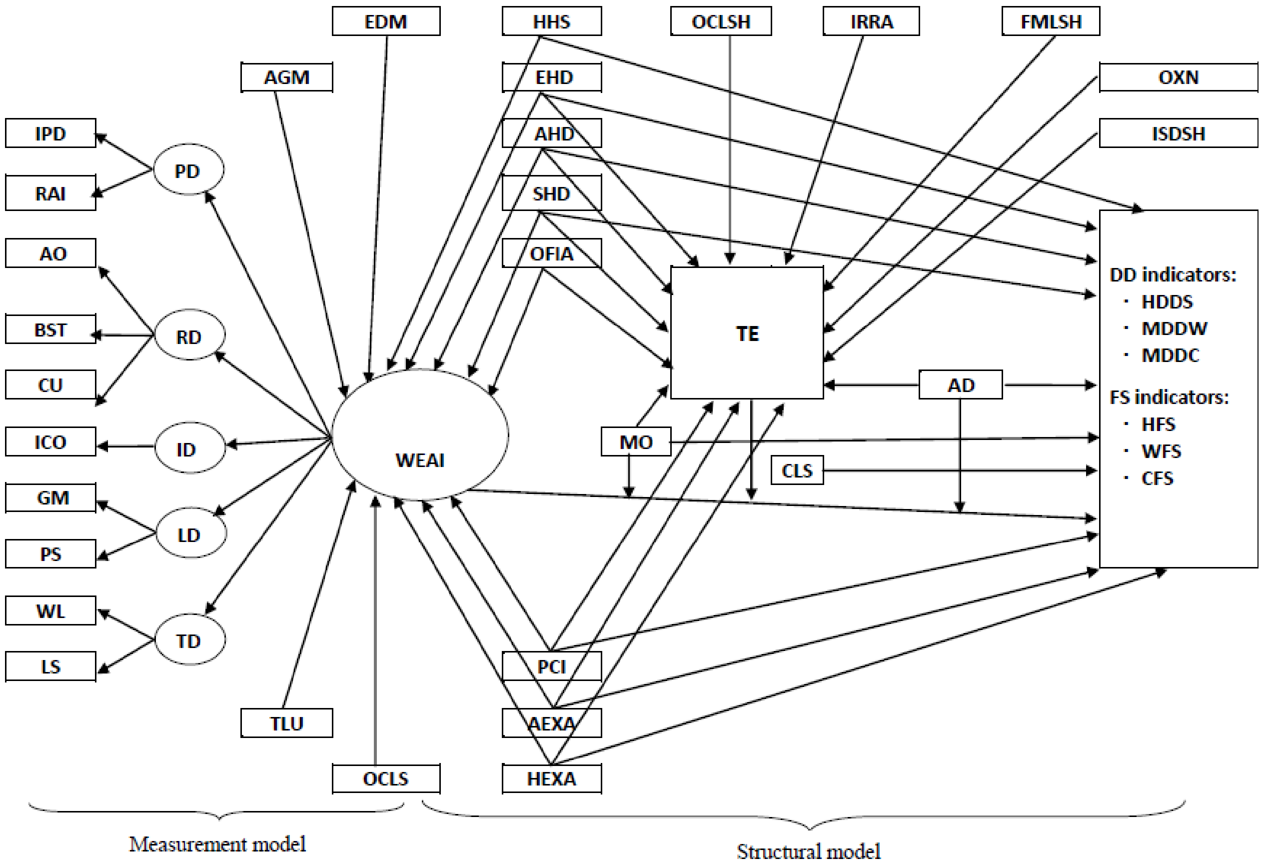


Figure 4.1. Conceptual framework of GSEM for analysis of WEA, TE and FS linkages

Policies that improve women's status and reduce gender disparities are expected to improve women, children and household well-being, owing to the important role of women in childcare and household food preparation in countries like Ethiopia. Although their role has tended to be unrecognized and incorrectly measured, women still continue to play a crucial role in agriculture. The other covariates our analytical framework treated include household size (HHS), education (EHD), age (AHD) and sex (SHD) of household head, off-farm income access (OFIA), per capita income (PCI), agriculture extension access (AEXA) and health extension access (HEXA) are among household characteristics expected to influence both the two key independent variables (WEAI and TE) and DD/FS outcomes (HDDS, MDDW, MDDC, HFS, WFS and CFS) as reflected by the three arrows originated from each covariate in Figure 4.1. Own cultivated land size (OCLS), livestock ownership (TLU), age of mother (AGM) and education of mother (EDM) are assumed to relate with WEAI only, while access to irrigation (IRRA), oxen ownership (OXN), female labor share (FMLSH), own cultivated land share (OCLSH) and improved seed share (ISDSH) are hypothesized to correlate with TE only, and cultivated land size (CLS) only with DD/FS outcomes. Agricultural diversification and market orientation are expected to influence both TE and DD/FS outcomes directly.

GSEM has several benefits over the linear regression model as it can accommodate relationships between multiple variables by simultaneously estimating multiple regression models. This allows to model indirect, mediating and co-varying relationships besides the direct relationships possible with stand-alone regression models. This estimation framework is generally composed of measurement models to construct the latent variables corrected for measurement errors and the structural model for analyzing linkages among WEAI, TE and DD/FS indicators.

4.4. Materials and Methods

4.4.1. Study Settings

This study was conducted in Libokemkem woreda randomly chosen from food insecurity vulnerable districts in northwest Ethiopia. It comprises 33 villages (kebeles) with an area of 1082 sq.km, of which 26 are under safety net programs where food insecurity is severe. Among population of 233,311 in the woreda, the rural areas and females accounted for 91 and 49% respectively (Libokemekem WoA report, 2019/20). More than 87% of the overall 48,261 households reside in rural areas and 19.3% are female headed households. Its altitude ranges from 1800 to 2850 m a.s.l. with annual rainfall range of 900 – 1200 mm and temperature 11.1 – 27.9 ^{O}C. The agro-ecology of the woreda is mainly characterized by mid altitude (Woynadega) about 77%, high altitude (Dega) 16% and low altitude (Qola) 7%; where brown soil is the dominant soil type comprising 60%, followed by red 22%, black 15%, and grey soil 3%. Mixed crop farming and livestock rearing is the dominant farming practices in the woreda that relies heavily on rain-fed production mainly of cereal crops, and has a growing experience in irrigation production on vegetable crops.

The primary data for this study were collected during June and July 2021 on 250 households, randomly chosen from five villages (Libo, Qeregna, Agelahana, Birkutie & Tibaga) in Libokemkem district following a two-stage sampling technique. However, we found 229 are dual households composed of primary female and male adults in which only 224 have administered the empowerment module completely. As both women and men from each household were interviewed, the total number of survey respondents comprised 448 adults. A team of eight data collectors and two supervisors were trained for two days to create understanding on contents of the questionnaire and the procedure to conduct face-to-face interview with farmers using local language and their wordings both in-door and in-field sessions including pilot testing of the questionnaire. All the necessary corrections were made based on the pretest findings prior to the main survey. At the end of every data collection day, each questionnaire was checked for its completeness and consistency by supervisors and the principal investigator, and pertinent feedbacks were given to data collectors and supervisors to correct it in the next data collection date. Wrongly filled questionnaires were excluded from the analysis to ensure data quality.

4.4.2. Construction of outcome and key independent variables

4.4.2.1. Food security

Food security is the outcome variable for this study that is assessed at household and individual levels. The study tends to measure food security (FS) operationally conceptualized in terms of household dietary diversity score (HDDS) to reflect the dietary quality of food consumed by households over 24 hour cycle prior to the survey. A variety of approaches were employed in empirical literature to measure dietary diversity (DD). The choice of the approach mostly depends on the relative abundance of some food types, dietary habits and food culture of the society, availability of data and the level of processing and other socioeconomic elements (Jones *et al.,* 2014; Sibhatu *et al.,* 2015). Evidence also suggests various approaches can be used to assess DD as long as they reflect comparative available qualities of particular food, diets and societal food behavior (Kennedy *et al.,* 2013; Swindale & Bilinsky 2006). In estimating dietary diversity score (DDS), individual food items consumed by household/individual need to be aggregated into broader food groups. Many studies have used 12 equally weighted food groups to calculate HDDS that the respondent reported consuming over 24 hour or 7 days recall period (e.g. Jones *et al.,* 2014; Sibhatu & Qaim, 2016; Snapp & Fisher, 2015), despite no international consensus on the best number to use (Ruel *et al.,* 2012). Sometimes, food groups with low micronutrient densities are excluded to reflect on more healthy diets (Kennedy *et al.,* 2011). Others consider a larger number of food groups to assess dietary patterns in particular situations (Keding *et al.,* 2012). This study uses the following 12 food groups to construct DDS at household level: (1) cereals; (2) tubers and roots; (3) vegetables; (4) fruits; (5) meat & poultry; (6) eggs; (7) fish; (8) pulses, legumes & nuts; (9) milk & milk products; (10) oils & fats; (11) sugar & honey; and (12) miscellaneous (spices, condiments & beverages) adopted from Swindale and Bilinsky (2006) and Kennedy *et al.* (2011). The index has a continuous score ranging 0 to 12.

DD measured at individual level has been repeatedly validated as indicative of diet quality and is associated with nutritional status across a range of countries and contexts, including a positive association between higher DD and reduced prevalence of stunting and underweight among children under five, and a positive association between DD and mean micronutrient adequacy for women and children. Nutritional needs are more likely to be met where diverse diets are the norm as a diverse diet is more likely to include a variety of nutrient dense foods required for good health than a monotonous one. The reviews by Ruel (2003) and Ruel *et al.* (2013) have summarized these findings and Individual Dietary Diversity Scores (IDDS) are now widely considered important indicators of diet quality and nutritional status in the developing world. However, very few studies have examined linkages between agriculture and nutrition using IDDS (Hirvonen & Hoddinott, 2014; Olney *et al.*, 2009). DD becomes an attractive outcome measure, for it is also responsive to current empowerment status of women, unlike anthropometric measures like height, which could be highly correlated with early childhood nutritional status (Alderman *et al.*, 2006) and empowerment status of caregiver during childhood.

This study also adopts individual assessment as the empowerment pathway induces to apply to evaluate its role on FS of women and children. As such, we used IDDS that have been validated for several age and sex groups as proxies for macro and micronutrient adequacies (Arimond *et al.,* 2010; Kennedy *et al.*, 2007). This is based on WHO (2010) and FAO (2016) guidelines of Minimum Dietary Diversity (MDD) with a 7 food group score for children under five years and Minimum Dietary Diversity for Women (MDD-W) with a 10 food group score for women in reproductive age. The two different sets of DDS reflect the differences in micronutrient requirements across the life course (Arimond *et al.*, 2010; Ruel *et al.*, 2010).

We also constructed dichotomous indicators to assess FS situations of households using data from FCS module, and the nutrition status of women and children derived from MDD-W and MDD modules respectively. Adopting the revised threshold (42) of the FCS, a household is defined as FI if its FCS is 42 and below, and FS otherwise. This implies that households in the FI group are those who have poor and borderline food consumption and those in the FS group have acceptable food consumption- i.e. adequate in dietary quality. Following FAO and FHI (2016), we described a woman in a reproductive age group has adequate nutrition status had she consumed at least 5 out 10 food groups defined in MDD-W module in the last 24 h prior to the survey, and poor nutrition status otherwise. Regarding children under five years, a nutritionally adequate child has consumed at least 4 out of 7 food groups defined in MDD module in previous 24 h, and those that consumed below this threshold are classified poor in nutrition status.

4.4.2.2. Women empowerment in agriculture

The fact that empowerment and autonomy is highly context specific and may have different meaning to different persons (Basu & Koolwal, 2005) and sensitive to thresholds set to qualify an individual as empowered (Gupta *et al.,* 2019), search for a universally satisfying measurement criterion of women's empowerment is quite challenging. Earlier scholars have traditionally used proxy indicators to measure empowerment such as parents' education (Haddad, 2000; Betri *et al.,* 2004), gender of household head (Rogers, 1996), control over income (Leroy *et al.,* 2008) and control over assets (Quisumbing & Maluccio, 2003); direct measures of empowerment such as mobility, decision making and attitudes toward verbal and physical abuse (Bhagowalia *et al.,* 2012). Few exceptions (Sraboni *et al.,* 2014; Alkrie *et al.,* 2013; Malapit *et al.*, 2015), most analyses have focused on women decision making within the household or on their reproductive roles, neglecting empowerment in productive domains. Few studies measure women empowerment in agricultural production as a pathway to improved nutrition, despite explicit targeting of women in several programs (Ruel & Alderman, 2013). The fact that such distinctions have policy relevance, it is vital to identify and compare agency achievements in different domains rather than in one alone (Alkire, 2007). Because agency and empowerment are experienced with different tasks and can be described and measured with different domains, Alkire (2005) suggests most measures of agency and empowerment should be domain specific.

In contrast to measures of status or bargaining power as detailed above, Kabeer (1999) viewed empowerment as a process that enables individuals to "exercise choice". This notion of empowerment focuses on three interrelated constructs: resources, agency and achievements. Nevertheless, ignoring complexity in defining and measuring women empowerment may produce unwarranted misleading information. The current paper adopts women empowerment in agriculture index (WEAI) from Alkire *et al.* (2013) to directly assess women empowerment across five domains in agriculture: production, resource, income, leadership and time use. Thus, WEAI is made up of two key indicators: five domains of empowerment (5DE) and gender parity index (GPI). The 5DE assesses the extent to which women are empowered in agriculture and is constructed from individual level empowerment scores, which reflects each person's achievements in the five domains as measured by 10 indicators with their corresponding weights and adequacy threshold defined in Table 4.1. The GPI focuses on intra-household empowerment gap between woman and man 5DE scores. Households are classified as having gender parity if either the woman is empowered (i.e. her empowerment score is 80% or higher) or her score is greater than the empowerment score of male decision maker in the household (Malpait & Quisumbing, 2015). Each indicator assumes a value of one if a person crosses a given threshold with respect to each indicator or zero otherwise. Accordingly, we estimated first the 5DE for woman and man separately as weighted sum of the 10 indicators; and then, the overall WEAI was calculated as a weighted sum of 5DE and GPI.

Table 4.1. Domains, weights and adequacy thresholds of WEAI indicators

Domain	Indicator	Weight	Definition of indicator's adequacy threshold
1. Production	Inputs in productive decisions	1/10	Sole or joint input at least into some decisions or feels can make own decisions at least medium extent over at least one productive activity.
	Autonomy in production	1/10	Decision more motivated by own values than by external influences over at least one productive activity.
2. Resources	Ownership of assets	1/15	Sole or joint ownership over at least one major household asset.
	Rights over assets	1/15	Sole or joint decision in purchase, sale or transfer over at least one type of agricultural productive assets owned.
	Access to credit	1/15	Access to credit & sole or joint input at least into some decisions about borrowing or use of credit at least from one source.
3. Income	Control over income	1/5	Sole/joint control over income at least from one activity or feels can make own decision on major expenditures at least medium extent.
4. Leadership	Group membership	1/10	A person is an active member in at least one economic/social group.
	Speaking in public	1/10	Comfortable speaking in public at least with great difficulty concerning issues relevant to oneself or one's community.
5. Time use	Workload	1/10	Worked $\leq$ time poverty line of 10.5 hours in the last 24 h.
	Leisure	1/10	Satisfaction level at least 5 from 1=not satisfied to 10=very satisfied with time available for leisure.

Source: Adopted from Alkire *et al.* (2013)

There are two equivalent ways in the literature identified to construct 5DE index. The first focuses on the percentage of empowered women and adequacies among the disempowered. The other highlights the percentage of disempowered women and the percentage of domains in which they lack adequate achievements. Following Alkire & Foster (2011), we used the second approach that directly measures disempowerment to identify the critical indicators that must be addressed to increase empowerment. This also enables decision makers to focus on the situation of the disempowered. Accordingly, we began by computing a disempowerment index across the five domains (E_0) as in Equation (4.1); then we computed 5DE index as specified in Equation (4.2).

$$E_0 = \sum_{k=1}^{5} \sum_{j=1}^{10} w_{j,k} x_{j,k} \tag{4.1}$$

$$5DE = 1 - E_0 \tag{4.2}$$

where $x_{j,k}$ is indicator j in domain k for household i, $w_{j,k}$ is weight of indicator j in domain k. $x_{j,k}$=1 for sole or joint decision on indicator j (j=1,2,…,10) in domain k (k=1,2,3, 4, 5).

Constructing WEAI through this approach, however, needs to apply two types of thresholds in the subsequent stages of estimating 5DE index. The first cutoffs are those used to define each indicator in the 5DE has a value of 1 if a woman crosses adequacy thresholds defined in Table 4.1 or zero otherwise. This requires to recode further the ten indicators from the women empowerment adequacy scores into women disempowerment inadequacy scores.

Let the 5DE index for woman is represented by a variable W5DE and a disempowerment index across the five domains as W5DD. We first compute W5DD as weighted sum of the 10 indicators defined using inadequacy thresholds in contrary to those shown in Table 4.1 (e.g., for the first indicator, it is defined a person has no or few input to sole or joint decision in any agricultural activity) and then the empowerment index for woman can be derived as $\mathrm{W5DE} = 1 - \mathrm{W5DD}$. Although this reveals the level of disempowerment or empowerment score quantitatively, it does not allow us to classify whether a woman is or is not disempowered. Here comes the relevance of the second threshold. When the disempowerment inadequacy score that obtained above (i.e. W5DD) is now censored to a threshold of 0.2 (or 20%), we get the new censored inadequacy disempowerment score for woman (denoted by W5DDc, for example); then the new censored empowerment adequacy score (W5DEc) can be estimated as: $\mathrm{W5DEc} = 1 - \mathrm{W5DDc}$. This cutoff allows to classify whether a person is disempowered, besides for consistency with WEAI and other Alkire and Foster indices.

The disempowerment cutoff is the share of inadequacies a woman must have to be considered disempowered. Following Alkire *et al.* (2013), this paper uses 20% (or 0.2) as the disempowerment threshold. A person is defined disempowered if his or her inadequacy score is greater than 20%. This means that a person is empowered if his/her adequacy score is at least 80%. Once the original inadequacy scores censored using this disempowerment threshold in the way that individuals whose original inadequacy scores (*W5DD*) less than or equal to 0.2, their score is replaced by 0, despite not 0 actually (W5DDc = 0), and any existing inadequacies are, therefore, not considered in the "censored headcounts". This is referred to as censoring inadequacies of the empowered (see Alkire & Foster, 2011) and those individuals whose original inadequacy score is higher than 0.2, their score remains their original inadequacy score (W5DDc = W5DD).

Now an individual can be classified whether she is or is not empowered based on 5DE approach. As W5DDc in our case is the woman disempowerment index representing the censored inadequacy score of the disempowered after censoring inadequacy of the empowered to zero, and W5DEc is the woman empowerment index after this censorship.

The WEAI was formulated in Equation (4.3) as the weighted sum of the 5DE and GPI, using 90 and 10% in order as their weights adopted from Alkire *et al.* (2013) empirically set after exploring the sensitivity of empowerment for different cutoffs.

$$\mathrm{WEAI_i} = 0.9 * \mathrm{5DE_i} + 0.1 * \mathrm{GPI_i} \tag{4.3}$$

An overall empowerment score was estimated using all the 10 indicators, and decomposability property of WEAI also applied to explore the domains and indicators in which women have the least adequate achievements. Each of the three 5DE, GPI and WEAI range from 0 to 1 as adequacy/parity/empowerment levels improve.

4.4.2.3. Technical efficiency

The major motivation of this subsection is to understand the association between WEA and farm productivity. The correlation may not be directly but in the context that empowerment influences productivity through enhancing production efficiency. For instance, when empowered, a woman could efficiently contribute in decision making on farming practices and activities expected to yield higher level of efficiency, and ultimately the household will attain higher productivity even with same inputs. Empowerment implies increased capabilities and agency for women and their family members as women have better access and possession of material, human and social resources. The manifold effects of knowledge on agricultural productivity mainly through gains in labor productivity, adoption of technologies and efficient use of resources are well-documented in the literature (Huffman, 2001). Through active participation in farmers' groups, a woman can gain access to new technologies and farming practices. She may also gain social influence or access to other supporting services and assistance (Quisumbing & Kumar, 2011).

Access to credit may expand women's capability to invest in efficiency-enhancing innovations and to smooth consumption or production shocks (Fletschner & Kenney, 2014). A woman may achieve a higher empowerment score despite reduced gender parity when her male counterpart decides to concentrate more on off-farm activities. This suggests empowerment may increase women's workload in agriculture but not necessarily contributes to improvements in efficiency.

Measuring economic performance in agriculture under this complex relationships requires understanding of production decisions and levels of technical efficiency (TE). TE as a precondition for economic efficiency safeguards the economic viability and sustainability of a farm. The concepts of efficiency and productivity are sometimes confused and used interchangeably but an important distinction exists between them. Sell *et al.* (2018) explain in simple terms that productivity can be viewed as a measure of amount of output produced per unit of inputs used (e.g. how much wheat is produced with a given amount of land, labor, seed and/or fertilizer). Farm productivity can be improved by adopting various technological inputs such as improved seeds, agrochemicals, fertilizers and new machineries.

Alternatively, productivity can be enhanced by changing how factors are combined to improve efficiency by which inputs are being transformed into output such that higher outputs are produced from same level of inputs (Coelli, 1995). Efficiency on the other hand measures the actual amount of output produced relative to how much could be produced with same level of inputs and technology. This suggests efficiency examines how much the actual output differs from the maximum potential output with a given bundle of inputs (Colli *et al.*, 2005). Production decisions by farmers also influence efficiency and overall productivity of a farm; for example, decisions by farmers to shift away from specialization towards adopting diversified production system (Ahmadzai, 2017).

Empirical research suggests farmers in developing countries fail to fully exploit the production technology and resources and often make inefficient decisions. Here it is attempted to analyze the level and determinants of efficiency of crop farmers using a stochastic frontier analysis (SFA) approach. As discussed above the concepts of efficiency can be seen into two: technical efficiency (output-oriented) and allocative efficiency (input-oriented). Allocative efficiency (AE) refers to the ability of a farm to use inputs in optimal proportions given their prices and technology (i.e. obtaining optimal profits with least cost of production). Technical efficiency relates to the ability of a farm unit to produce maximum level of output with given level of inputs and technology (Farrell, 1957). In measuring TE, the inputs are exogenously given and the objective is to maximize output as the only choice variable. The fact that the current paper deals with this issue in the context of Ethiopia, as part of a developing country, the main concern may be output shortfall rather than input over usage. Additionally, lack of price data implies the nuisance to address AE. The output-oriented approach is, therefore, preferred. A technically efficient production unit is operationally defined in this study as the one that attained maximum level of output in crop farm using available inputs and technology, and those that produced below this level are considered technically inefficient.

The literature on SFA employs econometric models to estimate production frontiers and technical (in)efficiency. Since its first introduction by Aigner, Lovell & Schmidt as well as Meeusen & van den Broeck, two groups of researchers who came up with the theoretical approach in 1977 (Kumbhakar & Lovell, 2000), SFA has been applied to study the productivity and efficiency of production units in various economic sectors. The stochastic frontier paradigm can be viewed as a generalization of the classical production function approach, where the optimal allocation in production is a testable restriction rather than a prior assumption usually assumed by the neoclassical production theory (Sickles & Zelenyuk, 2019). The distinctive feature of this paradigm is its non-symmetric two-component error, composed of a regular idiosyncratic noise and one-sided non-negative error component (Nguyen, 2021). The former accounts for factors such as measurement error, misspecification and the randomness of production process, while the latter represents technical inefficiency that reduces the actual output from its maximum feasible level.

Key evidence also shows that efficiency can be estimated using either a two-stage or single-stage approach. Early studies have used a two-step procedure, in which the efficiency scores derived from a stochastic frontier function estimated in the first stage are then regressed on a set of variables assumed to influence efficiency (z_i) using OLS or Tobit regression in the second stage. Scholars criticized this approach for its inconsistency relating to the assumptions regarding independence of the error components (Battese & Colli, 1995). Wang and Schmidt (2002) also claimed that exogenous determinants of inefficiency (z_i) might affect its input choices (x_i), and hence efficiency might be dependent on explanatory variables. Others confirmed even if x_i and z_i are uncorrelated, ignoring the dependence between them and of the inefficiency with z_i will cause the first-step TE score underdispersed implying the second-step regression results likely to be downward biased (Kumbhakar *et al.*, 2015). This suggests that efficiency is arguably endogenous. Recognizant of this advocated a single-stage approach for estimating efficiency when its determinants incorporated directly into inefficiency term (Battese & Colli, 1995; Kumbhakar & Lovell, 2000). Adopting this approach, we estimated efficiency and its determinants simultaneously as the mean of inefficiency term is hypothesized to be a function of explanatory variables. Thus, efficiency was estimated in this study using a production function that also encompasses a model for assessing factors influencing inefficiency simultaneously.

In a conventional production function (PF) assuming producers are perfectly efficient, the PF of farm i can be expressed as Equation (4.4),

$$y_i = f(x_i, \beta) \tag{4.4}$$

The SFA, however, relaxes this restrictive assumption and allows households to have different levels of efficiencies shaped by differences in demographic and socioeconomic factors specific to each household. Assuming each household potentially produces less than it might due to a degree of inefficiency, a stochastic production frontier (SPF) is specified as in Equation (4.5),

$$y_i = f(x_i, \beta)\varepsilon_i \tag{4.5}$$

where ε_i is the level of efficiency of household i which must be between 0 & 1. If $\varepsilon_i = 1$, the household is achieving optimal output with technology embodied in PF (Equation

4.4). As $\varepsilon_i < 1$ the household is not making the most from inputs x_i given technology embodied in PF. Since output is assumed to be strictly positive ($y_i > 0$), the level of TE is assumed to be positive ($\varepsilon_i > 0$). The output is also subject to random shocks, suggesting the PF has to be formulated further as Equation (4.6),

$$y_i = f(x_i, \beta)\varepsilon_i \exp(v_i) \quad (4.6)$$

After log transformation of Equation (4.6) in both sides and defining $u_i = -ln\varepsilon_i$, we get Equation (4.7) representing the SPF model used in this study as,

$$\ln y_i = \ln f(x_i, \beta) + v_i - u_i \quad (4.7)$$

$$e_i = v_i - u_i$$

$$v_i \sim iid\ N(0, \sigma_v^2)$$

$$u_i \sim iid\ N^+(0, \sigma_u^2)$$

where lny_i is the logarithm of output (kg) produced by farm household i (i=1,2, … n), $f(x_i, \beta)$ is the PF, x_i is a vector of inputs in logarithm-transformed form. e_i is a non-symmetric two-component error term, composed of a regular idiosyncratic noise (v_i) and a one-sided non-negative management related efficiency component (u_i). v_i is assumed to be identically and independently distributed as $N(0, \sigma_v^2)$ and u_i is i.i.d. half-normal as $N^+(0, \sigma_u^2)$ and takes values between 0 and 1, where 1 shows full efficiency and 0 implies perfectly inefficient.

An interesting generalization of stochastic frontier paradigm is extending SPF models to examine impact of determinants on technical inefficiency. It is usually done by parametersing parameters of inefficiency distribution-i.e. pre-truncated mean and/or variance, as a function of exogenous variables specified in Equation (4.8). Kumbhakar and Lovell (2000) argue that failing to consider heteroskedasticity associated with firm size, for example, may lead to bias in estimation of TE. By incorrectly assuming homoskedasticity, estimates for relatively small firms would be biased upward, while estimates for relatively large firms would be biased downward. Thus, error component u_i in Equation (4.7) represents any random shifts (i.e. effects of unobserved factors) on the frontier and is distributed as truncation at zero of normal distribution with mean $-z_i\delta$, and variance $\sigma_v^2\left(N\middle|-z_i\delta,\sigma_u^2\middle|\right)$, where z_i are correlates of inefficiencies on farm i. The resulting specific form of inefficiency effect can be presented as Equation (4.8),

$$u_i = \delta_0 + \sum_{d=1}^{D} \delta z_i + \omega_i \tag{4.8}$$

where z_i is a vector of inefficiency explaining variables; δ is a vector of parameters and ω_i is the unobservable random error term i.i.d. half-normal as $N^+(0,\sigma_w^2)$.

Technical efficiency of farm i (TE_i) is the ratio of the actual and potential output of the farm defined by the frontier function. Following Anik and Rahman (2020), the TE of farm household i is formulated in this study as Equation (4.9).

$$TE_i = \frac{y_i}{\exp(\beta x_i)} = \frac{\exp(\beta x_i - u_i)}{\exp(\beta x_i)} = \exp(-u_i) \tag{4.9}$$

4.4.3. Empirical Models and Estimation Strategies

Drawing from the conceptual framework explained above, we developed our empirical model using a flexible translog production technology widely cited in the stochastic frontier literature, to estimate the TE of crop farmers. The fact that its flexibility circumvents the problem of over restriction and allows a general specification of the model that can represent any underlying arbitrary structure of production at the chosen point of approximation (Tzouvelekas, 2000). The production behavior of a farm household was described in this study empirically with six inputs translog specification in Equation (4.10) as follows,

$$\mathrm{lny_i} = \beta_0 + \sum_{j=1}^{J} \beta_j \mathrm{lnx_{ji}} + \frac{1}{2}\sum_{j=1}^{J}\sum_{k=1}^{J} \beta_{jk} \mathrm{lnx_{ji}} \mathrm{lnx_{ki}} + v_i - u_i \qquad (4.10)$$

where i = 1, 2, …, N are observations; j, k = 1, 2,…, J are applied inputs; $\mathrm{lny_i}$ is logarithm of output produced in kg by household i; $\mathrm{lnx_{ji}}$ is logarithm of input j applied by household i, such as farm size (ha), family labor (AEU), chemical fertilizers (kg), seeds (kg), cattle ownership (number) and pesticide expenditure (ETB); β's are the vectors of parameters to be estimated.

As explained above the PF was estimated under a single-stage estimation using a translog specification as outlined in Belotti and colleagues, which allows for determinants of inefficiency can address endogeneity in the frontier or inefficiency that the standard frontier estimates ignore (Belotti *et al.*, 2013). The maximum likelihood estimates for all parameters associated with inputs $(x's)$ and inefficiency variables $(z's)$ were estimated using STATA v.13 software and *sfcross* stata command adopted from Belotti *et al.* (2013). All data of output and input variables were normalized around the sample mean, prior to logarithmic transformation to define the point of estimation. Normalizing around the sample mean was performed by dividing all observations by the sample mean.

For analyzing the role of WEA on FS of children and women, households that involved in one or more agricultural activities (growing crops or raising livestock) were considered so that individuals are not misclassified as disempowered when they do not participate in any agricultural activity. We hypothesize that empowered women are better to command the resources needed to provide food and health care to themselves, children and other household members, leading to optimal FS status measured in DD of foods consumed by children (MDD), women (MDD-W) and households (HDDS). To analyze linkages of WEA with TE and DD of individual/household, we estimated the regression models specified in Equations (4.11-4.13) using generalized structural equation modeling (GSEM) approach to capture endogeneity in TE and WEA with FS outcomes as follows:

$$\mathrm{DD_i} = \alpha_0 + \alpha_1 \mathrm{D_i} + \alpha_2 \mathrm{E_i} + \alpha_3 \mathrm{TE_i} + \alpha_4 \mathrm{E_i} * \mathrm{TE_i} + \alpha_5 \mathrm{I_i} + \alpha_6 \mathrm{H_i} + \varepsilon_\mathrm{i} \quad (4.11)$$

$$\mathrm{TE_i} = \gamma_0 + \gamma_1 \mathrm{D_i} + \gamma_2 \mathrm{E_i} + \gamma_3 \mathrm{H_i} + \mathrm{w_i} \quad (4.12)$$

$$\mathrm{E_i} = \beta_0 + \beta_1 \mathrm{D_i} + \beta_2 \mathrm{TE_i} + \beta_3 \mathrm{I_i} + \beta_4 \mathrm{H_i} + \mathrm{u_i} \quad (4.13)$$

where DD_i is the FS indicator of individual i, represented by minimum dietary diversity for women in reproductive age (MDD-W) or minimum dietary diversity for children under five years (MDD); D_i is a dummy variable with a value of 1 if the individual i is female; E_i is empowerment status of primary woman i derived from WEAI, the intrahousehold gender-gap in empowerment (GGE) in the household i, or one of its component indicators; TE_i is production efficiency of farm household i; I_i is characteristics of individual i; H_i is characteristics of household i; α_i, γ_i and β_i are parameters to be estimated; and ε_i, w_i and u_i is a normally distributed error term. α_2, α_3, α_4, γ_2 & β_2 are the key coefficients of interest, which capture the association between women empowerment, efficiency and DD of individual/household, after controlling for a set of observable individual and household characteristics.

Exploring from existing literature, WEA and TE are arguably endogenous variables in this study. Consequently we applied the GSEM mainly controlling for endogeneity bias resulting from simultaneity between these two variables as well as to investigate such linkages in a systemic perspective in which a set of equations specified above estimated simultaneously using a single-stage approach. The fact that our dependent (FS) variables operationally defined in terms of DD indicators (HDDS, MDD-W and MDD) are measured by counting the food groups consumed by households/individuals, we applied Poisson regression models framed in GSEM for estimating Equation 4.11. As empowerment and efficiency are continuous variables, Equations 4.12 and 4.13 were estimated using OLS regression models set in GSEM framework. In order to enhance robustness and ease use and communication of the results by policy makers and development planners, these outcome variables are also expressed with dichotomous indicators to demonstrate food and nutrition security situations in the study areas using the minimum acceptable diets as a threshhold. This also suggests an ordered logit/probit model is relevant to use. All these conditions imply it is more appropriate to use GSEM relative to structural equation modeling (SEM) that needs all variables to be continuous. Additionally GSEM can capture the interaction effects, as does not in SEM.

4.5. Results and Discussion

4.5.1. Descriptive Results

Among the total sample of 250 households, 91.6% were dual households composed of both primary male and primary female adults. We excluded four households (1.6%) without female adult decision maker and 17 households (6.8%) without male adult decision maker and one household that was not administered the WEAI module. Another four dual households (1.6%) with incomplete WEAI indicators were excluded in our econometric analyses as all 10 indicators are required to calculate WEAI. Only 244 households (97.6%) have complete WEAI indicators for female decision makers and 231

(92.4%) for male decision makers, of which 229 households have at least one co-resident adult female and adult male member, and 80 households have at least one co-resident child under five years.

Our final sample comprises 250 households, and 329 women adults, 361 male adults and 92 children under five years residing in the dual households. When there are multiple women and men adults in a household, we consider only a primary woman adult responsible for child care and primary man adult for individual level data needed to construct WEAI. Regarding multiple children, we took one randomly as our observation. However, the number of observations for specific regressions vary as some households comprise only female or male adult and/or children under five may not be from dual households, or have missing data on some variables. The actual estimation samples are presented in the relevant tables. The demographic and socioeconomic characteristics of farming households and outcome variables of this study are summarized across terciles of the two key independent variables (WEA and TE) and presented in the subsequent subsections.

4.5.1.1. Women empowerment in agriculture: composition and inequality

The composition and inequality distributions of women empowerment in agriculture (WEA) among surveyed households are presented in Table 4.2. The WEAI in Libokemkem woreda is 0.824, which reports to be 0.876 by the 5DE sub-index that lacks to consider intra-household gender inequality. The WEAI was 0.762 in Bangladish, 0.702 in Guatemala and 0.800 in Uganda (Alkire *et al.,* 2013) demonstrated that nowadays women have better empowerment in Ethiopia compared to women in these countries have ten years back. Around 64% of women in surveyed households are empowered, and the rest 36% who are not yet empowered have on average inadequate achievements in 34% of domains. This is also better than the situation in Bangladesh where only 40% of households have adequate women empowerment (Anik & Rahman, 2020). In contrast, 68% of men are empowered and 32% who are yet disempowered have an average inadequacy score of 29%. As indicated in Table 4.2, 76.8% of women have gender parity with primary males in their households. The empowerment gap among 23.2% of women who are less empowered was quite high as 17.6%, a bit lower than it was 22.3% in Uganda ten years back (Alkire *et al.*, 2013). The overall gender parity and gender-gap in empowerment averaged to be 0.959 and 0.081 in Libokemkem woreda.

Table 4.2. WEAI, GPI and GGE in Libokemkem district in rural Ethiopia

Indexes	Women	Men
Disempowered head count (%)	36.5	32.3
Average (intensity) of inadequacy score (%)	33.9	29.1
Disempowerment index (E_0)	0.124	0.094
Empowerment index (5DE)=1- E_0	0.876	0.906
Number of observations	245	233
Percentage of data used	99.6	99.1
Percentage of women with no gender parity	23.2	
Average (intensity) of empowerment gap (%)	17.6	
Gender parity index (GPI)	0.959	
Number of women in dual households	229	
Percentage of data used	97.8	
Gender-gap in empowerment (GGE)	0.081	
Women empowerment in agriculture index (WEAI)	0.824	
Percentage of empowered women (i.e. WEAI $\geq$ 0.80)	63.84	

Source: Authors calculations on survey data 2020/21.

Decomposing the disempowerment score (Table 4.3), time poverty (48%), lack of control over productive resources (22%) and weak leadership in the community (17%) are the key domains that contributed most to women disempowerment in Libokemkem. More than 76% of women who are not yet empowered do not have enough time to take care of themselves late alone for their children. The fact that the disempowered women have excessive workload significantly more than 46% of the empowered women worked 8.87

hours per day (Table 4.4). About 60% of women reported they have limited autonomy in decision making over productive resources, and 28% lack access to credit and the ability to make decisions about it. Workload, lack of time available for leisure, autonomy in production and speaking in public are the main indicators that showed women disempowerment to the extent that it greatly exceeds their expected level of empowerment.. This suggests these are the areas in which intervention is required to increase their empowerment.

Table 4.3 also demonstrates the pattern of women deprivations in empowerment is quite different from their men counterparts. Lack of leadership and influence in the community alloted much more to men disempowerment than to women's, as did in decision making around agricultural production. By contrast, men reported very little disempowerment in control over income and in time poverty relative to women.

Table 4.3. Summary statistics of 5DE decomposed disempowerment by domains and indicators

	Women (n=224)		Men (n=224)	
Domains/indicators	**Censored head count**	**Contribution (%)**	**Censored head count**	**Contribution (%)**
1. Production		*22.13*		*24.08*
Input in productive decisions	0.169	4.59	0.028	0.64
Autonomy in production	0.596	17.54	0.743	23.44
2. Resources		*6.29*		*8.93*
Ownership of assets	0.000	0.00	0.000	0.00
Rights over assets	0.000	0.00	0.000	0.00
Access to and decisions on credit	0.281	6.29	0.400	8.93
3. Income		*6.89*		*0.57*
Control over use of income	0.157	6.89	0.014	0.57
4. Leadership		*16.68*		*20.72*
Group membership	0.090	2.35	0.086	2.74
Speaking in public	0.438	14.33	0.557	17.98
5. Time use		*48.00*		*45.71*
Workload	0.787	25.34	0.886	28.80
Leisure	0.764	22.66	0.528	16.91

Source: Author's calculations on survey data 2020/21.

The time use of family labor is summarized in Table 4.4 which is generated based on specifications on primary and secondary activities of female and male adult members using a 24 hour time allocation module, with hours worked defined as the sum of time in work related tasks as primary activity plus 50% of time in work related tasks as secondary activity adopted from Alkire *et al.* (2013). The results indicate that women spent a significantly higher proportion of their time on domestic chores (6.75 h per day), more than five folds of men counterparts which spent only 1.33 hours per day. Meanwhile the men allocated their time only two folds the women used 4.15 hours for productive tasks in the last 24 hours prior to the survey. As Table 4.4 also shows at the bottom, approximately half of the women in surveyed households are not yet empowered with the time worked above poverty line of 10.5 hour per day compared to 44% for men counterparts. This suggests men showed lower level of disempowerment than women in all aspects of time allocation except in productive activities.

Table 4.4. Time-use among women and men household members

Activity in 24 h recall	Women (h)	Men (h)
Sleep	11.59	12.72
Domestic work	6.75	1.33
Productive work	4.15	8.47
Leisure	1.51	1.48
A workload by disempowered	12.94	12.00
A workload by empowered	8.87	8.02
A workload above 10.5 h (%)	49.59	44.40
Observations	244	232

Source: Author's calculations on survey data 2020/21.

4.5.1.2. Demographic and socioeconomic factors

We constructed additional covariates to describe demographic and socioeconomic characteristics of households that will be considered in the outcome estimation framework. Tables 4.5 and 4.6 present some selected covariates and outcome variables of our econometric models tabulated across the key independent variables of WEA and TE terciles, respectively. We used one way ANOVA and chi-square test statistics to assess household characteristics expressed in quantitative and qualitative values in order.

Around 64% of women in surveyed households are empowered with adequate WEAI score equals to or above threshold level of 0.80 defined by Alkire *et al.* (2013).

In our sample (n=250), 17.2% of households were female headed (11.2% among 224 dual households) a bit lower than 18% in the entire country reported in 2019 Ethiopia Demographic and Health Survey (EDHS and ICF, 2021). Among sample of 75 children under five years who reside in dual households, 55.3% were female with a mean age of 37 months. The female respondents in our sample were younger (39.4 years) than household heads (48 years) and have lower rate of literacy (13%) compared to 24% were literate heads that can read and write. The mean family size was 5.13 persons (or 4.12 adult equivalents) in the study areas nearly equal to 5 persons in the entire country (EDHS and ICF, 2021). The typical household cultivated on average 1.273 ha, of which own land shared 90.5%, with 4.93 livestock owned in tropical livestock units. Of the annual income 52863 ETB (1193 USD) the household earned, farm income and off-farm income contributed 86 and 14% respectively, while 62% of households have access to off-farm employment at least from one source. The per capita income was 10816 ETB (244 USD) per annum and 78% of household's annual expenditure 62342 ETB (1407 USD) went to food. Market orientation of crop farms operationally defined as a proportion of crops sold from total amount of outputs produced estimated to be 28%. More than 76 and 80% of households have better access to agricultural and health extension services in order.

Assessing the DD of children under five years, women in reproductive age (15-49 years) and households operationally measured in MDD, MDD-W and HDDS averaged to be 4.6, 5.1 and 7.8 in order (Table 4.5). The nutrition/FS status of children, women and households determined using the minimum acceptable diets defined as at least 4 food groups for MDD, 5 food groups for MDD-W and 42 for the food consumption score (FCS) revealed that 33.5% of households, 44.2% of women and 28% of children were food insecure in Libokemkem (Table 4.5). The WEAI in Libokemekem woreda averaged to be 0.824, while it was 0.687, 0.82 and 1 across lowest (LT), middle (MT) and highest (HT) terciles of households in women empowerment. Despite very little or no gender-gap in empowerment among the top two terciles, a significantly higher gender inequality was seen in the lowest tercile.

Table 4.5. Summary statistics of variables used in GSEM by women empowerment terciles

	Overall		WEAI terciles			
Variables	**Obs.**	**Mean**	**LT**	**MT**	**HT**	**p-value**
Dependent variables:						
HDDS	224	7.79	8.06	8.25	6.88	0.000***
MDD-W	224	5.05	5.33	5.47	4.19	0.000***
MDD	75	4.57	4.56	4.95	4.23	0.251
HFS status (1=FS, %)	224	66.5	77.8	65.8	53.1	0.007***
Woman nutrition status (1=adequate, %)	224	55.8	58.0	67.1	39.1	0.003***
Child nutrition status (1=adequate, %)	75	72.0	75.0	76.2	63.6	0.591
Key independent variables:						
WEAI	224	0.824	0.688	0.820	1.000	0.000***
GGE	224	0.081	0.149	0.076	0.000	0.000***
TE	224	0.651	0.692	0.622	0.634	0.002***
Covariates:						
Sex of head (1=male,%)	224	88.8	97.5	86.1	81.3	0.005***
Age of head (years)	224	47.96	47.89	47.37	48.78	0.793
Education of head (1=literate, %)	224	23.7	28.4	26.6	14.1	0.099*
Family size (#)	224	5.13	5.32	5.13	4.88	0.302
Age of mother (years)	224	39.42	37.80	39.48	41.41	0.196
Education of mother (1=Literate,%)	224	12.9	17.3	11.4	9.4	0.328
Cultivated land (ha)	224	1.273	1.392	1.256	1.143	0.025**
Livestock ownership (TLU)	224	4.93	5.61	4.89	4.11	0.006***
Proportion of crops sold (%)	224	27.8	35.3	27.9	18.2	0.000***
Per capita income ('000 ETB/y)[1]	224	10.82	16.09	9.89	5.28	0.000***
Off-farm income access (1=yes, %)	224	61.6	67.9	58.2	57.8	0.348
Agri-extension access (1=yes, %)	224	76.3	84.0	72.2	71.9	0.132
Health extension access (1=yes, %)	224	80.1	86.4	79.7	75.0	0.215
Location dummies:						
Libo (1=yes,%)	46	20.5	15.2	47.8	37.0	0.000***
Qergna (1=yes,%)	47	21.0	63.8	29.8	6.4	
Birkutie (1=yes,%)	45	20.1	26.7	51.1	22.2	
Agelahana (1=yes,%)	42	18.8	26.2	30.9	42.9	
Tibaga (1=yes,%)	44	19.6	47.7	15.9	36.4	

[1] ETB=Ethiopian Birr with an average exchange rate 1USD=44.32 ETB in 2020/21.

As the WEA increases to a certain level from lowest to middle tercile, the likelihood of women and households consumed diverse diets may improve by 0.26 and 0.19 units of MDDW and HDDS significantly at 1% level, respectively. Beyond this level, a rise in WEA from middle to highest tercile may significantly reduce DD of women and households by 0.36 and 1.37 units at 1% level in order. The same pattern of DD observed for children across these terciles, despite not varied significantly. However, the FS categories demonstrated that the propensity of a household to be FS may significantly reduce from 78 to 53% as WEA progressed from lowest to highest tercile, while empowerment may encourage the likelihood of a women to be FS improves from 58 to 69 % as WEA transformed from lowest to middle tercile, beyond which may have adverse effect. This suggests women empowerment has positive implication on FS of households, women and children had it been up to a certain level, above which may affect opposite.

The descriptive results in Table 4.5 also demonstrated that the efficiency of crop farmers might significantly be reducing by 5.8-7.0 percentage points as WEA transits from lowest to middle/highest tercile. The likelihood of woman in female headed household to be more empowered may significantly increase by 11.4-16.2 percentage points relative to woman in male headed household, as empowerment changes from LT to MT/HT. This implies that female headship may have positive implication for the women to be more empowered in agriculture. The propensity of woman to be more empowered might be significantly lower in literate heads than in illiterate counterparts by 1.8 and 14.3 percentage points as empowerment transits from LT to MT and HT respectively. This shows that household head's education and women empowerment might be significantly associated negatively, is a pattern that seeks further study to understand. Cultivated land, livestock ownership, market orientation of crop farm (proxied by proportion of crop sold) and per capita income are the other covariates that might significantly link with WEA adversely. While age of household head, family size, mother age, mother education, and access to off-farm income, agricultural extension and health extension might not be significantly related with WEA. Differences in location of households may also have important implication on WEA. Among the five sample kebeles, Agelahana demonstrated a significantly largest share of women (43%) in highest tercile of empowerment, whilst Birkutie affirmed highest rate of women (51%) in MT and Qeregna kebele (64%) in LT.

Table 4.6 summarizes some selected variables by efficiency terciles in crop production. The TE of crop farmers in Libokemkem district was 0.652. This suggests with same level of inputs and embodied technologies, crop production can be increased by 34.8% by simply enhancing the efficiency of smallholder farmers to attain optimum outputs. The efficiency of crop farmers in LT, MT and HT was 0.511, 0.634 and 0.809.

Crop production and productivity of a typical household in the study areas averaged to be 38.4 q and 12.6 q/ha in the year 2020/21. As efficiency of smallholder farmers transformed from LT to MT, MT to HT, and LT to HT, crop production might heve significantly improved by 31.6, 168.2 and 253% while crop productivity might have increased by 66.3, 88.8 and 213.2 %, respectively. The land size cultivated by household in the HT was 1.51 ha on average which is significantly larger than 1.28 ha in LT and 1.04 ha in MT. This may suggest a smaller farm size is more likely changed from lowest to middle efficient tercile, whilst the transition from LT to HT may require the farm size to be a bit larger. Regarding labor our evidence shows that as the labor units used in crop production diminish by 14.5%, the efficiency structure of crop farmers transformed more likely from LT to MT, whilst a reduction by 9.4% may further amplify the propensity of the lowest efficient farm changed into highest efficient tercile. This may suggest for a given output to produce a more efficient household uses lower labor units than the less efficient; but the labor units saved has to be up to a certain level (e.g. 9.4%) for the farm to be more efficient, instead of lowering beyond this level (e.g. 14.5%).

Table 4.6. Summary statistics of variables used in SFM by efficiency terciles

Variables	Overall mean	Efficiency terciles (n=224) LT	MT	HT	p-value
Dependent variable:					
Crop yields (q)[1]	38.42	19.79	26.04	69.84	0.000***
Input variables:					
Cultivated land (ha)	1.273	1.280	1.035	1.508	0.000***
Labor (AEU)	4.12	4.48	3.83	4.06	0.019**
Seeds (kg)	267.82	235.90	194.98	373.97	0.000***
Fertilizers (kg)	214.02	215.64	145.28	282.04	0.000***
Cattle ownership (#)	4.60	4.63	2.89	6.31	0.000***
Pesticide expenditure (ETB)	385.53	415.27	278.57	463.78	0.001***
Efficiency explaining variables:					
WEAI	0.824	0.811	0.886	0.773	0.000***
GGE	0.081	0.079	0.048	0.115	0.003***
GPI	0.959	0.966	0.983	0.929	0.000***
Age of head (years)	47.96	51.97	45.56	46.32	0.002***
Education of head (1=literate, %)	23.66	16.00	17.33	37.84	0.002***
Sex of head (1=male,%)	88.84	92.0	81.33	93.24	0.039**
Female labor share (%)	41.22	36.44	43.20	44.07	0.004***
Improved seed share (%)	22.77	18.19	20.91	29.30	0.002***
Own land share (%)	90.53	90.64	88.44	92.55	0.341
Off-farm income access (1=yes,%)	61.61	16.67	65.33	93.24	0.000***
Proportion of crops sold (%)	27.80	17.97	18.59	47.09	0.000***
Agricultural diversification	7.00	7.53	6.75	6.73	0.004***
Oxen owned	1.85	1.80	1.36	2.39	0.000***
Per capita income ('000 ETB/y)	10.82	4.23	4.46	23.93	0.000***
Access to irrigation (1=User,%)	82.59	78.67	76.00	93.24	0.011**
Agri-extension access (1=yes,%)	76.68	70.67	72.00	87.67	0.025**
Health extension access (1=yes,%)	81.2	76.0	73.3	94.5	0.001***
Location dummies:					
Libo (1=yes,%)	20.54	41.3	50.00	8.70	0.000***
Qergna (1=yes,%)	20.98	10.64	10.64	78.72	
Birkutie (1=yes,%)	20.09	71.11	26.67	2.22	
Agelahana (1=yes,%)	18.75	45.24	47.62	7.14	
Tibaga (1=yes,%)	19.64	0.00	34.09	65.91	

[1] q denotes quintal,1q=100 kg.

Similar trends have been observed regarding seed, fertilizer, pesticide and cattle use. Households in the highest efficiency tercile have used a significantly higher amount of seeds and fertilizers, more number of cattle and higher pesticide expenditure than those households in the lowest and middle efficiency terciles have applied. However, the crop farmer, who uses lower quantity of seeds, fertilizers, cattle and pesticide expenditure, is more likely to be in middle efficient than in lowest efficient group. This combined with the above finding may imply cultivating a smaller land size might significantly lead to better efficiency in crop production had it been combined with lower quantities of seeds, fertilizers, cattle and pesticide expenditure relative to a larger farm to be cultivated with such lower volume of these inputs as our evidence reveals in transition of efficiency from LT to MT. It may be possible for the crop farm to be transformed into more efficient structure as the larger farm size is combined with a bit higher units of these variables as a move in efficiency seen from LT to HT.

The propensity of women in the middle efficient stratum to be more empowered might have increased significantly by 9.25 percentage points relative to those in lowest efficient group. Beyond which, an increase in efficiency may magnify the likelihood of a woman to be less empowered by 12.75 percentage points. This suggests that empowering women in agriculture may enhance TE of crop farmers in Libokemkem had it been up to a certain level, beyond which may influence efficiency adversely. Similarly, the crop production structure of a typical household transformed more likely from lowest to middle efficient tercile, as gender parity between woman and her spouse increases by 1.76% or gender gap in empowerment reduces by 39.24%. Further improvement in gender equality and reduction in gender gap in empowerment may have negative implication on TE of crop farms in the study areas. This is a bit similar to the findings of studies in Bangladesh which revealed that reduced gender disparities within households are associated with higher levels of TE (Seymour, 2017), and both WEA and reduction in GGE significantly enhance production efficiency (Anik & Rahman, 2020). This suggests the need for policies specifically targeting women to enhance WEA and reduce GGE.

Age of household may have negative implication on efficiency of crop farm in the study areas. The crop farm cultivated by younger household head is more likely to be in the highest and middle efficient groups than in the LT. The likelihood of crop farm managed by female headed household to be in the MT (18.7%), which is significantly higher than 8% in LT and 6.8% in the HT. Education of household head, share of female labor, share of improved seeds, access to off-farm income, market orientation of crop farm and access to agricultural extension in the study areas might have been significantly correlated with crop farmers to be more efficient. A crop farm is more likely to be in the highest efficient structure (37.8%), middle efficient (17.3%) and lowest efficient (16%) as the household head became more literate. The share of female labor is the other factor that might significantly enhance the likelihood of a crop farmer in the highest (44.1%), middle (43.2%) and lowest (36.4%) efficient tercile. Share of improved seeds in crop production may also have positive implication for the farmers more likely to be in the highest (29.3%), middle (20.9%) and lowest (18.2%) efficient group.

Access to off-farm income might enhance the likelihood of crop farmer in the highest (93%), middle (65%) and lowest (17%) efficient group. Access to agricultural extension may have also boosted the possibility of the household in the HT (87.7%), MT (72%) and LT (70.7%) efficient group. Land ownership might not have a statistically significant association with TE of crop farmers. What matters is the land quality (proxied by access to irrigation) that may imply the household who cultivated land had better access to irrigation is more likely to be in the highest (93.2%) than in middle (76%) and lowest (78.7%) efficient stratum. Location dummies are the other variables treated in this paper as a proxy to capture agro-ecological differences might also significantly influence efficiency of crop farmers. Qergna kebele has shown the largest share of households (16.5%) in the highest efficient tercile, while Libo kebele illustrated the highest rate (10.3%) in MT group and Birkutie implied the largest rate (14.3%) in LT group. This suggests that location might have important implication for the efficiency of crop farmers to vary significantly.

4.5.2. Econometric Results

4.5.2.1. Production efficiency and its determinants

Following the approaches discussed in methodology section, here an attempted is made to estimate TE of crop farmers in the study areas using a translog stochastic production frontier with and without determinants of inefficiency specified in the model. Table 4.7 presents parameter estimates of the four alternative stochastic frontier specifications explored under different assumptions of the underlying distribution of inefficiency term. The first three models specified the distribution for inefficiency term without its determinants and the last treats the determinants in the specification of inefficiency for estimating TE of crop farmers using *sfcross* Stata command. The results of the first three models assuming the inefficiency term distributed half-normal (hnormal), exponential and truncated (tnormal) revealed that the TE of crop farmers was 0.822, 0.877 and 0.849 in Libokemkem district respectively when the TE and its determinants estimated separately using a conventional two-stage approach. In this case, the TE was estimated first without its determinants and the determinants would then be analyzed in the second stage via OLS regression model using the TE derived at the first sage as a dependent variable.

Table 4.7. Estimation results of SFMs with and without determinants of inefficiency

	Without			With
Frontier	**hnormal**	**exponential**	**tnormal**	**tnormal**
Log of cultivated land (ha)	0.181	0.124	0.143	0.610*
Log of labor used (AEU)	-0.069	-0.063	-0.068	-0.038
Log of fertilizer used (kg)	-0.077	-0.119	-0.092	-0.200
Log of seeds used (kg)	0.337***	0.370***	0.354***	0.537***
Log of pesticide expenditure (ETB)	0.104	0.059	0.084	0.064
Log of cattle owned (#)	0.146	0.118	0.138	0.289**
Log squared land	0.532**	0.573**	0.561***	0.015
Log squared labor	0.077	0.071	0.078	0.090
Log squared fertilizer	0.088	0.103	0.091	0.136
Log squared seed	-0.153***	-0.165***	-0.162***	-0.222***
Log squared pesticide expenditure	-0.055	-0.020	-0.038	-0.062
Log squared cattle owned	0.038	0.061	0.046	-0.102
_cons	0.156**	0.125	0.136*	0.300**
mu			-0.489	
Women empowerment score				-0.068
Age of head (years)				0.002*
Sex of head (1=Male, 0=Female)				-0.020
Education of head (1=Literate, 0=Illiterate)				-0.025
Off-farm income access (1=Yes, 0=No)				-0.163***
Irrigation access (1=User, 0=Nonuser)				0.043
Share of own land				-0.009
Share of female labor				-0.243***
Share of improved seeds				-0.130*
Proportion of crops sold				-0.429***
_cons				0.752***
lnsig2u	-2.680***	-3.931***	-1.978	-3.662***
lnsig2v	-4.338***	-3.955***	-4.171***	-5.802***
sigma_u	0.262***	0.140***	0.372	0.160***
sigma_v	0.114***	0.138**	0.124***	0.055
lambda	2.291***	1.012***	2.994***	2.915***
TE	**0.822**	**0.877**	**0.849**	**0.652**
Observations	250	250	250	224
Wald chi2(12)	743.86	710.04	742.02	222.57
Prob > chi2	0.000	0.000	0.000	0.000
Log likelihood	60.175	60.251	60.482	91.035

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

Whereas the TE of crop farmers that obtained through a single-stage approach estimating the TE and its determinants simultaneously was 0.652. This implies that TE is arguably endogenous in case of a single-stage approach controlling for determinants, whilst the second approach assumes TE as exogenous. As the latter approach ignores issues of endogeneity, all the three models estimated TE which is biased upward. Thus, the TE of crop farmers in the study areas is 0.652.

The LR test of the null hypothesis H_0: $\sigma_u^2 = 0$ against H_1: $\sigma_u^2 > 0$. All models except the third provide evidence that the null hypothesis of no inefficiency component in the model is rejected significantly at better than 1%, and hence the SFA is the appropriate approach to analyze the performance of crop farmers compared to OLS regression. But the magnitude of efficiency is quite different among these models. The first, second and forth model implies the household is technically efficient by 82, 88 and 65% respectively. The results of stochastic frontier model estimated through a single-step approach (see the last column in Table 4.7) illustrated that farm size, seeds and cattle ownership have positive implication on crop production frontier. It also implied that the technical inefficiency is statistically significant at 1%, which reduces the potential of households to achieve optimum production even with the same level of inputs and existing technologies by improving the efficiency by 35%. Access to off-farm income, share of female labor, share of improved seeds and market orientation of crop farm have significant and positive implication in reducing production inefficiency of crop farmers in the study areas, whilst it was only age of household head identified to affect TE adversely. WEA seems to have positive implication in reduction of inefficiency, despite not significant in magnitude. Similarly, male headship, education of household head and share of own land seem to influence TE positively, despite not significantly vary in magnitude.

4.5.2.2. Women empowerment, efficiency and food security nexus

This subsection discusses the estimation results of generalized structural equation modeling (GSEM) to assess the role of WEA and TE to DD and FS of households, women and children. Correcting for other covariates, the results of the main (direct) and interaction (indirect) effects of these two key independent variables on DD of households (HDDS), women (MDD-W) and children (MDD) and food security/nutrition status of these people including their determinants are presented in Table 4.8. Table 4.9 summarizes the results of GSEM on empowerment, efficiency and FS nexus focusing on the direct and interaction pathways of empowerment such as efficiency, market orientation and diversification of farm production. As Table 4.8 depicts WEA has a statistically significant and positive effect on both TE of crop farmers and DD & FS of households, controlling for confounders.

Despite adverse implication of TE on WEA, TE can significantly improve HDDS directly as the extra outputs a more efficient household expected to derive from existing inputs might improve own food consumption. However, the TE worsening WEA was significantly stronger in magnitude than the WEA enhanced TE (Table 4.8), the efficiency interaction pathway of empowerment ultimately implied a net reduction in HDDS by 2.48 points (Table 4.9). The effect of empowerment on market orientation of crop farm encouraged HDDS to rise significantly by 3.06 points.

Table 4.8. Estimation results of GSEM on empowerment, efficiency and FS linkages & their determinants

	Households		Women		Children	
Variables	**HDDS**	**FS status**	**MDD-W**	**FS status**	**MDD**	**FS status**
Women empowerment (WEAI)	1.417*	18.311*	1.686*	6.399	0.351	33.586***
Technical efficiency (TE)	2.199***	14.617	2.162**	1.595	1.497	35.648
Agricultural diversification (AD)	-0.026	0.276	0.040	0.359	-0.175	1.762
Crop market orientation (MO)	-1.054	5.801	-1.515*	-0.079	-0.594	-22.562**
WEAI × TE	-3.898***	-25.766	-4.306***	-10.670	-3.098	-62.673*
WEAI × AD	0.042	-0.327	-0.023	-0.379	0.247	-0.910
WEAI × MO	1.643**	-4.763	2.211***	2.208	0.488	23.629
Log per capita income (ETB/y)	0.002	0.304*	0.028	0.154	0.170***	2.991***
Cultivated land (ha)	0.136**	0.810**	0.128***	1.045***	0.062	-1.026
Household size (AEU)	-0.013**	0.088	-0.016	-0.036	0.081**	1.152
Age of head (years)	-0.0004	-0.007	0.00004	-0.008	-0.003	0.049
Education of head (years)	-0.007	0.304***	-0.001	0.039	-0.020	-0.143
Sex of head (1=Male)	-0.016	0.151	-0.018	-0.610	0.023	-0.450
Agri-extension access (1=Yes)	-0.116*	0.476	-0.108	-0.417		
Health extension access (1=Yes)	0.239***	1.598***	0.369***	1.581**		
Girl (1=Yes)					0.262	-6.674
Number of sons					-0.062**	-1.193*
Age of child in months					-0.001	-0.049**
WEAI × Girl					-0.465	4.829
_cons	1.189		0.354		0.322	
	TE	**WEAI**	**TE**	**WEAI**	**TE**	**WEAI**
Women empowerment score	0.266***		0.266***		0.584**	-1.418*
Technical efficiency		-0.458**		-0.458**		
Agricultural diversification	-0.013***		-0.013***		-0.029***	
Crop market orientation	0.258***		0.258***		0.348**	
Own cultivated land (ha)		0.029		0.029		0.029
Livestock ownership (TLU)		-0.006*		-0.006*		-0.009
Household size (AEU)		-0.007		-0.007		-0.006
Sex of head (1=Male)	0.018	0.016	0.018	0.016	0.049	0.058
Age of head (years)	-0.001	-0.006***	-0.001	-0.006***	0.001	-0.004**
Education of head (years)	0.006	-0.001	0.006	-0.001	0.016**	0.006
Age of mother (years)		0.006***		0.006***		0.006***
Education of mother (years)		0.004		0.004		0.008**
Agri-extension access (1=Yes)	0.008	-0.025	0.008	-0.025		
Health extension access (1=Yes)	-0.020	0.024	-0.020	0.024		
Log per capita income (ETB/y)	0.008*	-0.006	0.008*	-0.006	0.010	0.057*
Off-farm income access (1=Yes)	0.078***	0.047	0.078***	0.047	-0.009	0.166***
Irrigation access (1=Yes)	-0.035		-0.035		0.004	
Female labor share	0.117**		0.117**		0.200***	
Own cultivated land share	0.004		0.004		0.128**	
Improved seed share	0.039*		0.039*		0.006	
Oxen owned (#)	0.023***		0.023***		0.032**	
_cons	0.283***	1.189***	0.283***	1.189***	-0.158	1.151***
Observations	224	224	224	224	75	75

**** p<.01, ** p<.05, * p<.1. Note that standard errors adjusted for 5 clusters in kebele.*

Another interesting finding is that agriculture diversification (AD) alone does not necessarily imply improved DD and FS, it is the role of women empowerment in AD surprisingly matters for enhanced DD of households by 1.46 points and of women by 1.66 points as well as the propensity of a child to be nutritionally adequate increased significantly by 33% (Table 4.9). Size of cultivated land, per capita income, education of household head and health extension are the other factors significantly influencing DD and/or FS of households positively, whilst family size and access to agricultural extension impacted HDDS negatively, the latter shows a pattern that needs further study to understand (Table 4.8).

Similar to household well-being, both WEA and TE significantly enhanced DD of women directly while only WEA has positive implication on child FS significantly. This also suggests market orientation and efficiency interaction pathways of empowerment would have positive and adverse effect on women DD respectively (Table 4.9). Cultivated land size and access to health extension are the other covariates enhanced DD and FS of women significantly while market orientation of cropping adversely influenced women DD directly (Table 4.8).

As for children dietary quality outcomes, results revealed that empowerment has a significant and positive implication on dietary quality of children under five years. Women empowerment increased a child is likely to be nutritionally adequate by 33.6%. As coefficient of the girl-interaction term with empowerment score is not significant, empowerment does not have a differential effect on dietary quality of boys and girls. This is consistent with another study in Ethiopia (Tesfaye & Abidoye, 2020) finds WEA does not cause nutrition disparity between boys and girls. However, the joint implication of empowerment score and the girl interaction pathway reveals empowerment has a significant positive effect on child FS suggesting that girls are 38.4% more likely to be nutritionally adequate than sons in households where the female decision maker is more empowered in agriculture (Table 4.9). This may also imply empowerment might bring cultural shifts in the forefront of intra-household gender parity in dietary quality and food consumption among children under five years. However, the propensity of a child is nutritious reduces significantly as the number of sons and child's age progressed. Per capita income and household size are the other variables identified to affect child DD positively (Table 4.8).

Table 4.9. Results summary of empowerment & efficiency to DD & FS of households, women & children

	Households		Women		Children	
Variables	**HDDS**	**FS status**	**MDDW**	**FS status**	**MDD**	**FS status**
(a) Women empowerment score	1.417*	18.311*	1.686*	6.399	0.351	33.586***
	(0.737)	(10.217)	(1.033)	(10.140)	(2.571)	(11.717)
(b) Technical efficiency	2.199***	14.617	2.162**	1.595	1.497	35.648
	(0.852)	(11.874)	(0.951)	(8.544)	(3.320)	(27.248)
(c) Agricultural diversification	-0.026	0.276	0.040	0.359	-0.175	1.762
	(0.066)	(0.703)	(0.060)	(0.598)	(0.185)	(2.784)
(d) Crop market orientation	-1.054	5.801	-1.515*	-0.079	-0.594	-22.562**
	(0.732)	(7.011)	(0.816)	(3.498)	(1.068)	(10.791)
(e) Girl					0.262	-6.674
					(0.254)	(7.678)
(f) WEAI × TE	-3.898***	-25.766	-4.306***	-10.670	-3.098	-62.673*
	(0.876)	(16.106)	(1.101)	(10.626)	(4.199)	(39.158)
(g) WEAI × AD	0.042	-0.327	-0.023	-0.379	0.247	-0.910
	(0.062)	(0.739)	(0.049)	(0.608)	(0.228)	(2.912)
(h) WEAI × MO	1.643**	-4.763	2.211***	2.208	0.488	23.629
	(0.808)	(9.673)	(0.863)	(4.153)	(1.577)	(16.795)
(i) WEAI × Girl					-0.465	4.829
					(0.308)	(8.747)
Effect of empowerment on girls:					-0.114	38.415***
(a)+(i)=0					(2.673)	(11.923)
Effect of empowerment on TE:	-2.481***	-7.455	-2.620***	-4.270	-2.746	-29.087
(a)+(f)=0	(0.551)	(8.471)	(0.488)	(5.066)	(2.887)	(33.004)
Effect of empowerment on AD:	1.459**	17.984*	1.663*	6.021	0.598	32.676***
(a)+(g)=0	(0.698)	(9.733)	(0.992)	(9.598)	(2.480)	(12.666)
Effect of empowerment on MO:	3.060***	13.548	3.896***	8.607	0.839	57.215**
(a)+(h)=0	(1.121)	(18.758)	(1.316)	(13.385)	(3.705)	(25.296)
Effect of TE on empowerment:	-1.698***	-11.149**	-2.144***	-9.075***	-1.601*	-27.026**
(b)+(f)=0	(0.270)	(4.796)	(0.618)	(3.469)	(0.891)	(12.088)
Observations	224	224	224	224	75	75

Note: In parentheses are standard errors adjusted for 5 clusters in kebele. *** *p<.01*, ** *p<.05*, * *p<.1.*

Regarding determinants of TE of crop farmers, we identified women empowerment, market orientation of crop farm, per capita income, access to off-farm income, education of household head, share of female labor, share of improved seeds, share of own land and oxen ownership are the factors significantly influencing TE positively, but it was only AD observed to have an adverse effect. Whereas the determinants of WEA include age of mother, education of mother, per capita income and access to off-farm income are among those that affect empowerment positively, whilst TE, livestock ownership and age of household head significantly influenced empowerment adversely.

4.6. Conclusion and Policy Implications

Our estimation using SFA and GSEM is to determine the level and determinants of production efficiency of smallholder farmers and to examine the role of WEA and TE on DD and FS of women, children and households in case of Libokemkem woreda in rural Ethiopia. The descriptive results show that about 33% of households, 44% of women and 28% of children under five years were food insecure in the study areas. The production efficiency of crop farmers and the WEAI in Libokemkem in Ethiopia averaged to be 0.652 and 0.824. Around 64% of women in surveyed households are empowered and 36% who are not yet empowered have on average inadequate achievements in 34% of domains. Approximately 3 in 4 women (77%) have gender parity with their spouses and the empowerment gap among women who are less empowered is quite large as 17.6%. Time poverty (48%), lack of control over productive resources (22%) and weak leadership in the community (17%) are the key domains of women disempowerment in Libokemkem. More than 83% of women are yet disempowered with excessive workload more than 46% of the empowered women worked and approximately 1 in 2 women in surveyed households have high burden of workload above time poverty line.

Women spent a significantly higher share of their time on domestic tasks more than five folds the men counterparts worked, while the men used only two folds their spouses spent for productive activities. This suggests labor-augmenting technologies that reduce the time women need to spend on domestic chores may give them more freedom to choose among activities that are empowering in line with Gillespie *et al.* (2019) and Ruel *et al.* (2018) argued women's time and energy stress may also lead to reductions in care giving practices and risks for women's own health. About 60% of women reported they have limited autonomy in decision making over productive resources, and 28% lack access to credit and the ability to make decisions about it. Workload, lack of time available for leisure, autonomy in production and speaking in public are the main indicators contributing to women disempowerment that informed these are the areas of interventions to improve women empowerment. The descriptive findings in general suggest that WEA needs to be progressed up to a certain level beyond which improving empowerment may have adverse implication on TE of crop farming and FS outcomes across children, women and households.

WEA significantly improves DD of households and women by 1.42 and 1.67 points through its direct pathway while increasing the likelihood of a household and a child to be FS by 18 and 35% respectively. Despite adverse implication TE has on WEA, TE can directly enhance DD of women and households to increase significantly each by 2.2 points. However, the TE that worsened WEA was stronger in magnitude than the WEA enhanced TE, the efficiency interaction ultimately implied in a net reduction in DD of women and households by 2.62 and 2.48 points, respectively. The market orientation interaction pathway enhanced DD of households and women to rise significantly by 3.06

and 3.89 points respectively while it boosts the likelihood of a child is nutritious by 57% in line with the findings of Gupta *et al.* (2017) in India affirmed a strong relationship between market orientation and empowerment implies linking women to markets can be a pathway to enhancing their empowerment in agriculture domains to affect the FS and nutrition outcomes positively.

Another interesting finding of the current paper is that AD alone does not necessarily imply DD and FS of households/individuals to improve, the role of women empowerment in AD surprisingly matters DD of households and women to increase in order by 1.46 and 1.66 points, as well as the likelihood of a child (household) is FS rises significantly by 33% (18%) respectively. This is slightly similar to Malapit *et al.* (2015) in Nepal find that women empowerment can mitigate the adverse implication of low production diversity on maternal and child DD.

Size of cultivated land, access to health extension and per capita income are the other variables significantly influencing DD and FS situations of households, women and children positively. Family size and access to agricultural extension affected DD of households adversely while family size has an encouraging effect on child DD significantly, the latter two show a pattern that needs further study to understand. Education of household head observed to have a significant & positive implication on FS of households only.

The joint implication of empowerment score and the girl interaction pathway demonstrated that girls are 38% more likely to be FS than sons in households where the female decision maker is more empowered in agriculture. This may also suggest empowerment might bring cultural shifts in the intra-household gender parity frontier in dietary quality and food consumption among children under five years. The likelihood of children to be FS, however, reduces as the number of son members and child's age progressed. Women empowerment, market orientation of crop farm, per capita income, access to off-farm income, education of household head, share of female labor, share of improved seeds, share of own land and oxen ownership are the determinants of TE that significantly affected it positively, whilst AD implied an opposite effect. Age of mother, education of mother, per capita income and access to off-farm income are the determinants influencing WEA positively, whereas efficiency, livestock ownership and age of household head significantly influenced WEA adversely.

To this end, the estimation results of our econometric models suggested empowering women in agriculture has positive implication on DD and FS of women, children and households directly. The interaction pathways surprisingly revealed that the effect of empowerment on AD and market orientation of crop farms significantly encouraged DD and FS of households, women and children to increase, whilst the efficiency interaction pathway ultimately implied a net reduction in these outcome variables. This suggests the need for interventions to emphasize on these dimensions of empowerment, as some may imply gender has a disconnecting role in agriculture-food-nutrition nexus instead. Another interesting finding of this paper suggests that not AD alone important, it is the role of women empowerment on AD surprisingly matters these outcome variables to improve significantly.

Acknowledgments: The authors are grateful to all farmers and agricultural officials in the study districts for their dedicated participation in the study.

Conflicts of interest: The authors declare no conflict of interest.

References

Ahmadzai, H. (2017). Crop diversification and technical efficiency in Afghanistan: Stochastic frontier analysis, CREDIT Research Paper, No. 17/04, The University of Nottingham, Centre for Research in Economic Development and International Trade (CREDIT), Nottingham.

Anik, A.R., Rahman, S. (2020). Women's empowerment in agriculture: level, inequality, progress, and impact on productivity and efficiency. Journal of Development Studies, 1-19. doi.org/10.1080/00220388.2020.1817393.

Aguilar, A., Carranza, E., Goldstein, M., Kilic, T., Oseni, G. (2015). Decomposition of gender differentials in agricultural productivity in Ethiopia. Agricultural Economics, 46(3):311–334.

Alderman, H., Hoddinott, J., Kinsey, B. (2006). Long term consequences of early childhood malnutrition. Oxford Econ. Pap. 58 (3):450–474.

Alkire, S. (2005). Quantitative studies of human agency. Social Indicators Research, 74 (1):217–260.

Alkire, S. (2007). Measuring agency: Issues and possibilities. Indian Journal of Human Development, 1(1):169–178.

Alkire, S., & Foster, J. (2011). Counting and multidimensional poverty measurement. Journal of Public Economics, 95(7–8):476–487. doi:10.1016/j.jpubeco.2010.11.006.

Alkire, S., Meinzen-Dick, R., Peterman, A., Quisumbing, A., Seymour, G., & Vaz, A. (2013). The Women's Empowerment in Agriculture Index. World Development, 52:71–91. doi.org/10.1016/j.worlddev.2013.06.007.

Arimond, M., Hawkes, C., Ruel, M.T., et al. (2010). Agricultural interventions and nutrition: lessons from the past and new evidence. In: Thompson, B., Amoroso, L. (Eds.), Combating Micronutrient Deficiencies: Food-Based Approaches. FAO and CAB, Rome, p. 41-75.

Basu, A.M., Koolwal, G.B. (2005). Two concepts of female empowerment–Some leads from DHS data on women's status and reproductive health. A focus on gender–collected papers on gender using DHS data, ORC Macro, Calverton MD, pp.15-33

Battese, G. E. & Coelli, T. J. (1995). A model for technical inefficiency effects in a stochastic frontier production function for panel data. Empirical Economics 20(2):325-332.

Belotti, F., Daidone, S., Ilardi, G. & Atella, V. (2013). Stochastic frontier analysis using stata. The Stata Journal 13(4):719-758.

Berti, P. R., Krasevec, J., & FitzGerald, S. (2004). A review of the effectiveness of agriculture interventions in improving nutrition outcomes. Public Health Nutrition, 7(5):599–609.

Bhagowalia, P., Menon, P., Quisumbing, A. R., & Soundararajan, V. (2012). What dimensions of women's empowerment matter most for child nutrition: Evidence using nationally representative data from Bangladesh (IFPRI Discussion Paper No. 1192).

Coelli, T.J. (1995). Recent Development in Frontier Modelling and Efficiency Measurement. *Australian Journal of Agricultural Economics*, 39:219-245.

Coelli, T., Rao, D., O'Donnell, C., Battese, G. (2005). An introduction to efficiency and productivity analysis. Springer. New York.

Croppenstedt, A., Goldstein, M., Rosas, N. (2013). Gender and agriculture: inefficiencies, segregation, and low productivity traps. The World Bank.

Cunningham, K., Ploubidis, G. B., Menon, P., Ruel, M., Kadiyala, S., Uauy, R., & Ferguson, E. (2015). Women's empowerment in agriculture and child nutritional status in rural Nepal. Public Health Nutrition, 18(17):3134–3145.

FAO (2011). The state of food and agriculture. Women in agriculture: Closing the gap for development. FAO, Rome.

Ethiopian Public Health Institute (EPHI) and ICF (2021). Ethiopia Mini Demographic and Health Survey 2019: Final Report. Rockville, Maryland, USA: EPHI and ICF.

Farrell, M.J. (1957). The Measurement of Productive Efficiency. Journal of Royal Statistical Society, Series A, 120: 253-290.

Fletschner, D., Kenney, L. (2014). Rural Women's Access to Financial Services: Credit, Savings, and Insurance. In: Quisumbing, A.R., Meinzen-Dick, R., Raney, T.L., Croppenstedt, A., Behrman, J.A., Peterman, A. (Eds.), Gender in Agriculture and Food Security: Closing the Knowledge Gap. FAO, Rome, pp. 187–208.

FAO and FHI 360 (2016). Minimum dietary diversity for women: A guide for measurement. Rome: FAO.

Gillespie, S., Poole, N., van den Bold, M., *et al.* (2019). Leveraging agriculture for nutrition in South Asia: What do we know and what have we learned? Food Policy, 82:3-12.

Gupta, S., Pingali, P.L. & Pinstrup-Andersen, P. (2017). Women's empowerment in Indian agriculture: does market orientation of farming systems matter? Food Sec. doi.org/10.1007/s12571-017-0737-4.

Gupta, S., Vemireddy, V., Singh, D. and Pingali, P. (2019). Adapting the women's empowerment in agriculture index to specific country context: Insights and critiques from fieldwork in India. Global Food Security, 23:245-255.

Haddad, L. (2000). A conceptual framework for assessing agriculture-nutrition linkages. Food Nutrition Bulletin 21: 367-373.

Herforth, A., & Harris, J. (2014). Understanding and applying primary pathways and principles. Improving Nutrition through Agriculture Technical Brief 1. Arlington, VA: Strengthening Partnerships, Results, and Innovations in Nutrition Globally.

Hirvonen, K., Hoddinott, J. (2014). Agricultural production and children's diets: evidence from rural Ethiopia. ESSP Working Paper no. 69. Washington, DC: IFPRI.

Huffman, W.E. (2001). Human capital: Education and agriculture. Handbook of agricultural economics, 1, pp.333-381.

Johns, T., Powell, B., Maundu, P., et al. (2014). Agricultural biodiversity as a link between traditional food systems and contemporary development, social integrity and ecological health. J Sci Food Agric 93, 3433-42.

Jumrani, J. & Birthal, P.S. (2016). Livestock, women and child nutrition in rural India. Agricultural Economics Research Review, 28(2), 223.

Kadiyala, S., Harris, J., Headey, D., *et al.* (2014). Agriculture and nutrition in India: Mapping evidence to pathways. Annals of the New York Academy of Sciences 1331(1): 43-56.

Kennedy, G., Ballard, T., Dop, M. (2011). Guidelines for Measuring Household and Individual Dietary Diversity, United Nations, Food and Agriculture Organization: Nutrition and Consumer Protection Division.

Kennedy, G.L., Pedro, M.R., Seghieri, C., Nantel, G., Brouwer, I. (2007). Dietary diversity score is a useful indicator of micronutrient intake in non-breast-feeding Filipino children. J. Nutr. 137(2):472–477.

Kilic, T., Palacios-Lopez, A., Goldstein, M. (2015). Caught in a productivity trap: A distributional perspective on gender differences in Malawian agriculture. World Dev. 70:416–463.

Kjeldsberg, C., Shrestha, N., Patel, M., Davis, D., Mundy, G., Cunningham, K. (2018). Nutrition-sensitive agricultural interventions and gender dynamics: A qualitative study in Nepal. Maternal and Child Nutrition, 14(3):1-9.

Kumbhakar, S.C., Lovell, C.A.K. (2000). Stochastic Frontier Analysis. Cambridge University Press.

Kumbhakar, S.C., Wang, H. & Horncastle, A.P. (2015). A practitioner's guide to stochastic frontier analysis using Stata, Cambridge University Press.

Leroy, J., Ruel, M., Verhofstadt, E., & Olney, D. (2008). The micronutrient impact of multisectoral programs focusing on nutrition: examples from conditional cash transfer, microcredit with education, and agricultural programs. Innocenti Review 5.

Malapit, H.J., Kadiyala, S., Quisumbing, A.R., Cunningham, K. & Tyagi, P. (2015). Women's empowerment mitigates the negative effects of low production diversity on maternal and child nutrition in Nepal, The Journal of Development Studies, 51(8): 1097-1123. DOI:10.1080/00220388.2015.1018904.

Malapit, H. J. L., & Quisumbing, A. R. (2015). What dimensions of women's empowerment in agriculture matter for nutrition in Ghana? Food Policy, 52:54–63.

Malapit, H.J., Sproule, K., Kovarik, C., *et al.* (2014). Measuring progress toward empowerment: Women's empowerment in agriculture index: Baseline report. IFPRI Books.

Nguyen, B.H., Sickles, R.C. & Zelenyuk, V. (2021). Efficiency analysis with stochastic frontier models using popular statistical softwares.

Olney, K.D., Talukder, A., Iannotti, L.L. et al. (2009). Assessing impact and impact pathways of a homestead food production program on household and child nutrition in Cambodia. Food Nutr Bull 30, 355-69.

Quisumbing, A.R. (1996). Male-female differences in agricultural productivity: Methodological issues and empirical evidence. World Dev. 24(10):1579–1595.

Quisumbing, A.R., Maluccio, J. A. (2003). Resources at marriage and intrahousehold allocation: Evidence from Bangladesh, Ethiopia, Indonesia, and South Africa. Oxford Bulletin of Economics and Statistics, 65(3):283–327. doi.org/10.1111/1468-0084.t01-1-00052.

Rahman, S. (2010). Women's labour contribution to productivity and efficiency in agriculture: Empirical evidence from Bangladesh. J Agric Econ. 61(2):318–342.

Rahman S, Salim R. (2013). Six decades of total factor productivity change and sources of growth in Bangladesh agriculture (1948–2008). J Agric Econ. 64:275–294. doi.org/10.1111/1477-9552.12009.

Rogers, B. L. (1996). The implications of female household headship for food consumption and nutritional status in the Dominican Republic. World Development, 24(1):113–128.

Ruel, M.T., Alderman, H., Maternal Child Nutrition Study Group. (2013). Nutrition-sensitive interventions and programmes: how can they help to accelerate progress in improving maternal and child nutrition? The Lancet 382 (9891):536–551.

Ruel, M.T., Deitchler, M., Arimond, M., 2010. Developing simple measures of women's diet quality in developing countries: overview. J. Nutr. 140 (11):2048S–2050S.

Ruel, M.T., Quisumbing, A.R., Balagamwala, M. (2018). Nutrition-sensitive agriculture: What have we learned so far? Global Food Security, 17:128-153.

Santoso, M.V., Kerr, R.B., Hoddinott, J., Garigipati, P., Olmos, S., Young, S.L. (2019). Role of women's empowerment in child nutrition outcomes: A systematic review, 1-14.

Sell, M., Bäckman, s., Anang, B,T., Niemi, J.K. (2018). The unequal efficiency gap: Key factors influencing women farmer's efficiency in Uganda. Cogent Food & Agriculture, 4: 1551750. doi.org/10.1080/23311932.2018.1551750.

Seymour, G. (2017). Women's empowerment in agriculture: Implications for technical efficiency in rural Bangladesh. Agricultural Economics, 48(4):513-522. doi.org/10.1111/agec.12352.

Sibhatu, K.T., Krishna, V.V., Qaim, M. (2015). Farm production diversity and dietary diversity in developing countries. In: B.L. Turner, Arizona State University, Tempe, AZ (ed.), 112(34): 10657-10662.

Sibhatu, K.T., Qaim, M. (2016). Farm production diversity and dietary quality: linkages and measurement issues. Global Food Discussion Paper no. 80. University of Goettingen.

Sickles, R. & Zelenyuk, V. (2019). Measurement of Productivity and Efficiency, Cambridge: Cambridge University Press.

Sraboni, E., Malapit, H. J., Quisumbing, A. R. & Ahmed, A.U. (2014). Women's empowerment in agriculture: What role for food security in Bangladesh? World Development, 61, 11–52.

Swindale, A., Bilinsky, P. (2006). Household dietary diversity score for measurement of household food access: Indicator Guide (V.2). Washington, DC: FHI 360/FANTA III Project.

Tesfaye, G.B., Abidoye, B.O. (2020). Women empowerment in agriculture and child nutrition: Evidence from Ethiopia. AERC Working Paper GMBF-004. African Economic Consortium, Nairobi.

Tzouvelekas, E. (2000). Approximation properties and estimation of translog production function with panel data. Agricultural economics review,1(1):33-47.

Udry, C., Hoddinott, J., Alderman, H., Haddad, L. (1995). Gender differentials in farm productivity: Implications for household efficiency and agricultural policy. Food Policy, 20(5):407–423.

Wang, H..J. & Schmidt, P. (2002). One-step and two-step estimation of the effects of exogenous variables on technical efficiency levels. Journal of Productivity Analysis 18:129-144.

Webb, P., Kennedy, E. (2014). Impacts of agriculture on nutrition: nature of the evidence and research gaps. Food Nutr Bull 35:126-132.

WHO (World Health Organization). (2010). Indicators for Assessing Infant and Young Child Feeding Practices: Part II Measurement, Geneva.

CHAPTER FIVE

SYNTHESIS OF THE CHAPTERS AND METHODOLOGICAL AND THEORETICAL IMPLICATIONS

5.1. Synthesis of the Chapters

The research was set out to investigate the extent of food security situations of households and vulnerable individuals (women and children), and the agriculture, food and nutrition nexus from impact pathways perspectives in the rural settings of northwest Ethiopia. In understanding these situations, this thesis has applied various econometric models representing the different settings as explained in the conceptual framework section, such as a bivariate Tobit model for joint evaluation of HFS impacts of livestock and crop commercialization orientation of smallholder farmers and their determinants (Chapter Two); generalized linear model (GLM) to estimate dose response functions (DRFs) with generalized propensity score (GPS) matching approach to determine the effects of agricultural diversification and off-farm employment intensities on HFS (Chapter Three); and generalized structural equation modeling (GSEM) to assess impacts of women empowerment and production efficiency in agriculture on food security and dietary diversity of households, women and children in Libokemkem district in the way to capture the simultaneous relationships between variables and measurement errors (Chapter Four).

Estimates of bivariate Tobit regression model on a relative crop commercialization index demonstrated that both crop and livestock commercialization orientation can improve HFS among smallholder farmers, but in quite different ways. The income from crop sales was instrumental in allowing households to buy additional foods while livestock sales fostered crop production diversity for own personal consumption, by allowing farmers to purchase non-food items. Livestock commercialization was found more important than crop commercialization in improving HFS due to its strong net positive effect. Although the transition of crop farms from subsistence to commercially-oriented production can improve HFS through increased consumption of purchased foods, its adverse effect on subsistence consumption was significantly higher in magnitude, which ultimately implied a net reduction in HFS.

By contrast, commercialization orientation of farmers in their livestock production resulted in a net increment in HFS, as its synergy effect on diversification of crops for own consumption strongly overweighed in magnitude its adverse effect in reducing consumption of purchased foods. This suggested that agriculture and food security nexus may not require the production systems to be subsistent. From this one can conclude that commercialization of agriculture is vital not only for economic growth and food security, but also for the smallholder agriculture to be more nutrition sensitive.

Aiming to evaluate whether agriculture diversification and off-farm employment are viable intervention strategies in rural areas for better HFS as well as to differentiate effects of seasonal and sectoral variation in production, this research also assessed the role of crop diversification in rainy and in dry season and livestock diversification separately, using GLM for estimating the DRFs across each treatment (AD and OFI intensities) adjusting confounders for GPS as explained above. Despite previous studies exploring the relationships between AD, OFI and FS, the results have been mixed, and the impact may depend on the intensity of the interventions. Here the thesis investigated the role of AD and off-farm employment intensities in ensuring HFS in northwest Ethiopia. The findings revealed that crop diversification would have positive implication on HFS had it been in rainy season production whilst specialization in dry season could improve HFS in both FC and DD.

As estimates of DRFs showed that crop diversification intensity peaked at 0.3 Simpson score in rainy season may mean for most farmers a moderately increased diversification of crops from very limited food groups would be more beneficial in their FS situation. This suggested that capitalizing diverse production practices from being specific food group (i.e. cereals) to be from various food groups may enhance the crop farming system to be more nutrition sensitive, it might even without compromising benefits of specialization in an environmentally friendly way. It was entirely specialization in dry season helps improve HFS. This indicated that diversifying crops in the rainy season up to a certain level and specializing in the dry season improved food consumption and dietary diversity, which highlighted the importance of income generated from diverse farming in rainy season and specialization in dry season.

Furthermore, diversification in livestock production could have a positive effect on HFS, particularly when diversification occurred across diverse food groups (0.6), may suggest that livestock husbandry is more nutrition sensitive than cropping. Our analysis also suggests that AD across crop and livestock production can heighten the positive effects on HFS. This finding corroborates Herrero *et al.* (2010) that argued that the synergy between cropping and livestock husbandry can increase FS and income of the people. This research concludes that AD and off-farm employment are crucial factors in ensuring HFS in northwest Ethiopia, and that diversification across diverse food groups up to a certain level is essential for maximizing the positive impact of AD on HFS. Off-farm employment is also suggested as a means of ensuring household resilience to withstand shocks and improve agricultural productivity.

Finally the thesis examines how women empowerment in agriculture (WEA) and technical efficiency (TE) in crop production influence FS and DD of households and vulnerable individuals (women and children). Estimation using stochastic frontier analysis (SFA) is to determine the level and determinants of TE of smallholder farmers in crop farm and GSEM to investigate the role of WEA and TE on DD and FS of women, children and households in Libokemkem district in rural Ethiopia. The descriptive results illustrated that about 33% of households, 44% of women and 28% of children under five years were food insecure in the study areas. The production efficiency of crop farmers and the WEAI in Libokemkem woreda in Ethiopia averaged to be 0.652 and 0.824. Around 64% of women in surveyed households are empowered and 36% who are not yet empowered have on average inadequate achievements in 34% of domains.

Approximately 3 in 4 women (77%) have gender parity with their spouses and the empowerment gap among women who are less empowered is quite large as 17.6%. Time poverty (48%), lack of control over productive resources (22%) and weak leadership in the community (17%) are the key domains of women disempowerment in Libokemkem. More than 83% of women are yet disempowered with excessive workload more than 46% of the empowered women worked, and approximately 1 in 2 women in surveyed households have high burden of workload above time poverty line. Women spent a significantly higher share of their time on domestic tasks more than five folds the men counterparts engaged in, while the men used only two folds of the time their spouses spent for productive activities. This suggested that labor-augmenting technologies that reduce the time women need to spend on domestic chores may give them more freedom to choose among activities that are empowering in line with Gillespie *et al.* (2019) and Ruel *et al.* (2018) suggested women's time and energy stress may also lead to reductions in care giving practices and risks for women's own health.

About 60% of women reported they have limited autonomy in decision making over productive resources, and 28% lack access to credit and the ability to make decisions about it. Workload, lack of time available for leisure, autonomy in production and speaking in public are the main indicators contributing to women disempowerment. This informed that these are the areas of interventions to improve women empowerment. The descriptive findings in general suggested that WEA needs to be progressed up to a certain level beyond which improving empowerment may have adverse implication on TE of crop farming and FS outcomes across children, women and households.

The estimation results of GSEM also revealed that empowering women in agriculture significantly improves DD of households and women by 1.42 and 1.67 points through its direct pathway while it enhances the likelihood of a household (child) to be FS increases by 18% (35%) respectively. Despite adverse implication TE has on WEA, TE can directly enhance DD of women and households to increase significantly each by 2.2 points. However, the TE that worsened WEA was significantly stronger in magnitude than the WEA enhanced TE, the efficiency interaction pathway ultimately resulted in a net reduction in DD of women and households by 2.62 and 2.48 points, respectively. The market orientation interaction pathway of empowerment enhances DD of households and women to rise significantly by 3.06 and 3.89 points respectively as well as it boosts the propensity of a child is nutritious by 57% in line with Gupta *et al.* (2017) in India affirmed a strong relationship between market orientation and empowerment implies linking women to markets can be a pathway to enhancing their empowerment in agriculture domains to affect the FS and nutrition outcomes positively.

Another interesting finding of the current research is that AD alone does not necessarily imply DD and FS of households/individuals to improve, the role of women empowerment in AD surprisingly matters DD of households and women to increase by 1.46 and 1.66 points in order, as well as the likelihood of a child (household) is FS increases significantly by 33% (18%) respectively. This is slightly similar to Malapit *et al.* (2015) in Nepal find that women empowerment can mitigate the adverse implication of low production diversity on maternal and child DD.

Size of cultivated land, access to health extension and per capita income are the other variables significantly influencing DD and FS situations of households, women and children positively. Family size and access to agricultural extension affected DD of households adversely whilst family size on the other hand has an encouraging effect on child DD to increase significantly, the latter two show a pattern that needs further study to understand. Education of household head observed to have a significant and positive implication on FS of households only. The joint implication of empowerment score and the girl interaction pathway demonstrated that girls are 38% more likely to be FS than sons in households where the female decision maker is more empowered in agriculture. This may also suggest empowerment might bring cultural shifts in the intra-household gender parity frontier that can mitigate son-biased allocation of dietary foods among children under five years. The likelihood of a child to be FS, however, reduces as the share of son members and child's age progressed.

Women empowerment, market orientation, per capita income, access to off-farm income, education of household head, share of female labor, share of improved seeds, share of own land and oxen ownership are the determinants identified to affect TE positively, whereas AD implied an opposite effect. Age of mother, education of mother, per capita income and access to off-farm income are factors significantly impacting WEA positively, whilst efficiency, livestock ownership and age of household head influenced WEA adversely.

5.2. Theoretical and Methodological Perspectives

There was a tendency in the 1960s to accentuate the importance of linkages between agriculture, food and nutrition (AFN), during 1980s such linkages were often belittled. In the earlier decade a stable and sufficiently high level of food production in low income countries was often considered to be adequate for better FNS, but through years the perception grew that agricultural production and food availability were not particularly relevant to favorable nutrition outcomes (Kennedy & Bouis, 1993). The authors argue that these two extreme positions failed to recognize the relevance of agricultural development for improved FNS, need to be put in perspective. Improving agricultural productivity and the linkage of agriculture to FNS has become a central issue of development policies in Sub-Saharan Africa (Allen, 2003; Haddad, 2000) that stems from the role agriculture is expected to play as primary source of livelihood including food and nutrition in the developing world (Ehui & Pender, 2005; Hawkes & Ruel, 2006). The concept of nutrition-sensitive agriculture emanates from this perspective the fact that agricultural production practices have the potential to affect the underlying determinants of nutrition positively (Ruel *et al.*, 2018).

Our conceptual framework (Figure 1.1) that extracted from previous literature suggested understanding what and how agriculture contributes to FNS of smallholder farmers in the rural settings identified subsistence (AD), market (AC) and empowerment (WEA) as the key pathways hypothesized to run in AFN nexus (for details see Theoretical Foundation Subsection in Chapter 1). Theoretically it is possible to have positive, neutral or even negative associations between AD and DD in rural households. This association may, however, be influenced by the nature of agricultural production practices of smallholder farmers being subsistence or market-oriented, and the role of women in agriculture. This suggested that households' decisions about the mix of agricultural products to produce, consume and market have important implications for the AFN nexus brings about better FNS. This sequence of events represents the theoretical underpinning of the current research that conceptualized decision behaviors based on production and consumption theories of rural households who are both sellers and buyers of agricultural produces. Two types of theoretical scenarios are often used in the literature to explore linkages between production and consumption decisions characterized by the market situations that prevail in the world of rural household economy: separable and non-separable AHMs. The AHMs in general show that which factors determine the level of household production, consumption, demand for inputs and supply of labor, and their relationships under these circumstances.

The agriculture sector is an important source of income in most developing countries. Majority of the households in these areas are both producers and consumers of their own produces may complicate the traditional consumer theory. The inputs they use partly originate from the market and partly from their own production exacerbates the complexity. Accordingly this research will have important contribution from this theoretical perspective by identifying the theoretical model that is appropriate to explore the AFN linkages in such complex contexts of low income countries, specifically providing empirical evidence for Ethiopia.

The consumption and production decisions of households that prevail in situations with imperfect markets and heterogeneous transaction costs can be understood through the non-separable AHM. In this underpinning, it is generally assumed there will be nonrecursive relationships (or simultaneity) between production and consumption decisions of households in the rural economy. Proponents argue that this often happens in the developing world, where local (or decision) prices are determined endogenously by market prices and factors influencing transaction costs. Assuming a perfect market situation, the separable AHM on the other hand hypothesizes that there is a one-way (or recursive) relationship between production and consumption decisions. Advocates claim that the non-separable scenario can be quite complex under increasing opportunities for market participation, where households have more opportunities to trade, generate income and purchase different types of foods in the current globalization context. As the household is assumed market oriented in farm production, it tends to maximize profit independently of its decisions regarding consumption and labor supply, but the decisions on consumption and labor supply cannot be made independently from production decisions.

Prices in a separable scenario are assumed to be exogenously determined which allows separability of households' decisions of production from consumption. Consequently the household behaves as if its production decisions are made first and then the generated full income through farm profits is allocated between consumption of goods and leisure. This suggests that consumption (FS) depends on production decisions and household demographic characteristics, but not vice-versa. The theoretical framework of this research was built mainly in this context with the view that there is a one-way causation between production and consumption decisions among smallholder farmers. Accordingly the present research has formulated empirical models at household level based on bivariate Tobit, dose response functions and generalized structural equation modeling framework in the respective three manuscripts to explore the relationships between AFN nexus as explained hereunder.

A bivariate Tobit model

An empirical model was built for joint evaluation of HFS impacts of AC, whether had it been through trade-off or synergy effect between consumption of produced and purchased foods as well as for joint determinants of crop and livestock commercialization orientation based on a bivariate Tobit framework. Here it is postulated that farmers follow sequential decisions in consumption of any particular food. First, whether to choose to consume a particular (produced/purchased) food. Second, to what extent is the intensity of consumption conditional on choice? In such a case, it is appropriate to use the bivariate Tobit model developed at household level using FCS of produced foods and FCS of purchased foods as dependent variables for joint determination of how commercialization orientation affects HFS to better understand to what extent purchased foods are substituted for, or supplementary to, produced foods, after correcting for other covariates.

The role of commercialization on HFS was evaluated not only based on analyzing its total effect in FCS of all foods consumed by the household using a conventional Tobit approach, but also assessed decomposing the FCS from purchased and produced foods as dependent variables helps identify the transmission channels of AC to HFS, while at the same time controlling for potential endogeneity. Addressing the latter aspect calls for a bivariate Tobit, capable of jointly estimating all the parameters of interest, besides providing evidence whether trade-off/synergy effect AC has occurred between consumption of purchased and produced foods. Using 'share of crop income to agricultural income' (C_i in Eq. 2.8) as a measure of commercialization is the novelty of this research that discloses the relative importance of crop and livestock commercialization to HFS that most studies were limited in addressing.

A Tobit approach can, therefore, capture the decision to choose as well as the resulting outcome (intensity), while others such as probit or logit model provide information on the decision to choose only. This suggests the Tobit model can be framed conceptually to evaluate the relationship of one or more independent variables with a dependent variable having continuous observations but censored to either left, right or both. In our case, the dependent variable comprised nonnegative values, and was left-censored. If this relationship were estimated using OLS regression without censoring, the resulting estimators would be inconsistent and yield downward-biased slope coefficients and an upward-biased intercept. Maximum likelihood estimator (MLE) would, therefore, be consistent in the Tobit model. The fact that more than 96% of surveyed households consumed a mix of purchased and produced foods over a 7 d recall period, a bivariate Tobit framework is appropriate to capture both censorship and the tradeoff/synergy effects of commercialization between purchased and produced food consumption as the model specified in a set of Equations (2.10-2.14).

A control function approach was adopted to test whether C_i is an endogenous explanatory variable or not, by introducing the generalized residual and expectation of relative commercialization index $(\widehat{C}_i)$ into Equations (2.10-2.14). As the generalized residual was statistically insignificant, there was no endogeneity bias (see Table A1 in Appendix 1), and hence a direct estimation of the original model of bivariate tobit specified in Equations (2.10-2.14) would yield consistent estimates.

Impact evaluation framework: Dose response and generalized propensity score

Food insecurity is a critical development and health problem specifically in rural areas, where agriculture diversification and off-farm employment remain important in improving HFS. Previous studies exploring this relationship provide mixed results and yet, the effect may vary according to the extent of the two interventions. The conceptual framework for evaluating impact of AD and off-farm employment intensities was, therefore, developed from counterfactual perspective that allows to make causal claims in case of observational data and continuous treatments. The fact that units in observational studies are not randomized to different treatment levels, the imbalance in pre-treatment covariates may lead to confounding bias. To obtain consistent estimates, this selection bias has to be modeled.

In most FS studies, confounding adjustment is traditionally made by fitting a multivariate regression model with FS outcome as dependent variable, AD, for example, as a key independent variable and many potential confounders are additional independent variables. It has been well documented in the literature traditional regression methods do not allow for clear distinction between the design and analysis stages (Wu *et al.*, 2021), are susceptible to model misspecification and often their results cannot be interpreted as causal effects (Bellon *et al.*, 2016). In reply to this, some others have used the standard PSM method (Abebaw *et al.*, 2010; Justus *et al.*, 2015). This approach, however, cannot address continuous treatments. Many researchers have advocated for the development and implementation of methods for causal inference to inform FS and nutrition policy (e.g. Mofya-Mukuka & Kuhlgatz, 2016; Ogutu *et al.*, 2019).

When the treatments are continuous, like AD and OFI intensities in our case, there is no explicit way to distinguish units as exposed and unexposed, which calls for a different procedure. In such conditions, the generalized propensity score (GPS) specification is more appropriate than the standard PSM for estimating dose response functions (DRFs). The impact evaluation framework of this thesis was developed at household level with a generalized linear model (GLM) for estimating the DRFs at each treatment level using GPS for adjusting confounders.

Several econometric approaches are available in the literature on impact evaluation to re-establish a randomized setting in case of self-selection bias. Difference-in-differences is the one that is not applicable in this study, as this requires panel data over certain periods. The instrumental variables method is the other one that relies on parametric assumptions regarding functional form of relationship between outcomes and predictors as well as on exogeneity of instruments used. As this method is also quite sensitive to violation of these restrictive assumptions, we adopt the nonparametric, matching approach in which households of the group of diversified farmers are matched to those households in the control group, who are similar in their observable characteristics. Moreover, it is common in the impact evaluation literature to treat diversification as a binary decision variable in which most studies have employed propensity score matching (PSM) to address the selection bias. Yet, PSM is an oversimplification in situations when farmers produce at different intensity levels of diversification may have different effects on HFS.

The current research tries to extend this econometric setup to handle household's exposure to different levels of diversification, and measure its impact on HFS. So the GPS method was adopted from Hirano and Imbens (2004) to balance differences among farms of different intensity levels conditional on their observable characteristics. This approach has been used in observational studies since its formulation by Bia and Mattei (2008) addresses exposure to continuous treatments. Even Bia and Mattei have used the maximum likelihood estimator that does not allow for distribution assumptions other than normal density. Instead, a flexible GLM was used in this research following Guardabascio and Ventura (2014) for estimation of DRFs adjusted for GPS captures issues of both continuous and different distribution functions of a treatment. This means that adjusting for GPS removes all biases associated with differences in covariates. The unbiased impact of different intensities among farms of diversification on HFS can then be demonstrated with DRFs.

The results of continuous treatment effects of production diversification and off-farm employment intensities on HFS estimated the DRFs using GPS matching approach include the covariate balancing tests that compared three different groups varying in levels of each diversification indicators (CDSI, LDSI, ADSI, CDSS, LDSS & ADSS) as dependent variables of different models analyzed each separately. Before matching, most of the covariates for these three treatment groups differ significantly across all the six models. After matching, most of the differences turn insignificant. This implied that the variables used for balancing fairly balance the differences in household and farm characteristics, which in turn verified GPS is an appropriate approach for analyzing continuous treatment effects (see Table B1-B7 in Annex 2).

A generalized structural equation modeling and stochastic frontier analysis

Despite consistent gains in agricultural productivity in the last half century, lack of FS persists in many regions of the world. Addressing this issue is really pertinent in low income countries like Ethiopia, where most people at risk of food insecurity and malnutrition are located and women's engagement in agricultural and domestic tasks is remarkably high. Figure 4.1 presents the conceptual model developed to guide our empirical analysis of linkages between WEA, TE and FS in rural settings that is framed in generalized structural equation modeling (GSEM). The conceptual groups that map to reflect the three major pathways onto five domains of empowerment are abstract constructs best modeled using 10 indicators that are conceptually relevant and inter-correlated.

The first pathway (PW) is empowerment that refers to a link when the agricultural labor conditions can influence empowerment of women's control over nutrition-relevant resources and decision making outlined through different interrelated channels, such as women's role in food production and use of income, women's control over household resources and other decisions, and women's employment as source of income. The second is childcare PW relates to the pressures that heavy and prolonged women workloads in agriculture placed on childcare and feeding. The third PW is energy expenditure that reflects the risks of energy expenditure and health hazards on women could contribute to intergenerational malnutrition and poor health that the current research is limited in addressing. Instead, it considers the interaction PWs of empowerment with technical efficiency (TE), market orientation (MO) and diversification of agricultural production (AD) as shown in Figure 4.1 by arrows that originating from these variables pointing to the path linking WEAI to FS outcomes.

These pathways may have special significance for household nutrition outcomes, mainly for children's nutrition and health with the assumption that women have consistently been found to be more likely than men to invest in their children's health and well-being, and the income and resources that women control wield disproportionately strong effects on health and nutrition outcomes not just for themselves and their children but also for other family members. Policies that improve women's status and reduce gender disparities are expected to improve women, children and household well-being, owing to important role of women in childcare and household food preparation in many societies like in Ethiopia. Women also play crucial role in agriculture, although this role has tended to be unrecognized and incorrectly measured.

The other covariates our analytical framework treated include household size, education, age and sex of household head, off-farm income access, per capita income, and access to agriculture extension and health extension are among household characteristics expected to influence both the two key independent variables (WEAI and TE) and DD/FS outcomes as reflected by the three arrows originated from each covariate in Figure 4.1. Own cultivated land size, livestock ownership, age of mothers and education of mothers are assumed to relate with WEAI only, while access to irrigation, oxen ownership, female labor share, share of own cultivated land and share of improved seed are hypothesized to correlate with TE only, and cultivated land size only with DD/FS outcomes. AD and market orientation are expected to influence both TE and DD/FS outcomes directly.

GSEM has several benefits over the linear regression model as it can accommodate relationships between multiple variables by simultaneously estimating multiple regression models. This allows to model indirect, mediating and co-varying relationships besides the direct relationships possible with stand-alone regression models. This estimation framework is generally composed of measurement models to construct the latent variables corrected for measurement errors and the structural models for analyzing the linkages among WEAI, TE and DD/FS indicators.

Empirical research suggests farmers in developing countries fail to exploit fully the production technology and resources, and often make inefficient decisions. This research applies a stochastic frontier analysis (SFA) to estimate the level and determinants of efficiency of smallholder farmers in crop production. In measuring TE, the inputs are exogenously given and the objective is to maximize output as the only choice variable. As the current research studies this issue in the context of Ethiopia, as part of a developing economy, the main concern may be output shortfall rather than input over usage. Additionally, lack of price data implies the nuisance to address allocative efficiency, and hence output-oriented approach is preferred.

The literature on SFA employs econometric models to estimate production frontiers and technical (in)efficiency. SFA has been applied to study the productivity and efficiency of production units in various economic sectors, since its first introduction by Aigner, Lovell & Schmidt as well as Meeusen & van den Broeck who came up with the theoretical approach in 1977 (Kumbhakar & Lovell, 2000). The stochastic frontier paradigm can be viewed as a generalization of the classical production function approach, where the optimal allocation in production is a testable restriction rather than a prior assumption usually assumed by the neoclassical production theory (Sickles & Zelenyuk, 2019). The distinctive feature of this paradigm is its non-symmetric two-component error, composed of a regular idiosyncratic noise and one-sided non-negative error component (Nguyen, 2021). The former accounts for factors such as measurement error, misspecification and the randomness of production process, while the latter represents technical inefficiency that reduces the actual output from its maximum feasible level.

Key evidence also shows that efficiency can be estimated using either a two-stage or single-stage approach. Early studies have used a two-step procedure, in which the efficiency scores derived from a stochastic frontier function estimated in the first stage are then regressed on a set of variables assumed to influence efficiency (z_i) using OLS or Tobit regression in the second stage. Scholars criticized this approach for its inconsistency relating to the assumptions regarding independence of the error components (Battese & Colli, 1995). Wang and Schmidt (2002) also claimed that exogenous determinants of inefficiency (z_i) might affect its input choices (x_i), and hence efficiency might be dependent on explanatory variables. Others confirmed even if x_i and z_i are uncorrelated, ignoring the dependence between them and of the inefficiency with z_i

will cause the first-step TE score underdispersed implying the second-step regression results likely to be downward biased (Kumbhakar *et al.*, 2015). This suggests efficiency is arguably endogenous.

Recognizant of this advocated a single-stage approach for estimating efficiency when its determinants incorporated directly into inefficiency term (Battese & Colli, 1995; Kumbhakar & Lovell, 2000). Adopting this approach, the efficiency and its determinants estimated simultaneously as the mean of inefficiency term is hypothesized to be a function of explanatory variables. Efficiency was estimated in this study using a production function that also encompasses a model for assessing factors influencing inefficiency simultaneously.

An interesting generalization of stochastic frontier paradigm is extending SPF models to examine impact of determinants on technical inefficiency. It is usually done by parametersing parameters of inefficiency distribution-i.e. pre-truncated mean and/or variance, as a function of exogenous variables specified in Equation (4.8). Kumbhakar and Lovell (2000) argue that failing to consider heteroskedasticity associated with firm size, for example, may lead to bias in estimation of TE. By incorrectly assuming homoskedasticity, estimates for relatively small firms would be biased upward, while estimates for relatively large firms would be biased downward.

Drawing from the conceptual framework explained above, our empirical model was developed using a flexible translog production technology widely cited in the stochastic frontier literature, to estimate the TE of crop farmers. The fact that its flexibility circumvents the problem of over restriction and allows a general specification of the model that can represent any underlying arbitrary structure of production at the chosen point of approximation (Tzouvelekas, 2000). The production behavior of a farm household was described in this study empirically with six inputs translog specification in Equation (4.10), including farm size (ha), family labor (AEU), chemical fertilizers (kg), seeds (kg), cattle ownership (number) and pesticide expenditure (ETB). Accordingly the production function was estimated under a single-stage estimation using a translog specification as outlined in Belotti and colleagues, which allows for determinants of inefficiency, can address endogeneity in the frontier or inefficiency that the standard frontier estimates ignore (Belotti *et al.*, 2013). The maximum likelihood estimates for all parameters associated with inputs $(x's)$ and inefficiency variables $(z's)$ were estimated using STATA v.13 software and *sfcross* stata command following Belotti *et al.* (2013).

For analyzing the role of WEA on FS of children and women, households that involved in one or more agricultural activities (growing crops or raising livestock) were considered so that individuals are not misclassified as disempowered when they do not participate in any agricultural activity. We hypothesize that empowered women are better to command the resources needed to provide food and health care to themselves, children and other household members, leading to optimal FS status measured in DD of foods consumed by children (MDD), women (MDD-W) and households (HDDS). To analyze linkages of WEA with TE and DD of individual/household, we estimated the regression models specified in Equations (4.11-4.13) using GSEM approach to capture endogeneity in TE and WEA with FS outcomes.

Exploring from existing literature, WEA and TE are arguably endogenous variables in this study. Consequently the GSEM was applied mainly to controlling for endogeneity bias resulting from simultaneity between these two variables as well as to investigate such linkages in a systemic perspective in which a set of equations specified above estimated simultaneously using a single-stage approach. The fact that our dependent (FS) variables operationally defined in terms of DD indicators (HDDS, MDD-W and MDD) are measured by counting the food groups consumed by households/individuals, the Poisson regression model was used in GSEM framework for estimating Equation 4.11. As empowerment and efficiency are continuous variables, Equations 4.12 and 4.13 were estimated using OLS regression models set in GSEM framework.

In order to enhance robustness and ease use and communication of the results by policy makers and development planners, these outcome variables are also expressed with dichotomous indicators to demonstrate food and nutrition security situations in the study areas using the minimum acceptable diets as a threshhold. This also suggests an ordered logit/probit model is relevant to use. All these conditions imply it is more appropriate to use GSEM relative to structural equation modeling (SEM) that needs all variables to be continuous. Additionally GSEM can capture the interaction effects, as does not in SEM.

To this end, identifying the key pathways in such a systemic perspective by which agriculture can influence FNS of households/individuals in rural settings can serve as a guiding principle for this thesis to draw conclusions and policy implications that inform understandings of FNS issues in rural Ethiopia as briefly discussed in the next section.

5.3. Policy Implications and Further Research Areas

The findings of this thesis have crucial policy implications in food security and nutrition transition of smallholder farmers in majority of the developing countries specifically for Ethiopia and further contributes to extant literature on agriculture, food and nutrition nexus. Identifying the key potential pathways by which agriculture influences food security and nutrition of households and/or individuals can suggest concerned bodies that are working to mitigate food insecurity and malnutrition shall consider during planning interventions from such systemic perspectives may facilitate our country to achieve more of the development initiatives in the Sustainable Development Goals, specifically SDG2 targeted to "End hunger, achieve food security and improved nutrition and promote sustainable agriculture" by 2030. All the subsistence, income (market), agricultural productivity (production efficiency) and women empowerment pathways observed to have important implication on food security and nutrition of smallholder farmers in context of rural Ethiopia.

Strengthening and promoting crop diversification up to a certain level during rainy season and specialization in cash crops production in dry season can significantly improve DD and FS of households among smallholder farmers. Livestock diversification has also affected DD and FS of households positively but it seems a bit more diverse relative to crop production, which suggests livestock husbandry is likely to be more nutrition sensitive than cropping. Diversification of agriculture combining both crops and livestock further heightened its role not only in improving DD and FS but also increasing income of households mainly resulted from their synergy effects. In terms of commercialization of agriculture, livestock husbandry also identified to offer a high potential of bringing about a net improvement in DD while the transition of crop farms from subsistence to commercially-oriented production would ultimately yield a net reduction in DD.

Coming to women empowerment in agriculture and production efficiency pathways, both have positive implications on DD and FS of women, children and households directly. The production efficiency of a typical household in the study areas was 65.2% in crop farm. This suggests that crop production can be increased by around 35% with given inputs by simply enhancing the efficiency of farmers to attain optimum outputs. The interaction pathways surprisingly revealed that the effect of empowerment on AD and market orientation of crop farms encouraged DD and FS of households, women and children to increase significantly, whereas the efficiency interaction pathway ultimately implied a net reduction in these outcome variables. As the descriptive findings suggest that WEA has to progress up to a certain level beyond which improving empowerment may have an adverse implication on TE of crop farmers and FS outcomes across children, women and households. This may be the fact that interventions for empowering women may create women's stress in time and energy as identified time poverty (workload) and lack of autonomy in productive decisions are the two major domains of agriculture that contributed to 48 and 22% of women disempowerment in this research, respectively.

Here can be suggested that labor-saving technologies that reduce the time women need to spend on domestic chores may give them more freedom to choose among activities that are empowering, as women's time and energy stress may lead to reductions in care giving practices and risks for women's own health. It also informed that policy and program interventions shall emphasize these dimensions of women disempowerment (workload, participation in productive decisions & leadership in the community) to increase empowerment that can influence AFN nexus positively, as some may imply gender has a disconnecting/adverse role in such nexus, instead. Another interesting finding of this research suggested that not AD alone important, it is the role of women empowerment in AD surprisingly matters the FS outcomes to improve significantly. This also illustrated women empowerment can mitigate the adverse implication of low production diversity on household, woman and child DD. A strong positive relationship between market orientation and empowerment suggested that linking women to markets can be a pathway to enhancing their empowerment in agriculture domains to affect the FS and nutrition outcomes positively.

All these, however, require supporting investments in improving road infrastructure, both in terms of access and quality to function all weather conditions, establishing better access to institutional services (such as credit, extension, off-farm employment and land markets) and enhanced awareness of extension towards promoting commercialization and diversified food consumption are the viable intervention areas to improve the role of AC to FS for vulnerable households. Further increasing AD may not be the most effective strategy to improve HFS, as (Hirvonen *et al.*, 2016; Sibhatu *et al.*, 2015; Koppmair *et al.*, 2016) affirmed, because diversification beyond a certain level might prevent gains from specialization that could, in turn, lead to income losses potentially affecting HFS adversely. Transformation of agriculture from subsistence to commercially-oriented production seems to be more promising, similar to the findings of (Hirvonen *et al.*, 2016; Bellon *et al.*, 2016) that identified market access is more important than FD for FS to improve.

All these suggest AC is vital, not only for economic growth and improved wellbeing of households, but also because it plays a crucial role for the smallholder agriculture to be more nutrition sensitive. It is also recommended that households focus on cash crops production to increase income during dry season, and promoting diversification up to certain level during rainy season to increase FS through subsistence and income pathways. Strengthening and promoting off-farm employment opportunities in rural areas is the other aspect suggested for household resilience to withstand shocks, income diversification and improve agricultural productivity.

While several tests confirmed robustness of our findings, a few limitations remain. The analysis was based on cross-sectional data limited to capture seasonal differences and identification strategy, and, as argued by Kirimi *et al.* (2013), a household's FS position is dynamic with the possibility that a household that is FS today may not be so tomorrow and vice-versa. Using bivariate Tobit is limited to address the interaction effects between variables. Future studies with panel data considering changes in the level of AC, AD, WEA and FS position of households over time with large sized samples and adopting the approach that can capture interaction effects, besides controlling for the complex relationship between variables in an integrative system, will enhance the robustness of the findings in AFN linkages. Additionally, some variables were found to be different from expected and when compared to other studies and need to be further researched.

References

Abebaw Degnet, Fentie Yibeltal & Belay Kassa (2010). The impact of a food security program on household food consumption in Northwestern Ethiopia: A matching estimator approach. *Food Policy*, 35:286–293.

Adam Bekele, Belay Kassa., Belaineh Legesse & Tesfaye, Lemma (2010). Effects of crop commercial orientation on productivity of smallholder farmers in drought-prone areas of the Central Rift Valley of Ethiopia. Ethiop. *J. Agric. Sci.*, 20:16–34.

Alene, A.D., Manyong, V.M., Omanya, G., Mignouna, H.D., Bokanga, M. & Odhiambo, G. (2008). Smallholder market participation under transactions costs: Maize supply and fertilizer demand in Kenya. *Food Policy*, 33:318–328.

Allen, L.H. (2003). Interventions for micronutrient deficiency control in developing countries: Past, present and future. *J. Nutr.*, 133:3875S–3878S.

Andrew, S. & Halcomb, E. J. (2012). Mixed Method Research. In Borbasi, S. & Jackson, D. (Eds.) Navigating the Maze of Research: Enhancing Nursing & Midwifery Practice. 3rd ed. Marrickville, New South Wales, Elsevier.

Antonakis, J., Bendahan, S., Jacquart, P. & Lalive, R. (2010). On making causal claims: A review and recommendations. *The Leadership Quarterly*, 21:1086-1120.

Amore, M.D. & Murtinu, S. (2021). Tobit models in strategy research: Critical issues and applications. *Glob. Strategy J.*, 11:331–355. doi.org/10.1002/gsj.1363.

Arimond, M., Hawkes, C., Ruel, M.T., et al. (2010). Agricultural interventions and nutrition: lessons from the past and new evidence. In: Thompson, B., Amoroso, L. (Eds.), Combating Micronutrient Deficiencies: Food-Based Approaches. FAO and CAB, Rome, pp. 41-75.

Austin, P.C. (2019). Assessing covariate balance when using the generalized propensity score with quantitative or continuous exposures. *Statistical Methods in Medical Research*, 28(5):1365–1377.

Barrett, C.B. (2008). Smallholder market participation: Concepts and evidence from eastern and southern Africa. *Food Policy*, 33:299–317.

Battese, G.E. & Coelli, T.J. (1995). A model for technical inefficiency effects in a stochastic frontier production function for panel data. *Empirical Economics*, 20(2):325-332.

Belotti, F., Daidone, S., Ilardi, G. & Atella, V. (2013). Stochastic frontier analysis using stata. *The Stata Journal*, 13(4):719-758.

Bellemare, M.F., Christopher, B. & Barrett, C.B. (2005). An Ordered Tobit Model of Market Participation: Evidence from Kenya and Ethiopia; WP 2005-10; Cornell University: Ithaca, NY, USA.

Bellon, M.R., Ntandou-Bouzitou, G.D. & Caracciolo, F. (2016). On-farm diversity and market participation are positively associated with dietary diversity of rural mothers in Southern Benin, West Africa. PLoS ONE,11(9):e0162535.

Berry, E.M., Dernini, S., Burlingame, B., Meybeck, A. & Conforti, P. (2015). Food security and sustainability: Can one exist without the other? *Public Health Nutr.*, 18:2293–2302.

Bia, M. & Mattei, A.A. (2008). Stata package for the estimation of the dose-response function through adjustment for the generalized propensity score. *The Stata Journal*, 8(3):354–73.

Bowers, B., Cohen, L. W., Elliot, A. E., Grabowski, D. C., Fishman, N. W., Sharkey, S. S., Zimmerman, S., Horn, S. D. & Kemper, P. (2013) Creating and supporting a mixed methods health services research team. *Health Services Research,* 48:2157-2180.

Chang, H.H. & Mishra, A. (2008). Impact of off-farm labor supply on food expenditures of the farm household. *Food Policy*, 33(6):657–664.

COHE (2012). The cost of hunger in Ethiopia: Implications in the Growth and Transformation Plan. In The Social and Economic Impact of Child Undernutrition in Ethiopia Summary Report; Central Printing Press: Addis Ababa, Ethiopia.

De Janvry, A. & Sadoulet, E.(2006). Progress in the modeling of rural households' behavior under market failures. In Poverty, Inequality and Development; Springer: Berlin/Heidelberg, Germany, pp.155–181.

Dillon, B. & Barrett, C. B. (2014). Agricultural Factor Markets in Sub-Saharan Africa: an Updated View with Formal Tests for Market Failure. Washington, DC: World Bank Group.

Dillon, A, McGee, K. & Gbemisola, O. (2015). Agricultural production, dietary diversity and climate variability. *J Dev Stu.*, 51:976–995.

Ehui, S. & Pender, J. (2005). Resource degradation, low agricultural productivity and poverty in sub-Saharan Africa: Pathways out of the Spiral. *Agric. Econ.*, 32:225–242.

FAO (2014). The State of Food and Agriculture 2014: Innovation in Family Farming; FAO: Rome, Italy, 2014.

FAO (2018). Country factsheet on small family farms-Ethiopia 2018.

FAO (2021). World Food and Agriculture- Statistical Yearbook 2021.

Farrell, M.J. (1957). The Measurement of Productive Efficiency. *Journal of Royal Statistical Society, Series A*, 120: 253-290.

Feleke, S.T., Kilmer, R.L. & Gladwin, C.H. (2005). Determinants of food security in Southern Ethiopia at the household level. *Agric. Econ.*, 33:351–363.

Gebremeskel Berhane & Abidoye, B.O. (2020). Women empowerment in agriculture and child nutrition: Evidence from Ethiopia. AERC Working Paper GMBF-004. African Economic Consortium, Nairobi.

Gillespie, S., Poole, N., van den Bold, M., *et al.* (2019). Leveraging agriculture for nutrition in South Asia: What do we know and what have we learned? *Food Policy,* 82:3-12.

Glogowska, M. (2011) Paradigms, pragmatism and possibilities: Mixed-methods research in speech and language therapy. *International Journal of Language & Communication Disorders,* 46:251-260.

Guardabascio, B. & Ventura, M. (2014). Estimating the dose-response function through a generalized linear model approach. *The Stata Journal,* 14(1):141–158.

Gupta, S., Pingali, P.L. & Pinstrup-Andersen, P. (2017). Women's empowerment in Indian agriculture: does market orientation of farming systems matter? *Food Sec.* doi.org/10.1007/s12571-017-0737-4.

Haddad, L. (2000). A conceptual framework for assessing agriculture-nutrition linkages. *Food Nutr. Bull.,* 21:367–373.

Hawkes, C. & Ruel, M. (2006). The links between agriculture and health: An intersectoral opportunity to improve the health and livelihoods of the poor. *Bull. WHO,* 84:984–990.

Hazell, P., Poulton, C., Wiggins, S. & Dorward, A. (2010). The future of small farms: trajectories and policy priorities. *World Dev.;* 38:1349-1361.

Herforth, A. & Harris, J. (2014). Understanding and applying primary pathways and principles. Improving Nutrition through Agriculture Technical Brief 1. Arlington, VA: Strengthening Partnerships, Results, and Innovations in Nutrition Globally.

Herrador, Z., Perez-Formigo, J., Sordo, L., Gadisa, E., Moreno, J., Benito, A., Aseffa, A. & Custodio, E. (2015). Low Dietary Diversity and Intake of Animal Source Foods among School Aged Children in Libo Kemkem and Fogera Districts, Ethiopia. *PLOS ONE*, 10(7).

Herrero, M., Thornton, P.K., Notenbaert, A.M., Wood, S., et al. (2010). Smart investments in sustainable food production: Revisiting mixed crop-livestock systems. *Science*, 327(5967):822–825.

Hirano, K. & Imbens, G.W. (2004). The propensity score with continuous treatments. In: Applied Bayesian Modeling and Causal Inference from Incomplete-Data Perspectives, pp.73–84 (Gelman, A. & Meng, X.L., eds.). West Sussex, England: Wiley InterScience.

Hirvonen, K. & Hoddinott, J. (2014). Agricultural production and children's diets: evidence from rural Ethiopia. ESSP Working Paper no. 69. Washington, DC: IFPRI.

Hirvonen, K., Hoddinott, J., Minten, B. & Stifel, D. (2017). Children's Diets, Nutrition Knowledge and Access to Markets. *World Development,* 95:303–315.

Hirvonen, K., Taffesse, A.S. & Hassen, I.W. (2016). Seasonality and household diets in Ethiopia. *Public Health Nutr.,* 19:1723–1730.

Hoddinott, J. (2012). Agriculture, health and nutrition: Towards conceptualizing the linkages. In Reshaping Agriculture for Nutrition and Health; Fan, S., Pandya-Lorch, R., Eds.; IFPRI: Washington, DC, USA.

Hoddinott, J., Headey, D. & Dereje, M. (2014). Cows, Missing Milk Markets and Nutrition in Rural Ethiopia. International Food Policy Research Institute (IFPRI) and Ethiopian Development Research Institute (EDRI).

Holmes R., Jones N. & Wiggins W. (2008). Understanding the impact of food prices on children. Report of the Overseas Development Institute.

Ickowitz, A., Powell, B., Rowland, D. Jones, A. & Sunderland, T.C. (2019). Agricultural intensification, dietary diversity, and markets in the global food security narrative. *Glob. Food Secur.*, 20:9–16.

Jones, A.D. (2017). Critical review of the emerging research evidence on agricultural biodiversity, diet diversity, and nutritional status in low- and middle-income countries. *Nutrition Reviews,* 75(10):769–782.

Jones, A.D., Shrinivas, A. & Bezner-Kerr, R. (2014). Farm production diversity is associated with greater household dietary diversity in Malawi: Findings from nationally representative data. *Food Policy,* 46:1-12.

Justus, O., Knerr, B., Owuor, G. & Ouma, E. (2015). Agricultural commercialization and household food security: The case of smallholders in Great Lakes Region of Central Africa. In: Proceedings of the 2015 Conference of International Association of Agricultural Economists, pp.1–25. Milan, Italy.

Kalkuhl M., Kornher, L., Kozicka, M., Boulanger, P. & Torero, M. (2013). Conceptual framework on price volatility and its impact on food and nutrition security in the short term. Food Secure Working paper no.15.

Keleman, A., Hellin, J. & Flores, D. (2013). Diverse varieties and diverse markets: scale-related maize “profitability crossover” in the Central Mexican Highlands. *Hum Ecol Interdiscip J.,* 41:683–705.

Kirimi, L., Gitau, R. & Olunga, M. (2013). Household food security and commercialization among smallholder farmers in Kenya. In Proceedings of the Fourth International Conference of African Association of Agricultural Economists (AAAE), Hammamet, Tunisia, 22–25 September 2013. doi.org/10.22004/ag.econ.161445.

Kjeldsberg, C., Shrestha, N., Patel, M., Davis, D., Mundy, G. & Cunningham, K. (2018). Nutrition-sensitive agricultural interventions and gender dynamics: A qualitative study in Nepal. *Maternal and Child Nutrition,* 14(3):1-9.

Koppmair, S., Kassie, M. & Qaim, M. (2016). Farm production, market access and dietary diversity in Malawi. *Public Health Nutr.*, 20:325–335.

Kumbhakar, S.C. & Lovell, C.A.K. (2000). Stochastic Frontier Analysis. Cambridge University Press.

Kumbhakar, S.C., Wang, H. & Horncastle, A.P. (2015). A practitioner's guide to stochastic frontier analysis using Stata, Cambridge University Press.

Malapit, H.J., Kadiyala, S., Quisumbing, A.R., Cunningham, K. & Tyagi, P. (2015). Women’s empowerment mitigates the negative effects of low production diversity on maternal and child nutrition in Nepal. *The Journal of Development Studies*, 51(8):1097-1123.

Mason, N.M. & Smale, M. (2013). Impacts of subsidized hybrid seed on indicators of economic well-being among smallholder maize growers in Zambia. *Agric. Econ.,* 44:659-670.

Meerman J. & Aphane J. (2012). Impact of high food prices on nutrition. FAO Expert Consultation on Policy Responses to High and Volatile Food Prices. FAO.

Mofya-Mukuka, R. & Kuhlgatz, C. (2016). Impact of agricultural diversification and commercialization on child nutrition in Zambia: A dose response analysis. *Journal of Agricultural Science*, 8(4):60–75.

Muhanji, G., Roothaert, R.L., Webo, C. & Stanley, M. (2011). African indigenous vegetable enterprises & market access for small-scale farmers in East Africa. *Int J Agri Sust.*, 9:194-202.

Nguyen, B.H., Sickles, R.C. & Zelenyuk, V. (2021). Efficiency analysis with stochastic frontier models using popular statistical softwares.

Ogutu, S.O., Godecke, T. & Qaim, M. (2019). Agricultural commercialisation and nutrition in smallholder farm households. *Journal of Agricultural Economics,* 71:534–555.

Olwande, J., Smale, M., Mathenge, M.K., Place, F. & Mith€ofer, D. (2015). Agricultural marketing by smallholders in Kenya: A comparison of maize, kale and dairy. *Food Policy,* 52:22–32.

PDC (2020). Ten-year Perspective Economic and Development Plan (2020-2030). The FDRE Planning and Development Commission. Addis Ababa, Ethiopia.

Qureshi, M.E., Dixon, J. & Wood, M. (2015). Public policies for improving food and nutrition security at different scales. *Food Security,* 7(2):393–403.

Rahman, S. & Chima, C.D. (2016). Determinants of food crop diversity and profitability in Southeastern Nigeria: A multivariate Tobit approach. *Agriculture,* 6:14. doi.org/10.3390/agriculture6020014.

Ruel, M.T. (2003). Operationalizing dietary diversity: a review of measurement issues and research priorities. *Journal of Nutrition,* 133:3911S-3926S.

Ruel, M.T., Quisumbing, A.R. & Balagamwala, M. (2018). Nutrition-sensitive agriculture: What have we learned so far? *Global Food Security*, 17:128–153.

Savy M, Martin-Prevel Y, Sawadogo P, Kameli Y, Delpeuch F. (2005). Use of variety/diversity scores for diet quality measurement: relation with nutrition status of women in a rural area in Burkina Faso. Eur J Clin Nutr., 58:703–716.

Seng, K. (2016). The Effects of Market Participation on Farm Households' Food Security in Cambodia: An Endogenous Switching Approach. MPRA Paper No.69669, 19 Mar 2016.

Sibhatu, K.T., Krishna, V.V. & Qaim, M. (2015). Farm Production Diversity and Dietary Diversity in Developing Countries. *Proc. Natl. Acad. Sci. USA*, 112:10657–10662.

Sibhatu Kibrom & Qaim, M. (2018). Review: Meta-analysis of the association between production diversity, diets, and nutrition in smallholder farm households. *Food Policy*, 77:1–18.

Sickles, R. & Zelenyuk, V. (2019). Measurement of Productivity and Efficiency, Cambridge: Cambridge University Press.

Simons, L. & Lathlean, J. (2010). Mixed methods. In Gerrish, K. & Lacey, A. (Eds.) The Research Process in Nursing. 6th ed. London, Wiley-Blackwell.

Singh, L., Squire, L., Strauss, J. (1986). Agricultural household models. Baltimore: Johns Hopkins University Press.

Strauss J. (1983). Socioeconomic determinants of food consumption and production in rural Sierra Leone: Application of an agricultural household model with several commodities. MSU International Development Papers. Michigan State University, East Lansing, Michigan.

Torheim, L.E., Ouattara, F., Diarra, M.M., Thiam, F.D., Barikmo, I., Hatløy, A. & Oshaug, A. (2004). Nutrient adequacy and dietary diversity in rural Mali: Association and determinants. *Eur. J. Clin. Nutr.*, 58:594–604. doi:10.1038/sj.ejcn.1601853.

Tzouvelekas, E. (2000). Approximation properties and estimation of translog production function with panel data. *Agricultural economics review*,1(1):33-47.

Wang, H.J. & Schmidt, P. (2002). One-step and two-step estimation of the effects of exogenous variables on technical efficiency levels. *Journal of Productivity Analysis*, 18:129-144.

Webb, P. & Kennedy, E. (2014). Impacts of agriculture on nutrition: nature of the evidence and research gaps. *Food Nutr. Bull.*, 35:126–132.

Wenhold, F., Faber, M., Van Averbeke, W., Oelofse, A., van Jaarsveld, P., van RensburG, W.S.J., van Heerden, I. & Slabbert, R. (2007). Linking smallholder agriculture and water to household food security and nutrition. *Water SA*, *33:*327–336.

Wu, X., Mealli, F., Kioumourtzoglou, M., Dominici, F. & Braun, D. (2021). Matching on generalized propensity scores with continuous exposures. doi.org/10.48550/arXiv.1812.06575.

Yotopoulos, P. (1983). A microeconomic-demographic model of the agricultural household in the Philippines. FAO Economic and Social Development Paper, Rome, Italy.

Appendices

Appendix 1. A Control Function to test Endogeneity of Explanatory Variable

Table A1. Results of simultaneous equation for censored endogenous explanatory variable

	Reduced form (Tobit)	Structural form (Bivariate Tobit)							
		Observed response				Expected response			
		Without GRs		With GRs		With GRs		Without GRs	
Variables	**rcci**	**FCS_{PF}**	**FCS_{OF}**	**FCS_{PF}**	**FCS_{OF}**	**FCS_{PF}**	**FCS_{OF}**	**FCS_{PF}**	**FCS_{OF}**
rcci	-	3.44(3.38)	-7.96(3.69)**	3.88(5.72)	-13.93(6.3)**	3.88(5.72)	-13.93(6.3)**	2.73(5.6)	-11.23(6.2)*
grs	-	-	-	-0.47(6.04)	5.89(6.6)	3.41(3.4)	-8.04(3.7**	-	-
profcrop	0.01(0.004)*	-0.03(0.14)	-0.11(0.16)	-	-	-	-	-	-
proflvst	-.003(.001)***	-0.003(0.02)	0.02(0.02)	-	-	-	-	-	-
cdim	0.04(0.02)**	-1.69(0.8)**	2.97(0.89)***	-1.67(0.8)**	3.27(0.9)***	-1.67(0.8)**	3.23(3.68)***	-1.64(0.8)**	3.21(0.9)***
cdir	0.01(0.01)	-1.76(0.7)**	-1.32(0.76)*	-1.8(0.7)***	-1.35(0.75)*	-1.8(0.7)***	-1.35(0.75)*	-1.77(0.7)***	-1.42(0.8)*
ldi	-0.04(0.01)***	-0.07(0.44)	2.18(0.5)***	-0.04(0.5)	1.98(0.54)***	-0.04(0.5)	1.98(0.54)***	-0.042(0.5)	1.99(0.5)***
aghd	-0.01(0.01)	-0.53(0.6)	-1.11(0.64)*	-0.53(0.59)	-1.14(0.64)*	-0.53(0.6)	-1.14(0.64)*	-0.56(0.6)	-1.08(0.7)*
aghdsq	0.0001(.0001)	0.005(0.01)	0.013(0.01)*	0.004(0.01)	0.013(0.01)**	0.004(0.01)	0.013(0.01)**	0.005(0.01)	0.013(0.01)***
edhdy	0.004(0.01)	-0.45(0.3)	0.433(0.3)	-0.46(0.3)*	0.45(0.31)	-0.48(0.3)	0.45(0.31)	-0.47(0.3)*	0.47(0.31)
edmoy	-0.004(0.01)	0.18(0.36)	0.55(0.4)	0.19(0.36)	0.53(0.40)	0.19(0.36)	0.53(0.40)	0.19(0.36)	0.52(0.4)
dmalhd	-0.052(0.06)	2.08(2.9)	-1.22(3.2)	2.113(2.92)	-1.50(3.20)	2.11(2.92)	-1.50(3.20)	2.08(2.93)	-1.41(3.2)
hszn	-0.01(0.01)	0.17(0.45)	0.125(0.5)	0.18(0.45)	0.09(0.49)	0.18(0.45)	0.09(0.49)	0.18(0.45)	0.10(0.5)
owculha	0.03(0.03)	3.88(1.8)**	-1.24(1.97)	3.83(1.82)**	-1.14(1.99)	3.83(1.8)**	-1.14(1.99)	3.89(1.83)**	-1.28(2.01)
ldri	-0.064(0.11)	2.14(4.7)	-2.76(5.12)	2.16(4.7)	-3.16(5.13)	2.16(4.7)	-3.16(5.13)	2.14(4.7)	-3.10(5.2)
crac	-0.01(0.04)	1.15(1.74)	-0.99(1.9)	1.15(1.74)	-1.04(1.9)	1.15(1.74)	-1.04(1.90)	1.10(1.74)	-0.92(1.92)
ofia	-0.02(0.03)	3.18(1.8)*	-4.44(1.97)**	3.11(1.8)*	-4.73(1.94)**	3.11(1.77)*	-4.73(1.94)**	3.15(1.8)	-4.81(1.95)**
plm	0.14(0.07)**	7.41(2.8)***	3.35(3.02)	7.28(2.84)***	4.05(3.10)	7.28(2.84)***	4.05(3.10)	7.35(2.84)***	3.88(3.12)
mtd	-0.07(0.01)***	-1.1(0.73)	-2.86(0.8)***	-1.05(0.8)	-3.21(0.85)***	-1.05(0.8)	-3.21(0.85)***	-1.08(0.78)	-3.14(0.9)***
fgt	0.005(0.03)	0.76(1.7)	-0.41(1.84)	0.72(1.7)	-0.46(1.83)	0.72(1.7)	-0.46(1.83)	0.72(1.7)	-0.48(1.84)
extac	0.093(0.07)	0.25(2.85)	-4.83(3.11)	0.22(2.9)	-4.25(3.15)	0.22(2.9)	-4.25(3.15)	0.31(2.9)	-4.47(3.2)
irac	-0.064(0.05)	-1.52(2.46)	8.52(2.7)***	-1.44(2.45)	8.25(2.7)***	-1.44(2.45)	8.25(2.7)***	-1.48(2.5)	8.34(2.7)***
_cons	0.99(0.3)***	37.3(14.7)**	41.34(16.04)***	36.63(15.2)**	46.73(16.6)***	36.63(15.2)**	46.73(16.2)***	37.85(15.2)**	43.84(16.7)***
σ_1			12.62(0.53)***		12.62(0.53)***		12.62(.53)***		12.65(.53)***
σ_2			13.80(0.57)***		13.81(0.57)***		13.81(.57)***		13.92(.58)***
$\boldsymbol{\rho_{12}}$			**-0.725(0.12)*** **		**-0.724(0.12)*** **		**-0.724(.12)*** **		**-0.733(.12)*** **

*** p<0.01, ** p<0.05, * p<0.1; GRs (or grs)= generalized residuals

Appendix 2. GLM Regression and Covariate Balancing Tests

Table B1. GLM (Fractional logit) regression for estimating generalized propensity scores

Variables	GLM farm production diversification					
	CDSI	CDSS	LDSI	LDSS	ADSI	ADSS
Age of household head	0.003	-0.006	0.006	0.004	0.004	-0.001
Male headship	0.282**	-0.077	0.032	0.048	0.337**	0.156
Education level of head (years)	-0.008	0.009	0.009	0.006	-0.001	0.007
Household size (#)	0.028**	0.096***	0.033	0.025	0.043***	0.064***
Cultivated land (ha)	0.159***	-0.247***	0.324***	0.285***	0.266***	0.049
Farm income	0.0003	0.002***	-0.0003	-0.0004	-0.001	0.0002
Market travel distance (hr)	-0.138***	-0.039	-0.031	-0.018	-0.100***	-0.033
Presence of local market (dummy)	-0.089	0.326*	0.191	0.070	0.032	0.144
Road quality (dummy)	0.232***	0.394***	-0.043	-0.042	0.086	0.149**
Irrigation access	0.127	0.428***	-0.126	-0.129	0.012	0.126*
Credit access	-0.132**	-0.308***	-0.107	-0.063	-0.129**	-0.173***
Extension access	0.475***	0.548***	-0.058	-0.075	0.288**	0.267**
Off-farm income access	0.029	-0.081	0.113	0.158	0.043	0.018
Bure district (dummy)	-0.156	0.369**	-0.269	-0.299*	-0.179	0.022
Dangla district (dummy)	0.025	-0.330**	0.322*	0.263	0.229*	-0.002
Constant	-0.201	-1.444***	-0.394	-0.204	-0.607**	-0.987***
Observations	295	295	286	286	295	295
Log pseudo-likelihood	-123.655	-128.020	-125.707	-127.866	-126.270	-135.579

Source: Authors. *Note:* GLM = generalized linear model, CDSI = crop diversity Simpson index, LDSI = livestock diversity Simpson index, ADSI = agricultural diversity Simpson index, CDSS = crop diversity Simpson score, LDSS = livestock diversity Simpson score, and ADSS = agricultural diversity Simpson score. ***,** and * significant at 1, 5 and 10% level respectively.

Table B2. Covariate balancing tests for GPSM across three treatment groups of CDSI

Covariates	Before matching			After matching		
	TG1 (0,0.66]	TG2 [0.67,0.75]	TG3 [0.76,0.86]	TG1 (0, 0.66]	TG2 [0.67,0.75]	TG3 [0.76,0.86]
Household & farm characteristics:						
Age of household head	0.004	0.009	0.008	0.814	-1.709	0.563
Male headship	0.335	0.266	0.918*	-0.007	-0.004	0.001
Education level of head (years)	-0.015	0.007	0.061*	0.047	0.202	0.065
Household size (#)	0.051	0.051	-0.015	0.302	-0.175	-0.104
Cultivated land (ha)	0.217*	0.090	0.051	-0.029	-0.073	0.052
Farm income	0.001	-0.000	-0.001	4.836	-9.875	5.227
Market travel distance (hr)	-0.251***	-0.277***	-0.354***	0.048	-0.072	0.343**
Presence of local market (dummy)	-0.187	-0.334	-17.160**	-0.009	-0.044	0.066
Road quality (dummy)	0.389***	0.362**	0.453	0.021	-0.044	-0.037
Irrigation access	0.330*	0.239*	1.492***	0.040	-0.006	-0.063
Credit access	-0.267**	-0.007	-0.106	-0.014	0.040	0.010
Extension access	0.930**	0.853***	1.060***	0.006	-0.016	0.004
Off-farm income access	0.191	0.012	0.071	0.058	-0.061	0.010
Location dummies:						
Bure district	-0.047	-0.082	0.013	-0.013	-0.005	0.0003
Dangla district	0.231	-0.023	0.669	0.042	0.056	-0.020

Source: Authors. *Note:* TG=treatment group. The treatment groups (TG1-TG3) are of equal size, based on households' level of diversification in production of crop species; levels of this diversification are shown in brackets. Mean values of each TG are compared with mean values of all other TGs combined. ***,** and * significant at 1, 5 and 10% level respectively. The balancing property is satisfied at level 0.01.

Table B3. Covariate balancing tests for GPSM across three treatment groups of CDSS

Covariates	Before matching			After matching		
	TG1 (0, 0.30]	TG2 (0.31,0.46]	TG3 (0.47,0.81]	TG1 (0, 0.30]	TG2 (0.31,0.46]	TG3 (0.47,0.81]
Household & farm characteristics:						
Age of household head	-0.008	-0.013	0.001	-1.203	1.089	-0.090
Male headship	-0.075	-0.136	0.520	0.026	0.001	-0.009
Education level of head (years)	-0.005	0.025	0.125	0.210	-0.186	0.513
Household size (#)	0.166***	0.155***	0.116	-0.438	0.573**	0.024
Cultivated land (ha)	-0.500***	-0.240*	-0.449	0.054	-0.045	0.152
Farm income	0.003***	0.002	-0.002	10.686	-4.724	-7.216
Market travel distance (hr)	-0.251*	0.015	0.029	0.035	0.044	0.034
Presence of local market (dummy)	0.193	0.041	0.442	0.037	-0.067	0.020
Road quality (dummy)	0.521***	0.370*	-0.170	0.030	0.051	-0.029
Irrigation access	0.771***	0.252	1.286**	-0.075	0.058	-0.166**
Credit access	-0.470***	-0.334*	-0.133	0.004	-0.001	0.081
Extension access	1.326**	0.843*	0.149	0.018	-0.058	0.028
Off-farm income access	-0.233	-0.038	-0.060	0.005	-0.107*	0.068
Location dummies:						
Bure district	0.823**	0.049	-17.366**	0.075	-0.077	-0.002
Dangla district	-0.200	-0.850***	-18.879**	-0.091	0.115**	0.065

Source: Authors. *Note:* TG=treatment group. The treatment groups (TG1-TG3) are of equal size, based on households' level of diversification in production of crop groups; levels of this diversification are shown in brackets. Mean values of each TG are compared with mean values of all other TGs combined. ***,** and * significant at 1, 5 and 10% level respectively. The balancing property is satisfied at level 0.01.

Table B4. Covariate balancing tests for GPSM across three treatment groups of LDSI

Covariates	Before matching			After matching		
	TG1 (0, 0.64]	TG2 [0.65,0.75]	TG3 [0.76,0.87]	TG1 (0, 0.64]	TG2 [0.65,0.75]	TG3 [0.76,0.87]
Household & farm characteristics:						
Age of household head	0.010	0.012	-0.036	-1.079	0.940	-1.433
Male headship	-0.311	-0.289	-0.226	-0.048	0.055*	-0.015
Education level of head (years)	0.023	0.010	-0.034	0.199	0.189	-0.081
Household size (#)	0.021	0.056	0.243	0.049	0.079	-0.250
Cultivated land (ha)	0.532***	0.428***	-0.458	-0.030	0.074	-0.081
Farm income	0.001	0.002	0.012	-1.942	10.446	-10.235
Market travel distance (hr)	-0.067	0.008	0.219	0.043	0.045	-0.014
Presence of local market (dummy)	0.240	0.114	9.787**	-0.008	0.065	-0.074
Road quality (dummy)	-0.115	-0.254	-2.265	-0.068	-0.006	0.073
Irrigation access	-0.124	-0.236	-1.873	-0.080	0.060	-0.055
Credit access	-0.186	0.292	2.329	0.134**	0.021	-0.099
Extension access	-0.191	-0.032	1.325	0.022	0.003	-0.001
Off-farm income access	0.277	-0.050	-0.661	-0.015	-0.046	0.073
Location dummies:						
Bure district	-0.605**	-0.529	0.520	-0.103*	0.058	0.045
Dangla district	0.519	0.292	11.027**	0.106*	-0.067	0.024

Source: Authors. *Note:* TG=treatment group. The treatment groups (TG1-TG3) are of equal size, based on households' level of diversification in production of livestock species; levels of this diversification are shown in brackets. Mean values of each TG are compared with mean values of all other TGs combined. ***,** and * significant at 1, 5 and 10% level respectively. The balancing property is satisfied at level 0.01.

Table B5. Covariate balancing tests for GPSM across three treatment groups of LDSS

Covariates	Before matching			After matching		
	TG1 (0, 0.62]	TG2 [0.63,0.74]	TG3 [0.75,0.85]	TG1 [0, 0.62]	TG2 [0.63,0.74]	TG3 [0.75,0.85]
Household & farm characteristics:						
Age of household head	0.006	0.010	0.094*	-0.879	0.747	-2.034
Male headship	-0.184	-0.327	3.543*	-0.021	0.028	-0.018
Education level of head (years)	0.012	0.009	0.019	-0.101	0.373	-0.274
Household size (#)	0.010	0.054	0.176	0.005	0.005	-0.001
Cultivated land (ha)	0.406***	0.357**	-2.309	-0.065	0.078	-0.084
Farm income	-0.001	-0.000	0.015	-2.171	4.335	-15.808*
Market travel distance (hr)	-0.043	-0.011	-0.426	0.070	-0.038	0.096
Presence of local market (dummy)	0.146	0.047	1.357	-0.020	0.024	-0.005
Road quality (dummy)	-0.066	-0.161	-3.081*	-0.134**	0.029	0.062
Irrigation access	-0.127	-0.101	-5.872*	0.002	0.023	-0.141**
Credit access	-0.117	0.190	3.540*	0.102	0.067	-0.131*
Extension access	-0.397	-0.011	3.610*	0.018	-0.014	0.033
Off-farm income access	0.189	0.127	-3.997**	-0.033	0.025	-0.033
Location dummies:						
Bure district	-0.515	-0.352	3.320*	-0.145***	0.067	0.067
Dangla district	0.422	0.290	4.502	0.107*	-0.046	0.011

Source: Authors

Note: TG=treatment group. The treatment groups (TG1-TG3) are of equal size, based on households' level of diversification in production of livestock groups; levels of this diversification are shown in brackets. Mean values of each TG are compared with mean values of all other TGs combined. ***,** and * significant at 1, 5 and 10% level respectively. The balancing property is satisfied at level lower than 0.01.

Table B6. Covariate balancing tests for GPSM across three treatment groups of ADSI

Covariates	Before matching			After matching		
	TG1 [0.16,0.65]	TG2 [0.66,0.72]	TG3 [0.73,0.84]	TG1 [0.16,0.65]	TG2 [0.66,0.72]	TG3 [0.73,0.84]
Household & farm characteristics:						
Age of household head	0.017**	0.005	0.039	-0.091	0.636	-2.373*
Male headship	1.006	0.375	2.124**	-0.066**	0.016	0.004
Education level of head (years)	0.009	-0.008	-0.253*	-0.045	0.553	-0.458
Household size (#)	0.062*	0.022	0.631*	-0.078	-0.299	0.184
Cultivated land (ha)	0.362***	0.413***	-1.151	0.010	-0.032	-0.111
Farm income	0.001	0.001	-0.015	4.072	10.919	-16.321*
Market travel distance (hr)	-0.252***	-0.213***	-0.382	-0.206	-0.140	0.283
Presence of local market (dummy)	0.205	0.274	8.888**	0.036	0.073*	-0.094**
Road quality (dummy)	0.116	0.233	2.472*	0.032	-0.070	-0.0003
Irrigation access	-0.008	0.131	5.847*	-0.022	-0.021	-0.0001
Credit access	-0.311*	-0.123	0.632	-0.032	0.102*	-0.076
Extension access	0.600*	0.428*	-0.527	0.040	0.027	-0.069
Off-farm income access	0.088	-0.048	1.641*	0.044	0.040	-0.075
Location dummies:						
Bure district	-0.036	-0.374	4.355	0.033	-0.006	0.003
Dangla district	0.881***	0.327	7.225**	-0.047	-0.056	0.085

Source: Authors

Note: TG=treatment group. The treatment groups (TG1-TG3) are of equal size, based on households' level of diversification in species of agricultural produces; levels of this diversification are shown in brackets. Mean values of each TG are compared with mean values of all other TGs combined. ***,** and * significant at 1, 5 and 10% level respectively. The balancing property is satisfied at level 0.01.

Table B7. Covariate balancing tests for GPSM across three treatment groups of ADSS

Covariates	Before matching			After matching		
	TG1 [0.09,0.44]	TG2 [0.45,0.55]	TG3 [0.56,0.78]	TG1 [0.09,0.44]	TG2 [0.45,0.55]	TG3 [0.56,0.78]
Household & farm characteristics:						
Age of household head	0.001	-0.004	0.014	-0.341	-0.238	0.626
Male headship	0.611	-0.176	0.030	-0.026	-0.030	0.045
Education level of head (years)	-0.001	0.030	0.128	-0.490	0.501	-0.114
Household size (#)	0.089**	0.085**	0.097	-0.225	-0.154	0.197
Cultivated land (ha)	0.015	-0.040	-0.204	-0.052	-0.147*	0.163*
Farm income	0.001	0.001	-0.001	-1.249	6.378	-11.924
Market travel distance (hr)	-0.111*	-0.035	0.127	-0.198	0.045	0.149
Presence of local market (dummy)	0.063	0.193	0.590	0.025	0.034	-0.085*
Road quality (dummy)	0.171	0.173	0.517	-0.011	-0.007	-0.037
Irrigation access	0.217	0.156	0.475	-0.013	0.080	-0.088
Credit access	-0.303**	-0.303**	-0.156	0.001	-0.013	0.076
Extension access	0.592***	0.338	0.748	0.043	-0.061	-0.015
Off-farm income access	0.020	0.078	0.155	0.025	-0.048	-0.018
Location dummies:						
Bure district	0.306	-0.017	-15.636**	0.032	0.015	-0.046
Dangla district	0.254	-0.189	-15.925**	-0.033	-0.078	0.130**

Source: Authors. *Note:* TG=treatment group. The treatment groups (TG1-TG3) are of equal size, based on households' level of diversification in groups of agricultural produces; levels of this diversification are shown in brackets. Mean values of each TG are compared with mean values of all other TGs combined. ***,** and * significant at 1, 5 and 10% level respectively. The balancing property is satisfied at level 0.01.