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Access to Physical Infrastructure and Rural Livelihoods: Evidence from Ethiopia

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Bahir Dar University
College of Business and Economics
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**Access to Physical Infrastructure and Rural Livelihoods: Evidence from
Ethiopia**

By
Getaye Gizaw

February, 2026
Bahir Dar, Ethiopia

Bahir Dar University
College of Business and Economics
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**Access to Physical Infrastructure and Rural Livelihoods: Evidence from
Ethiopia**

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A Dissertation Submitted in Partial Fulfillment of the Requirements for the
Degree of Doctor of Philosophy in Economics

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February, 2026

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Declaration

I declare that the dissertation titled “Access to Physical Infrastructure and Rural Livelihoods: Evidence from Ethiopia”, submitted to the Department of Economics, College of Business and Economics, Bahir Dar University, in partial fulfillment of the requirements for the degree of Doctor of Philosophy in Economics, is a record of original work carried out by me and has never been submitted to this or any other institution to get any other degree or certificates. The assistance and help I received during the course of this investigation have been duly acknowledged.

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Acronyms

ADLI	Agricultural Development Led Industrialization
AHM	Agricultural household model
CFA	Control Function Approach
CRE	Correlated Random Effect
CSA	Central Statistics Agency of Ethiopia
DID	Difference-in-Difference
EA	Enumeration Areas
EELPA	Ethiopian Electric Light and Power Authority
ERA	Ethiopian Roads Authority
ESS	Ethiopian Socioeconomic Survey
ETB	Ethiopian Birr
EPRDF	Ethiopian people's revolutionary democratic front
GDP	Gross Domestic Product
GTP	Growth and Transformation Plan
LSMS-ISA	Living Standards Measurement Study-Integrated Surveys on Agriculture
MAER-Net	Meta-Analysis of Economics Research-Network
MRA	Meta Regression Analysis
NEP	National Electrification Program
PRISMA	Preferred reporting items for systematic reviews and meta-analyses
SDGs	Sustainable Development Goals
SHCI	Smallholder Crop Output Commercialization Index
SLF	Sustainable Livelihoods Framework
SSA	Sub-Saharan Africa
TCT	Transaction cost theory
TLU	Tropical Livestock Unit
UEAP	Universal Electrification Access Program
URRAP	Universal Rural Road Access Program

Dedicated to my Family

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- Gizaw, G., Demissie, W.M. & Dilie, S. M. Access to Rural Road Transport and Smallholder Commercialization in Ethiopia: Evidence from the Ethiopian Socioeconomic Survey. Under review at poverty and public policy journal.

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1. General Introduction and Summary of the Dissertation

1.1. Introduction

Infrastructure services and facilities are closely related to rural development (Baah-Dwomoh, 2016). Rural and agricultural development depend on the presence of physical and other infrastructure facilities (Pinstrup-Andersen et al., 2008). Where there is a lack of services in the areas of rural road transportation, electricity, small scale irrigation, education, health, and training, it is impossible to achieve rapid and sustained agricultural and overall rural development. There are general acceptance that economic and social expansion needs infrastructure investment including the delivery of megaprojects to enable physical mobility, deliver water supply, deliver energy to homes and businesses, accommodate social services, facilitate sewage disposal and processing, and house people in healthy conditions (Sturup et al., 2019).

The beginning of constructing public infrastructures traced back to the Roman Empire about two thousand years ago (Nagesso et al., 2019). Infrastructure is now the foundation of wealth and economic confidence around the world. For rural residents to experience sustained and quick social, economic, and political development, access to infrastructure is frequently cited as a critical aspect (Mensah et al., 2014). Infrastructure is decisive means for agriculture, Agro-industries and general socio-economic and political development. Rural infrastructure can be defined as the essential physical and organizational services and facilities (such as roads, power supplies, irrigation network, communication and information facilities, extension services, warehouses, storage facilities) required for a rural community to function (Memon et al., 2020).

Physical infrastructure helps to increase the connectivity of rural areas with rural roads, better integrating farmers with markets and increasing their productive capacity by improving their access to irrigation and high-quality extension advice (Dillon et al., 2011). Moreover, physical infrastructure affects agricultural output and productivity through the creation of institutions such as domestic markets and financial institutions which make it easier for rural residents to access input and output markets as well as liquidity and credit, respectively (Llanto, 2012). Investment in physical infrastructure is essential to stimulate the rural non-farm economy and vitalize rural towns, as well as to facilitate the integration of less-favored rural areas into national and international economy's (Pinstrup-Andersen et al., 2008).

There are major differences in access to physical infrastructure across different communities and socio-economic groups and between men and women, including differences in terms of their needs and priorities in relation to the type and location of infrastructure (Canning et al., 2008). Sectoral studies focusing on the rural infrastructure by the World Bank, revealed that infrastructure benefit is higher in less-developed communities than in more-developed ones because increased access to market and banking services, increased communication, and a reduced cost of doing business are usually more evident in less-developed communities. Increased access to mobile communication and increased rural road networks increase people's interaction among and within community especially hill and mountain communities than for plains due to their highly-dispersed settlement (Choe et al., 2015).

The provision of basic physical infrastructure is a pre-requisite for enabling African countries to stimulate economic growth and to reach the targets for economic recovery and poverty alleviation through increasing and diversifying agricultural output and employment, promoting domestic market activity and market integration, and facilitating and developing access to export markets (Monitor, 2012). Like most of the poorer economies in Africa, the bulk of the Ethiopian population lives in rural areas, relying on subsistence agriculture. The primary source of income for over 77.3 % of Ethiopia's rural residents is agriculture (Tilahun et al., 2019). The rural areas of Ethiopia are characterized by limited access to physical infrastructure such as roads, electricity, water supply, and communication networks, despite rural infrastructure development being at the center of Ethiopia's economic strategy (Hausmann et al., 2023; Moneke, 2020).

Limited access to physical infrastructure directly affects the livelihoods of rural communities. Poor road networks, limited electrification, and inadequate irrigation systems hinder agricultural productivity, market participation, nonfarm enterprise participation, and overall livelihood improvement. Due to this, rural households remain highly vulnerable to poverty, food insecurity, and income shocks. Furthermore, even though Ethiopia has made progress in expanding infrastructure coverage since 2000, rural communities still struggle with long-standing livelihood challenges stemming from limited access to physical infrastructure, which limits their capacity to support infrastructure for sustainable livelihoods (Desalegn et al., 2022; Shiferaw, 2017).

Several studies have examined the impact of access to physical infrastructure on rural development outcomes, from several countries, spanning from Africa to Asia and Latin America (Bhattacharyay et al., 2012; Calderón et al., 2010; Chakamera et al., 2018; Gachassin et al.,

2010; Khandker, Bakht, et al., 2009; Kodongo et al., 2016; Pinstup-Andersen et al., 2008). But evidence from developing countries is limited and refers almost exclusively to Asian countries. Studies conducted in different contexts has shown that improved access to roads, electricity, irrigation facilities, and communication networks positively influences agricultural productivity, income diversifications, poverty reduction, food security, employment opportunities, and access to education and healthcare services. However, there is a limited understanding of these dynamics specifically within the Sub-Saharan African context.

The findings of few quantitative studies in African countries (Lenz et al., 2017; Mabiso et al., 2019; Mogues, 2011; Pauw et al., 2014; Peter, 2011) are not consistent and remains an open question. For instance, using firm-level data from Benin, Peters et al. (2011) found that electrification has a significant effect on firm creation. However, Lenz et al. (2017) did not find a change in the income-generating activity of households following electrification in Rwanda. Moreover, a recent study by Pelz et al. (2023) in Ethiopia and Nigeria indicated that rural electrification did not have an impact on non-farm enterprise and employment outcomes for 2-4 years of connection. In addition, Hassan et al. (2022) shows that households' operation of business enterprises increased by 5% among households with connection to electricity, but the effect is insignificant in the short run.

There is little research on the developmental impact of access to physical infrastructure on the livelihoods of rural households, despite the fact that a substantial number of Ethiopians live and work in underdeveloped rural areas. Researchers (Amsalu, 2014; Aragaw, 2012; Assefa et al., 2013; Demenge et al., 2015; Gafarso et al., 2019; Kedanemariam et al., 2013; Lebeta, 2017; Nagesso et al., 2018; Shiferaw et al., 2015; Terefe, 2012; Tucker et al., 2013; Wassie et al., 2021; Wondemu et al., 2012) studied the role and impact of access to a given specific physical infrastructures in improving the life of rural people in socio-economic and political aspects.

A number of studies revealed inconsistent results on the impact of access to small-scale irrigation on rural livelihood outcomes in various parts of Ethiopia. While (Asayehegn, 2012b; Bacha et al., 2011; Belete et al., 2020; Dawit et al., 2020; Gebregziabher et al., 2012; Hagos et al., 2009; Jambo et al., 2021; Jatana et al., 2024; Maru et al., 2023; Mume, 2021; Mume et al., 2023; Solomon et al., 2015; Tesfaye et al., 2008) finds a positive impact of access to small-scale irrigation on rural livelihood outcomes in Ethiopia, others (Annys et al., 2019; Asayehegn, 2012a; Belete et al., 2020; Fitsum Hagos et al., 2017; Kassie, 2020; Peden et al., 2009; Pender et

al., 2008) shows insignificant and negative impact. Researchers and policymakers face difficulty in generalizing the inconsistent and inconclusive results from various studies (Ayana et al., 2022). However, meta-analysis can address this issue by combining and providing an objective summary of findings from multiple primary studies (Stanley et al., 2012). Consequently, this study aims to fill these gaps in knowledge by examining the impact of access to small-scale irrigation on rural livelihood outcomes in Ethiopia.

Though agricultural marketing and rural nonfarm enterprise activities, especially, in rural communities are considered as an income smoothing opportunities, the existing studies (Anega et al., 2023; Eneyew et al., 2014; Nakamura et al., 2020; Terefe, 2012; Wassie et al., 2021) are biased towards outcome variables such as agricultural productivity, income, and poverty alleviation among farm households. That is, the impact of access to physical infrastructure on crop output market participation and participation in non-farm enterprise activities have rarely been studied and insufficient to draw solid conclusions. Furthermore, the existing empirical studies (Nagesso et al., 2018; Tadesse, 2020; Tamene et al., 2017; Tesfay, 2021; Wondimagegnhu et al., 2020) are not only few but also have tended to be cross-sectional studies, which did not show the dynamics impact of physical infrastructure on rural communities.

In spite of the growing importance of small-scale irrigation, rural road, and grid electrification infrastructures in rural development, with some exceptions (Hassan et al., 2022; Mekonnen et al., 2017), no research has been carried out on the impact of access to these infrastructures in Ethiopia. For instance, in their scholarly work, Mekonnen et al. (2017) estimated the effects of access to rural road transport on smallholder commercialization using the first panel of the Ethiopian Socioeconomic Survey. Despite the merit of their work, their analysis does not fully capture the evolving dynamics of smallholder commercialization. In addition, their study assumed identical determinants for both the decision to participate in the crop output market and the level of market participation, limiting its ability to identify stage-specific barriers. Furthermore, the impact of climate change and natural shocks, which are increasingly shaping smallholder farmers decisions, was not taken into account in their study. Their study essentially ignored spatial heterogeneity, assuming uniform effects of road access across Ethiopia, which limit the generalizability of the findings at the national level. So, there is divergence between these previous studies and the current study in terms of methodology employed and theoretical lens used to investigate the topic under investigation.

Likewise, Hassan et al. (2022) studied the effect of access to grid electrification on non-farm enterprises in Ethiopia. However, they used single-wave cross-sectional data or short panels, which makes it difficult to capture dynamic effects. The finding of their study indicates that access to grid electrification has no influence on rural non-farm enterprises. This is because, the full effect of electrification may not have been reached by then and households do not have the liquidity to pay for connection fees, and broader knock-on effects unfold over time. This study addresses these gaps by using both Panel I and Panel II of the Ethiopian Socioeconomic Survey to track long-term effects and mitigate attrition bias.

Generally, there is often insufficient localized and aggregated evidence for policy decisions. For instance, little is known about its actual effects on rural nonfarm business enterprise activities or employment at the household level, although electrification is widely promoted under national development plans. In a similar manner, although road development is prioritized, it is still unclear whether it translates into meaningful market access and commercialization for smallholder farmers. Additionally, irrigation studies also vary in scope and quality, making it difficult to draw generalizable conclusions. This fragmented and inconsistent evidence creates a critical knowledge gap and weakens efforts to design targeted and cost-effective rural development interventions. It is unclear at this time how rural residents' lives are affected by access to basic physical infrastructures in Ethiopia. Failing to adapt to changes, particularly infrastructural development, has an impact on how well-off a community is.

This dissertation focuses on small-scale irrigation, rural road transport, and grid electrification as core dimensions of rural physical infrastructure because they represent the three major channels through which infrastructure affects rural livelihoods in agrarian economies. Small-scale irrigation relaxes natural production constraints by reducing rainfall dependence and improving agricultural productivity. Rural road transport reduces transaction costs, enhances market access, and facilitates commercialization. Grid electrification enables livelihood diversification through non-farm enterprise development and productivity-enhancing activities.

These infrastructures jointly capture the production, market access, and diversification pathways emphasized in infrastructure-led development theory and the sustainable livelihoods framework. Empirically, these three infrastructures are also among the most consistently measured and policy-prioritized infrastructure variables in the Ethiopian Socioeconomic Survey (ESS), allowing for rigorous and comparable analysis across studies. Other infrastructure types such as

water supply, telecommunications, and health facilities are acknowledged as important; however, they are excluded due to data limitations, and the need to maintain analytical focus on infrastructure types with direct and measurable effects on agricultural production, market participation, and livelihood diversification.

This dissertation comprises three self-contained papers to address the aforementioned research gaps. The first paper emphasizes meta-analysis of access to small-scale irrigation and rural livelihood outcomes in Ethiopia. The second paper examines the effect of access to rural road transport on smallholder commercialization in Ethiopia. The third paper investigates the effect of access to grid electrification on rural non-farm enterprise participation in Ethiopia.

1.2. Theoretical Framework Underpinning the Study

This section presents a theoretical framework that underpins the study while providing analysis of the theoretical basis which contextualized the study. It deals about the theoretical framework supported by different authors regarding access to physical infrastructure and rural livelihood linkage.

This study adopted a theory of infrastructure-led development together with sustainable livelihood framework under sustainable livelihood approach established by Agénor et al. (2006) to explore the impact of access to physical infrastructure on rural livelihoods in Ethiopia. According to the sustainable livelihood framework, households build livelihood strategies using multiple capital assets, including human, natural, physical, social, and financial. Infrastructure, such as roads, irrigation, and electricity is regarded as a key physical capital that alters access to markets, inputs, and services, which in turn reshapes livelihood strategies. Infrastructure-led development theory enhances this micro perspective by emphasizing the supply side and spatial dynamics, how investments in connectivity and energy reduce transaction costs, encourage agglomeration, and change local economic structure.

The sustainable livelihood framework inspired the choice of outcome indicators and control variables (household assets, human capital, shocks, social capital), while infrastructure theory guided identification strategies and heterogeneity tests (distance measures, community vs. household access, and interaction terms to capture complementarities). This dual framing enables interpretation both at the household livelihood level and at the system level, where local markets and opportunities are shaped by infrastructure.

According to Agénor (2010), the theoretical foundation claims that a lack of quality infrastructure development has seen several low-income countries, including Sub-Saharan Africa, struggling to achieve acceptable economic and social progress in a sustainable manner. In his analysis, Agénor argues that the impact of poor-quality infrastructure development has most notably revealed socio-economic issues that continue to force people to live below the poverty lines.

The theory, therefore, postulates that sustainable livelihoods depend directly on the availability of adequate and quality social and economic infrastructure, namely roads, electricity, telecommunication, sewage, water and sanitation, education and health care services. Thus, the theory advocates that access to electricity facilitating mechanization, lowering input costs, expanding business hours, and allowing the use of modern technologies. Access to all weather road enable accessibility of various areas and reducing transportation costs, resulting in business investment and tourism. Furthermore, access to water directly increases productivity which in turn, improves the living conditions of the people. Srinivasu et al. (2013) agree with Agénor (2010) by emphasizing that poor quality or lack of infrastructure, in terms of roads, water, sanitation, electricity and health services, is the key obstacle to growth and development for any country or province. In the same vein, Olaseni et al. (2012) affirm that sustainable livelihood is unlikely to occur in a country without infrastructural facilities and services, as commodities will be available at a very high price and cost.

In line with the above assertion, there is a precise link with the main objective of this study. For example, it has been subsequently suggested that for people to access water, electricity, and all weather roads amongst other things, it requires the use and development of quality infrastructure projects. Chotia et al. (2017) assert that infrastructure development expands the accessibility of productive opportunities for the poor which, as a result, increases the values of their assets. Equally, Nagesso et al. (2018) confirm that improved rural infrastructure stimulates the expansion of markets, improves food security, social and female participation and job opportunities.

Based on a wider body of literature on the significance of rural infrastructure development, it is evident that the theoretical claims presented are appropriate, thereby justifying the selection of theory for this study. The theory has met the general acceptance that investment in physical infrastructural facilities results in the ability of rural households expanding their means of

survival. Therefore, it improves the rural livelihoods. Scholars including (Aziz, 2015; Buthelezi, 2021; Fizza, 2014; Kari et al., 2019; Mustapha et al., 1999; Tamene et al., 2017) have examined the impact of infrastructure development for the development of rural communities at the lens of the theory. Their findings confirm that sustainable development is attainable through the development of quality infrastructure which becomes a powerful tool for poverty reduction, while poor infrastructural project selection, dismal financial control and poor project implementations are amongst the major setbacks for infrastructure development.

This dissertation adopts an integrated theoretical framework combining infrastructure-led development theory and the sustainable livelihoods framework. Infrastructure is conceptualized as a form of physical capital that relaxes key constraints faced by rural households and enables livelihood transformation. While each paper focuses on a specific type of infrastructure and outcome variable, they collectively examine complementary transmission mechanisms through which infrastructure affects rural livelihoods. Small-scale irrigation primarily operates through agricultural productivity and risk reduction channels, rural road transport facilitates market participation and commercialization by lowering transaction costs, and grid electrification promotes livelihood diversification through non-farm enterprise development. Together, these mechanisms reflect different but interconnected pathways leading to improved rural livelihood outcomes.

1.3. The Link Between Physical Infrastructure and Rural Livelihoods

Based on the existing literature, **Figure 1.1** presents a dialectic model of access to physical infrastructure and rural livelihood diversification. It describes the causal relationship between physical infrastructure and rural livelihoods. The arrow of the lines shows the direction of the flow of impact. It is obvious that the increasing access to physical infrastructure services, such as rural road transportation, grid electrification, and small-scale irrigation, directly benefits individuals and households, communities, and companies. It benefits individuals and households by improving farm and non-farm productivity, which further help to reduce private costs, save time, and employment generation of an individual, which ultimately raises the level of income and consumption (Gachassin et al., 2010; Khandker, Barnes, et al., 2009). Such effects clearly lead to an improved level of rural welfare.

Similarly, communities can benefit through expanded market opportunities, reduced cost of production, and increased production of goods and services, increasing land and labor

productivity, market integration and expansion, increased interactions with group members and also social inclusion through increased social mobility (Bhattacharyay et al., 2012; Mu et al., 2011). For instance, Kirubi et al. (2009) showed the significant contribution of community-based electric microgrids on rural development through community development in Kenya. While individuals' and communities' wellbeing rise, they create further demands for infrastructure services. Similarly, infrastructural development also helps to increase the quality and quantity of infrastructure services through increased investment in infrastructure development (Bhattacharyay et al., 2012).

Moreover, the conceptual framework for this study hypothesizes that access to physical infrastructure, specifically small-scale irrigation, rural road transport, and grid electricity, has significant and interrelated effects on rural livelihoods. Access to small-scale irrigation enhances natural assets (water access) and increases financial assets (crop sales), which leads to income stability and agricultural productivity, which in turn increases crop diversification and improves food security or resilience. Rural road access boosts physical assets (market access) and financial assets (commercialization), reduces transport costs, strengthen market integration, and increases crop sales and income. Grid electrification increase energy access, strengthens human assets (technology adoption), and increases financial assets (non-farm enterprises), which leads to income diversification.

Even though each physical infrastructure addresses distinct bottlenecks (irrigation: farm-level, rural road: market-level, and electrification: enterprise-level), all lead to enhanced rural livelihoods. In addition, household characteristics, contextual factors, and institutional support mediated the impacts. When physical infrastructures are combined with household-level characteristics and institutional factors such as education, gender, household size, credit access, and extension services, the impact on rural livelihoods is stronger. The inclusion of household demographic and institutional variables is guided by the Sustainable Livelihood Framework, which emphasizes that livelihood outcomes depend not only on access to physical infrastructure but also on households' access to human, financial, and institutional capital. Variables such as age, gender, education, and household size represent human capital that influences labor availability, skills, and decision-making capacity. Credit access reflects financial capital that enables households to invest in productive activities and respond to new opportunities created by infrastructure access. Extension services represent institutional and social capital that facilitates

information dissemination, technology adoption, and market integration. These factors are therefore included as moderating variables that condition the extent to which infrastructure access translates into improved livelihood outcomes.

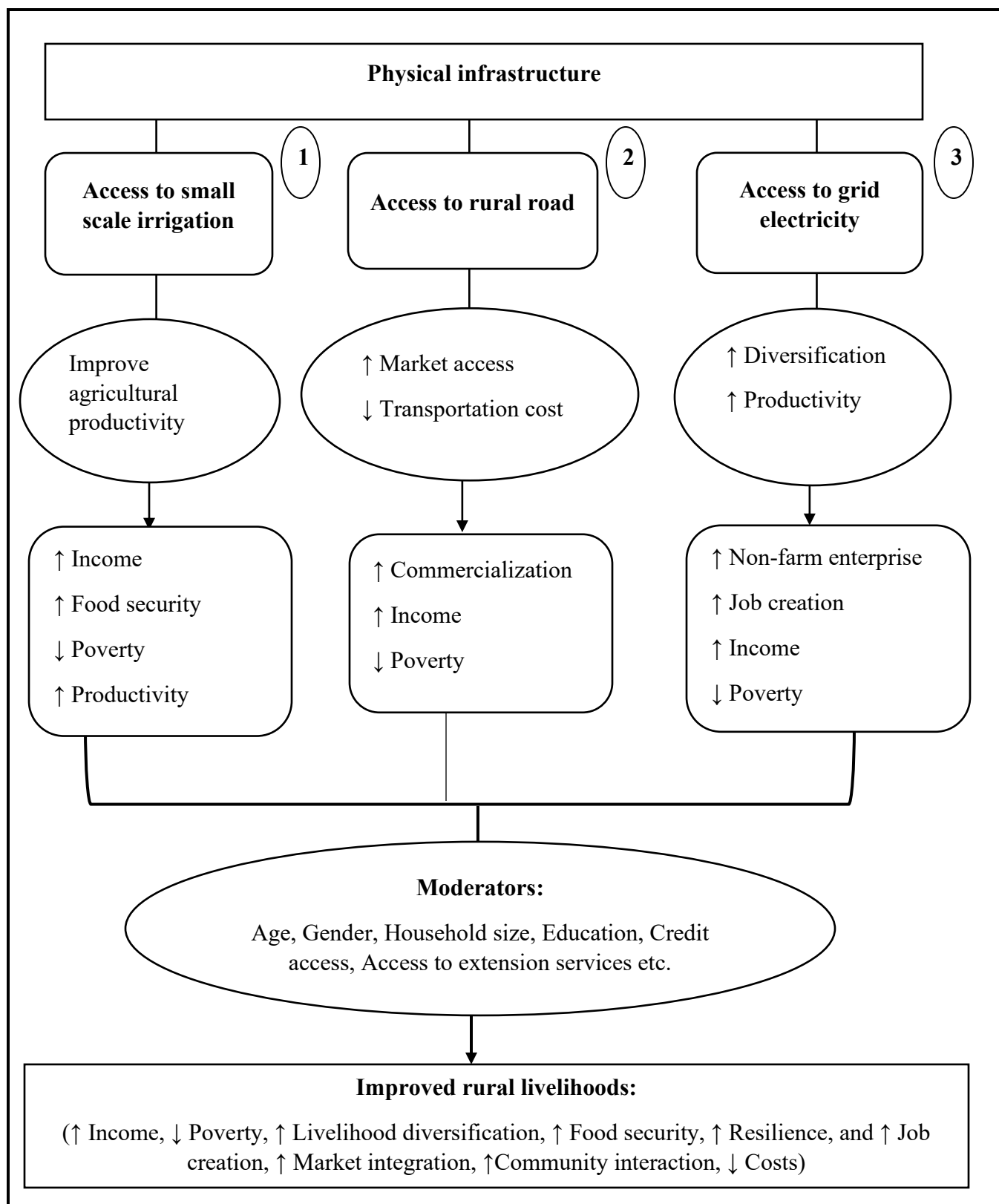


Figure 1.1: Conceptual framework for the study

Source: Own design from literature, 2025

1.4. Scope and Delimitation of the Study

The scope of this study is limited to examining how access to physical infrastructure, specifically small-scale irrigation, rural road access, and grid electrification, affects rural livelihoods in Ethiopia. This study focuses on fundamental livelihood dimensions like crop-output market participation, non-farm enterprise activities, income, consumption expenditure, agricultural productivity, poverty, and food security. Due to data limitations and scope constraints, this study is restricted to three physical infrastructures and does not address other forms of infrastructure (like, ICT or other facilities). It also examines the influence of such physical infrastructures on selected economic livelihood outcomes but not broader social or environmental aspects.

This empirical study is based on available literature between 2005 and 2024 and nationally representative data compiled from Ethiopian socio-economic survey (ESS 2011, ESS 2013, ESS 2015, ESS 2018, and ESPS 2021) rounds. As a result, it captures infrastructure livelihood dynamics during a decade of significant rural transformation in Ethiopia. However, the findings are particularly applicable to rural areas and not intended to represent urban contexts, as the livelihood structures and infrastructure effects in urban areas differ substantially. The analysis is conducted through three empirical papers, each using three distinct methodologies to address a specific objective.

1.5. Methodological Approaches and Data Sources

1.5.1. Research design

This study employs a mixed-methods quantitative approach integrating a meta-regression analysis (MRA) and panel data econometric techniques to examine three structured empirical components within the positivist paradigm. The positivist paradigm focuses on empirical and objective measurements, aiming to explain phenomena through a cause-and-effect relationship. Therefore, the research design is observational, quasi-experimental, and explanatory, employing both cross-study synthesis (meta-analysis) and household-level longitudinal data analysis to draw robust conclusions on causal relationships.

1.5.2. The data

For the first paper, secondary data derived from peer reviewed published journal articles, and literature were used. Reported effect sizes (like coefficients, means, or impact estimates) and associated standard errors or standard deviations were extracted from each selected study. Data

was extracted based on study identification (last name(s) and initials of all authors, year of publication, and title of the article); study characteristics (study design, sample size, and study location); household characteristics (household size, age, and education level); livelihood outcomes (income, food security, poverty, consumption expenditure, and agricultural productivity, etc.), and relevant statistical reports of the studies.

For the second and third papers, the data is compiled from the Ethiopian Socioeconomic Survey (ESS), run by Central Statistics Agency of Ethiopia (CSA) and the World Bank Living Standards Measurement Study-Integrated Surveys on Agriculture (LSMS-ISA) team. The survey is said to be broadly representative of rural households engaged in sedentary agriculture. The scope of the survey includes individual, household, and community-level characteristics. Moreover, the ESS collects information on household agricultural activities along with other information on the households, like human capital, other economic activities, and access to services and resources. The household survey gathers quantitative data on various variables reflecting both household and villages-level characteristics. This includes the average land holdings size, number of oxen owned, input usage per hectare, household head average age and years of schooling, household size, altitude above sea level, average temperature, and village distance to the nearest town, among others.

The dataset remains unbalanced, with most households contributing data for all rounds but some contributing only partially. The absence of some households in some rounds could be due to migration, or inconsistencies in data collection and conflict in northern Ethiopia (non-random attrition). Finally, following the exclusion of missing data and outliers, we have managed to have unbalanced panel data for 1,967 rural households for the second paper and 3,415 rural households for the third paper.

1.5.3. Method of data analysis and presentation

Different empirical models were used to estimate the specific research objectives. This study used meta-regression analysis to quantitatively synthesize results from multiple studies to estimate the average impact of access to small-scale irrigation on rural livelihood outcomes, identify sources of heterogeneity, and filter out publication bias. To assess the effect of access to rural road transport on smallholder commercialization in Ethiopia, this study adopted the double hurdle econometric approach. This model is selected because it helps to identify factors influencing market participation and level of commercialization at the same time and to model the two decisions

sequentially. To examine the causal effect of access to grid electricity on non-farm enterprise participation, this study used correlated random effect (CRE) probit model. This model is appropriate because the dependent variable is binary, and panel is unbalanced with many households observed in only one or two rounds of the survey. Furthermore, the model is used to account for unobserved heterogeneity that is correlated with explanatory variables in binary outcome models (participation in nonfarm enterprise activities), allow estimation of both within and between-effects, and controlling for time-invariant heterogeneity.

The study employed two statistical approaches for data analysis. First, descriptive statistics and inferential statistics were applied to describe the variables used for analysis. The second analysis approach involved econometric analysis to assess the impact of access to physical infrastructure on livelihoods. The study used MS-Excel and STATA versions 17 for data analysis purposes. The data analysis of the study is presented by using tables and figures. Basic post estimation tests were conducted for the robustness check and no significant estimation issues were found during the econometric analysis of each study.

Heterogeneity diagnosis test was used to assess heterogeneity of the studies and identify the outliers in the first paper. There were substantial between-study heterogeneity and meta-regression was used to explore the relationship between the effect sizes and study-level covariates of interest. In the second paper, to check for the influence of time-varying factors on the outcome and selection equations, we used correlated random effect approached by adding the averaged values of time-varying variables. In addition, the issue of endogeneity due to potential correlation with unobserved time-varying heterogeneity was addressed using the control function approach with a dummy variable distance to asphalt road as an instrumental variable (IV). To strengthen the analysis and interpretation, we run a fixed-effect linear probability model for comparison and as a robustness check for the third paper.

1.6. Executive summary

This section gives a summary of the three papers with their respective objectives and main findings.

The first paper discusses that irrigation increases production and income, but without access to rural road transport and markets, farmers cannot supply their production surplus. Thus, roads become the second basic infrastructure after irrigation to translate production gains into market gains. Therefore, the second paper assesses the role of access to rural road transport in enabling

smallholder commercialization. Access to rural road enables market participation, but to move from agriculture into non-farm enterprises and value addition, households need access to electricity. Therefore, rural electrification along with rural road access enables diversification and rural transformation. Sustainable livelihood diversification beyond agriculture requires energy access. Hence, the third paper examines how access to grid electrification facilitates rural non-farm enterprise activities. Thus, the three physical infrastructures act in a sequenced and complementary manner.

Agriculture in developing countries, relies heavily on rainfall, making the sector vulnerable to the unpredictable nature. Therefore, diversifying the income sources of rural dwellers through promoting non-farm enterprises (NFEs) can be one technique to escape the adverse shocks of farming activity and reduce rural poverty and unemployment as well as realize the sustainable development goals (SDGs). In Ethiopia, agriculture is the primary economic sector, contributing nearly 32.7% of the GDP, generating 81.5% of the foreign exchange earnings, and providing employment for around 63.66% of the labor force. The production output from rain-fed agriculture has varied greatly across regions in Ethiopia due to rainfall variability. The agricultural sector is mostly featured by smallholder farming, with limited commercialization and market integration. This low degree of commercialization is the main obstacle to agricultural transformation, rural income growth, and poverty alleviation.

The use of small-scale irrigation could reduce risks and shocks by providing a more dependable source of water for crop production all year round. This can lead to higher crop yields and increased agricultural productivity, which would eventually raise household incomes. Furthermore, farmers can also engage in multiple growing seasons and diversify their crops. One of the major barriers to smallholder commercialization is limited access to rural road infrastructure. The limited road density and the seasonal conditions of the road impose significant constraints on rural producers. Farmers in remote areas often face higher transport costs, post-harvest losses, and information asymmetries, leading to inefficient market outcomes. Although one of the broader development effects of access to grid electricity is considered to be the structural transformation of the rural economy away from a dependence on agricultural livelihoods, there remains little robust evidence describing the causal effect of improving electricity access on the diversification of rural non-farm enterprise activities in the country, particularly in rural communities.

The first paper provides a meta-analysis on assessing the impact of access to small-scale irrigation on rural livelihood outcomes in Ethiopia. The combined estimate (0.263), shows a statistically significant and positive impact of access to small scale irrigation on rural livelihoods outcomes in Ethiopia, confirming its role as a pro-poor rural development strategy. The result of the study indicated that households with access to small-scale irrigation facilities can improve their livelihoods by 0.263 as compared to farmers who have no access to small-scale irrigation facilities. Furthermore, the sub-group meta-analysis shows a positive and statistically insignificant impact of access to small-scale irrigation on rural livelihood outcomes in Amhara and Tigray regions and a positive and significant impact in Oromia and SNNP regions, which may be due to study variation and regional contextual factors.

The relatively lower impact on rural livelihood outcomes implies that irrigation alone may not be sufficient to lift households out of multidimensional poverty, increase income, and improve food security, without complementary interventions. The study suggests public policy interventions to expand small-scale irrigation programs in the country to boost and improve rural households' way of life. Policymakers should adopt a context-specific approach in order to customize irrigation projects to the particular needs of various geographical areas and farming communities.

The second paper examines the effect of access to rural road transport on smallholder commercialization in Ethiopia. The study used an independent double-hurdle model by assuming that output market participation and levels of output market participation by smallholder farmers are two independent, sequential, and not simultaneous decisions. The result of the study found that rural road access positively and significantly increases the probability of smallholder farmers output market participation (5.1%). It also found a positive and significant effect on the extent of participation (the volume of crop output sold), though the effect is smaller.

The study also found that participation and the degree of participation in the crop output market are influenced by market accessibility, credit accessibility, access to extension services, availability of irrigation facilities, off-farm income, natural shocks, land size, total quantity of output produced, and rainfall availability. Furthermore, regional dummies and dummies for survey periods influence farmers market participation and the extent of participation. Policymakers should prioritize targeted infrastructure development in regions with lower

participation, such as expanding rural infrastructures (enhancing market access, promoting irrigation and modern agricultural technologies, and providing institutional supports).

The third paper investigates the effect of access to rural grid electricity on non-farm enterprise participation in rural Ethiopia. Correlated random effect (CRE) probit model is used to estimate the causal effect. As compared to households without access to grid electricity, households with access are 7.3 % more likely to engage in non-farm enterprise activities in rural Ethiopia. Community-wide access to electricity has a stronger impact (13%). Access to rural infrastructure like roads and financial services is inconsistent, pointing to challenges in rural development and inclusion. To unlock the potential of rural non-farm enterprises, policymakers should complement electrification programs with targeted infrastructure development (such as roads and electricity) and financial services (credit access and MFIs).

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Paper One:

The Effect of Small-Scale Irrigation on Rural Livelihood Outcomes in Ethiopia: A Meta-Regression Analysis

The Effect of Small-Scale Irrigation on Rural Livelihood Outcomes in Ethiopia: A Meta-Regression Analysis

Abstract

*Ethiopia is largely an agrarian nation and over 80% of its population living in rural areas. The availability of irrigation facilities may have extensive influence on livelihood outcomes in these areas. This study aims to employ meta-regression approach to uncover true effects, objectively synthesize the primary studies effect size, and assess the extent of small study effect. Therefore, this study integrates effect size estimates from various studies that examine how access to small scale irrigation affects rural livelihood outcomes in Ethiopia, using a meta-regression approach. Findings indicate that households with access to small-scale irrigation experience a **0.263** improvement in livelihood outcomes compared to those without such access. The study reveals a statistically significant, positive impact of small-scale irrigation access on rural livelihood indicators after accounting for publication bias. This study recommends public policy actions aimed at expanding small-scale irrigation initiatives in Ethiopia to enhance and improve rural livelihoods. Policymakers should adopt a context-specific approach in order to customize irrigation projects to the particular needs of various geographical areas and farming communities. Therefore, the findings of the study hold significant implications for policymakers and collaborated development agencies targeted rural development in Ethiopia.*

Keywords: impact, livelihoods, meta-regression, rural, small-scale irrigation, Ethiopia

1. Introduction

Agriculture is still a crucial sector worldwide and it accounts four percent of the total economic productivity (Gautam et al., 2022). The economies of the least developed nations are centered on the agriculture sector (Kane, 2023). It contributes significantly to the GDP (30-60%), employment (40%-90%). It is also the major source of foreign exchange (25%-95%) and it supplies the majority of basic food, subsistence, and other income for the majority of LDCs.

Ethiopia is predominantly an agricultural country with over 80% of the population residing in rural areas, and the development of rural infrastructure is crucial for boosting the country's socioeconomic development. In Ethiopia, agriculture is the primary economic sector, contributing nearly 32.7% of the GDP, generating 81.5% of the foreign exchange earnings, and providing employment for around 63.66% of the labor force (Tegegne et al., 2022). The production output from rain-fed

agriculture has varied greatly across regions in Ethiopia due to rainfall variability (Moges et al., 2021). Crop failure becomes inevitable when there is uneven and insufficient rainfall distribution, and making food insecurity and poverty major problems in rural communities.

The use of small-scale irrigation could reduce risks and shocks by providing a more dependable source of water for crop production all year round. This can lead to higher crop yields and increased agricultural productivity, which would eventually raise household incomes (Dawid et al., 2023). Furthermore, farmers can also engage in multiple growing seasons and diversify their crops. This boosts total productivity and makes it possible for households to generate income from different sources. Thus, building a contemporary small-scale irrigation system, especially a small concrete canal around farmers' residents, is essential to reducing reliance on rain-fed agriculture, enhancing food security and self-sufficiency, improving nutritional status, supplying industrial raw materials, and expanding rural employment opportunities.

Many small scale irrigation (SSI) programs encounter performance issues, even though Ethiopia has focused on SSI as a means of enhancing food security and lowering dependency on rain-fed agriculture. A number of studies revealed inconsistent results on the impact of access to small-scale irrigation on rural livelihood outcomes in various parts of Ethiopia. That is, several investigations showed mixed findings (positive, negative, or no effect at all). While (Asayehegn, 2012b; Bacha et al., 2011; Belete et al., 2020; Dawit et al., 2020; Gebregziabher et al., 2012; Hagos et al., 2009; Jambo et al., 2021a; Jatana et al., 2024; Maru et al., 2023; Mume, 2021; Mume et al., 2023a; Solomon et al., 2015; Tesfaye et al., 2008) finds a positive impact of access to small-scale irrigation on rural livelihood outcomes in Ethiopia, others (Annys et al., 2019; Asayehegn, 2012a; Belete et al., 2020; Fitsum Hagos et al., 2017; Kassie, 2020; Peden et al., 2009; Pender et al., 2008) shows insignificant and negative impact.

Indeed, due to different factors, such as the methodology, type of data, range, sample size, and study location, the result of the studies can vary. As a result, there is no comprehensive and reliable, well-studied document regarding the potential impact of small-scale irrigation on rural livelihood outcomes in the Ethiopian context. Therefore, combining all findings from different parts of Ethiopia is necessary to arrive at a common conclusion. This necessitates for a study that combines the result of various studies conducted in different region of the country.

Researchers and policymakers face difficulty in generalizing the inconsistent and inconclusive results from various studies (Ayana et al., 2022). However, meta-analysis can address this issue

by combining and providing an objective summary of findings from multiple primary studies (Stanley et al., 2012). The motivation for applying a meta-analysis in this study arises from the existence of a large but fragmented empirical literature on small-scale irrigation and rural livelihood outcomes in Ethiopia. Previous studies report mixed and sometimes inconsistent findings due to differences in study regions, sample sizes, methodological approaches, and outcome measurements. As a result, individual studies provide context-specific evidence but do not offer a generalizable estimate of irrigation impacts at the national level.

A meta-analytic approach is therefore appropriate because it allows systematic synthesis of existing empirical evidence, estimation of an overall effect size, and identification of sources of heterogeneity across studies. In the Ethiopian context, where agro-ecological conditions, institutional arrangements, and irrigation technologies vary substantially across regions, meta-regression helps explain why impact estimates differ and provides more policy-relevant conclusions than individual studies alone. Furthermore, meta-analysis enables formal assessment of publication bias, which cannot be evaluated through narrative reviews. Moreover, no study has been conducted as a meta-analysis or systematic review to carry out the impact of access to small-scale irrigation on rural livelihood outcomes at the national level. Consequently, this study aims to fill these gaps in knowledge by examining the effect of access to small-scale irrigation on rural livelihood outcomes in Ethiopia.

This study makes a significant contribution in many ways: (1) to the best of our knowledge, it is the first meta-analysis to objectively analyze and quantify the impact of access to small-scale irrigation on rural livelihood outcomes in Ethiopia. By doing so, it uncovers the cause of variation in effect size estimates across primary studies, evaluate the extent of publication bias, and assess the true impact of small-scale irrigation. (2) the study offers valuable insights for policymakers on expanding small-scale irrigation initiatives in the Ethiopia. Additionally, the study explores factors that might influence the strength or direction of this effect.

The main hypothesis is that access to small-scale irrigation positively affect rural livelihood outcomes in Ethiopia. To test this, the study applies two methods: descriptive and meta-regression analysis. The descriptive analysis combines study effect size estimates into a single weighted mean. The meta regression analysis, on the other hand, aims to identify the true impact

of access to small-scale irrigation on rural livelihood outcomes after accounting for small study effect and examining the sources of variability in effect size across primary studies.

2. Literature Review

In this section, the researcher first presents the development of small-scale irrigation and its role in improving the livelihoods of rural communities in Ethiopia. Then, in the subsequent part, the researcher draws conclusions from the related empirical studies published on access to small-scale irrigation and rural livelihood outcomes in Ethiopia.

2.1. Overview of Irrigation Development in Ethiopia

Ethiopia's current irrigation history dates back to the 1950s, when private and government-owned schemes began to grow sugar, fruit, and cotton in the middle Awash valley, and continues to be an integral part of Ethiopian agriculture. During the 1960s, the primary aim of irrigation development was to supply industrial crops to the nation's expanding agro-industries, and it was seen as part of the modernization of the country's agricultural economy. It was also considered an important investment for improving rural income through increased agricultural production. The irrigated private farms were nationalized and turned into state farms by the Derg regime, following the rural land proclamation in 1975.

The recurring cycle of drought and famine in the 1980s brought the need for small-scale irrigation development expansion to other parts of the country. The Derg regime has responded to drought and famine through promoting and building irrigation infrastructure aimed at boosting agriculture production. The irrigation infrastructures were traditional, small, medium, and large-scale irrigation schemes that operate at various levels. Following the overthrow of the Derg regime, the EPRDF government has implemented a number of initiatives aimed at expanding irrigation across the nation, and irrigation development was viewed as a critical component of sustainable development in the nation's Agricultural development Led Industrialization (ADLI) policy. Thus, it was intended to stimulate the development of irrigation, especially small-scale irrigation.

The current Ethiopian government has made a commitment to expand and modernize irrigation infrastructure in order to increase agricultural productivity and food security. The government has set a target of irrigating 3.5 million hectares of land by 2025, up from the current 1.5 million hectares (Awulachew, 2019). The actual irrigated area is around 640,000–850,000 hectare, and SSI accounts for over 60% of this area. To achieve this goal, the government has implemented

policies and programs to promote sustainable irrigation practices, improve water management, and support smallholder farmers in adopting irrigation technologies. One of the key components of the government's irrigation policy is the promotion of small-scale irrigation schemes, which are seen as a way to improve resilience to climate change and increase household incomes. The government has also been working to improve the efficiency and effectiveness of irrigation systems through the use of new technologies, such as drip irrigation and solar-powered irrigation pumps. Additionally, the government has been investing in building dams and reservoirs to increase water storage capacity and improve water management.

Smallholder farmers in Ethiopia used surface irrigation (traditional furrow and basin methods), motorized and manual pumps (river/lake water lifting for horticulture and cash crops), small dams, ponds, and cisterns (community and household water storage) and to some extent modern methods (drip and sprinkler irrigation) for cultivation. Irrigation typology of Ethiopia is categorized as small-scale (less than 200 hectare), medium scale (200–3000 hectare), and large-scale (greater than 3000 hectare) irrigation, for the sake of planning and development convenience. Large gap between potential and actual irrigated area, poor design and construction quality in some schemes, sedimentation of ponds, water scarcity and competition especially in dryland areas, institutional fragmentation, and limited access to affordable credit for irrigation technologies are among the key challenges for smallholder farmers to practice small-scale irrigation in Ethiopia.

2.2. Empirical Literature Review

Small-scale irrigation contributes to livelihood improvement through its direct and indirect benefits (Gidey, 2020). Irrigation directly reduces poverty, generates income, and provides food security. The poor also gain from irrigation because it increases productivity, lowers crop failure risk, and creates more year-round jobs on farms and in non-farm sectors. Indirectly, irrigation areas may develop into growth hubs that draw foreign investment in other services and infrastructure, like banking, to facilitate this expansion.

A good deal of studies on the impact of access to small-scale irrigation on rural livelihood outcomes has been conducted in various parts of Ethiopia. Different scholars (Abdissa et al., 2017; Bacha et al., 2011; Dawit et al., 2015; Dereje et al., 2016; Gebregziabher et al., 2009; Gebrehiwot et al., 2015; Getaneh, 2011; Hagos et al., 2012; Hagos et al., 2009; Hagos et al., 2014; Hando, 2021; Jambo et al., 2021b; Mekonnen et al., 2023; Muez, 2014; Tedros, 2014;

Temesgen et al., 2018; Tesfaw, 2018; Tesfay, 2021; Wehabrebi, 2014; Zeweld et al., 2015) have studied particularly on: the impact of access to small-scale irrigation on food security, crop yield, consumption, income, alleviation of rural poverty, diversification, and generating farm and off-farm activities. These studies vary in their findings and by the types of livelihood outcomes they used to examine how access to small-scale irrigation affect rural livelihoods in Ethiopia.

For instance, access to irrigation helps to accumulate assets like livestock, and allows to stabilize household consumption by using these assets during the time of production shocks in northern Ethiopia (Gebregziabher et al., 2009). However, the study shows an inverse relationship between off-farm income and access to irrigation. According to (Bacha et al., 2011), irrigation has probably contributed to the observed inequalities between irrigation user and non-user in terms of welfare in Ambo district, Ethiopia. However, the proportion of impoverished people is alarmingly high, indicating the existence of severe and pervasive poverty in rural areas of Ethiopia. According to (Belete et al., 2020), women in households that use small-scale irrigation technology enjoy empowerment in only 66.8% of the empowerment domain, which is 12% less than the empowerment experienced by women in households without access in Amhara region.

A study by (Muez, 2014) found that access to small-scale irrigation has a positive impact on households' farm income and food security in Tigray region, Ethiopia. The construction of dams and dyke has reduced flooding, leading to a decrease in rice yield and a shifts towards lower value cropping systems in the Tekeze River region of northern Ethiopia (Annys et al., 2019). (Hagos et al., 2014) found that households with access to irrigation had higher level of consumption expenditure compared to non-irrigator households in eastern Ethiopia. Conversely, (Hagos et al., 2013) show that household access to ponds and wells has no significant impact on welfare. (Van Den Berg et al., 2006) revealed that irrigation access significantly enhance household expenditure in Ethiopia, but (Peden et al., 2006) and (Pender et al., 2008) found no significant impact of irrigation access on farmers' income. (Zeweld et al., 2015) confirms that there is a significant difference between the treated and controlled households in terms of income, overall spending, asset accumulation, and expenditures on agricultural inputs. However, no significant difference is observed between treated and controlled households in terms of livestock resources, food consumption, expenditure on education, and health.

Moreover, small-scale irrigation in Ethiopia is performing below design expectations, leaving vast areas out of irrigation. Recent studies (Abera et al., 2019; Annys et al., 2021; Dawid et al.,

2023; Gurmu et al., 2022; Habtu et al., 2020), point to low performance of access to small-scale irrigation in Ethiopia. All in all, findings on impact of access to small-scale irrigation on rural livelihood outcomes in Ethiopia varies across studies and are mixed in magnitude, direction, and conclusions. Existing studies generally suggest that irrigation improves agricultural productivity and income; however, the magnitude of impacts varies substantially across regions and institutional contexts. This heterogeneity suggests that irrigation outcomes depend on complementary factors such as market access and institutional support, an issue insufficiently addressed in the Ethiopian literature. To clarify this inconclusiveness, this study carried out a meta-regression analysis aiming to synthesize the effect size estimates from primary studies and identify the sources of heterogeneity in effect size estimates.

3. Identification of Relevant Studies and Data Collection

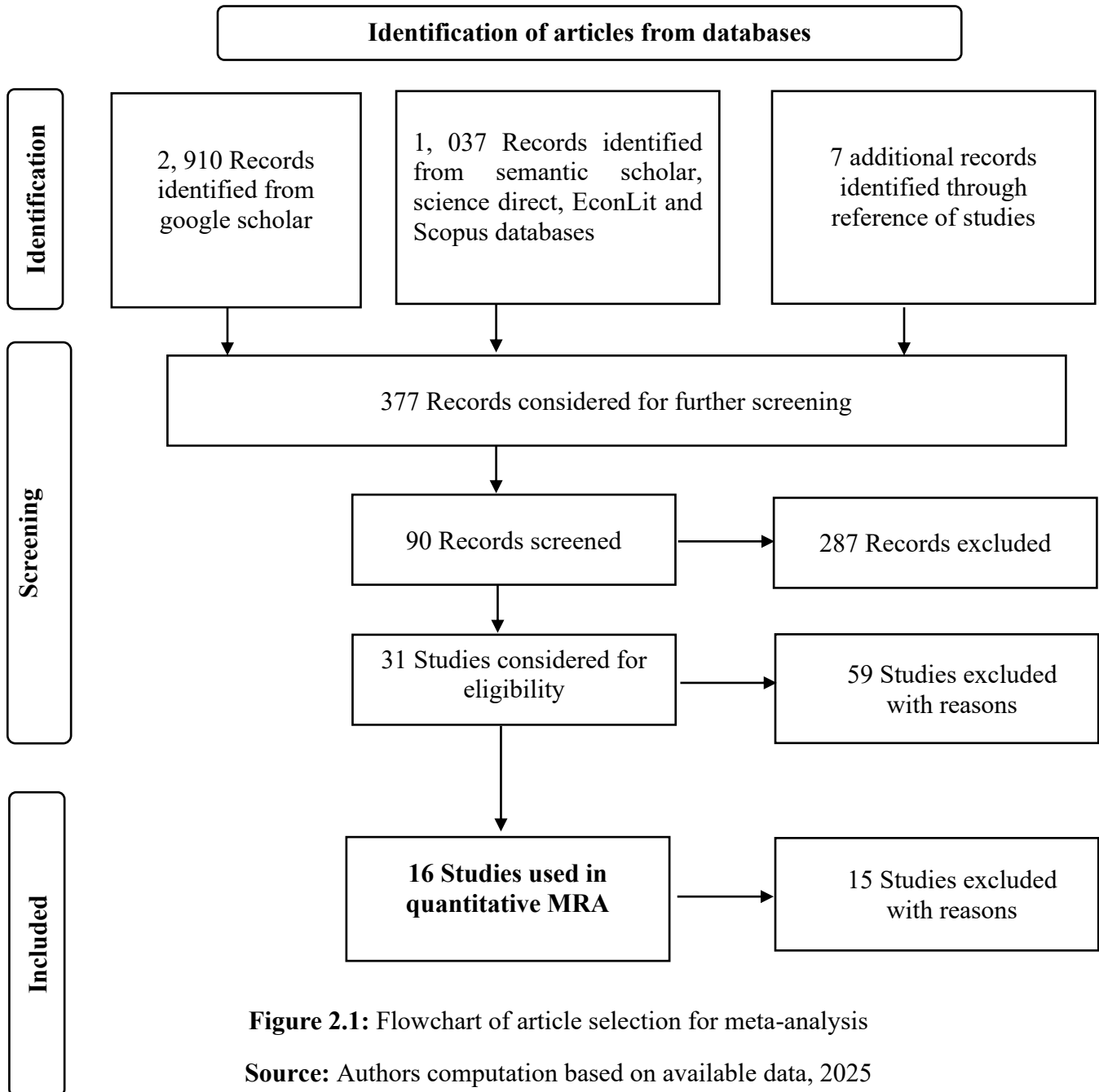
In conducting this Meta-analysis, the study searched, reviewed, coded, and analyzed the results of rigorous studies related to small-scale irrigation and rural livelihoods in Ethiopia. The study used (Havráněk et al., 2020) meta-analysis reporting guidelines. To find and select relevant studies, the researcher used the following databases; google and google scholar, Scopus, semantic scholar, ScienceDirect, web of science, and EconLit. To capture relevant studies, the study used keywords, such as small-scale irrigation; food security; crop diversification; poverty reduction; drought resilience; crop yields; agricultural productivity; and water management. The search included keywords individually and in together with the Boolean operators “OR” or “AND.” The keywords used for search were ("irrigation systems" or "water management" or "small-scale irrigation") AND ("poverty" or "agricultural productivity" or "drought resilience" or "crop yields" or "food security") AND "Ethiopia" in English databases. In addition to electronic databases, the study also manually incorporates certain studies from cross-references.

3.1. Inclusion/Exclusion Criteria

These meta-analyses include studies conducted between 2005 and 2024 in Ethiopia, and the researchers searched and critically scrutinized those studies between February 1, 2024 and June 30, 2024. The study used the following inclusion/exclusion criteria's: (1) Studies must specifically assess the impact of access to small-scale irrigation on rural livelihood outcomes in Ethiopia (2) Studies that used small-scale irrigation as independent variables are considered (3) Studies that provide comparative data and report statistical measures, such as standard error, t-

value, standard deviation etc. (4) Studies that provide data on both access to small-scale irrigation and indicators of rural livelihoods (e.g., income, food security, crop yields, poverty, etc.) are considered (5) Studies that used quantitative methods with a clear research design (such as impact evaluations, and user and non-user studies with control groups) are considered (6) Studies conducted only in English language are included (7) To ensure recent and relevant information studies published after 2005 are considered.

By using preferred reporting items for systematic reviews and meta-analyses (PRISMA) procedure outlined by (Moher et al., 2009), the final studies selection process for this meta-analysis is as follows (**Figure 2.1**):



From 3,954 total studies, 3,577 studies were excluded from the list in the first phase due to duplication. So, the initial screening gives 377 studies regarding to the impact of access to small-scale irrigation on rural livelihood outcomes in Ethiopia. Lastly, based on the abstracts and titles of the articles, the researchers methodically evaluated them step by steps. Initially, the title and abstract of each study were compared to the inclusion criteria. Second, entire texts were

reviewed for inclusion after a recursive search. There were 16 articles that fit the criteria in the final meta-database.

3.2. Data Extraction

STATA version 17 and Excel software were used for the data extraction and analysis. A coding protocol was applied to extract standardized effect sizes (Hedges' g), standard errors, estimation techniques, study location, and year. Data accuracy and uniformity were ensured by using the standardized data extraction form. Data was extracted based on study identification (last name(s) and initials of all authors, year of publication, and title of the article); study characteristics (study design, sample size, household characteristics, and study location); rural livelihood outcomes (income, calory intake, food security, nutrition, poverty, and agricultural productivity, etc.) and relevant statistical reports of the studies (**Table 2.1**). For meta-analysis, studies with standardized metrics across various contexts would be ideal. Because of reporting variability, it is difficult to obtain the basic information in the data analysis section of each study. To enhance data completeness, missing statistical values, including standard errors, can imputed using appropriate methods outlined in the Cochrane Handbook (Chandler et al., 2019). This approach improved the overall quality and robustness of the meta-analysis. While imputation can introduce uncertainty, this approach was considered necessary to maximize the available data for meta-analysis.

Table 2.1: Studies included in Meta analysis (all studies are conducted in Ethiopia)

Author Name	Publication Year	Livelihood Outcomes	Study Area	Model employed	Sample Size
Adela et al. (2019)	2019	Income	SNNP	ESR	240
Ahmed (2022)	2022	Nutrition	¹ Ethiopia	ESR	2879
Haji (2014)	2014	Agricultural Production	Oromia	SPF and PSM	200
Alemu et al. (2022)	2022	Income	Amhara	Logit and PSM	200
Bacha et al. (2011)	2011	Income Consumption Expenditure	Oromia	Heckman selection	222
Belete et al. (2020)	2020	Women Empowerment	Amhara	PSM	201
Fitsum Hagos et al. (2017)	2017	Poverty incidence	Ethiopia	FGT	588
Gebregziabher et al. (2009)	2009	Poverty incidence Income	Tigray	Logit and PSM	613
Hagos et al. (2012)	2012	Poverty incidence	Ethiopia	FGT and PSM	1470
Jambo et al. (2021a)	2021	Calory intake	Oromia	Logit and PSM	194
Kassie et al. (2021)	2021	Food security score	Amhara	PSM	395
Mume et al. (2023b)	2023	Income	Oromia	PSM	288

¹ For the sake of the subgroup meta-analysis, this meta-analysis treated the included studies that were carried out throughout Ethiopia (in all of its regions) as a single study region.

Sisay (2024)	2024	Income Food security score Calory intake Dietary diversity score	SNNP	Logit and PSM	419
Solomon et al. (2015)	2015	Consumption Expenditure	Amhara	FGT and PSM	180
Tesfay (2021)	2021	Consumption Expenditure Income	Tigray	CRE double Hurdle	407
² Zemarku et al. (2022)	2022	Income Asset Consumption Expenditure	SNNP	Logit	134

Source: Authors computation based on available data, 2025

In this meta-analysis, rural livelihood outcomes refer to the measurable economic and welfare conditions that shape the well-being and resilience of rural households. Consistent with the sustainable livelihood's framework, livelihood outcomes are defined along five dimensions: economic outcomes such as household income, agricultural production, and consumption expenditure; food and nutrition security measured using calorie intake, dietary diversity score, and food security score; poverty and vulnerability captured through poverty incidence; assets and resource ownership including physical and productive assets; and empowerment and intra-household agency reflected in women's decision-making power and control over resources. These indicators collectively capture how households earn, consume, adapt, and build resilience.

The fundamental premise is that small-scale irrigation increases access to reliable water, which reduces dependence on rainfall and stabilizes agricultural production. Improved water availability leads to higher crop yields, the possibility of growing high-value and multiple-season crops, and better management of climate risks. Increased production raises household income,

² Some studies included in this meta-analysis examined the effects of access to small-scale irrigation on multiple livelihood outcome variables (for instance, Zemarku et al., 2022 on; income, asset, and consumption expenditure).

enabling households to spend more on food, health, education, and farm investment. Higher income and diversified production enhance dietary quality, reduce seasonal food shortages, and support asset accumulation. Over time, control over productive resources can strengthen women's bargaining power in decision-making.

4. Empirical Design of the Study

4.1. Meta Analysis

Meta-analysis is a method used to combine the findings of various randomized control studies to improve the precision of effect sizes (Bruns, 2013). Another crucial area of the meta-analysis is investigating and identifying publication bias, which arises when the results of smaller studies deviate consistently from those of larger studies. Meta-analysis increases the accuracy of estimates, corrects biases, and provides a weighted estimated mean by combining the estimates of related studies (Stanley, 2019). This method provides a quantitative summary effect size from primary studies, where effect size represents the numerical value of a variable used to test a hypothesis (Ayana et al., 2022; Kelley et al., 2012). Effect size can be statistical measures (like correlations, standardized mean differences and odd ratios) or economic effects like elasticities (Wimmer et al., 2021).

4.2. Random Effect Model for Meta Regression Analysis

In meta-analysis, the fixed effects and the random-effect approaches are the two commonly used methods to combine the effect size estimates from primary studies (Jackson et al., 2016). The key distinction between these methods is their assumptions about effect size estimate. The fixed effect method assumes that reported effect size estimates from primary investigations are derived from a homogeneous population and the variation in effect size is solely due to sampling errors (Geyer-Klingenberg et al., 2020). In addition, this method assigns a weight (W_i) to each study, that is the inverse of variance ($W_i = \frac{1}{SE^2}$), the effect size. As a result, studies with small standard are given greater weight, thereby having a greater impact on the weighted average effect.

In contrast, a random effect model assumes that effect size estimates are drawn from study-specific populations (Geyer-Klingenberg et al., 2020). Accordingly, variations in effect size estimates are not only attributed to sampling error (sampling variability), but also to between-study variation (heterogeneity, denoted by τ^2) (Stanley et al., 2015). Thus, in a random effects model, studies are weighted by the inverse of the additive of these two components of variances

$(W_i = \frac{1}{SE^2} + \tau_i^2)$. Bruns (2013) suggests that between-study variation in effect size estimates could be due to country/regional contexts and methodological variations (like estimation techniques, type of data used, variable definitions, and sets of control variables used).

The fixed-effect approach can rarely be used in actual practice (Mulusew et al., 2023). Because in real-world synthesis, the effect size estimate of studies varies due to contextual and methodological differences among studies. Therefore, it seems that a random-effects approach is sufficient and effective in most meta-analyses (Gavrilidis et al., 2020). Moreover, random effect model weight studies relatively equally than fixed effect model.

Therefore, the observed effect of the study Y_i , is explained by the true effect θ_j and the within-study error ε_i . Where, θ_j , is the sum of average true effects, μ , and the between-study error, ζ_i . Accordingly, for any observed effect of Y_i ,

$$Y_i = \theta_j + \varepsilon_i = \mu + \zeta_i + \varepsilon_i \quad (2.1)$$

The true effect sizes θ are distributed around μ with a variance τ^2 . So, both within-study (ε_i) and between-study (ζ) sampling errors can be addressed to allocate weights and estimate μ . In a random-effects analysis, the variance is decomposed by first calculating the overall variance and then separating the within-study variance (Mulusew et al., 2023). If each study has the same genuine effect, the study could compute Q , or the total variance, and df , or the expected variance. That is:

$$Q = \sum_{i=1}^k w_i (Y_i - Y^2) \quad (2.2)$$

To weight each of the squared deviations, the inverse variance of the study can be used and in the random effect analysis, each study is weighted by the inverse of its variance. That is:

$$w_i = \frac{1}{V_i} \quad (2.3)$$

Given, V_i^* is the sum of between-studies variance and within-study variance for study (i)

$$V_i^* = V_i + Y^2 \quad (4.4)$$

The weighted mean ($\bar{T}$) can be calculated as:

$$\bar{Y} = \frac{\sum_{i=1}^k w_i Y_i}{\sum_{i=1}^k w_i} \quad (2.5)$$

The inverse of the sum of weights can be to get the variance of the overall effect;

$$V = \frac{1}{\sum_{i=1}^k W_i} \quad (2.6)$$

Thus, a random-effects meta-regression is applied to account for between-study heterogeneity. The model tests whether impact estimates vary by study region, outcome category (income, food security, production, etc.), method used (PSM, IV, etc.), publication year, and household socioeconomic characteristics.

4.3. Publication Bias

Publication bias occurs when studies with statistically significant results are preferred to be published, but studies with insignificant results are left unpublished (Stanley, 2008). This occurs when reviewer, editors, researchers, or others prefer significant findings (Ayana et al., 2022; D. A. Stanley et al., 2013). When insignificant studies are excluded from publications, there could be correlation between estimated effect size and its standard error in the primary studies. Ideally, all studies that meet prespecified selection criteria must be included in the analysis. It is rare for this to be possible in reality. Thus, meta-regression analysis is a valuable approach in detecting and minimizing small study effect to show the true effect of effect sizes estimates from primary studies (Bruns, 2013; Ioannidis et al., 2017; Stanley et al., 2019).

4.3.1. Funnel plot

The funnel plot is a representation of the relationship between effect size and standard error or precision. Large studies are shown near to the top of the graph and frequently cluster close to the mean effect size, but smaller studies are shown at the bottom of the graph and spread throughout a range of values (Mulusew et al., 2023). An asymmetric distribution in a funnel plot indicates publication bias.

4.3.2. Egger's test of the intercept

In order to forecast the true effect and to assess the publication bias, Egger advises utilizing precision which is the inverse of the standard error (Mulusew et al., 2023). In this test, the slope of the regression line (β_1) shows the magnitude of the treatment effect and the intercept (β_0) shows the bias. Thus, significant and non-zero intercept (β_0) indicates the presence of bias, and close to zero intercept (β_0) suggests no publication bias. More generally,

$$Y_i = \beta_0 + \beta_1 * se_i + \varepsilon_i \quad (2.7), \varepsilon_i \sim N(0, se_i^2 * \Phi)$$

Where, Φ is a multiplicative dispersion parameter computed from the data which allows for heterogeneity.

4.3.3. Begg and Mazumdar rank-correlation test

Small studies are more likely to be included when they demonstrate a relatively large effect size, while large studies are more likely to be included regardless of their effect size (Mulusew et al., 2023). In these situations, there will be an inverse relationship between the size of the study and the magnitude of the effect size. Begg and Mazumdar called this association as a test for publication bias. It examines whether the effects sizes are systematically related to their standard error (variance). The null hypothesis is that no rank correlation between effect size and standard error (no publication bias). If publication bias exists, smaller studies with larger standard errors tend to report larger or more significant effect size.

4.3.4. Duval and Tweedie's trim and fill

Duval et al. (2000) provide another technique to enable us to impute missing studies and identify small study effect. In this scenario, the researcher should identify the likely positions of the missing studies in the funnel plot and include them in the analysis, and then recalculate the overall effect. That is:

$$Y_i = \alpha_0 + \beta_1 SSize_i + \varepsilon_i \quad (2.8)$$

Where, Y_i , weight of study i , $SSize_i$, sample size of study i , and ε_i error terms.

4.4. Analysis of Study Heterogeneity

Heterogeneity is the degree of variability or inconsistency in the result of multiple studies used in meta-analysis. The heterogeneity test used to determine whether combined studies are approximately similar to pool their results. A forest plot can be used for heterogeneity test, because, it shows a detailed information of each study considered in the meta-analysis. The Cochran test is based on the chi-square test.

$$I^2 = \frac{Q - df}{Q} * 100\% \quad (2.9)$$

Where; Q is chi-square statistics, and df is the degree of freedom.

4.4.1. Q-test for heterogeneity

The null hypothesis, that all studies included in the analysis have a uniform effect size estimate can be tested by the Q -statistic (Mulusew et al., 2023). If every study had the same true effect size, the expected value of Q would be equal to the degrees of freedom.

4.4.2. The I-squared statistic for heterogeneity

The *I*-squared statistic indicates the degree of variation in effect size among studies. It also shows the relative influence of sampling error and variation in actual and observed effects. High values of heterogeneity indicates that the result of individual studies may be too different to combine.

4.4.3. The Tau-squared test for heterogeneity

Tau-squared is used to estimate and quantify the extent of heterogeneity among effect sizes across studies that is not due to chance. Quantification of heterogeneity among effect sizes is estimated by the between study variance. τ^2 values range from 0 to infinity. Larger values of τ^2 indicate greater heterogeneity among effect sizes.

4.5. Meta-Regression Model

According to (Card et al., 1995) and (Solomon et al., 2019), the prime aim of a meta-analysis is to show the causes behind variations in effect size estimates between studies and identify patterns of estimates. Different primary studies have various reported estimates, which leads to heterogeneous average effects (Stanley et al., 2013). Biased results from MRA can be occurred if heterogeneities in estimates from primary studies are not considered (Efendic et al., 2011). To address this, (Doucouliagos et al., 2009) recommended meta regression analysis with extra moderator variables for the sake of identifying the source of heterogeneity in primary studies that could affect the reported effect size estimates.

The following meta-regression model is estimated to look at how the impact of small-scale irrigation on rural livelihood outcomes varies among studies. Start with a simple random-effects meta-regression model:

$$Y_i = \beta_0 + \beta_1 * Z_i + U_i + \varepsilon_i \quad (2.10)$$

Where;

y_i is the effect size of study i , β_0 is the overall mean effect size

β_1 is the coefficient for the predictor variable (access to small-scale irrigation)

z_i is the value of the predictor variable for study i , u_i is the random effect for study i

ε_i is the residual error.

From the above equation, Z_i represent vector of moderator variables explaining variation in effect sizes for study i , and $\beta_1, \beta_2, \dots, \beta_6$ are coefficients to be estimated.

Table 2.2: Moderator variables and their descriptions

Variables	Variable descriptions
y_i	The effect size of study i
Off-farm income	Total off-farm income per household per year
Education level	Years of education
Age	Age of household head in years
Household size	Total household size in number
Sample size	The no of sampled households in a primary study
Model employed	The model that the studys used
Amhara dummy	= 1 if a study is conducted in the Amhara region, otherwise 0
Oromia dummy	= 1 if a study is conducted in the Oromia region, otherwise 0
SNNP dummy	= 1 if a study is conducted in the SNNP region, otherwise 0
Tigray dummy	= 1 if a study is conducted in the Tigray region, otherwise 0
National dummy	= 1 if a study is conducted in all regions of Ethiopia

Source: Authors computation based on available data, 2025

5. Results and Discussions

5.1. Summary Statistics

Table 2.3 shows each study's effect size estimate, the 95% confidence interval, and the overall effect size estimate, named, theta. The positive effect size indicates that access to small scale irrigation improves rural livelihood outcomes and while negative values suggest the opposite. For this study, the combined estimate is **0.263** (theta). This suggests a statistically significant and positive impact of access to small scale irrigation on rural livelihoods in Ethiopia, confirming its role as a pro-poor rural development strategy. In other word, the result indicated that households with access to small-scale irrigation facilities can improve their livelihoods by 0.263 as compared to farmers who have no access to small-scale irrigation facilities. The estimated effect size estimate (0.263) is statistically significant but economically low. The existence of substantial heterogeneity among studies was also reported from the heterogeneity statistics $I^2 = 86.76$ which indicates a large portion of the observed variance in effect-size estimates is due to differences among studies rather than random error. The between-study variance (τ^2) is 0.07.

The presence of high level of heterogeneity may be due to factors such as geographical, contextual, and socioeconomic factors.

Table 2.3: Random effect model using Hedges's g as a measurement of effect size

Author Name	Hedges's g	[95% conf. interval]		%weight
Adela et al., 2019	0.667	0.393	0.941	3.94
Ahmed, 2022	0.038	-0.079	0.155	4.80
Ahmed et al., 2014	0.529	0.248	0.810	3.90
Alemu et al., 2022	0.639	0.356	0.922	3.89
Bacha et al., 2011a	0.265	0.001	0.528	4.01
Bacha et al., 2011b	0.515	0.248	0.781	3.99
Belete et al., 2020	-0.283	-0.566	0.000	3.88
Fitsum Hagos et al., 2017	-0.301	-0.473	-0.128	4.54
Gebregziabher et al., 2009a	-0.007	-0.165	0.152	4.61
Gebregziabher et al., 2009b	0.203	0.044	0.362	4.61
Hagos et al., 2012	-0.005	-0.109	0.098	4.85
Jambo et al., 2021	0.412	0.129	0.696	3.88
Kassie et al., 2021	0.000	-0.198	0.198	4.40
Mume et al., 2023	0.816	0.575	1.056	4.15
Sisay, 2024a	0.512	0.318	0.706	4.42
Sisay, 2024b	0.192	0.000	0.384	4.44
Sisay, 2024c	0.144	-0.047	0.336	4.44
Sisay, 2024d	0.197	0.006	0.389	4.44
Solomon et al., 2015	0.618	0.321	0.916	3.79
Tesfay, 2021a	0.151	-0.063	0.365	4.31
Tesfay, 2021b	0.248	0.033	0.462	4.31

³ Zemarku et al., 2022a	0.527	0.174	0.881	3.44
Zemarku et al., 2022b	0.302	-0.048	0.652	3.47
Zemarku et al., 2022c	0.237	-0.112	0.586	3.47
theta	0.263	0.146	0.379	

Number of studies = 24⁴

Test of heterogeneity: tau-squared = 0.0700; I-square (%) = 86.76 and $H^2 = 7.55$

Test of theta = 0: z = 4.42; Prob > z = 0.0000

Test of homogeneity: $Q = \chi^2(23) = 154.89$; Prob > $Q = 0.0000$

Source: Authors computation based on available data, 2025

5.1.1. Sub-group meta-analysis

The subgroup meta-analysis is represented using the subgroup by region (**Table 2.4**). The first table indicates the individual studies with effect sizes for each region and group specific overall effect size. The combined effect size across regions is also reported at the bottom of the table. The I^2 heterogeneity statistics using subgroup table are relatively low and significant (except the Amhara region). Amhara region has high heterogeneity ($I^2 = 91.43\%$), suggests variability of effect sizes among studies in the region. Oromia, Tigray, and SNNP have relatively low heterogeneity, indicating more consistent effect size across studies in these regions. Moreover, Ethiopia dummy and Tigray region exhibits a negative and statistically insignificant impact of access to small-scale irrigation on rural livelihood outcomes, but Oromia and SNNP show positive and significant impact, which may be due to study variation and regional contextual factors.

³ This meta-analysis summary displayed the same author more than ones (for instance, Zemarku et al., 2022a, Zemarku et al., 2022b and Zemarku et al., 2022c), because those studies investigated the impact of access to small-scale irrigation on various rural livelihood outcomes.

⁴ Although a total of 16 articles were chosen for the meta-analysis, some of the studies analyzed multiple livelihood outcomes, leading to a repetition of studies and a total of 24 studies in the meta-analysis summary result. Each outcome can be considered a separate study for the purposes of meta-analysis. This is because each outcome represents a distinct research question and may have different results.

Table 2.4: Random effect model output of sub-group meta-analysis (by study region)

Author name	Hedges's g	[95% conf. interval]		% weight
Group: Amhara				
Alemu et al., 2022	0.639	0.356	0.922	3.89
Belete et al., 2020	-0.283	-0.566	0.000	3.88
Kassie et al., 2021	0.000	-0.198	0.198	4.40
Solomon et al., 2015	0.618	0.321	0.916	3.79
theta	0.239	-0.207	0.686	
Group: Ethiopia				
Ahmed, 2022	0.038	-0.079	0.155	4.80
Fitsum Hagos et al., 2017	-0.301	-0.473	-0.128	4.54
Hagos et al., 2012	-0.005	-0.109	0.098	4.85
theta	-0.080	-0.277	0.118	
Group: Oromia				
Ahmed et al., 2014	0.529	0.248	0.810	3.90
Bacha et al., 2011a	0.265	0.001	0.528	4.01
Bacha et al., 2011b	0.515	0.248	0.781	3.99
Jambo et al., 2021	0.412	0.129	0.696	3.88
Mume et al., 2023	0.816	0.575	1.056	4.15
theta	0.513	0.327	0.698	
Group: SNNP				
Adela et al., 2019	0.667	0.393	0.941	3.94
Sisay, 2024a	0.512	0.318	0.706	4.42
Sisay, 2024b	0.192	0.000	0.384	4.44
Sisay, 2024c	0.144	-0.047	0.336	4.44
Sisay, 2024d	0.197	0.006	0.389	4.44
Zemarku et al., 2022a	0.527	0.174	0.881	3.44
Zemarku et al., 2022b	0.302	-0.048	0.652	3.47

Zemarku et al., 2022c	0.237	-0.112	0.586	3.47
theta	0.334	0.195	0.474	
Group: Tigray				
Gebregziabher et al., 2009a	-0.007	-0.165	0.152	4.61
Gebregziabher et al., 2009b	0.203	0.044	0.362	4.61
Tesfay, 2021a	0.151	-0.063	0.365	4.31
Tesfay, 2021b	0.248	0.033	0.462	4.31
theta	0.140	0.021	0.258	
Overall theta	0.263	0.146	0.379	

Heterogeneity summary:

Group	df	Q	P > Q	tau ²	% I ²	H ²
Amhara	3	31.82	0.000	0.189	91.43	11.66
Ethiopia	2	10.88	0.004	0.026	86.12	7.20
Oromia	4	9.94	0.041	0.026	58.84	2.43
SNNP	7	17.92	0.012	0.024	61.38	2.59
Tigray	3	4.85	0.183	0.006	40.07	1.67
Overall:	23	154.89	0.000	0.070	86.76	7.55

Test of group differences: $Q_b = \chi^2(4) = 22.70$; Prob > $Q_b = 0.000$

Number of studies = 24; Sub-Group: study region

Source: Authors computation based on available data, 2025

5.1.2. Forest plot diagnostic test

The result of forest plot displays the same result as with the meta summary, but it is now displayed on a graph⁵ (**Figure 2.3**). The overall effect size estimate is represented by a green diamond with the respective confidence interval. In this study, it is evident that, there are many studies whose effect-size estimates are very different from the combined size estimate, which indicates the presence of study variability.

⁵ The interpretation of the forest plot is similar to that of the meta summary analyzed above already.

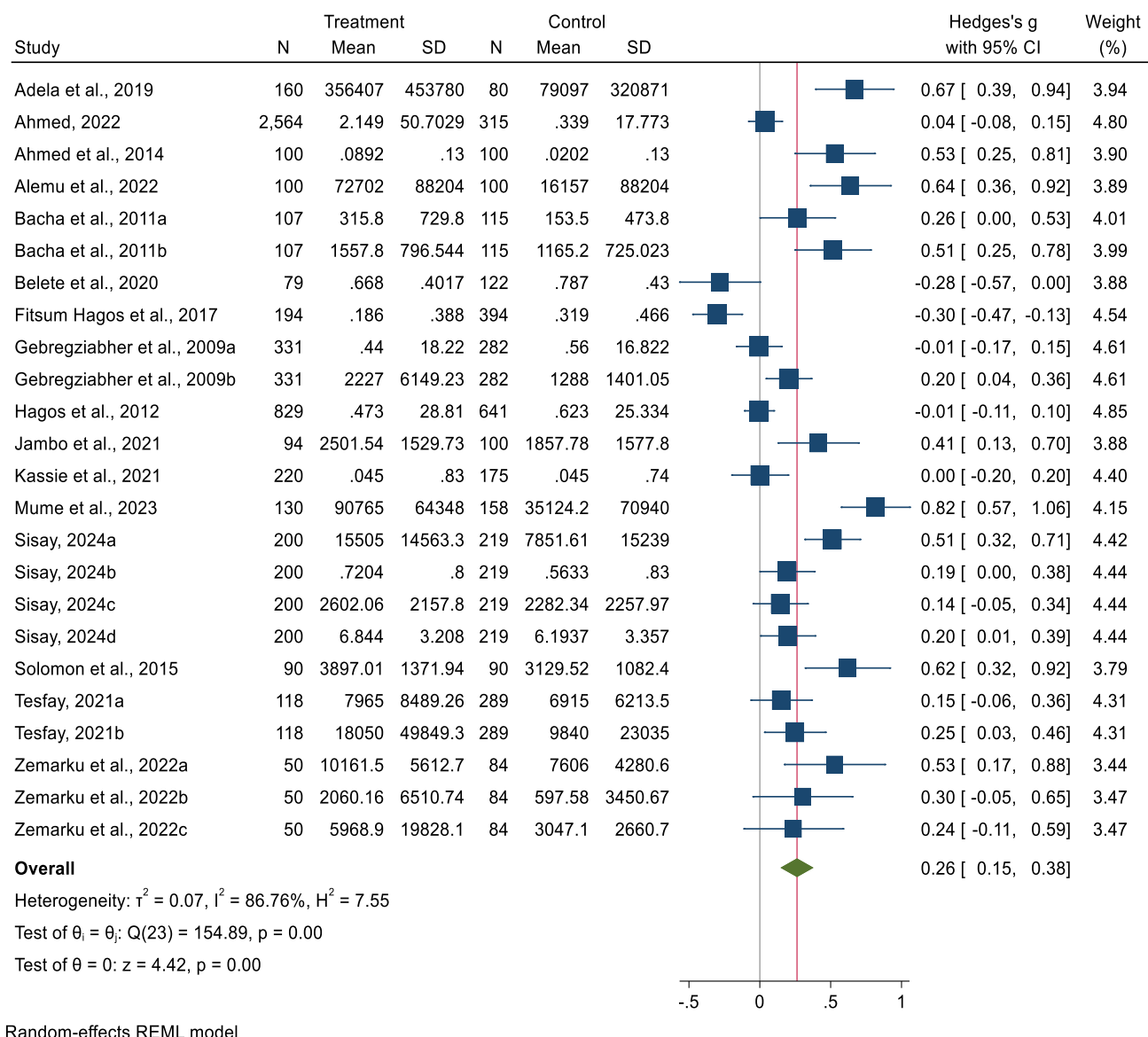


Figure 2.3: Random effect model output for forest plot

Source: Authors computation based on available data, 2025

5.1.3. Heterogeneity diagnostic test

The Galbraith plot (Galbraith, 1988), assess heterogeneity of the studies in meta-analysis and identify the outliers. These graphs plot standardized effect sizes and precision of each study in regression line through the origin. In this study, there are three studies that are on the reference line ($y = 0$), indicating no effect (**Figure 2.4**). Most of the studies (19) are above the reference line, suggesting that they are consistent with the combined effect size and moderate heterogeneity. The remaining few (2) studies are below the line, suggesting the potential outliers

which might contribute to heterogeneity. Therefore, the study suspects the presence of some sort of heterogeneity aligned with the random effect model but it may not be severed.

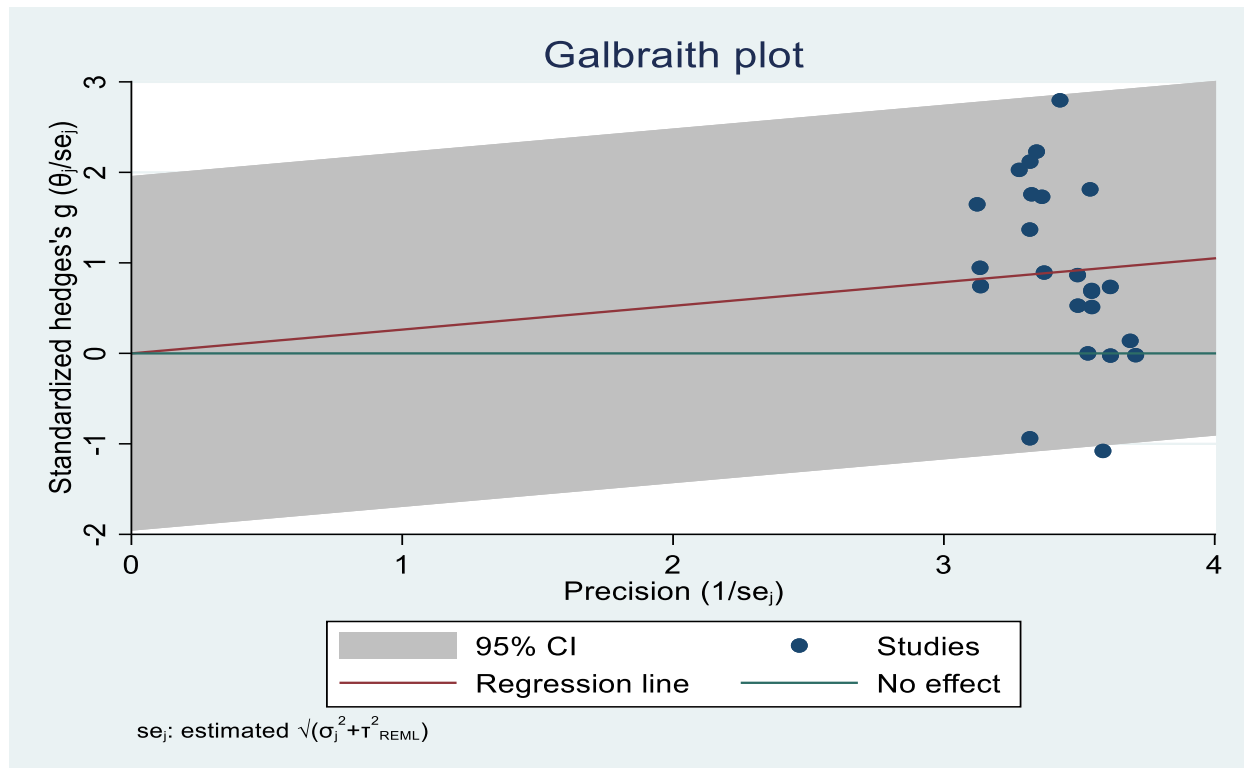


Figure 2.5: Random effect model output for Heterogeneity

Source: Authors computation based on available data, 2025

5.1.4. Funnel plot for small study effect

The funnel plot for this study produces the effect size of each study (Hedges's g) against its precision. Studies with higher precisions are located at the top of the funnel, but those with lower are located at the bottom. Accordingly, the funnel plot indicates a moderate degree of asymmetry, suggesting potential presence of publication bias in this study (**Figure 2.5**). The distribution of the effect size estimate is slightly scattered, implying the presence of publication bias for the study.

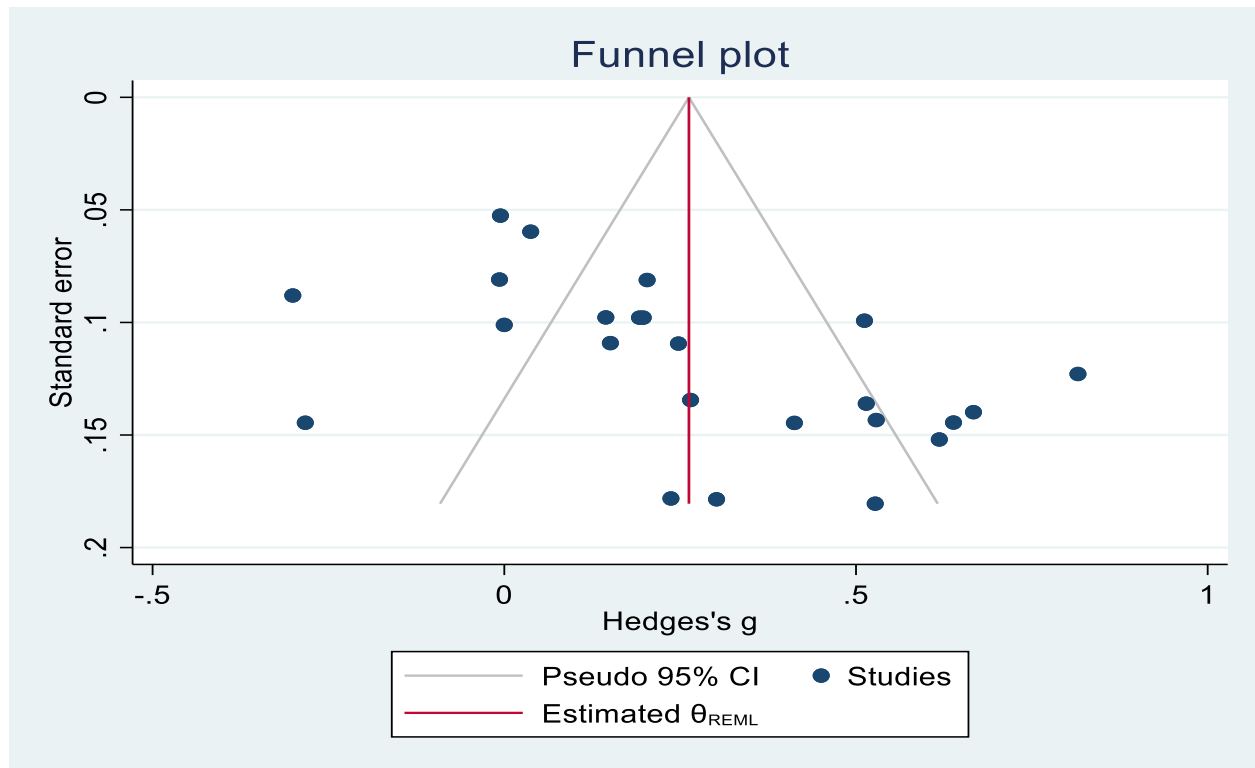


Figure 2.6: Random effect model output for Funnel plot

Source: Authors computation based on available data, 2025

5.1.5. Regression-based testing for small-study effects

5.1.5.1. Egger test for small-study effects

The presence of publication bias can be tested by using regression-based tests. This study uses the Egger test. publication bias for this study reports the estimated slope (β_1) = 4.21 with a standard error of 1.479, and a test statistic of z-test statistic of 2.85 with a p-value of 0.0044 (**Table 2.5**). Therefore, there is statistically significant evidence to reject the null hypothesis of no publication bias in the dataset.

Table 2.5: Random effect model output of Egger test for small-study effects

beta1	4.21
SE of beta1	1.479
Z-value	2.85
Prob > Z	0.0044
<i>H0: beta1 = 0; no small-study effects</i>	

Source: Authors computation based on available data, 2025

5.1.5.2. Begg and Mazumdar rank-correlation Test

This test checks whether Kendall's rank correlation between the effect sizes and their variances equals zero. For this study, the p-value is significant at a 1% level of significance (0.0059), which implies that, there is a potential publication bias (**Table 2.6**).

Table 2.6: Random effect model output of Begg and Mazumdar test for small-study effects

Kendall's score	112.00
SE of score	40.315
Z-value	2.75
Prob > Z	0.0059

Source: Authors computation based on available data, 2025

5.1.5.3. Trim-and-fill analysis for publication bias

To check whether any studies are estimated to be missing, the study performs a trim-and-fill analysis. Trim-and-fill analysis adjusts for missing studies and reduces the overall effect size slightly, but the impact remains positive and significant. The mean effect size based on the 24 observed studies is 0.263 with a 95% confidence interval of [0.146; 0.379] (**Table 2.7**). Meta trim fill reports that there are no hypothetical studies that are expected to be missing. This means that the meta-analysis is likely less affected by publication bias. However, the absence of missing studies in the regression analysis doesn't guarantee the complete absence of publication bias. Because other factors, such as selective reporting of outcomes within studies, and differences in study quality, could still influence the results.

Table 2.7: Random effect model output of trim-and-fill analysis of publication bias

Studies	Hedges's g	[95% confidence interval]	
Observed	0.263	0.146	0.379
Observed + Imputed	0.263	0.146	0.379
<i>Number of studies = 24; observed = 24; imputed = 0</i>			

Source: Authors computation based on available data, 2025

5.2. Meta-Regression Analysis

It is not uncommon for the studies in a meta-analysis to report varying effect-size estimates. But it is mandatory to understand and account for such variation during the meta-analysis to obtain reliable results (Thompson et al., 1999). Since there is substantial between-study heterogeneity in this study, meta-regression was used to explore the relationship between the effect sizes and

study-level covariates of interest. The meta regression for this study is based on the random effect model. The reported I^2 statistic is 51.74%, which suggests that 52% of the variability in the residuals is still attributed to the between-study variation, whereas the remaining 48% is attributed to the within-study variation. (Table 2.8). This moderate heterogeneity even after including potential moderators may be due to within study variation, i.e., due to different types of rural livelihood outcomes included in the study. As indicated by R^2 statistic, 80% of the between-study variance is explained by the covariates.

Finally, the main factors significantly influencing the effect size of the study are age of household, household size, and education level. Additionally, study characteristics such as model employed, study region, and sample size are among the variables that affect the variation in effect size of the study. The combined effect of all regions (Tigray, Amhara, Oromia, SNNPR, Ethiopia) is 0.467 with a p -value of 0.000, which is significant and different across regions (Table 2.8). This is an indication of variation in the reported effect size estimates is largely caused by geographical location. Moreover, the number of observations being examined in each study affects the effect size estimate across studies for this meta-regression.

So, the parameter estimates of models used have a positive and significant effect of the effect size estimate of the study. From this, we can say that, the selected studies used in the meta-regression analysis can be relied upon to appropriately represent the impact of small-scale irrigation on rural livelihood outcomes in Ethiopia.

Table 2.8: Random-effects meta-regression

Meta_es	Coefficient	Std. errs.	Z	P>z	[95% confidence interval	
Modelemployed	0.162	0.083	1.940	0.052	-0.002	0.325
Studyregion	0.467	0.131	3.560	0.000	0.210	0.724
Offfarminc	-0.078	0.061	-1.290	0.199	-0.197	0.041
SS	-0.004	0.002	-2.650	0.008	-0.007	-0.001
Hhsize	0.194	0.062	3.150	0.002	0.073	0.314
Edulev	-0.105	0.061	-1.710	0.087	-0.225	0.015
Age	0.101	0.038	2.660	0.008	0.027	0.175
_cons	-5.969	1.994	-2.990	0.003	-9.878	-2.060

Test of residual homogeneity: $Q_{res} = chi2(5) = 10.18$ Prob > $Q_{res} = 0.0703$
Number of Obs = 13
Residual heterogeneity: $\tau^2 = 0.1435$; I^2 (%) = 51.74; $H^2 = 2.07$
R-squared (%) = 79.9; Wald $chi2(7) = 31.56$; Prob > $chi2 = 0.0000$

Source: Authors computation based on available data, 2025

5.3. Multidimensional Connections Between the Small-scale Irrigation and Rural Livelihoods in Ethiopia

Ethiopia's economy is largely dependent on agriculture, a primary livelihood for a large portion of its population (Chemedda et al., 2025; Dawid et al., 2021; Debie et al., 2025; Sinore et al., 2024). From 16 published peer reviewed papers, it is clear that small-scale irrigation has a positive impact on rural livelihood outcomes in Ethiopia. The substantial economic and societal impacts of small-scale irrigation affect many aspects of people's lives and well-being. Moreover, the impacts are multidimensional and context-dependent. This section elaborates on the broader implications of small-scale irrigation practices for livelihood improvement in Ethiopia, drawing insights from the study's findings.

By enabling multiple harvests and reducing dependency on rain-fed agriculture, small-scale irrigation (SSI) helps to alleviate poverty, improve food security, asset accumulation, sustained income growth, and economic resilience in Ethiopia. Small-scale irrigation (SSI) plays a significant role in rural livelihoods, with impacts extending beyond agricultural productivity, such as promoting diversification and lowering vulnerability to climate variability. Furthermore, Small-scale irrigation (SSI) raises household income and employment opportunities, which may enable investments in health, education, or other programs that enhance livelihood activities. Indeed, participation in the small-scale irrigation has a favorable and positive effect on majority of the livelihood indices, and an expansion of irrigation schemes is a good strategy in the water-stressed and drought-prone areas of Ethiopia.

The observed improvement in livelihood outcomes as a result of small-scale irrigation (SSI) adoption is consistent with previous finding, but our study reveals significant regional variations, indicating the need for smart interventions. There is less impact of small-scale irrigation (SSI) technologies in the Amhara and Tigray regions. This variation is due to differences in climate, resource availability, water availability, institutional support, and socioeconomic circumstances. Addressing this inequality is important for equitable development. The positive impact is in line with more broader goals such as poverty reduction, ensuring food security, and improved rural livelihoods, all of which are central to Ethiopia's development goal and the Sustainable Development Goals (SDGs).

Numerous studies have confirmed that the impact of small-scale irrigation on rural livelihood outcomes is already being observed in Ethiopia. Small-scale irrigation (SSI), both directly and

indirectly, has a significant impact on improving farmers' livelihoods through diversification of crops grown, as well as increased agricultural production, household income, employment opportunity, and participation in community decisions (Bacha et al., 2011; Bojago et al., 2023; Gebregziabher et al., 2009; Maru et al., 2023; Tesfaye et al., 2008). The adoption of small-scale irrigation schemes promotes food security by increasing farm income and consumption. It also encourages farmers to grow nutritionally rich crops like vegetables and fruit and implement productivity-enhancing technologies such as inorganic fertilizer (Adela et al., 2019; Ahmed, 2022). The labor absorption potential of irrigated farming is higher as compared to rainfed farming in Ethiopia (Gebregziabher et al., 2009). In other words, irrigators employ more labor and have lower participation in off-farm activities.

Participating in irrigated agriculture has a positive and significant impact on total crop income, consumption expenditure, market participation, calorie intake and diet, and household asset accumulation (Gebru et al., 2025; Sisay, 2024). Small-scale irrigation practices helped farmers in becoming resilient to the effects of climate change by increasing output and yields through crop diversification and raising rural households' standard of living (Dawid et al., 2021). Small-scale irrigation technology increases production and productivity, which reduces the risk of rainfall variability and raises the income of rural farm households. Moreover, small-scale irrigation in climate-smart agriculture plays a significant role in improving the living standard of rural households (Bojago et al., 2023).

To optimize the benefits of Small-scale irrigation (SSI), investments should concentrate on integrating irrigation systems with more comprehensive rural development programs, such as training programs and market access projects. Policymakers should adopt a context-specific approach in order to customize irrigation projects to the particular needs of various geographical areas and farming communities. Irrigation by itself may not maximize rural livelihood outcomes, so complementary policies, including improved access to agricultural inputs, credit, markets, and extension services, should be integrated to increase the benefits of irrigation.

6. Conclusion and Policy Implications

The introduction of small-scale irrigation can help to reduce poverty by providing a more reliable water source for crop production throughout the year. This can lead to increased agricultural productivity and higher crop yields, ultimately translating into higher household incomes. This meta-analysis aims to address questions about the impact of access to small-scale irrigation on

rural livelihood outcomes in Ethiopia. Having examined 16 studies conducted in five study regions in Ethiopia, the analysis indicates access to small-scale irrigation has a substantial positive impact on rural livelihood outcome.

The overall estimate is 0.263. This indicated that households who have access to small-scale irrigation facilities can improve their livelihoods by around 0.263 as compared to households who have no access to small-scale irrigation facilities. Therefore, access to small-scale irrigation is vital to alleviate deep-rooted poverty in the country, especially in rural areas, to generate more income and diversify income sources, improve food security score and calory intake, reduce consumption expenditure, empower women, and improve other livelihood outcomes. The relatively lower impact on rural livelihood outcomes implies that irrigation alone may not be sufficient to lift households out of multidimensional poverty, increase income, and improve food security, without complementary interventions.

Furthermore, the result of meta-regression shows that study characteristics such as model employed, location of the study (study region), and sample size significantly affect the variation in effect size among the sample studies at a 1% and 5% significant level. These result urge academics and researchers to be observant in order to pinpoint study-specific characteristics that have a substantial impact on the variation in effect size among the sample studies in Ethiopia. The results of the study also confirmed that there is evidence of systematic publication bias in the literature. The study suspected the presence of some sort of heterogeneity, and tried to investigate the reasons behind it using subgroup meta-analysis, and meta-regression.

The Ministry of Irrigation and Lowlands should expand small-scale irrigation programs in the country to boost and improve rural households' way of life. To optimize the benefits of small-scale irrigation (SSI), the government, together with collaborators, should concentrate on integrating irrigation systems with more comprehensive rural development programs, such as training programs and market access projects. The regional irrigation bureaus should adopt a context-specific approach to customize irrigation projects to the particular needs of various geographical areas and farming communities. Irrigation by itself may not maximize rural livelihood outcomes, so complementary policies, including improved access to agricultural inputs, credit, markets, and extension services, should be integrated to increase the benefits of irrigation.

7. Limitations

This study also has its own limitations. The scope can be further broadened by incorporating studies on road access, access to electrification, and market related variables. We recognize that lack of these variables in the selection criteria can affect the differences in the livelihood outcomes of the smallholder farmers.

8. Area for further study

Therefore, future assessments can address this gap by considering climate adaptation and resilience variables. In addition, future researchers can conduct a similar study at regional, (like Sub-Saharan Africa) continental or global level.

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Paper Two:

**Access to Rural Road Transport and Smallholder
Commercialization in Ethiopia: Evidence from the
Ethiopian Socioeconomic Survey**

Access to Rural Road Transport and Smallholder Commercialization in Ethiopia: Evidence from the Ethiopian Socioeconomic Survey

Abstract

With more than 80% of the population living in rural areas and Ethiopia being primarily an agrarian nation, the development of rural infrastructure is crucial for boosting the country's socioeconomic development. Since 2010, Ethiopia has acknowledged the importance of rural road development and has invested significantly in this area. The study aims to investigate how access to rural road transport affects smallholder commercialization in Ethiopia. For this study, the data is compiled from the Ethiopian Socioeconomic Survey, run by the Central Statistics Agency of Ethiopia and the World Bank Living Standards Measurement Study-Integrated Surveys on Agriculture team. The descriptive statistics result shows that approximately 54.35% of households in rural Ethiopia have access to an all-weather road, indicating a moderate level of connectivity. The study finds that road access significantly improves market participation and the extent of commercialization, though the effect on sales is small. The study also found that participation and the degree of participation in the crop output market are influenced by market accessibility, credit accessibility, access to extension services, availability of irrigation facilities, off-farm income, natural shocks, land size, total quantity of output produced, rainfall availability, regional dummies, and dummies for survey periods. Therefore, there should be investments in market infrastructure, access to institutional supports, agricultural productivity, irrigation, and climate-smart agriculture in addition to rural roads to help farmers produce more and supply output to the market. Furthermore, designing region-specific policies can enhance output market participation of smallholder farmers.

Keywords: Agriculture, impact, infrastructure, market participation, output.

1. Introduction

Smallholder farming has traditionally served as the primary economic activity in the Sub-Saharan region and is expected to play a crucial role for some time to come (Gollin, 2014). There is no exception in the case of Ethiopia (Megerssa et al., 2020). Due to a lack of rural infrastructure linkage and the sector's subsistence nature, market integration and participation continue to be a big challenge. In developing countries like Ethiopia, agriculture determines the economic, social, and political system of society (Leykun et al., 2014). With more than 80% of the population living in rural areas and Ethiopia being primarily an agrarian nation, the development of rural infrastructure is crucial for boosting the country's socioeconomic development. In Ethiopia, agriculture is the dominant economic sector, contributing approximately 32.7% to the GDP, generating 81.5% of foreign exchange earnings, and providing employment for around 63.66% of the population (Tegegne et al., 2022).

However, the agricultural production system in rural areas is marked by restricted land access, limited availability of inputs, underdeveloped irrigation facilities, weak market orientation, insufficient infrastructure, outdated technology, inadequate extension services, and low productivity (Balew et al., 2010). The agricultural sector is mostly featured by smallholder farming, with limited commercialization and market integration (Gebresilasse, 2023; Jemal et al., 2019; Stifel et al., 2017). Many smallholder farmers produce primarily for subsistence, with only a small portion of the produce entering formal markets. This low degree of commercialization is the main obstacle to agricultural transformation, rural income growth, and poverty alleviation. Moreover, most smallholder farmers in Ethiopia engaged in subsistence farming, with minimal connection between their production and consumption decisions (Muller, 2014). In addition, relying on subsistence agriculture does not guarantee their food security and overall household wellbeing.

Factors determining smallholder commercialization can be external and are beyond the smallholder's control (Gebreselassie et al., 2008; Hagos et al., 2016). They include the development of infrastructure, market institutions and regulations, cultural and social factors, agro-climatic conditions, the development of the non-farm sector, population growth and demographic change, technological change and introduction of new commodities, rising labor costs, and trade and sectoral policies. Moreover, factors such as smallholder resource endowments, such as land and other natural capital, labor, physical capital, and human capital,

are household-specific and considered to be internal determinants (Jaleta et al., 2009). One of the major barriers to smallholder commercialization is limited access to rural road infrastructure. The limited road density and the seasonal conditions of the road imposes significant constraints on rural producers (Jemal et al., 2019; Tamene et al., 2017). Poor road networks in rural areas increase transaction costs, reduce market participation, and limit farmers' ability to sell their produce at competitive prices. Farmers in remote areas often face higher transport costs, post-harvest losses, and information asymmetries, leading to inefficient market outcomes. A large portions of population raised and engages in production activity far from main roads, markets, and other socio-economic service centers (Worku, 2010).

Furthermore, inadequate conditions as well as the absence of essential infrastructure such as roads and transport services create significant barriers for impoverished people in accessing markets and their associated services (Starkey et al., 2014b). Therefore, enhancing access to transport infrastructure can help boost the productivity of agricultural households by lowering transportation costs and enabling them to obtain better price for their products. This is due to the fact that a well-developed rural road network facilitates the efficient delivery of agricultural input and expands opportunity for farmers to access market and sale their products. In Ethiopia, rural transport infrastructure and services play a crucial role to in shifting subsistence and semi-subsistence production systems towards market-oriented and commercialized agriculture (Assefa et al., 2013).

The Ethiopian government has implemented various policies, strategies, and programs aimed at fostering agricultural development, ensuring food security, and enhancing resilience (Melesse, 2015; Shiferaw, 2017). A key focus among these strategies is market-oriented agricultural production policies, which aim to promote the production and marketing of high-value agricultural products to strengthen farmers competitiveness in both national and international markets (Tufa et al., 2014). Additionally, the government introduced the second Growth and Transformation Plan for the period 2016–2020 to boost agricultural productivity and commercialization with the overreaching goal of attaining middle-income status by 2025.

Since 2010, Ethiopia has recognized the relevance of rural road development and committed substantial investment to this area. The government launched an ambitious program, the Universal Rural Road Access Program (URRAP), in 2010 to promote the construction and upgrading of more than 70,000 km of rural roads in the country. The aim of the program is to

provide all-weather connections to all rural communities across the nation. According to a recent report by Ahmed et al. (2024), connectivity and accessibility of rural Ethiopians have improved since 2010. Consequently, between 2010 and 2016, the average travel time to the closest town decreased by nearly 30 minutes. The rural accessibility index (RAI) increased from 46 in 2010 to 52 in 2016, meaning that an additional 6% of rural Ethiopians have access to rural roads during the same period of time.

Additionally, through the Universal Rural Road Access Program (URRAP), the government has alongside development partners has been working to deliver all-weather road access to rural communities. The government allocated 37.3 billion birrs (approximately \$1.1 billion) to support the rural road development program in fiscal year 2018/19 (Alamirew et al., 2022). As of 2019/20, Ethiopia had 144,024 kilometers (89,492 miles) of all-weather roads, representing approximately 41% of the country's required road network. Moreover, Ethiopia plans to invest 3.0 trillion birrs (approximately \$58 billion) in the road sector over the next decade, aiming to construct an additional 102,000 km and upgrading 28,000 km of federal highways, thereby doubling the rural road network from the current 56,000 km to 109,000 kilometers (Alamirew et al., 2022). Despite the efforts by the government and various national and international development programs to expand rural road infrastructure many farmers are isolated both geographically and economically (Gebresilasse, 2023; Jemal et al., 2019; Tamene et al., 2017; Wudad et al., 2021).

Numerous empirical studies have shown that road accessibility is a crucial factor in influencing various socioeconomic and rural livelihood outcomes of interest in Ethiopia, including income, market participation, agricultural productivity, reducing poverty, enterprise development, and economic growth and development. However, instead of differentiating between urban-rural types of roads (such as feeder roads, gravel roads, and asphalt roads) and their differential effects on rural livelihood outcomes, some studies look at road infrastructure at an aggregate level (Ahmed et al., 2024; Bekele et al., 2015; Haile, 2023; Shiferaw et al., 2012, 2015; Terefe, 2012; Worku, 2010). These studies tend to treat road infrastructure as homogeneous and assume that all forms of road access offer comparable advantages across different areas. However, the effects of access to roads may differ considerably depending on proximity to markets, agroecological conditions, and regional dynamics. This study accounts for spatial heterogeneity by incorporating location-specific factors into the analysis.

On the other hand, some others link roads to overall economic indicators but do not explicitly examine the effects on specific economic activities, like smallholder commercialization (Ahmed et al., 2024; Anega et al., 2023; Dercon et al., 2009; Iimi et al., 2018; Kebede, 2024; Kifle, 2010; Nakamura et al., 2020; Stifel et al., 2012; Wondemu et al., 2012). The focus of this study shifts to micro-level rural livelihood indicators (market participation and levels of commercialization) instead of broad macroeconomic outcomes. Furthermore, the majority of previous studies on Ethiopia have been primarily location-specific and depend on small samples taken from one or two districts that do not allow generalization and limit the ability to assess causal relationships and dynamic effects over time (Alamirew et al., 2022; Bhatta, 2012; Ewnetu, 2023; Gafarso et al., 2019; Nagesso et al., 2019; Tadesse, 2020; Tamene et al., 2017; Wudad et al., 2021). In order to capture long-term impacts and offer a more detailed understanding of how road access affects commercialization, this study utilized panel data from the Ethiopian Socioeconomic Survey (ESS) (2018/19 and 2021/22).

With the exception of Mekonnen et al. (2017), who estimated the effects of access to rural road transport on smallholder commercialization using the first panel of the Ethiopian Socioeconomic Survey (ESS Panel I), no prior study has made such a distinction. Despite the merit of their work, however, their analysis does not fully capture the evolving dynamics of smallholder commercialization. The earlier study assumed identical determinants for both the decision to participate in the market and the level of commercialization, limiting its ability to identify stage-specific barriers. Moreover, the impact of climate change and natural shocks, which are increasingly shaping smallholder farmers decisions, was not taken into account in the previous study. The prior study essentially ignored spatial heterogeneity, assuming uniform effects of road access across Ethiopia. More significantly, these studies not only fail to capture the variability across regions (geographic and agro-ecological), but also limit the generalizability of the findings at the national level.

Indeed, this study makes the following additions to the current body of knowledge on smallholder commercialization. First, in contrast to the previous study, this study utilizes ESS Panel II (2018/19 and 2021/22). The use of a more recent dataset accounts for changes in infrastructure development, market conditions, and rural livelihoods over time, ensuring that findings reflect the current realities of smallholding farmers in Ethiopia. Second, by using a double-hurdle model that accounts for distinct explanatory variables in market participation and

levels of commercialization decisions, this study advances the methodology. This distinction provides a clearer understanding of the different constraints farmers encounter at each stage, leading to more focused policy insights.

Third, this study explicitly includes climate-related factors such as rainfall variability and natural shocks, recognizing their role in determining both market participation and commercialization intensity. By integrating these variables, this research provides a more holistic analysis of smallholder resilience and adaptation strategies in response to environmental challenges. Lastly, in recognition of the fact that the impact of road infrastructure differs based on geographical, agroecological, and institutional factors, this study also includes regional dummies. This study provides more localized findings that are more appropriate for region-specific policy interventions by examining regional differences. Therefore, in this study, we address such gaps by using recent data, better methodological approach, and a broader set of explanatory variables, and offering a more comprehensive and policy relevant findings for rural development policy in Ethiopia.

Given that the majority of Ethiopia's livelihoods are rural and agriculture dominates the Ethiopian economy, agricultural development is currently linked to efforts to develop rural areas. Moreover, achieving development goals requires a comprehensive rural development policy and actual implementation. Despite the significant efforts put forward in the stirring scale of the investment and general consensus on the importance of rural roads, empirical evidence on the impacts of rural road development has been scarce in Ethiopia.

Accordingly, this paper examines the issue from both theoretical and practical perspectives using Ethiopian socio-economic survey data. Understanding this relationship is crucial for designing policies that enhance market participation, improve rural livelihoods, and support agricultural commercialization strategies in Ethiopia. In doing so, this study provides empirical insight into the extent to which rural roads affect the livelihoods of agricultural households through commercialization. The findings and recommendations of this study provide valuable input for the realization of the strategic pillars of Ethiopia's development plan, which maps the country's pathways to promote rural income growth to accelerate poverty reduction. The main aim of the study is to examine the effect of access to rural road transport on smallholder commercialization in Ethiopia.

2. Literature Review

2.1. Historical Development of Rural Road in Ethiopia

Ethiopia's road infrastructure was underdeveloped and largely concentrated in urban centers and strategic corridors before the 1990s (Shiferaw et al., 2012). Agricultural market participations of rural communities were limited because market access was only by footpaths or animal tracks. Between the 1990s and the 2000s, the government recognized that poor rural accessibility was a major constraint to economic growth. Therefore, to oversee construction, upgrading, and maintenance, there were significant road sector reforms and the establishment of the Ethiopian Roads Authority (ERA). Currently, the rural road access status in Ethiopia is around 160,000 km (all types of roads) of which the district and community roads constitute a large share, though the quality of the roads varies greatly. There is a significant improvement in rural road accessibility (percentage of rural population within 2 km of all-weather road) from 24% in the mid-1990s to over 70% by 2020 (Moneke, 2020). The remaining gaps are in remote, low-density, and mountainous areas. Though major highways are in fair to good condition, many rural roads suffer from seasonal inaccessibility due to poor drainage and maintenance gaps.

The Universal Rural Road Access Program (URRAP) was launched in 2011, which was implemented by regional governments with support from ERA. The program aims to provide all-weather road access to every kebele in Ethiopia using community-based, labor-intensive construction (to reduce costs and create jobs). The program achieved a dramatic increase in rural road coverage, especially in the Oromia, Amhara, and SNNP regions. Maintenance problems (many newly built rural roads deteriorate quickly without proper upkeep), seasonal inaccessibility (flooding and erosion cut off rural communities during rainy seasons), funding gaps (insufficient funds for the rapidly expanding network), and capacity constraints (technical and managerial gaps in woreda-level offices) were the major challenges of the program.

2.2. Theoretical Base of the Study

2.2.1. The transaction cost theory (TCT)

Ronald Coase, who was considered to be a welfare economist and the pioneer of transaction-cost economics proposed the transaction cost theory in 1937 (Madhok, 2002). Ronald Coase tried to define the relationship between the firm and the market. Even though transaction cost theory has been extensively used in the areas of finance and management disciplines, there is, however, increasing interest among researchers in fields of agricultural economics to understand how and

why transaction costs affect smallholder farmers' participation decision in agricultural output markets. According to the transaction cost theory, farmers' decision to participate in markets and the degree of participation are determined by the magnitude of transaction costs. The transaction costs that limit or restrict the decision and extent of output market participation includes costs resulting from distance from markets, imperfect market information, poor infrastructure, transportation costs due to poor road quality, costs for bargaining procedures in search of market partners, and supervision and incentive costs.

Smallholder farmers incur both fixed and proportional transaction costs in selling their agricultural outputs on markets (Key et al., 2000). Fixed transaction costs are invariant to the quantities of output sold and mostly determine a smallholder farmer's initial decision to participate in the market (Goetz, 1992). These fixed transaction costs are further influenced by the proximity of the market place and sources of market information. On the other hand, the proportional transaction costs are those costs that increase proportionally in quantity with the quantities of output sold and mostly determine the intensity or volume of output market participation. Therefore, smallholder farmers' intensity of output market participation is further influenced by geographic location (distance to market), the price of the output, ownership of means of transport and availability of family labor.

Market participation decision of smallholder farmers is primarily influenced by transaction costs, household characteristics, and access to infrastructure. Once a farmer enters the market, the extent of commercialization is influenced by production capacity, liquidity constraints, and weather conditions. Market participation decision is driven by fixed transaction costs and household constraints such as road access, market accessibility, and household characteristics (such as gender, age, and hhsz). Additionally, exposure to natural shocks and asset ownership (livestock and land) determine whether a farmer engages in commercialization. The extent of commercialization is influenced by production capacity, liquidity constraints, and weather conditions (include farm productivity, financial resources, credit access, and institutional support and rainfall variability).

2.2.2. The agricultural household model (AHM)

The agricultural household model views smallholder farmers as both producers and consumers, make decision to participate in the crop output markets and how much they sell based on market conditions, prices, and resource constraints (Singh et al., 1986). According to the AHM, households will participate

in markets only if the expected utility of selling exceeds autarky utility. A household's decision to participate in the market depends on endowments, preferences, and transaction costs. That is, household assets, access to roads, distance to markets, risk aversion, and institutional constraints (like access to credit). These variables influence whether a farmer can and is willing to participate in the market. Conditional on market entry, the extent of commercialization is influenced by production capacity, market access, and price incentives. That is, farm size, productivity, transport costs, market linkages, and price expectations. These factors determine how much the farmer is able and willing to sell.

Most previous studies used the same explanatory variables for the two-stage decisions of participation in the crop output market and the intensity of commercialization, assuming identical determinants for both hurdles. However, economic theory suggests that different factors affect these decisions at each stage. Market participation decisions can be driven by transaction costs, household characteristics, and access to infrastructure, and the extent of commercialization may depend more on production capacity, liquidity constraints, and weather conditions. This study departs from previous works by using a double-hurdle model that allows for different determinants at each stage, aiming to improve the precision of policy recommendations. This distinction is based on theoretical justifications from the Transaction Cost Theory (TCT) and Agricultural Household Model (AHM). Moreover, Ndoro et al. (2014) applied the double hurdle model with different explanatory variable in analyzing cattle commercialization in South Africa. The model has also been applied in dairy, and crop marketing. Notably, Eakins (2014) applied model to Petrol and Diesel household expenditures in Ireland.

2.3. Empirical Literature Review

Several empirical studies on the relationship between access to rural road transport and smallholders' commercialization were conducted worldwide, such as (Aggarwal, 2018; Asomani-Boateng et al., 2015; Barrett et al., 2017; Berechman, 2010; Berg et al., 2018; Bhandari et al., 2021; Bhatta, 2012; Bucheli et al., 2018; Casaburi et al., 2013; Jemal et al., 2019; Kebede, 2020; Kemmerling et al., 2015; Kienzle et al., 2014; Motatsa et al., 2014; Mu et al., 2011; Soseco, 2016; Starkey et al., 2014a; Tamene et al., 2017). Reviews and findings of some of the studies are presented below.

Poor people in developing countries find it challenging to access markets and their services due to poor circumstances and a lack of basic infrastructure, such as roads and access to transportation services (Starkey et al., 2014a). Poor road accessibility and subpar roads increase transportation expenses, making it more difficult to access high-quality inputs and restricting

local markets to the sale of producers' goods (Bhandari et al., 2021). The absence of roads connecting rural areas and farms along with the resulting high transportation costs for agricultural inputs and outputs is recognized as a significant barrier to small-scale agriculture in African (Bhatta, 2012; Kienzle et al., 2014). Furthermore, Mercandalli et al. (2017) identified limited access to rural transport infrastructure as one of the primary factors contributing to low agricultural productivity across the continent. As a result, factors such as distance to market centers, transport costs, and ownership of transport means, are likely to constrain the levels of smallholder farmers' participation in output market (Jagwe, 2011). According to Jagwe (2011) and Nikolaeva et al. (2016), high fixed transaction costs encountered by smallholder farmers can lower the probability of their participating in agricultural output markets.

On the other hand, rural transportation infrastructure has been shown to enhance market access, which is widely recognized as a crucial strategy for improving the wellbeing of the global rural poor (Asomani-Boateng et al., 2015; Lokeshia et al., 2017; Stifel et al., 2017). The economic benefits of rural transportation infrastructure are primarily linked to improved market access, which in turn contributes to higher household consumption and income, enhanced human capital development, a rise in local GDP, and greater agricultural production (Aggarwal, 2018; Berg et al., 2018; Bucheli et al., 2018). Additionally, studies highlight that rural transport infrastructure facilitates access to agricultural markets for the rural community, contributing to increased agricultural output (Asomani-Boateng et al., 2015; Berechman, 2010).

Mu et al. (2011) used double difference and matching methods to overcome potential selection bias in finding impacts and found positive and significant average benefits of rural road restoration on local (commune level) market growth in Vietnam. The authors observe that less developed beginning markets tend to have greater impacts in poorer regions. In addition, the development of rural roads can substantially enhance smallholder market participation and commercialization by promoting market integration and lowering transportation cost burden. Motatsa et al. (2014) and Soseco (2016) also brought attention to the relationship between rural transportation and rural development and emphasizing that transportation is an essential component of both economic and social progresses and plays a vital role in the production and marketing of agricultural produces.

Empirical studies in Ethiopia (Haile, 2023; Iimi et al., 2018; Jemal et al., 2019; Kebede, 2024; Stifel et al., 2012; Tamene et al., 2017; Wudad et al., 2021) show that road transport has a

positive impact on the marketing of agricultural output and smallholder commercialization. The expansion of rural road resulted in notable increases in the relative prices of cash crops and prompted a reallocation of farmland towards the cultivation of cash crops within village's (Kebede, 2020). These mechanisms contribute the majority of the estimated welfare gain. Adamopoulos (2018) reports a 13.6% increase in aggregate agricultural yield as a result of road expansion and upgrades the lower trade costs between Ethiopian districts and national grain market centers.

Moreover, between 2012 and 2016, rural road expansion resulted in a total welfare gain of 13% for a village in Ethiopia with an average increase in market access. Haile (2023) reveals that agricultural commercialization is significantly higher for agricultural households living within two km of tar/asphalt roads than for those who cannot access tar/asphalt roads within two km. Similarly, agricultural households spend more hours in off-farm activities if they reside within two km of a tar/asphalt road. Overall, access to quality roads has a significant impact on agricultural households' net farm income indirectly through their agricultural commercialization decisions.

Wudad et al. (2021) show that road access conditions have a significantly positive influence on the marketing of vegetables and rural household annual income in the rural area of the Oromia region, Ethiopia. According to Iimi et al. (2018), as a result, output market access was improved by major and feeder road accessibility, though the impact seems to be relatively weak. That is, farmers may sell extra produce in their neighboring markets, but the market participation is generally still limited. Stifel et al. (2012) found that investments in rural feeder roads in Ethiopia are cost-effective ways for rural households that market agricultural surplus and reduce transportation costs by 50 US dollars per metric ton.

Due to the country's low road density and seasonal road conditions, rural producers in Ethiopia face challenges (Jemal et al., 2019; Tamene et al., 2017). Numerous individuals reside and work in areas that are far from major highways, marketplaces, and other socioeconomic service hubs. In addition, smallholder agricultural farmers pay high transportation expenses, which drives up input prices and restricts access to the market, resulting in low productivity, poor education, and bad health, all of which impede economic progress (Worku, 2010). Further, Bhatta (2012) shows that due to poor transportation services, farmers sell their produce at a lower price while paying higher for the commodities they buy in Ethiopia. Furthermore, they confirm that road

accessibility plays a significant role in reducing the farm gate prices of manufactured goods while increasing farm gate prices of agricultural goods.

Tadesse (2020) highlighted the likelihood of smallholder farmers' output market participation decision positively and significantly influenced by road accessibility, land size, household head being male, education status of household, the number of oxen, accessibility of credit service, access to extension services, access to telecommunication, and electricity. Mekonnen et al. (2017) report that communities with better accessibility exhibits higher level of commercialization and market participation compared to those that are less accessible.

3. Methodology of the study

3.1. Data Source

For this study, the data is compiled from the Ethiopian Socioeconomic Survey (ESS) of 2018/19 and the Ethiopian Socioeconomic Panel Survey (ESPS) of 2021/22, run by the Central Statistics Agency of Ethiopia (CSA) and the World Bank Living Standards Measurement Study-Integrated Surveys on Agriculture (LSMS-ISA) team. The survey is said to be broadly representative of rural households engaged in sedentary agriculture. The scope of the survey includes individual, household, and community-level characteristics. Moreover, the ESS collects information on household agricultural activities along with other information on the households, like human capital, other economic activities, and access to services and resources. The household survey gathers quantitative data on various variables reflecting both household and villages-level characteristics. This includes the average land holdings size, number of oxen owned, input usage per hectare, household head average age and years of schooling, household size, altitude above sea level, average temperature, and village distance to the nearest town, among others.

These survey rounds were chosen due to recency and availability of ample observations on key variables relevant to the study. The sample attrition is low; 1,357 households (68.88%) have observations in both periods, while 570 households (28.91%) have observations in only the first (2018/19), and only 40 households (2.21%) have data only in the second period (2021/22). The dataset remains unbalanced, with most households contributing data for both periods but some contributing only partially. The absence of some households in the second round could be due to conflict in northern Ethiopia (non-random attrition), migration, or inconsistencies in data collection. Ultimately, an unbalanced panel dataset comprising 1,967 rural households was successfully constructed.

The commercialization analysis is restricted to crop-producing households with complete information on market participation and quantity sold in rural Ethiopia, resulting in a smaller estimation sample. The analyses rely on unbalanced panel datasets, which is consistent with the structure of the Ethiopian Socioeconomic Survey, where attrition and missing observations occur across survey waves. The econometric model, the double-hurdle model and remain valid under unbalanced panel settings.

3.2. Econometrics Model Specifications and Variables Description

Dependent variable: Smallholder commercialization⁶, measured as the proportion of crop output sold by smallholders in a particular area. The binary dependent variable for estimating the probability of output market participation in the Tobit/Probit regression model takes the value of one, for a farmers that participate in crop output market, and zero for a smallholder farmers that did not participate. The outcome variable for the truncated regression model is the gross values of crop output sold, subject to the first decision to participate.

Independent variable: The key independent variable of interest is access to rural road transport. Access to rural road transport, measured as availability of all-weather road, in the rural area. A value of 1 is given for villages that have good road access and 0 for villages with poor road access. Although smallholder commercialization is influenced by multiple household, institutional, and environmental factors, this study focuses on rural road access as the primary variable of interest because of its role as an enabling infrastructure within the rural economy. Rural roads reduce transaction costs, improve market accessibility, and facilitate access to complementary services such as credit, extension, and input markets. While multiple factors influence market participation, this study isolates rural road access as the primary variable of interest in order to identify its independent contribution after controlling for household, institutional, and agro-ecological factors.

Control variables: These includes variables that are known to influence smallholder commercialization. Other independent variables included in the model specification are land size, access to credit, access to extension services, livestock's, quantity of output produced, off-farm income, and farm household agroecological, socio-economic, and demographic characteristics. The inclusion of variables such as irrigation access, credit availability, extension

⁶ Smallholder commercialization is the same as crop output market participations of farmers for this study.

services, off-farm income, and climatic conditions serves to control for other determinants of commercialization and isolate the marginal effect of road access. Therefore, the analysis does not assume that road access is the sole determinant of commercialization but rather evaluates its independent contribution within a broader system of complementary factors.

The concept of commercialization in this study is used to assess farmers participation mainly in the crop output market. Following Braun et al. (1994) and Strasberg et al. (1999), household crop output market participation for annual crops can be calculated as the ratio of the value of crop sales to the total value of crop production, expressed as a percentage by multiplying the result by 100. Accordingly, the commercialization index of smallholder farmers can be constructed using the following simple formula for data with a panel structure.

$$SHCI_{it} = \frac{\text{gross values of crop sales by hh } i \text{ in year } t}{\text{gross values of all crop production by hh } i \text{ in year } t} \times 100 \quad (1)$$

Where, $SHCI_{it}$ = smallholder crop output commercialization index.

There was no need for conversion, as the output quantities were already recorded in standard measurement. However, quantities originally reported in grams were converted into kilograms for consistency. The value of production in Ethiopian Birr (ETB) was then calculated using the following procedure. First, by dividing the total value of output sold by the corresponding quantity sold in the market, the unit price of each crop was calculated. Since crop-level data on both quantity and value of sales were available, this calculation was feasible. Once the unit price was obtained, it was multiplied by the amount of output produced to drive the total value of each crop produced (Mekonnen et al., 2017). For farmers who did not report any crop sales in the market, the mean village-level price of each crop was used to convert the quantity produced into its corresponding values. Finally, utilizing 2018 as the base year and CSA production pricing data, the nominal value of production was adjusted to real values to account for inflation.

3.2.1. The double hurdle model

The double-hurdle model was first developed or formulated by Cragg (1971). The model assumes that smallholder farmers make two sequential or independent decisions with regard to crop output market participation and levels of participation. The double-hurdle model helps to deal with survey data that has many zero observations in a continuous dependent variable (Gujarati, 1995). The model assumes that zero values can be reported in both decision stages. The zeros reported in the first stage arise from zero crop output market participation by

smallholder farmers, and those in the second hurdle come from zero levels of crop output market participation due to the farmer's deliberate decision or random circumstances. The potential for zero outcomes in the second hurdle may arise from the individual's intentional decision or random circumstances. Moreover, in the double hurdle model, it is assumed that the two residuals are jointly normal and either uncorrelated or independently distributed. The model also requires a joint application of the probit and truncated regression models, sequentially or simultaneously.

Following (Gujarati, 1995; Mekonnen et al., 2017; Tamir et al., 2015; Xu, 2008); Yami et al. (2013), this study adopted the same econometric approach to measure the impact of access to rural road transport on smallholder farmers crop output market participation in Ethiopia. The model is selected because it helps to identify factors influencing market participation and level of commercialization at the same time. The study used an independent double-hurdle model by assuming that output market participation and levels of output market participation of smallholder farmers are two independent, sequential, and not simultaneous decisions.

The theoretical foundation of the double-hurdle estimation framework as proposed by Cragg (1971) is based on the probit model where the probability of market participation at observation t , $p(Et)$, is expressed as:

$$P(Et) = \int_{-\infty}^{\beta'x_t} (2\pi)^{-\frac{1}{2}} \exp\{-Z^2/2\} dz \quad (3.1)$$

Where, X_t is a $K \times 1$ vector of exogenous variables at observation t and β represents a vector of parameter estimates. Then the cumulative unit normal distribution is designated as:

$$C(Z) = \int_{-\infty}^Z (2\pi)^{-\frac{1}{2}} \exp\{-t^2/2\} dt \quad (3.2)$$

The double hurdle model specification has two main parts: the first hurdle and the second hurdle. The first hurdle is a binary (a probit model) that examines whether or not a household or farmer engages in commercialization activities. The second hurdle is a truncated regression model that examines the determinants of the levels of commercialization conditional on having engaged in commercialization activities. In this model, a different latent variable is used to model each decision process. Each hurdle is conditioned by smallholder farmers demographic, socio-economic, and institutional characteristics. The Double hurdle model for crop output market participation decision and Levels of participation is specified as follows:

Output market participation decision equation:

$$Y_{1it} = X_{it}'\beta + c_{1i} + \varepsilon_{1it} \quad (3.3)$$

$$Y_{1it} = 1 \text{ if } Y_{it}^* > 0$$

$$Y_{1it} = 0, \text{ otherwise}$$

Where, Y_{1it} is the binary outcome variable indicating whether or not household i at time t engages in commercialization activities, Y_{it}^* is the latent variable for commercialization, which is a function of (X_{it}) , a set of independent variables, β is the vector of parameters to be estimated in the first hurdle.

It is expected that crop output market participation and the level of participation can be influenced by variation in agro-ecological conditions and other geographical factors. Therefore, regional dummy⁷ variables for Oromia and SNNP regional states are constructed and included among the explanatory variables. The Amhara region is excluded from the model and serve as a reference category in the analysis. Building on the econometric framework outlined above, the probit model for the crop output market participation decision (Mp_{it}) is specified as follows:

$$Pr(Mp_{it} = 1|X_t)$$

$$= \beta_0 + \beta_1 \text{AvaiRoad}_{it} + \beta_2 \text{LanSize}_{it} + \beta_3 \text{MktAcc}_{it} + \beta_4 \text{DisTown}_{it}$$

$$+ \beta_5 \text{LivOw}_{it} + \beta_6 \text{ShockNatu}_{it} + \beta_7 \text{FamSize}_{it} + \beta_8 \text{Sexhh}_i + \beta_9 \text{Agehh}_{it}$$

$$+ \gamma_i R_i + \varepsilon_{it} \quad (3.4)$$

Levels of output market participation equation:

$$Y_{2it} = Z_{it}'\alpha + c_{2i} + \varepsilon_{2it} \quad (3.5)$$

$$Y_{2it} = 1 \text{ if } Y_{it}^* > 0$$

$$Y_{2it} = 0, \text{ otherwise}$$

Where Y_{2it} is the continuous outcome variable representing the level of smallholder commercialization, Y_{it}^* is the latent variable for commercialization, which is a function of a set of independent variables (Z_{it}), α is the vector of parameters to be estimated in the second hurdle. The truncated regression model for determining the levels of crop output market participation is specified as follows:

⁷ Due to the 2021/22 ESPS wave not covering the Tigray region, the analysis excludes Tigray as a base category in regressions involving regional dummies. The remaining three regions were used to construct comparison groups, ensuring consistency across all survey waves.

$$\begin{aligned}
SHCI_{it} = & \alpha_0 + \alpha_1 \text{AvaiRoad}_{it} + \alpha_2 \text{LanSize}_{it} + \alpha_3 \text{AccExt}_{it} + \alpha_4 \text{DRoad}_{it} \\
& + \alpha_5 \text{AccCre}_{it} + \alpha_6 \text{AnnuRain}_{it} + \alpha_7 \text{OutPro}_{it} + \alpha_8 \text{OffInc}_{it} \\
& + \alpha_9 \text{AvailIrri}_{it} + \alpha_{10} \text{Sexhh}_i + \alpha_{11} \text{Agehh}_{it} + \alpha_{12} \text{MktAcc}_{it} \\
& + \beta_{13} \text{FamSize}_{it} + \varepsilon_{it}
\end{aligned} \tag{3.6}$$

The parameters estimate (α , β , and γ_i) accord the signs of the partial effects of the explanatory variables, X_{it} , Z_{it} , and R_i , on the probability of the outcome variables.

There are two error terms in the model specification. The first component refers to time-invariant unobserved heterogeneity, denoted by c_{1i} and c_{2i} in equations (3.3) and (3.5), respectively. These time-invariant individual characteristics influence both the decisions of households to participate in crop output markets and the quantity of output traded. Such factors may include preferences, land quality, the farmer's management ability, and risk aversion elements, that are typically unobservable or challenging to quantify due to their qualitative nature. The second component of the error term captures time-varying unobserved shocks that influence households' decision to participate in the market, and their crop output supply, denoted by ε_{1it} and ε_{2it} , respectively. To assess the impact of the regressors on the dependent variables, marginal effects were calculated from the double hurdle model.

The empirical model specification is guided by agricultural household models and transaction cost theory, which suggest that market participation decisions are influenced by market access and transaction costs, production capacity, and household socio-economic characteristics. Some theoretically relevant variables, such as transport costs, road quality, price expectations, and storage facilities, are not consistently available in the Ethiopian Socioeconomic Survey across survey waves and therefore could not be included without compromising panel consistency. Moreover, certain variables were excluded to avoid over-controlling for channels through which rural road access affects commercialization. Including such mediating variables could bias the estimated effect of infrastructure access. To maintain model parsimony and avoid multicollinearity among closely related institutional variables, only the most theoretically and empirically relevant proxies were retained.

Table 3.1: Definition of variables used in the crop output market participation and smallholder commercialization equations

Variables code	Definition of variables		Expected sign
Dependent variables			
Mp_{it}	Household participation in output market at time t	Dummy (1 = participated in crop output market, 0 = otherwise)	
SHC_{it}	Level of smallholder commercialization	Quantity of crop output marketed by household i at time t (kg or quintal)	
Independent variables			
AvaiRoad_{it}	Availability of all-weather road in village j at time t	Dummy (1 = access, 0 = otherwise)	+
LanSize_{it}	Land size (area) of the i^{th} household at time t	Hectares (ha)	+
AccExt_{it}	Access to extension service for the i^{th} household at time t	Dummy (1 = access, 0 = otherwise)	+
AccCre_{it}	Credit access availability for the i^{th} household at time t	Dummy (1 = access, 0 = otherwise)	+
MktAcc_{it}	Market access for the i^{th} household at time t	Dummy (1 = access, 0 = otherwise)	+
LivOw_{it}	Number of livestock owned for household i at time t	Tropical Livestock unit (TLU)	+
OutPro_{it}	Value of total output produced by the i^{th} household at time t	Ethiopian Birr (ETB)	+
OffInc_{it}	Off farm income of the i^{th} household at time t	Dummy (1 = yes, 0 = otherwise)	+
AvailIrri_{it}	Availability of irrigation access in village j at time t	Dummy (1 = yes, 0 = otherwise)	+

Sexhh_i	Sex of the i^{th} household	Dummy (1 = yes, 0 = otherwise)	-/+
Agehh_{it}	Age of the i^{th} household at time t	Years	+/-
DRoad_{it}	Distance from the road at time t	Kilometers	-
DisTown_{it}	Distance from the nearest town at time t	Kilometers	-
AnnuRain_{it}	Average annual rainfall 12 months before the survey at time t	Millimeters (mm/year)	-
FamSize_{it}	Family size of the i^{th} household at time t	Number of household members	-
R_{i1}	Dummy if household lives in Oromia region	1 = Oromia, 0 = otherwise	+/-
R_{i2}	Dummy if household lives in SNNP region	1 = SNNP, 0 = otherwise	+/-

Source: Compiled from various empirical literature, 2025

3.2.2. Controlling for unobserved heterogeneity

The first estimation issue is the existence of an unobservable individual heterogeneity effect. Given the dependent variables (crop-output market participation decision and level of smallholder commercialization) which are non-linear in nature, we cannot use the traditional standard methods like fixed effects to control for potential endogeneity problem (Wooldridge, 2011). Thus, the decision of households who produce agricultural output but did not sell anything is considered as rational economic agents in their decision and zero observations are included in the second hurdle (as smallholder commercialization is considered to be output sold divided by output produced, those households who produced but did not sell anything have zero commercialization index). Thus, zero is assigned to those who produce but did not sell. In this regard, the Craggit double hurdle model could be applied to panel data using a pooled estimator and clustering at the household level in order to control for possible autocorrelation of the error term within households (Burke, 2009). So, we can assume independence of errors because the zeros are real values rather than unobserved (Burke, 2009).

In order to estimate a consistent result in panel data setting, the explanatory variables must not be correlated with the time-constant unobserved term (α_i) that is, we have to control for unobserved heterogeneity (Wooldridge, 2011). In a panel data set, the fixed-effect model can fix the problem of unobservable heterogeneity through the demeaning procedure. However, the fixed-effect model is a workforce for linear models and is not applicable to the nonlinear model due to the

incidental parameter problem (Verkaart et al., 2017; Wooldridge, 2011). For non-linear panel data models, a correlated random effect (CRE), which is the work of (Chamberlain, 1982; Mundlak, 1978), is used and eases the assumption of strict exogeneity (Ricker-Gilbert et al., 2011).

The CRE consists of a vector of variables containing the means of all time varying covariates for each household (Burke et al., 2014). These additional control covariates have the same value for each household during the period under study but vary across households (Burke et al., 2014). Their coefficients account for the differences between households over the entire period (due to unobservable time constants), while the coefficients of the time varying covariates explain the within household effects or simply the effect of a deviation from the household average over time (Burke et al., 2014). In estimation, variables that are the same for each household are excluded from $\mathbf{x}_i$. In the first stage, the model is estimated using CRE probit by controlling for those unobserved effects. The second stage of the model is executed with a CRE truncated regression. A truncated regression is a linear estimation of parameters with a dependent variable that is limited at some value. The truncated regression is estimated on only the households with greater than zero market participation indexes.

The CRE approach expresses the unobservable heterogeneity variable (C_i) in the output market participation equation as a function of the mean of the time-variant variables denoted by $\mathbf{X}_i$ and the intercept (ϑ_0) and the error term assumed with zero mean and constant variance (U_i) (Wooldridge, 2011):

$$C_i = \vartheta_0 + \varpi \bar{X}_i + u_i \quad (3.7)$$

Finally, following the work of (Mekonnen et al., 2017; Ricker-Gilbert et al., 2011), the Craggit double hurdle model that considers the CRE Probit and truncated Tobit models is presented in the following equation.

$$Pr(Mp_{it} = 1 | X_t = \beta_1 x_i + \gamma_1 \bar{X}_i + \varepsilon_i) \quad (\text{Market participation equation}) \quad (3.8)$$

$$SHCI_i = \rho + \beta_2 x_i + \gamma_2 \bar{X}_i + \varepsilon_i \quad (\text{smallholder commercialization index}) \quad (3.9)$$

Where Mp_{it} is the decision to participation in market, equal to **1** if the household chose to participate in the market and equal to **0** otherwise, and,

$SHCI_i$ is the commercialization index that takes values between 0 and 100.

x_i is the set of all explanatory variables common to both hurdle;

ρ is the constant intercept estimated in second hurdle;

β_1 is the set of coefficients estimated on x_i in first hurdle;

β_2 is the set of coefficients estimate on x_i in second hurdle;

γ_1 is the set of coefficients estimated on mean values in hurdle 1;

γ_2 is the set of coefficients estimated on mean values in hurdle 2.

3.2.3. Endogeneity test for Craggit double hurdle model

In order to make the result of the study more robust and consistent, the model for output market participation and smallholder commercialization should be strictly exogenous (Woodridge, 2010). Otherwise, the estimates will still be inconsistent if the independent variables are correlated with unobservable time-varying shocks. So, we have to also test endogeneity. Endogeneity would occur if unobserved factors affecting output market participation affect the level of commercialization (Mekonnen et al., 2017; Ricker-Gilbert et al., 2011; Woldeyohanes et al., 2017; Woodridge, 2010). The possible way of solving the endogeneity sourced from unobservable time-varying heterogeneity is using the instrumental variable method. Alternatively, for a nonlinearly endogenous regressor, a control function approach (CFA) relies on the same kind of identification conditions (Woodridge, 2010).

The study applied the control function approach (CFA) to test and control for potential endogeneity problem in the Craggit estimation. As (Mekonnen et al., 2017; Woldeyohanes et al., 2017) indicated, there could be potential simultaneity of off-farm income, (which is one of the explanatory variables of market participation or level commercialization) with crop output market participation decision and the level of commercialization. For example, while smallholder level of commercialization could be affected by off-farm earnings, increased income as a result of high level of commercialization could also help farmers to overcome financial constraints and engage in own off-farm business that would probably increase off-farm income. In this case, off-farm income is likely to be endogenous and correlated with unobserved time varying shocks (Woldeyohanes et al., 2017).

To test for endogeneity of off-farm income, one needs to estimate the reduced-form model from which the residuals can be extracted. The reduced-form model for off-farm income is estimated using Tobit model. The CFA requires an instrumental variable (IV) to be used in a reduced-form model but excluded from the structural model of crop output market participation and levels of commercialization. The instrumental variable (IV) should be correlated with the potentially endogenous variable (off-farm income) but should not be correlated with unobserved time

varying shocks in the structural model. For this purpose, household labor supply (family size as proxy variable) was used in adult equivalent unit as an instrumental variable (IV) in the reduced form model (Mekonnen et al., 2017). Household labor supply measures the amount of labor available to participate in off-farm work and determines earnings from off-farm source.

The strength of this instrumental variable was checked by using the partial correlation in the reduced form model. If there is strong partial correlation between family size (household labor supply) and potentially endogenous off-farm income, we can test the endogeneity of off-farm income using the control function approach. In order to do so, the residuals from the reduced model were included as covariates in hurdle one (output market participation decision) and in hurdle two (the level of commercialization). In the CFA, the test of endogeneity is the statistical significance of the coefficient of the residual in both decision models (Woldeyohanes et al., 2017). The null hypothesis is: there is no correlation between off-farm income and the error terms in the structural models. The result shows there is no strong partial correlation between labor supply and potentially endogenous off-farm income which is statistically insignificant. Thus, we feel confident that labor supply is not a strong and valid instrument for potentially endogenous variable, off-farm income.

4. Result and Discussion

4.1. Descriptive Results

Table 3.2: Summary statistics for continuous variables used in the analysis

Variables	Obs	Mean	Std. dev	Min	Max
Commercialization index	1967	6.55	8.52	0	31.01
Distance to Road (KM)	1,967	12.92	14.104	0	80.1
Distance to Town (KM)	1,967	36.38	186.46	0	2020
Age of household head (Year)	1,967	39.75	16.68	19	97
Household size (number)	1,967	4.657	1.982	1	13
Livestock owned (TLU)	1,967	3.827	4.451	0	54.8
Land size (Hectar)	1,967	0.464	7.572	0.0001	1471
Total quantity of crop Harvested (KG)	1,967	3035	234.5	0	15150
Average annual rainfall (mm)	1,967	945.13	276.04	211	1646

Source: Authors computation based on Ethiopian socio-economic survey data, 2025

Based on panel data from 1,967⁸ smallholder farmers, the summary statistics of dummy variables included in the analysis are presented in **Table 3.2**. Though it varies significantly across households, the smallholder commercialization index has an average of 6.55. Some farmers are highly commercialized as the maximum index value of 31.01 suggests. With a considerable variation, on average, households are located 12.92 km from the nearest road, while the average distance to the nearest town is 36.38 km. However, the large standard deviation indicates a highly skewed distribution.

The average age of the household head is 39.75 with a relatively high variation. On average, households have 4.66 members, with some households as small as 1 member. Households own an average of 3.83 tropical livestock units, with significant variation. The average landholding of

⁸ The number of observations is not that large, because the study only considers rural smallholder farm households and the absence of some households in the second round due to conflict in northern Ethiopia (non-random attrition).

a household is around 0.46 hectares, but with a high standard deviation indicating the presence of a few large landholders skewing the distribution. Smallholder farmers harvest an average of 3,035 kg of crop per year, with a significant variation suggesting considerable disparity in production levels. There is also regional climatic variability in rural Ethiopia since the average annual rainfall is 945.13 mm with a range from 211 mm to 1646 mm.

Table 3.3: Summary statistics for Dummy and categorical variables used in the analysis

Variable	Category	Frequency	Percent	Cumulative (%)
Market participation	Non participant	1,356	68.94	68.94
	Participant	611	31.06	100.00
Rural road access	No access	728	37.01	37.01
	Access	1,239	62.99	100.00
Market access	No access	963	48.96	48.96
	Access	1,004	51.04	100.00
Gender	Female	1,034	52.57	52.57
	Male	933	47.43	100.00
Oromia (Dummy)	No	945	48.44	48.44
	Yes	1,022	51.66	100.00
SNNP (Dummy)	No	1,573	80.74	80.74
	Yes	394	20.26	100.00
Natural shock occurrence	No	1,530	77.78	77.78
	Yes	437	22.22	100.00
Off-farm income	No	1,525	77.53	77.53
	Yes	442	22.47	100.00
Credit access	No access	1,829	92.98	92.98
	Access	138	7.02	100.00
Extension participation	Not participate	1,216	61.82	61.82

Variable	Category	Frequency	Percent	Cumulative (%)
Irrigation access	Participate	751	38.18	100.00
	No access	844	42.91	42.91
	Access	1,123	57.09	100.00
Year-2022	2019	1,086	55.21	55.21
	2022	881	44.79	100.00

Source: Authors computation based on Ethiopian socio-economic survey data, 2025

Based on panel data from 1,967 smallholder farmers, the summary statistics of dummy and categorical variables included in the analysis are presented in **Table 3.3**. Around 31% of these farmers participate in the crop output market, indicating that the majority of rural households are not engaged in crop marketing. Approximately 63% of households in rural Ethiopia have access to an all-weather road, indicating a moderate level of connectivity. Furthermore, about 51.07% of households have access to the market. There is near gender parity among household heads because about 47.43% of the households are male-headed. The result suggests a geographical diversity because more than 50% of the households in the sample are located in Oromia, followed by SNNP (20%), while the remain are from another region included in the sample. The result of the study shows that 22.22% of households experience a natural shock, like drought and flood, and around 22.47% of households have off-farm income sources.

The result of the study also highlights a potential constraint on financial resources in rural Ethiopia because only 7.02% of households have access to credit. Furthermore, the study indicates a moderate access to agricultural support programs, with 38.18% of households participating in extension services activities. With 57.09% of households having accessibility, access to irrigation for smallholder farmers is relatively high.

Table 3.4: Mean comparison of continuous variables by survey year

Variables	2022	2019	Difference	P-value
	N = 881	N = 1086	(1) - (0)	
Distance to Road (KM)	8.125	17.63	-9.506	0.0000 ***
Distance to Town (KM)	17.34	35.37	-18.02	0.0019***
Age of household head (Year)	49.48	48.74	1.649	0.0315**
Household size (number)	5.094	4.192	0.901	0.0000***
Livestock owned (TLU)	3.715	4.132	-0.416	0.0821*
Land size (Hectar)	2.754	0.900	1.853	0.239
Total quantity of crop harvested (KG)	4133	2826	1307	0.0361***
Average annual rainfall (mm)	1025.6	866.2	159.4	0.0000***

p<0.05, *p<0.01, *p<0.001.

Source: Authors computation based on Ethiopian socio-economic survey data, 2025

The comparison of the mean values of continuous variables⁹ used in the analysis between the survey years 2022 and 2019 is presented in **Table 3.4** above. The result suggests a significant improvement in rural road infrastructure and proximity to roads over the survey period. The average distance to the nearest road was 8.13 km in 2022 and 17.63 km in 2019. Furthermore, there is improvement in accessibility to towns over time, which may be due to better transportation networks or changes in household locations. In 2022, households are 17.35 km away from a town and 35.37 km away in 2019, on average.

The average age of a household head increased slightly from 48.74 in 2019 to 49.48 in 2022 perhaps due to a slight aging of the surveyed population. But household size increased significantly from 4.19 members in 2019 to 5.09 members in 2022, indicating either changes in survey coverage or household expansion. The result indicates an improvement in agricultural productivity and conditions in 2022 because smallholder farmers harvested an average of 4,134 kg of crops in 2022, and 2,826 kg in 2019. Moreover, average rainfall was significantly higher in 2022 relative to 2019, potentially contributing to improved agricultural outcomes like higher crop harvests.

⁹ We used a paired T-test to compare the mean values of continuous and dummy variables between survey periods.

Table 3.5: Mean comparison of dummy variables by survey year

Variables	2022	2019	Difference	P-value
	N = 881	N = 1086	(1) - (0)	
Road access (= 1 if access all weather)	0.608	0.647	-0.038	0.0754*
Market access (= 1 if access to market)	0.523	0.5	0.023	0.3048
Gender (= 1 if head is male)	0.474	0.474	0.000	0.991
Oromia (Dummy if household lives in Oromia region)	0.267	0.173	0.094	0.0000***
SNNP (Dummy if household lives in SNNP region)	0.194	0.143	0.050	0.0028**
Off farm income (= 1 if yes)	0.280	0.179	0.100	0.0000***
Natural shock (= 1 if yes)	0.257	0.193	0.064	0.0000***
Access to credit (= 1 if yes)	0.077	0.064	0.012	0.2720
Extension service access (=1 if yes)	0.328	0.425	-0.097	0.0000***
Irrigation access (= 1 if yes)	0.582	0.561	0.020	0.3589

p<0.05, *p<0.01, *p<0.001.

Source: Authors computation based on Ethiopian socio-economic survey data, 2025

Table 3.5 compares the mean value of the dummy variables used in the analysis between survey periods. With 60.84% of households having access to an all-weather road in 2022 and 64.73% in 2019, there was no substantial difference in road access between the survey periods. Moreover, road access declines overtime, perhaps due to the reason that Tigray region (which is relatively good in rural road access) was not in the survey round 2021/22 due to conflict (non-random attrition). In the Oromia region, the proportion of sampled households increased from 17.31% to 26.79% in 2019 and in 2022, respectively, suggesting an increase in survey coverage. Furthermore, the proportion of sampled households increased from 14.36% to 19.41% in the SNNP region, indicating larger representation from this region in 2022.

There was a rise in adverse environmental events as the proportion of smallholder farmers experiencing natural shocks increased from 19.34% in 2019 to 25.77% in 2022, and there was also a growth in diversification of income sources over time because the proportion of off-farm income sources increased from 17.96% in 2019 to 28.04% in 2022. Moreover, households

participating in extension services decreased from 42.54% in 2019 to 32.80% in 2022, indicating the decline in engagement with or availability of agricultural extension programs.

Table 3.6: Mean comparison of smallholder commercialization index and market participation by survey year

Variables	2022	2019	Difference	P-value
	N = 881	N = 1086	(1) - (0)	
Commercialization index	7.399	5.739	1.660	0.0000***
Market participation	0.347	0.280	0.066	0.0000***

p<0.05, *p<0.01, *p<0.001.

Source: Authors computation based on Ethiopian socio-economic survey data, 2025

Table 3.6 shows a change in the structure of the rural economy in Ethiopia between 2019 and 2022 that has a positive impact on smallholder farmers market engagement and commercialization. On average, the commercialization index of smallholder farmers was 7.4 in 2022 and 5.74 in 2019, indicating a substantial increase in smallholder farmers market participation over time. This suggests that smallholder' farmers sold a larger proportion of their agricultural produce in 2022, perhaps due to an improvement in market access, better production conditions, or any other economic incentives. Households' participation in the crop output market increases from 28% to 34.7% in 2019 and in 2022, respectively, indicating that the number of smallholders engaged in market activities has raised. This may be due to different factors such as enhanced rural infrastructure, better market integration, or increased production surplus.

4.2. CRE Double Hurdle Model Estimation Results

4.2.1. Estimation issues

4.2.1.1. Accounting for unobservable heterogeneity

The first estimation issue is the existence of an unobservable individual heterogeneity effect. In order to estimate a consistent result in a panel data setting, the explanatory variables must not be correlated with the time-constant unobserved term; that is, we have to control for unobserved heterogeneity (Wooldridge, 2011). The correlated random effect (CRE) approach has been used to control unobserved heterogeneity by incorporating time-averaged variables. The intention is to account for the influence of time-invariant factors on the outcome and selection equations by

adding the averaged values of time-varying variables. The result¹⁰ shows that time-averaged variables do not significantly contribute to explaining participation and commercialization. Therefore, removing time-averaged variables from the model improves estimation efficiency by reducing collinearity and complexity. Since time-averaged variables are not jointly significant, a standard random effects model (without CRE adjustments) is sufficient.

4.2.1.2. Accounting for the endogeneity problem

Although the correlated random effect (CRE) specification accounts for time-invariant factors, participation in the crop output market may still be endogenous due to potential correlation with unobserved time-varying heterogeneity. To test for endogeneity of rural road access, we have used the control function approach with a variable distance to asphalt road as an instrumental variable (IV). This is because of the following reasons: First, as road networks typically branch out from major roads, households located far away from an asphalt road are less likely to have access to all-weather roads. Second, governments and development agencies often prioritize road construction near existing asphalt roads, making distance a strong predictor of rural road access. Third, except through its impact on rural road access, distance to an asphalt road cannot directly affect smallholder commercialization. While proximity to an asphalt road may influence factors such as market access, we control for these effects by including variables like market access, household characteristics, and shocks in our estimation model. The remaining endogeneity is accounted for by including the residuals from the one-step Tobit regression¹¹ in the second stage of the control function approach.

Distance to asphalt road is significantly correlated with road access but not directly with commercialization. We estimated the reduced-form model, from which the residuals were subsequently derived. The instrumental variable distance to asphalt road is negative and highly significant ($p = 0.001$), meaning that greater distance from an asphalt road decreases the probability of having rural road access, which indicates that distance to asphalt road is correlated with road access and a valid IV. Therefore, the data provide evidence to reject the null hypothesis of no correlation between access to rural road transport and the error terms in the structural models. Accordingly, we estimated the double hurdle model, incorporating the residual

¹⁰ The estimation result of Wald test for Joint significance test for time-averaged variables is presented in the appendix section.

¹¹ The One-step Tobit estimator results from the reduced-form model, which examines the factors influencing levels of smallholder commercialization are presented in the appendix section.

term as additional covariate. The residual from the reduced form model is included as an additional covariate in Tier 2 (second hurdle), and its coefficient is statistically significant ($p = 0.000$). This result confirms the endogeneity of rural road access in the outcome equation. The residual from the one-step Tobit regression is included, and it has a strong negative impact on the second hurdle, indicating that the base model likely suffered from endogeneity. The instruments appear to be strong, as the F-statistic¹² is above the conventional threshold of 10, and the minimum eigenvalue statistic suggests the instruments are relevant.

Moreover, we conducted a validity check for the exogeneity of the instrument (distance to asphalt road), and the result confirmed that the instrument is uncorrelated with the error term in the model. To test whether adding the residuals significantly improves the fit of the Craggit double hurdle model, we used the likelihood ratio (LR) test¹³ to compare the restricted and unrestricted models, indicating that the difference between the two models is statistically significant. This suggests that including the residuals in the second-stage equation significantly improves the fit of the Craggit double hurdle model.

¹² See the F-static of the one-step-Tobit estimation result in the appendix section.

¹³ See the likelihood ratio test in the appendix section.

Table 3.7: Marginal effect estimates of variables used in the independent¹⁴ double-hurdle model

Variables	With endogenous variable		Without endogenous variable	
	Tier I: probability of participation	Tier II: extent of Participation	Tier I: probability of participation	Tier II: extent of participation
Road access (dummy)	0.051(0.02) **	7.384(3.38) **	0.051(0.022) **	0.006(0.01) *
Distance to Road (KM)		-1.614(0.34) ***		-0.000(0.00) ***
Distance to Town (KM)	0.000(0.00) ***		0.000(0.00) ***	
Market access (dummy)	0.062(0.02) ***	-6.71(3.19) **	0.062(0.02) ***	-0.004 (0.00)
Gender (dummy)	0.020(0.02)	-1.986(3.10)	0.020(0.02)	0.002(0.00)
Age (Year)	0.000(0.00)	0.086(0.89)	0.000(0.00)	0.000(0.00)
Household size (No)	0.007(0.00)	0.840(0.78)	0.007(0.00)	-0.000(0.00)
Oromia (Dummy)	0.131(0.03) ***		0.131(0.03) ***	
SNNP (Dummy)	0.284(0.03) ***		0.284(0.03) ***	
Livestock (TLU)	-0.002(0.00)		-0.002(0.00)	
Land size (Hectar)	0.001(0.00)	-0.09(0.02) ***	0.001(0.00)	-0.000(0.00)
Total quantity (KG)		0.022(0.00) ***		0.000(0.00) ***
Natural shock (dummy)	-0.054(0.02) **		-0.054(0.02) **	
Off farm income (dummy)		-6.231(3.74) *		-0.002(0.01)
Access to credit (dummy)		-22.170(8.91) **		-0.007(0.02)
Extension access (dummy)		-17.76(4.26) ***		-0.009(0.02) **
Irrigation access (dummy)		10.474(4.21) **		-0.001(0.00)
Average rainfall (mm)		0.014(0.00)		-0.000(0.00) ***
Year dummy	0.111(0.02) ***	-25.47(7.37) ***	0.111(0.02) ***	0.002(0.01)

p<0.05, *p<0.01, *p<0.001. Numbers in parentheses are robust standard errors.

Source: Authors computation based on Ethiopian socio-economic survey data, 2025

The double hurdle model states that the extent of participation in the crop output market needs to be estimated on the condition of the likelihood of participation. This proposes that farmers participation decisions are sequential: first determining whether to participate, followed by

¹⁴ To test independence assumption, we run Heckman two step approach (see in the appendix section).

deciding the extent of commercialization. Furthermore, the model permits a given variable to have different explanatory power across the first and the second hurdle. This suggests that a variable significantly influencing the first hurdle may not have a significant effect in the second, supporting the assumption that the decision to participate and extent of participation are determined through separate process. The errors in the participation equation and the intensity equation are uncorrelated, and the factors influencing each decision are completely separate in the independent double hurdle model.

Table 3.7 presents the estimation results from the independent double hurdle model of factors influencing farmers' decision to participate in the crop output market and levels of participation. The results are presented both with and without the inclusion of endogenous variables for comparison. This approach is employed to test the robustness of the model estimation and to assess whether the exclusion of endogenous variables affects model results. Accordingly, the exclusion of endogenous variables alters the result, and as a result, the interpretation of the findings relies solely on strictly exogenous variables.

In both models (with and without the endogenous variable), rural road access positively and significantly increases the probability of smallholder farmers output market participation (5.1%). Thus, the probability of participating in crop output market increases by 5 percentage points for smallholder farmers in villages with good road access as compared to smallholder farmers in villages with poor access. It also has a positive and significant effect on the extent of participation (the volume of crop output sold) (7.38%). Thus, the commercialization index for smallholder farmers with access to all weather roads is 7.38 percentage points above the commercialization index of farmers who have no good access to all weather roads. This may be due to the fact that the volume of sales depends on smallholder farmers production capacities, access to institutional services, market conditions, and other complementary factors such as irrigation and household consumption strategies. Rural road access increases smallholder commercialization by 7.38% when the endogenous variable is accounted for, but this effect decreases to 0.6% when endogeneity is not taken into account. This suggests that better road access lowers barriers to market entry and facilitates greater market engagement. This result is consistent with the findings of (Gebremedhin et al., 2010; Mekonnen et al., 2017; Tadesse, 2020;

Tamene et al., 2017). However, Tadesse (2020) has addressed the issue using zone¹⁵-specific data and did not use national data.

The study also found that participation and the degree of participation in the crop output market are influenced by market accessibility, credit accessibility, access to extension services, availability of irrigation facilities, off-farm income, natural shocks, land size, total quantity of output produced, and rainfall availability. Furthermore, regional dummies and dummies for survey periods influence farmers market participation and the extent of participation.

Even though access to the market has a positive and significant impact on the probability of market participation (6.2%), for the model with the endogenous variable, it has a negative effect on the amount sold (-6.71%). This suggests that while access to markets encourages participation, farmers may sell smaller quantities due to transaction costs or market imperfections. This result is also consistent with the findings of Gebremedhin et al. (2010). Households far away from a road supply a lower amount of output to the market (-1.61% per additional km). This confirms that smallholder farmers ability to sell their output reduced because of physical distance. As the distance to town increases (a positive but small effect), market participation increase.

Access to credit negatively affects the extent of participation (-22.17%). This unexpected result may indicate that households having credit access prioritize direct consumption over commercialization on agricultural production. The finding is consistent with the finding of Mekonnen et al. (2017) and inconsistent with the findings of Tadesse (2020). Furthermore, the amount of crop output sold is negatively affected by access to extension service (-17.76% with endogeneity and -0.9% without endogeneity). This indicates that the focus of extension services might be on production rather than marketing. This result is inconsistent with the work of Tadesse (2020) and Woldeyohanes et al. (2017) and consistent with the finding of Mekonnen et al. (2017). In the model with endogeneity, irrigation access increases the amount of crop output sold (10.47%), highlighting a critical role of irrigation in smallholder commercialization.

The probability of participation in the crop output market is larger for smallholder farmers in the Oromia, and SNNP regions compared to the Amhara region, with the largest proportion for the SNNP region (28.4%). This could be due to the fact that variation in infrastructure, market access

¹⁵ In the country's governance structure, Zone is an administrative division that falls below a region and above a district.

institutional supports, and the agro-ecological zones of the regions are more favorable for agricultural production. This result is consistent with the findings of Woldeyohanes et al. (2017). The occurrence of natural shocks negatively affects market participation (-5.4%), showing that natural shocks reduce the capacity to produce marketable output and reduce commercialization. Furthermore, off-farm income affects the extent of market participation negatively in the model with the endogenous variable (-6.23%), suggesting income diversification may reduce dependence on crop sales. This may be because of the reason that households use off-farm income for consumption purpose rather than production. This finding is consistent with the work of Woldeyohanes et al. (2017) and inconsistent with the work of Mekonnen et al. (2017). Land size has a negative effect on sales (-9.96%), implying that larger landholders may focus on subsistence farming or other crops that are not primarily for sale. This finding consistent with the work of (Tadesse, 2020) and inconsistent to that of Woldeyohanes et al. (2017) and Mekonnen et al. (2017). The total quantity of output produced has a strong positive effect on the amount of output sold (2.24%), confirming that output levels determine commercialization and higher output facilitates greater commercialization. This result contradicts that of Mekonnen et al. (2017), who found that the level of output had a negative and statistically significant effect on the commercialization smallholder farmers in Ethiopia. The result of the endogenous model indicates that rainfall availability affects smallholder market participation negatively, reflecting that weather variabilities have an impact on market participation. The probability of market participation increases (11.1%) but a reduction in the amount sold (-25.47%) over the year in the endogenous model. This suggests that while more farmers entered markets over time, they sold smaller quantities, possibly due to seasonality and crop availability, market conditions, consumption pattern, and policy shifts or external economic conditions. This result is consistent with the findings of Woldeyohanes et al. (2017).

5. Conclusion and Policy Implication

The descriptive statistics result shows that approximately 54.35% of households in rural Ethiopia have access to an all-weather road, indicating a moderate level of connectivity, and with 60.84% of households having access to an all-weather road in 2022 and 64.73% in 2019, there was no substantial difference in road access between the survey periods. The study finds that road access significantly improves market participation and the extent of commercialization, though the effect on sales is small. This indicates that better road access lowers barriers to market entry and

facilitates greater market engagement. However, increasing the volume of sales depends on other constraints in addition to rural road transport. Therefore, there should be investments in market infrastructure, access to institutional supports, agricultural productivity, irrigation, and climate-smart agriculture by the Ministry of Agriculture to help farmers produce more and supply output to the market.

The study also indicates that access to credit, extension services, and off-farm income negatively affects smallholder commercialization. The existence of these institutional barriers needs wider policy attention to link smallholder farmers and the output market. Market extension agents and agricultural development agents should address institutional bottlenecks to enhance market engagement. The potential option may be expanding and strengthening institutional support services to intensify agricultural production. The study indicates that natural shocks remain key constraint. The occurrence of natural shocks negatively affects market participation, showing that natural shocks the capacity to produce marketable output and reduce commercialization. Therefore, expanding climate-smart agriculture and irrigation facilities and promoting resilience-building strategies, like insurance against natural shocks, can make smallholder farmers more resilient to natural shocks. In the same manner, the result of the study also indicates that rainfall availability affects smallholder market participation negatively, reflecting that weather variabilities have an impact on market participation. Thus, encouraging income diversification and risk management strategies by Ethiopian agricultural insurance program could enable smallholder farmers to resist and overcome unpredictable weather conditions.

The finding of this study indicates that the probability of participation in the crop output market is larger for smallholder farmers in the Oromia, and SNNP regions compared to the Amhara region, with the largest proportion for the SNNP region (28.4%). This could be due to the fact that variation in infrastructure, market access, institutional supports, and the agro-ecological zones of the regions are more favorable for agricultural production. Government should prioritize targeted infrastructure development in regions with lower participation, such as expanding rural infrastructure, enhancing market access, promoting irrigation and modern agricultural technologies, and providing institutional supports. Furthermore, regional governments could design region-specific policies that can enhance crop output market participation.

6. Limitations

This study acknowledged the existence of survey coverage missing in the Ethiopian Socioeconomic Panel Survey (ESPS) of 2021/22 (non-random attrition) due to conflict in northern Ethiopia. Therefore, we cannot make inferences specifically about Tigray or any region in comparative analyses involving it in 2021/22. This study is limited to analyze the impact of rural road access on smallholder commercialization using panel two of Ethiopian socioeconomic survey data.

7. Area for Further Study

There is a need for further research to analyze whether the impact of rural road access changed over time and across different household cohorts using both panels. Future studies should include non-economic rural livelihood outcomes like education and health indicators. Moreover, future impact evaluation studies would further explore how communication and information technologies interact with road access to influence smallholder commercialization in Ethiopia.

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Appendix A2

Figure 1-A2: Wald test for Joint significance test for time-averaged variables

```
. test avg_age avg_hhsize avg_shock_natural avg_total_tlu avg_totalharvest_Q avg_irrig_access avg_credit_access avg_ext_parti avg_
> income_source Avgannual_rainfall
```

```
( 1) [Tier1]avg_age = 0
( 2) [Tier2]avg_age = 0
( 3) [Tier1]avg_hhsize = 0
( 4) [Tier2]avg_hhsize = 0
( 5) [Tier1]avg_shock_natural = 0
( 6) [Tier1]avg_total_tlu = 0
( 7) [Tier2]avg_totalharvest_Q = 0
( 8) [Tier2]avg_irrig_access = 0
( 9) [Tier2]avg_credit_access = 0
(10) [Tier2]avg_ext_parti = 0
(11) [Tier2]avg_income_source = 0
(12) [Tier2]Avgannual_rainfall = 0
```

```
chi2( 12) = 19.21
Prob > chi2 = 0.0836
```

Source: Authors computation based on Ethiopian socio-economic survey data, 2025

Table 1-A2: Factors affecting extent of smallholder commercialization using one step Tobit estimator-reduced form model

Variables	Coefficient	Std. errs.	P> t
Distance to Asphalt (KM)	-.0017594	.0005117	0.001
Distance to Road (KM)	-.0039628	.0008545	0.000
Market access (dummy)	-.0117622	.0213271	0.581
Gender (dummy)	-.0187154	.021256	0.379
Age (years)	.000259	.0006378	0.685
Household size (No)	.0048137	.0053784	0.371
Total quantity (KG)	4.74e-06	.0000774	0.951
Land size (Hectar)	-.0002729	.0003058	0.372
Off-farm income (Dummy)	-.0190999	.0257505	0.458
Access to credit (Dummy)	-.0683307	.0426013	0.109
Extension access (Dummy)	-.0497379	.0229948	0.031
Irrigation access (Dummy)	.0455708	.0223141	0.041
Average rainfall (mm)	.0002019	.0000368	0.000
Year (dummy)	-.124298	.0242127	0.000

_cons	.5759153	.0532037	0.000
Var (e. road access)	.2207432	.0070388	
Number of Obs = 1,967		Pseudo R2 = 0.0395	
LR chi2(14) = 107.37		Prob > chi2 = 0.0000	

Note: *, **, *** indicates that the corresponding coefficients are significant at the 1%, 5%, and 10% levels, respectively.

Source: Authors computation based on Ethiopian socio-economic survey data, 2025

Figure 2-A2: Instrument relevance test using F-test

First-stage regression summary statistics

Variable	R-sq.	Adjusted R-sq.	Partial R-sq.	F(1,1946)	Prob > F
dummy_road	0.1136	0.1045	0.0074	14.578	0.0001

Minimum eigenvalue statistic = 14.578

Critical Values # of endogenous regressors: 1
H0: Instruments are weak # of excluded instruments: 1

	5%	10%	20%	30%
2SLS relative bias	(not available)			
2SLS size of nominal 5% Wald test	16.38	8.96	6.66	5.53
LIML size of nominal 5% Wald test	16.38	8.96	6.66	5.53

Source: Authors computation based on Ethiopian socio-economic survey data, 2025

Figure 3-A2: Likelihood ratio test for residuals

```
. lrtest restricted unrestricted
```

Likelihood-ratio test

Assumption: restricted nested within unrestricted

LR chi2(1) = 20.71

Prob > chi2 = 0.0000

Source: Authors computation based on Ethiopian socio-economic survey data, 2025

Figure 4-A2: Marginal effects on the probability of market participation

```
. margins, dydx(dummy_road distance_districttown mkt_access dummy_gender age hhsz dummy_amhara dummy_oromia dummy_snp shock_natu
> ral total_tlu land_hectares year_2022) expression(normal(xb(Tier1)))
```

Average marginal effects
Model VCE: Robust

Number of obs = 1,967

Expression: normal(xb(Tier1))

dy/dx wrt: dummy_road distance_districttown mkt_access dummy_gender age hhsz dummy_amhara dummy_oromia dummy_snp
shock_natural total_tlu land_hectares year_2022

	Delta-method					
	dy/dx	std. err.	z	P> z	[95% conf. interval]	
dummy_road	.051846	.0225788	2.30	0.022	.0075924	.0960995
distance_districttown	.0002182	.0000487	4.48	0.000	.0001227	.0003136
mkt_access	.0621546	.0210402	2.95	0.003	.0209166	.1033925
dummy_gender	.0196604	.0209411	0.94	0.348	-.0213835	.0607043
age	.0003256	.0006255	0.52	0.603	-.0009003	.0015515
hhsz	.0069526	.0054177	1.28	0.199	-.0036659	.0175712
dummy_amhara	.0808955	.0324823	2.49	0.013	.0172313	.1445596
dummy_oromia	.131062	.0271247	4.83	0.000	.0778986	.1842255
dummy_snp	.2843635	.0317691	8.95	0.000	.2220972	.3466298
shock_natural	-.0542961	.0253362	-2.14	0.032	-.1039541	-.0046381
total_tlu	-.002161	.0019102	-1.13	0.258	-.0059048	.0015829
land_hectares	.0015335	.0012755	1.20	0.229	-.0009664	.0040333
year_2022	.1098372	.0214765	5.11	0.000	.0677441	.1519304

Source: Authors computation based on Ethiopian socio-economic survey data, 2025

Figure 5-A2: Marginal effects on the latent outcome variable conditional on passing Tier 1

```
. margins, dydx(dummy_road dist_road residuals mkt_access dummy_gender age hhsz totalharvest_Q land_hectares income_source credi
> t_access ext_parti irrig_access Avgannual_rainfall year_2022) predict(e(Tier2))
```

Average marginal effects
Model VCE: Robust

Number of obs = 1,967

Expression: Linear prediction, predict(e(Tier2))

dy/dx wrt: dummy_road mkt_access dummy_gender age hhsz land_hectares year_2022 dist_road residuals totalharvest_Q
income_source credit_access ext_parti irrig_access Avgannual_rainfall

	Delta-method					
	dy/dx	std. err.	z	P> z	[95% conf. interval]	
dummy_road	7.384948	3.385373	2.18	0.029	.7497382	14.02016
mkt_access	-6.710805	3.199074	-2.10	0.036	-12.98088	-.4407348
dummy_gender	-1.986645	3.108639	-0.64	0.523	-8.079465	4.106175
age	.0861898	.0890228	0.97	0.333	-.0882917	.2606713
hhsz	.8407125	.7822201	1.07	0.282	-.6924107	2.373836
land_hectares	-.099604	.0275952	-3.61	0.000	-.1536895	-.0455185
year_2022	-25.47332	7.370571	-3.46	0.001	-39.91937	-11.02726
dist_road	-1.614773	.3434583	-4.70	0.000	-2.287939	-.9416066
residuals	-213.4158	49.36141	-4.32	0.000	-310.1624	-116.6692
totalharvest_Q	.0224013	.0041822	5.36	0.000	.0142043	.0305984
income_source	-6.231132	3.748061	-1.66	0.096	-13.5772	1.114933
credit_access	-22.17068	8.919925	-2.49	0.013	-39.65341	-4.687951
ext_parti	-17.75967	4.26041	-4.17	0.000	-26.10992	-9.409419
irrig_access	10.47499	4.215417	2.48	0.013	2.212923	18.73705
Avgannual_rainfall	.014837	.009812	1.51	0.131	-.0043942	.0340682

Source: Authors computation based on Ethiopian socio-economic survey data, 2025

Figure 6-A2: Heckman twostep approach for independence test

```
. truncreg real_shfci dummy_road dist_road mkt_access dummy_gender age hhsize totalharvest_Q land_hectares income_source credit_ac
> ccess ext_parti irrig_access Avgannual_rainfall year_2022 IMR, ll(0) vce(robust)
(719 obs truncated)
```

Fitting full model:

```
Iteration 0: log pseudolikelihood = -4330.352
Iteration 1: log pseudolikelihood = -4111.3839
Iteration 2: log pseudolikelihood = -4108.9666
Iteration 3: log pseudolikelihood = -4108.6729
Iteration 4: log pseudolikelihood = -4108.6613
Iteration 5: log pseudolikelihood = -4108.6613
```

Truncated regression

```
Limit: Lower = 0 Number of obs = 1,248
Upper = +inf Wald chi2(15) = 43.10
Log pseudolikelihood = -4108.6613 Prob > chi2 = 0.0002
```

real_shfci	Coefficient	Robust std. err.	z	P> z	[95% conf. interval]	
dummy_road	4.935756	4.115285	1.20	0.230	-3.130054	13.00157
dist_road	-.4313218	.1558613	-2.77	0.006	-.7368044	-.1258393
mkt_access	-5.254443	4.101658	-1.28	0.200	-13.29355	2.78466
dummy_gender	-.3796747	4.141238	-0.09	0.927	-8.496352	7.737002
age	-.0157616	.0972868	-0.16	0.871	-.2064402	.174917
hhsize	-.4681841	.8369352	-0.56	0.576	-2.108547	1.172179
totalharvest_Q	.0042215	.0271117	0.16	0.876	-.0489164	.0573593
land_hectares	-.0327659	.0285846	-1.15	0.252	-.0887907	.0232589
income_source	-3.564747	4.312797	-0.83	0.408	-12.01767	4.888181
credit_access	-8.042926	8.668044	-0.93	0.353	-25.03198	8.946129
ext_parti	-9.929519	4.001988	-2.48	0.013	-17.77327	-2.085767
irrig_access	-1.298299	3.408374	-0.38	0.703	-7.978588	5.381991
Avgannual_rainfall	-.0277898	.0072332	-3.84	0.000	-.0419666	-.013613
year_2022	-1.488013	6.508291	-0.23	0.819	-14.24403	11.268
IMR	65.07946	86.73571	0.75	0.453	-104.9194	235.0783
_cons	-12.49132	18.41023	-0.68	0.497	-48.57472	23.59208
/sigma	22.64735	2.008086	11.28	0.000	18.71157	26.58313

Source: Authors computation based on Ethiopian socio-economic survey data, 2025

Table 2-A2: Conversion factors for livestock

Livestock Type	Conversion factor to TLU
Bull	0.8
Oxen	1.0
Cow	1.0
Steer	0.8
Heifer	0.75
Calves	0.4
Horse	0.8

Mule	0.7
Donkey	0.5
Camel	1.25
Sheep	0.2
Goat	0.2
Poultry (chicken)	0.01
Bee colony	0.02

Source: (Storck et al., 1991; Woldu et al., 2016), commonly used in Ethiopian livestock and household surveys.

Table 3-A2: Conversion factors for land Size

Local unit	Conversion factor to hectare
Hectare	1.0
Square meters (m ²)	0.0001 ha
Timad	≈ 0.25 ha
Boy	≈ 0.025 ha
Senga/Kert	≈ 0.05 ha
Tilm	≈ 0.1 ha
Medeb	≈ 0.017 ha
Gemed (Rope)	≈ 0.01 ha
Ermija	≈ 0.0067 ha

Note: Since local units were used in the original data, conversions were made using region-specific conversion factors.

Source: Wigton et al., 2009, Agriculture Statistical Methodology in Ethiopia

Paper Three:

**The Effect of Grid Electrification on Rural Nonfarm
Enterprises in Ethiopia**

The Effect of Grid Electrification on Rural Nonfarm Enterprises in Ethiopia

Abstract

In low-income nations, the growth of rural non-farm enterprise activities is as important as agriculture for rural development. These non-farm enterprises can be an important channel for diversifying income, generating employment, and reducing poverty. One of the key constraints to the development and productivity of rural non-farm enterprises is limited access to reliable and modern infrastructure, particularly electricity. This study investigated how access to grid electricity affects rural non-farm enterprise participation in Ethiopia, using correlated random effect probit model. For this study, the data is compiled from the Ethiopian Socioeconomic Survey, run by the Central Statistics Agency of Ethiopia and the World Bank Living Standards Measurement Study-Integrated Surveys on Agriculture team. The descriptive statistics show that around 22.6% of households are engaged in nonfarm enterprises (NFEs), which is a relatively low participation rate that reflects the dominance of agriculture in rural livelihoods, though a substantial minority is diversifying. As compared to households without access to grid electricity, households with access are 7.3% more likely to engage in non-farm enterprise activities in rural Ethiopia. The between-household effect shows that households in more electrified areas are 13% more likely to participate in NFEs indicating a strong contextual effect of electricity beyond individual access. Access to rural infrastructure like roads and financial services is inconsistent, pointing to challenges in rural development and inclusion. Policymakers should complement electrification programs with targeted infrastructure development, such as roads and electricity, and financial services, like credit access and MFIs, to unlock the potential of rural non-farm enterprises.

Keywords: diversification, effect, infrastructure, off-farm income, rural.

1. Introduction

Agriculture is still a crucial sector worldwide and it accounts four percent of the total economic productivity (Gautam et al., 2022). The economies of the least developed nations are centered on the agriculture sector (Kane, 2023). It contributes significantly to the GDP (between 30 and 60%), employment (between 40% and 90%). It is also the major source of foreign exchange (between 25% and 95%) and it supplies the majority of basic food, subsistence, and other income for the majority of LDCs. However, agriculture in developing countries relies heavily on rainfall, making the sector vulnerable to the unpredictable nature.

Ethiopia is predominantly an agricultural country with over 80% of the population residing in rural areas, and the development of rural infrastructure is crucial for boosting the country's socioeconomic development. In Ethiopia, agriculture is the primary economic sector, contributing nearly 32.7% of the GDP, generating 81.5% of the foreign exchange earnings, and providing employment for around 63.66% of the labor force (Tegegne et al., 2022). The production output from rain-fed agriculture has varied greatly across regions in Ethiopia due to rainfall variability (Moges et al., 2021). Crop failure becomes inevitable when there is uneven and insufficient rainfall distribution, and making food insecurity and poverty major problems in rural communities.

Agriculture in developing countries, relies heavily on rainfall, making the sector vulnerable to the unpredictable nature. Therefore, diversifying the income sources of rural dwellers through promoting non-farm enterprises¹⁶ (NFEs) can be one technique to escape the adverse shocks of farming activity and reduce rural poverty and unemployment as well as realize the sustainable development goals (SDGs) (Mekonen et al., 2024). Farming alone cannot provide adequate livelihood opportunities in rural areas; thus, nonfarm economic activities have played an important role in reducing rural poverty and increasing the income portfolio of rural societies (Gordon et al., 2001). In addition, non-farm enterprises are often lauded as income diversification opportunities, helping to smooth income in the farming off-seasons in developing countries, which are highly dependent on agriculture (Kowalski et al., 2016). The risk-mitigating opportunities that NFEs may provide are also linked to the issue of food security, which may reduce a household's within-year variability of the capacity to purchase or produce food (Ali et al., 2012; Owusu et al., 2011).

In low-income nations, the growth of rural non-farm enterprise activities is as important as agriculture for rural development (Tshabalala et al., 2020). These non-farm enterprises can be an important channel for diversifying income, generating employment, and reducing poverty. Non-farm enterprises may represent an income-smoothing opportunity (Loening et al., 2008). This is because of the fact that NFEs provide diversified income sources when agricultural earnings are low, thereby mitigating income risk (Davis et al., 2010). Moreover, by generating household

¹⁶ Non-farm enterprise is defined as any income generating business a household operates which does not involve the primary production of crops or livestock. Included in this definition of NFEs are activities that add value to primary production, such as the processing of agricultural by-products.

income during the agricultural off-season, non-farm enterprises may also create a buffer for households to rely on in the face of negative shocks, thus reducing vulnerability. non-farm enterprises may also provide further means of risk diversification in the face of aggregate shocks to agricultural production, such as drought (Haggblade et al., 2010).

Rural non-farm enterprises are of importance to rural livelihood. Non-farm enterprises tend to offer higher returns and are less physically demanding when compared to wage employment (Rahut et al., 2015). In addition, NFEs are the largest contributor to non-farm income, provide employment for excess labor and the landless poor who could otherwise not be employed in farm activities, and play a significant role in poverty reduction (Rahut et al., 2015; Senadza, 2012; Weldegebriel, 2015). Rural communities' economic and social problems could be addressed by stimulating and supporting nonfarm economic activities (Copus et al., 2015).

Economic activity requires energy to produce goods and services, to convert materials into desired forms, and to transport products, inputs, and people (Stern et al., 2019). Electricity is one of the energy carriers from the point of supply to consumption. Compared to other energy carriers, electricity also provides more efficient lighting (Fouquet, 2008), information and telecommunication technology, and better energy in production (Kander et al., 2014). Rural electrification has long been considered a crucial component in promoting socioeconomic development in developing countries. The provision of reliable electricity can improve living standards, create new economic opportunities, and enhance overall productivity in rural communities. In particular, access to electricity can significantly impact a household's non-farm business ownership and off-farm income share (Dinkelman, 2011; Lipscomb et al., 2013).

One of the key constraints to the development and productivity of rural NFEs is limited access to reliable and modern infrastructure, particularly electricity. Lack of access to electricity is one of the major impediments to growth and development of the rural economies in developing countries (Kaygusuz, 2012). That is why access to modern energy, in particular electricity, has been one of the priority themes of the World Bank and other development organizations. Providing universal, reliable, sustainable, and affordable access to electricity falls under goal 7.1 of the Sustainable Development Goals (SDGs) set for the year 2030 (Mondal et al., 2017). Rural electrification projects are often justified because they are intended to promote household welfare by providing a better quality of life or more productivity (Cook, 2011).

In developing nations, rural electrification has long been considered a crucial component in promoting socioeconomic development. However, access to modern energy remains absent in many households. An estimated 1.2 billion people (17%) of the global population still lack access to electricity (Cozzi et al., 2015). Despite significant progress in improving electricity access, sub-Saharan Africa is lagging behind the rest of the world. In 2018, despite ambitious electrification plans implemented in the last decades, around 600 million people in sub-Saharan Africa had no access to electricity (International Energy Agency, 2019).

In rural areas where energy constraints limit productivity, income diversification, and overall well-being, availability of electricity is an important factor for economic development (Blimpo et al., 2019; Lee, 2023). Access to electricity in rural areas is largely considered as a key driver of the structural shift away from reliance on agricultural livelihoods (Fried et al., 2021). In rural communities, access to reliable electricity can raise living standards, create new economic opportunities, and enhance overall productivity. Specifically, non-farm business ownership and off-farm income share of a household can be greatly affected by access to electricity (Dinkelman, 2011; Lipscomb et al., 2013).

With access, the welfare benefits of electrification can accrue through various channels. For instance, rural electrification enhances greater output for household members engaged in income-generating activities, such as sewing, knitting, and other handicraft activities. Electricity is used to power machinery, which is used to replace the manual ones. Electric-based devices are better in terms of output and time efficiency, thereby yielding higher income and profits (Bridge et al., 2016; Dinkelman, 2011; Grogan et al., 2013; S. R. Khandker et al., 2013). Additionally, by facilitating mechanization, lowering input costs, expanding business hours, and allowing the use of modern technologies, grid electrification has the potential to improve rural economic activities. As a result, household participation in non-farm activities and the profitability of such activities can be directly influenced by electricity access. It is vital to obtain empirical evidence on the impact of rural electrification on rural development outcomes, given this potential of the increasing rate of returns. The creation of business enterprises, which provide opportunities for alternative income-generation activities outside agriculture, is one of the potential benefits of access to electricity in rural areas.

In developing countries like Ethiopia, rural electrification has been widely promoted as a means of stimulating economic transformation beyond agriculture (Fried et al., 2021). Ethiopia has been

undertaking remarkable development in the energy sector in general and the electric sector in particular since 2000 (Benti et al., 2021). Through the country's Universal Electricity Access Program (UEAP), several off-grid villages and regions have been connected to the national electricity grid through public investment. The national grid coverage to rural towns increased from 13% in 2002 to 55% in 2016, and the percentage of households that are actually connected to grid electricity also increased from 7% in 2002 to 33% in 2016 (Barnes et al., 2016). Moreover, in terms of energy production, in 2005, the country was producing about 2900 megawatts (MW) of electricity, but in 2017, the total electricity production reached about 4180 MW. Even when Ethiopia's grand national electrification program is completed, only 65% of the total population will have access to electricity by 2025 (Abdulahman, 2021). This means that the remaining 35% (more than 12 million) of households, mainly in rural areas, will still be living without electricity (Abdulahman, 2021; Ahmed et al., 2019; Getie, 2020).

The demand for electricity in recent decades has dramatically increased in Ethiopia due to rapid economic and population growth (Gebremeskel et al., 2021). Because of this, the government has invested a significant number of resources in electricity access and distribution of the infrastructure. More than eight hydropower plants with an installed capacity of 4500 MW have been built throughout the country. Despite such efforts, the current generation capacity is far below the required level, with nearly 55% of the total population not connected to the gridline (Pappis et al., 2019). Furthermore, there is considerable variation in electrification rates between urban and rural areas. For instance, only about 33% of the rural population (which accounts for 80% of the total population) has access to electricity, whereas 92% of urban dwellers have access to electricity (Tirkaso et al., 2019).

Although one of the broader development effects of access to improved electricity is considered to be the structural transformation of the economy away from a dependence on agricultural livelihoods, there remains little robust evidence describing the causal effect of improving electricity access on the diversification of rural non-farm enterprise activities in regions with developing infrastructure, such as Sub-Saharan Africa, particularly in rural communities. Among the fundamental constraints to ensuring sustainable development, food security, and global poverty reduction, access to electricity is the basic one (Kebede et al., 2010; Lee et al., 2008). The literature has extensively examined the development interlinkages of these goals, which range from broad economic growth to other SDGs like education, gender equality, and

healthcare (Fuso Nerini et al., 2018; McCollum et al., 2018). The positive correlation of the productive use of electricity and corresponding shift away from agricultural livelihoods in rural areas has often been discussed (Malah Kuete et al., 2023; Perez-Sebastian et al., 2020).

There remains limited empirical evidence on the impact of grid electrification on rural nonfarm enterprises participation in Ethiopia, despite these theoretical links. Though non-farm enterprise activities, especially in rural communities, are considered as an income-smoothing opportunity, the majority of previous studies (Barnes et al., 2016; Bernard et al., 2015; Beyene, 2018; Fried et al., 2021; Gashaye et al., 2025; Gebrehiwot et al., 2022; Getie, 2020; Hassan et al., 2022; Mekonen, 2012; Meles, 2020; Nigussie et al., 2015; Pelz, 2020; Pelz et al., 2023; Tirkaso et al., 2019; Wassie et al., 2021) tend to concentrate on the effects of access to electrification on rural livelihood outcomes like education, health, household welfare, food security scores, consumption expenditure, and gender-based outcomes.

Urban areas are the primary focus of the majority of studies on access to electricity and its impact in Ethiopia (Aweke et al., 2022; Barnes et al., 2016; Beyene et al., 2013; Gebremeskel et al., 2021; Guta, 2014; Kebede et al., 2010; Mekonnen et al., 2009). Moreover, the majority of the available empirical research is mostly focused on fuel shortage and selection in relation to conventional biomass use. Even though research on rural electrification in Ethiopia is growing, most of the existing studies use descriptive statistics or straightforward cross-sectional regressions (Barnes et al., 2016; Beyene et al., 2013; Meles, 2020; Nigussie et al., 2015; Wassie et al., 2021), which are not capable of identifying causal relationships, fail to take account of unobserved heterogeneity, ignore selection bias, and cannot control for time-invariant household characteristics.

Furthermore, there are still critical gaps in existing literature that examines the impact of access to electrification on rural welfare in Ethiopia. First, prior studies (Gashaye et al., 2025; Getie, 2020; Meles, 2020) predominantly focus on agricultural outcomes and household welfare, overlooking systematic analysis of non-farm enterprises as a distinct rural livelihood strategy. Second, empirical research on non-farm enterprises typically uses single-wave cross-sectional data or short panels (Hassan et al., 2022; Pelz, 2020; Pelz et al., 2023; Tirkaso et al., 2019), which makes it difficult to capture dynamic effects. According to these studies, access to grid electrification has no influence on rural non-farm enterprises. However, the full effect of electrification may not have been reached by then, because households do not have the liquidity

to pay for connection fees, and broader knock-on effects unfold over time. This study addresses these gaps by exploiting both Panel I and Panel II of the Ethiopian Socioeconomic Survey to track long-term effects and mitigate attrition bias. Therefore, this study estimates the dynamics of outcome for up to ten years after electrification.

Additionally, the estimation methods of the previous studies often ignore unobserved time-invariant heterogeneity. To overcome these issues, this study applies the correlated random effect to control for household-level unobservable characteristics. Thus, the study presents methodological innovations for policy evaluation in the context of rural infrastructure expansion in general and grid electricity access in particular. This study assesses the impact of grid electricity access on non-farm enterprise participation in Ethiopia, using panel data from the Ethiopian Socioeconomic Survey. The finding of the study contributes to the current policy discussions on rural electrification and its potential to support economic diversification and inclusive development in Ethiopia. The main objective of the study is to assess the effect of access to rural grid electricity¹⁷ on non-farm enterprise participation in rural Ethiopia.

2. Literature Review

2.1. Historical Context of Rural Electrification in Ethiopia

Ethiopia's electricity sector began in the early 20th century with small hydropower plants serving urban centers like Addis Ababa (Gebremeskel et al., 2021). Its supply was limited to major towns and negligible in rural areas. The state-owned Ethiopian Electric Light and Power Authority (EELPA) began expanding generation capacity, mostly from hydropower. Since EELPA's establishment, more than ten hydropower dams have been built and are generating over 4,500 MW of electric power (Lavers et al., 2021). All power stations and substations are connected to a high-voltage transmission line that carries power to the national gridline.

The demand for electricity across the country increased due to rapid economic and population growth in recent decades. For this reason, the government has devoted significant resources to electricity generation and distribution infrastructure. Despite such efforts, the current generation capacity is far below the required level, with nearly 55% of the total population not connected to

¹⁷ Grid electricity refers to access to electricity for homes, businesses, and institutions through connection to a national or regional power grid, as opposed to off-grid sources like solar home systems, diesel generators, or mini-grids.

the gridline (Asres, 2021). There is considerable variation in electrification rates between urban and rural areas. For example, only about 33% of the rural population, which accounts for 80% of the total population, has access to electricity, whereas 92% of urban dwellers have access to electricity (Fried et al., 2021). Around 50–60% of the population has access to electricity currently, but most rely on off-grid sources, with only 30% through the national grid.

The Universal Electrification Access Program (UEAP) aims to rapidly expand the grid to rural towns and villages by extending medium-voltage lines and connecting rural transformers to households. There is a significant increase in the number of rural towns connected, but many households in connected areas still could not afford in-house wiring and connection fees. The National Electrification Program (NEP) in 2017 also adopted a grid and off-grid integrated approach and aimed to reach 65% grid access and 35% off-grid by 2025 (Biramo, 2020). However, many rural households in grid-connected villages cannot afford connection fees or wiring; there are frequent power outages (especially during dry seasons when hydropower output falls); there are high per-connection costs due to scattered rural settlements; and there is utility under-recovery of costs due to low tariffs and high expansion costs.

Some rural non-farm enterprises, such as petty trade or small services, do not directly require electricity. In this study, the objective was not to measure electricity-dependent enterprises only, but to examine whether access to grid electricity increases overall participation in rural non-farm enterprises. Electricity can influence enterprise participation both directly and indirectly. Directly, through productive uses such as agro-processing, refrigeration, and manufacturing; and indirectly, by improving working hours, information access, and local economic activity. Therefore, even enterprises that do not directly use electricity may benefit from electrified environments. The estimated effect should therefore be interpreted as the average effect of electrification on overall non-farm enterprise participation rather than on electricity-intensive enterprises alone.

2.2. Empirical Literature Review

Rural infrastructures, together with rural electrification, have the ability to provide access to higher education, better healthcare, higher incomes, and more business opportunities (Khandker et al., 2013). Households are less likely to have a higher income share from the non-farm sector if they live in a remote location with poor-quality roads, access to electricity, and frequent power

outages (Gibson et al., 2010). Moreover, electricity availability boosts productivity and income and transforms household activities (Ahmad et al., 2014; Ikhsan et al., 2022; Saurel et al., 2023). Comprehensive studies have been conducted by different scholars on the effects of access to rural electrification on non-farm activities in developed and developing countries (Akpan et al., 2013; Bensch et al., 2020; Bensch et al., 2011; Blimpo, 2019; Chhay et al., 2021; Dinkelman, 2011; Gibson et al., 2010; Grogan et al., 2013; Hassan et al., 2022; Jha et al., 2022; Khandker et al., 2009; Khandker et al., 2013; Khurana et al., 2022; Pelz et al., 2023; Peters et al., 2019; Rud, 2012; Tagliapietra et al., 2020; Tirkaso, 2023).

A wide range of literature shows that the establishment of non-farm businesses in rural communities strongly depends on access to reliable electricity. For instance, a study by Akpan et al. (2013) in Nigeria revealed that limited rural electrification reduces the establishment of rural micro-enterprises. Enterprises in communities connected to electricity are 16.2 percent more profitable than enterprises without electricity. A similar study by Rud (2012) shows that the growth of electricity infrastructure in India enhanced the entry of small firms, which in turn increased manufacturing production at the state level by 14%. Dinkelman (2011), found that a widespread rural electrification program in South Africa increased micro-enterprises across rural villages and created non-farm employment opportunities for rural households. In addition, it is simple to launch new businesses, adopt cutting-edge technologies, and mechanize agricultural practices when there is access to electricity.

More importantly, communities connected to grid electricity produce outputs and services such as increased quality of lighting, access to non-agricultural activities, modernization of agriculture, attraction of infrastructure (like health facilities, roads, and water supply), access to information and knowledge, improved food preservation, higher quality of comfort, productive motive power, and healthy and improved cooking (An, 2008). Furthermore, improvements in the productivity of non-agricultural economic activities through increased revenue can raise the earnings of electrified communities (Dinkelman, 2011). The use of electric-powered tools and equipment, such as refrigerators and freezers, can enable small and medium enterprises to produce more goods and services and increase the quantity and quality of agricultural products in rural areas (Tuntivate, 2011).

Some studies reported that rural electrification had no significant impacts on different development outcomes, particularly in the short run. While the importance of electricity is

undoubtedly huge, recent evidence shows that it has little short-run impact (Blimpo, 2019). For instance, a study by Jha et al. (2022) in India showed that electrifying rural villages did not produce the expected economic gains in the medium term. Similarly, Akpan et al. (2013), from a randomized field experiment in India, revealed that electrification did not improve households' socioeconomic development indicators such as savings, spending, business creation, and time spent on working or studying. Moreover, Van de Walle et al. (2017), from India, find that access to rural electrification increased non-farm employment for only males and over a period of 17 years. Chhay et al. (2021) find that the shifts in the labor market toward non-farm sectors in Cambodia due to access to rural electrification are non-negligible over a ten-year period.

Some researchers are still trying to determine the welfare impact of access to grid electricity on rural welfare in Ethiopia (Aragaw, 2012; Getie, 2020; Hassan et al., 2022; Nigussie et al., 2015; Pelz, 2020; Pelz et al., 2023; Tirkaso, 2023). For instance, according to Tirkaso (2023), households that have access to electricity are more likely to own non-farm businesses and have higher off-farm income shares. In addition, when complementary infrastructures like markets, roads, and financial services are simultaneously implemented, rural electrification has a significant positive influence on rural non-farm enterprises. In particular, households with electricity access have around 0.21% higher off-farm income than non-electrified households. Furthermore, the estimate shows that electrified households far from the nearest market are less likely to own non-farm businesses and be involved in non-farm employment activities than those close to the markets, financial institutions, and road network.

A similar recent study by Pelz et al. (2023) in Ethiopia and Nigeria indicated that rural electrification did not have an impact on non-farm enterprise and employment outcomes for 2-4 years of connection. They conclude that in order to fully leverage the short-and medium-term impacts of rural electrification, it is necessary to assess related programs in most developing countries. In addition, they found that rural electrification significantly and positively impacts girls study time at home, while its impact on women's empowerment is not significant. This could be partly explained by the fact that not only in most Ethiopian rural towns but also in most Ethiopian urban towns, connected households do not use electricity to ease and support women's household chores, which could help them save some time for social and economic affairs. The estimated result of Hassan et al. (2022) shows that households' operation of business enterprises increased by 9% between 2011 and 2016 among households without connection to electricity,

whereas connection to grid electricity increased rural households' operation of businesses by 5%. However, the effect is insignificant in the short run.

Rural electrification leads to substantial structural transformation of village economies and slows rural-urban migration in Ethiopia (Fried et al., 2021). Moreover, electrifying a village leads to a shift from agricultural to non-agricultural activities, and increases in household durable ownership. They also find that electrified villages were more likely to provide access to tap water over the same period, and it is most likely that electricity led to the tap water access, rather than the other way around. A study by Tikuneh et al. (2018) in Ethiopia, assessed the economic and social impact of the Universal Electrification Access Program (UEAP) using cross-sectional data on energy consumption, cost of energy, and household income, by applying propensity score matching and qualitative analysis. The study found that the program significantly improved the welfare of rural households.

Indeed, a large body of literature paints a somewhat mixed picture about the short run and long run economic viability of access to rural electrification. The effects of access to electricity on rural non-farm entrepreneurship is contested. While many studies found substantial benefits from access to electrification on income, labor supply and education results, there is no sufficient studies on nonfarm enterprise participation and development. There is also little empirical evidence from Africa and the available studies are mostly based on descriptive statistics. Building on this foundation, the influence of access to electricity to rural household emerges as a critical area of research in developing country like Ethiopia. It has implications across various aspects of household welfare, such as non-farm enterprise participation, labor market outcomes, and gender equality.

3. Methodology

3.1. Data Source

For this study, the data is compiled from the Ethiopian Socioeconomic Survey (ESS) and the Ethiopian Socioeconomic Panel Survey (ESPS), run by the Central Statistics Agency of Ethiopia (CSA) and the World Bank Living Standards Measurement Study-Integrated Surveys on Agriculture (LSMS-ISA). The survey is said to be broadly representative of rural households engaged in sedentary agriculture. The scope of the survey includes individual, household, and community-level characteristics. Moreover, the ESS collects information on household agricultural activities along with other information on the households, like human capital, other

economic activities, and access to services and resources. The household survey gathers quantitative data on various variables reflecting both household- and village-level characteristics. This includes the average land holdings size, number of oxen owned, input usage per hectare, household head average age and years of schooling, household size, altitude above sea level, average temperature, and village distance to the nearest town, among others.

The survey was chosen due to its representativeness and the availability of ample observations on key variables relevant to the study. Following the exclusion of missing data and outliers, the study utilized information from 3,415 rural households. That is, there are 3,415 households observed over 5 rounds (2011 to 2021). The dataset remains unbalanced, because most households have data for 1 up to 3 rounds only and there is no household who have the full 5 rounds. The absence of households in some rounds could be due to non-random attrition, migration, and the panel nature. The electrification analysis includes all rural households regardless of agricultural production status, leading to a larger sample size. The analyses rely on unbalanced panel datasets, which is consistent with the structure of the Ethiopian Socioeconomic Survey, where attrition and missing observations occur across survey waves. The econometric models employed, the correlated random effects probit remain valid under unbalanced panel settings.

3.2. Econometrics Model Specifications and Variables Description

3.2.1. The correlated random effects (CRE) probit model

For the econometric model specification of the causal effect of access to grid electricity on non-farm enterprise participation, we include the following variables.

Dependent variable: non-farm enterprise participation, which is a binary outcome variable that takes the value 1 if a household in a rural Ethiopia engages in non-farm enterprise activities, and 0 otherwise.

Key independent variable: The key independent variable of interest is access to grid electricity, which is a binary predictor variable that takes the value 1 if the household has access to grid electricity, and 0 otherwise. Access to grid electricity is expected to have a positive impact on non-farm enterprise participation.

Control variables: are other relevant explanatory variables that could affect the non-farm enterprise's participation of rural households. Household level characteristics including; household size, age of household, marital status, gender of household head, education level of

household head, households' total expenditure per month, and availability of off-farm income sources. Community level characteristics such as; access to credit (1 = yes, 0 = no), the presence of road networks (1 = yes, 0 = no), distance to urban center (km), and MFI availability (dummy for access vs. not access), and the time fixed variable year (categorical), to control for temporal shocks.

Since the dependent variable is binary, and panel is unbalanced with many households having only one or two waves, correlated random effect (CRE) probit or logit models are most appropriate. Unbalanced panel data where some units do not have a complete set of observations in some time periods, are prevalent in empirical work. As is well known, unbalanced panel data in a linear model context can be handled by fixed effects estimation provided the selection is based on observed variables or unobserved time-constant heterogeneity. But as pointed out in Wooldridge (2019), unbalanced panels cause significantly more difficulties in nonlinear panel data models and proposes a correlated random effect approach to allow the heterogeneity to be correlated with time-constant functions of selection indicators for general nonlinear panel data models. The correlated random effect approach is a good compromise between random effect and fixed effect for unbalanced panels.

Unlike fixed-effects probit/logit, which drops single-wave households, correlated random effect keeps all households and accounts for correlation between time-invariant household characteristics and the treatment (access to grid electricity). Based on the Mundlak adjustment (Mundlak, 1978), a correlated random effect include household-level means of time-varying variables to address unobserved heterogeneity. In addition, a correlated random effect model estimates both time-varying and time-invariant effects while controlling for endogeneity that arises when regressors are correlated with unobserved panel level characteristics and correct bias. The model can be more robust to certain types of serial correlation than pooled models, which don't explicitly address individual-specific heterogeneity. The parameters of the correlated random effect probit model are typically estimated using maximum likelihood estimation.

The correlated random effect probit model augments the random effects model by including household-level averages of time-varying covariates, following the Mundlak (1978) correction, to account for correlation between unobserved heterogeneity and explanatory variables.

The correlated random effect probit model is:

$$\Pr (Y_{it} = 1 | X_{it}, \bar{X}_i, \alpha_i) = \Phi (X'_{it}\beta + \bar{X}'_i\theta + \delta_t + \alpha_i + \varepsilon_{it}) \quad (4.1)$$

Where:

$Y_{it} = 1$ if household i participates in non-farm enterprise activity in year t , and 0 otherwise.

$\bar{X}_i$: time-averaged covariates for household i (correlated random effect component).

$\Phi(\cdot)$: cumulative distribution function of standard normal distribution.

α_i : unobserved individual-specific effect.

X_{it} : time-varying covariates.

δ_t : year dummies capturing macro trends.

ε_{it} : Idiosyncratic error term.

The econometric model for the probability of participating in non-farm enterprise as a function of grid electricity access, while accounting for household heterogeneity and time-varying covariates is as follows:

$$\begin{aligned} \Pr(\text{Nonfarm_part}_{it} = 1 \mid X_{it}, \bar{X}_i, \alpha_i) \\ = \Phi(\beta_1 \text{GridEle}_{it} + \beta_2 \text{HHSIZE}_{it} + \beta_3 \text{Gender}_{it} + \beta_4 \text{Age}_{it} + \beta_5 \text{EduLevl}_{it} \\ + \beta_6 \text{MaritalSta}_{it} + \beta_7 \text{OffFarmInc}_{it} + \beta_8 \text{TotExp}_{it} + \beta_9 \text{RoadAcc}_{it} \\ + \beta_{10} \text{DistUrban}_{it} + \beta_{11} \text{MFIAcc}_{it} + \beta_{12} \text{CreditAcc}_{it} + \theta_1 \text{AVeGridEle}_i \\ + \theta_2 \text{AVeHHSIZE}_i + \theta_3 \text{AVeAge}_i + \theta_4 \text{AVeMaritalSta}_i + \theta_5 \text{AVeOffFarmInc}_i \\ + \theta_6 \text{AVeTotExp}_i + \theta_7 \text{AVeRoadAcc}_i + \theta_8 \text{AVeCreditAcc}_i + \text{Year}_t + \alpha_i \\ + \varepsilon_{it} \quad (4.2) \end{aligned}$$

In order to estimate a consistent result in panel data setting, the explanatory variables must not be correlated with the time-constant unobserved term (α_i) that is, we have to control for unobserved heterogeneity (Wooldridge, 2011). In a panel data set, the fixed-effect model can fix the problem of unobservable heterogeneity through the demeaning procedure. However, the fixed-effect model is a workforce for linear models and is not applicable to the nonlinear model due to the incidental parameter problem (Verkaart et al., 2017; Wooldridge, 2011). For non-linear panel data models, a correlated random effect (CRE), which is the work of (Chamberlain, 1982; Mundlak, 1978), is used and eases the assumption of strict exogeneity (Ricker-Gilbert et al., 2011).

The CRE consists of a vector of variables containing the means of all time varying covariates for each household (Burke et al., 2014). These additional control covariates have the same value for each household during the period under study but vary across households. Their coefficients

account for the differences between households over the entire period (due to unobservable time constants), while the coefficients of the time varying covariates explain the within household effects or simply the effect of a deviation from the household average over time. In estimation, variables that are the same for each household are excluded from $\mathbf{x}_i$.

The CRE approach expresses the unobservable heterogeneity variable (C_i) in the non-farm enterprise participation equation as a function of the mean of the time-variant variables denoted by $\mathbf{X}_i$ and the intercept (ϑ_0) and the error term assumed with zero mean and constant variance (U_i) (Wooldridge, 2011):

$$C_i = \vartheta_0 + \varpi \bar{X}_i + u_i \quad (4.3)$$

Finally, following the work of (Mekonnen et al., 2017; Ricker-Gilbert et al., 2011), the CRE Probit is presented in the following equation.

$$\begin{aligned} Pr(NFES_{it} = 1 | \mathbf{X}_t) \\ = \beta_1 \mathbf{x}_i + \gamma_1 \bar{X}_i + \varepsilon_i \text{ (non - farm enterprise participation equation)} \end{aligned} \quad (4.4)$$

Where $NFES_{it}$; is the decision to participation in non-farm enterprise activities, equal to 1 if the household chose to participate and equal to 0 otherwise.

$\mathbf{x}_i$ is the set of all explanatory variables;

β_1 is the set of coefficients estimated on $\mathbf{x}_i$;

γ_1 is the set of coefficients estimated on mean values;

$\bar{X}_i$ are time-averaged covariates for household i ;

ε_i is the error term

Table 4.1: Definition of variables used in the correlated random effect probit model

Variables code	Definition of variables		Expected sign
Dependent variables			
Nonfarm_part_{it}	Households engage in non-farm enterprise/not engage in non-farm enterprise at time t	Dummy (1 = participates in non-farm enterprise, 0 = otherwise)	
Independent			

variables			
GridEle_{it}	Household's access to grid electricity at time t	Dummy (1 = access, 0 = otherwise)	+
DistUrban_{it}	Distance to urban center at time t	Kilometers	-
MFIAcc_{it}	Availability of MFI in village j at time t	Dummy (1 = access, 0 = otherwise)	-
RoadAcc_{it}	Availability of road networks in village j at time t	Dummy (1 = access, 0 = otherwise)	+
OffFarmInc_{it}	Off-farm income of household i at time t	Dummy (1 = yes, 0 = otherwise)	+
CreditAcc_{it}	Credit access for household i at time t	Dummy (1 = access, 0 = otherwise)	+
TotExp_{it}	Total household expenditure per year at time t	Ethiopian Birr (ETB/ year)	-
Gender_{it}	Gender of the i^{th} household	Dummy (1 = male, 0 = female)	-
Age_{it}	Age of the i^{th} household at time t	Years	+/-
EduLevl_{it}	Years of Schooling of the head at time t	Years education	+
HHSize_{it}	Household size at time t	Number of household members	+
MaritalSta_{it}	Marital status of household head at time t	Dummy (1 = married, 2 not married, 3= otherwise)	+

Source: Compiled from various empirical literature, 2025

4. Result and Discussion

4.1. Descriptive Results

Table 4.2: Summary statistics for continuous variables used in the analysis

Variables	Obs	Mean	Std. dev	Min	Max
Household size (number)	3,415	3.971	2.467	1	19
Age of household head (number)	3,415	46.51	17.35	15	100
Years of education (number)	3,415	0.291	1.839	0	17
Total expenditure (number)	3,415	64387.65	91897.46	880	2067814
Distance to town KMs)	3,415	73.51	84.57	0	1300

Source: Authors computation based on Ethiopian socio-economic survey data, 2025

Based on pooled panel data from 3,415 households, the summary statistics of continuous variables included in the analysis are presented in **Table 4.2**. The average household size is approximately four people, which is moderate. Household labor supply could be a factor in enterprise participation. Smaller household sizes could reflect urbanizing trends or migration. Furthermore, the result shows a matured leadership with experience in managing livelihood strategies, as the average age of the household head is about 46.5 years. Rural households are headed by middle-aged individuals in general. Though age is positively associated with experience, being too old might reduce entrepreneurship propensity.

Most rural household heads have no formal education, with the mean years of education is 0.29, which is very low, indicating that education could be a major constraint on both electricity usage and NFEs participation. Limited human capital may constrain business enterprise entry and success. Education is often a strong predictor of entrepreneurship. There are large income disparities among rural households since the variation in household expenditure is high. This indicates that some households are far wealthier, reflecting different levels of asset ownership, income diversification, inequality in household living standards, and perhaps different enterprise capacities. On average, households are 73.5 km away from the nearest town, which is quite far. This isolation could significantly impact market access, supply chains, and electricity infrastructure expansion.

Table 4.3: Summary statistics for dummy and categorical variables used in the analysis

Variable	Category	Frequency	Percent	Cumulative (%)
NFEs Participation	Non-participants	2,643	77.39	77.39
	Participants	772	22.61	100.00
Grid electricity Access	No access	2,674	78.30	78.30
	Access	741	21.70	100.00
Gender	Female	1,277	37.39	37.39
	Male	2,138	62.61	100.00
Marital status	Not married	245	7.17	7.17
	Married	2,023	59.24	66.41
	¹⁸ Others	1,147	33.59	100.00
Off-farm income	No	2,497	73.12	73.12
	Yes	918	26.88	100.00
Road access	No	1,011	29.60	29.60
	Yes	2,404	70.40	100.00
Credit Access	No	2,765	80.97	80.97
	Yes	650	19.03	100.00
MFIs	No	2,585	75.70	75.70
	Yes	830	24.30	100.00

Source: Authors computation based on Ethiopian socio-economic survey data, 2025

Based on pooled panel data from 3,415 households, the summary statistics of dummy and categorical variables included in the analysis are presented in **Table 4.3**. About 22.6% of households are engaged in nonfarm enterprises (NFEs), which is a relatively low participation

¹⁸ The category others for the categorical variable marital status includes households that are divorced, separated, widowed, or in informal unions.

rate that reflects the dominance of agriculture in rural livelihoods, though a substantial minority is diversifying. In five rural households, only one participates in non-farm enterprises. This raises questions about barriers to entry in the nonfarm sector and indicates a significant rural labor concentration in agriculture. The descriptive statistics also show that around 21.7% of households have access to grid electricity, which is still very limited in rural Ethiopia. This means that almost four out of five households still do not have access to the grid, indicating the severity of infrastructure gaps in rural Ethiopia. This low access could constrain participation in nonfarm enterprise activities, though electricity is typically a critical input for running enterprises.

Around 63% of the households are male-headed, while 37% are female, reflecting male dominance in household leadership with a significant female representation. Enterprise decision-making and access to capital or networks may be influenced by gender differences. A small proportion of household heads have not married (7%), and the majority are married (59%), which often correlates with economic responsibility. A large share (34%) falls in this other category of marital status, potentially many widowed and divorced, which could affect access to resources or decisions about enterprise. Marital status may affect risk preferences, household responsibilities, and access to networks or finance. The descriptive result also shows that only 27% of households have access to off-farm income in rural Ethiopia, which is almost similar to the NFEs participation rate. The implication is that rural household reinforcing still depends on farm income, and there is very limited diversification.

Moreover, around 70% of households have access to roads, which is relatively high, indicating that physical access may not be the main barrier. A large portion of households are reachable by road, which supports their market access. Only 19% of households have access to credit, which is quite low and may limit investment in enterprises or electricity connection. Limited credit availability could be a key constraint on enterprise development. Only about 1 in 4 households have access to microfinance institutions (MFIs), another financial constraint for rural households. Similar to formal credit access, microfinance penetration is low but possibly growing.

Table 4.4: Descriptive summary statistics by access to grid electricity

Variable	No Access (N = 2,674)	Access (N = 741)
NFEs participation (=1 if yes)	0.176 (0.381)	0.406 (0.491)
Household size	4.10 (2.49)	3.50 (2.31)
Gender (=1 if male)	0.635 (0.482)	0.595 (0.491)
Age of household head	47.82 (17.40)	41.78 (16.36)
Years of education	0.183 (1.35)	0.684 (2.97)
Never married	0.052 (0.221)	0.144 (0.352)
Married	0.608 (0.488)	0.537 (0.499)
Other marital status	0.341 (0.474)	0.318 (0.466)
Off-farm income (=1 if yes)	0.257 (0.437)	0.313 (0.464)
Total expenditure (ETB)	61,376 (89,748)	75,255 (98,568)
Road access (=1 if yes)	0.653 (0.476)	0.888 (0.316)
Credit access (=1 if yes)	0.195 (0.396)	0.174 (0.379)
Distance to town (km)	79.76 (90.27)	50.96 (53.98)
MFI access (=1 if yes)	0.197 (0.398)	0.410 (0.492)

Note: Values are means, with standard deviations in parentheses. Dummy/categorical variables are shown in percentages.

Source: Authors computation based on Ethiopian socio-economic survey data, 2025

Table 4.4 compares households with and without access to grid electricity in relation to their non-farm enterprise (NFEs) participation and other household characteristics. About 17.6% of households without access to grid electricity participate in non-farm enterprises, and 40.6% of households with access to grid electricity participate in non-farm enterprises. Households with

electricity access are more than twice as high as those who have no access to grid electricity in participating NFEs. This implies that grid electricity access and participation in nonfarm enterprise activities are highly and positively associated, potentially due to electricity access enabling income-generating opportunities such as small businesses, shops, and services.

The number of households with grid access is slightly smaller. Possibly, larger families may be common in less developed areas with poor infrastructure, possibly increasing subsistence burdens and limiting enterprise risk-taking. More male-headed households without electricity access (63.5%) than with access (59.5%). Gender dynamics may influence infrastructure access and economic decisions, though the difference is modest. Electrified households are headed by younger individuals, which could suggest greater willingness to adopt new infrastructure or settle in electrified areas and to adopt entrepreneurial activities, possibly reflecting migration or targeting of infrastructure. Households with electricity have much higher education levels. Electrified communities may be more developed or targeted for development. Education enhances the ability to engage in and manage enterprises. A higher share of not married household heads is in electrified areas, and fewer married household heads are in the electrified areas, which again supports the idea that younger people may be more likely to live in areas with infrastructure.

Around 31.3% have off-farm income sources among electrified households, which supports the idea that electricity access may facilitate income diversification or may enable diversification of other income sources beyond agriculture. The mean expenditure is higher for households with grid electricity access, implying that they are relatively wealthier. This could be due to pre-existing differences and the economic benefits of electrification. Electrified households are relatively wealthier, possibly due to enterprise income or improved economic conditions.

Grid electricity access is concentrated in better-connected areas, and electrified households are much more likely to have road access. This implies that rural electrification occurs in better-connected areas, and physical and market access facilitates enterprise development. Electrified households have a slightly lower credit access opportunity. Financial access may be a bottleneck, despite better infrastructure access, highlighting a potential policy gap. Electrified households are twice as likely to have access to microfinance, and the availability of microfinance may complement electricity in enabling non-farm enterprise development. On average, electrified

households are closer to towns. Moreover, proximity to towns is associated with infrastructure availability and market access, supporting enterprise viability.

Table 4.5: Cross-tabulation of grid electricity access and nonfarm participation

Grid Electricity	Nonfarm non-participants	Nonfarm Participants	Total
No Access	2,203 (82.39%)	471 (17.61%)	2,674
Access	440 (59.38%)	301 (40.62%)	741
Total	2,643 (77.39%)	772 (22.61%)	3,415

Source: Authors computation based on Ethiopian socio-economic survey data, 2025

Table 4.5 compares households with and without access to grid electricity in relation to their non-farm enterprise (NFEs) participation. As compared to those without access to grid electricity (17.61%), households with access to grid electricity show a significantly higher rate of nonfarm enterprise participation (40.62%), indicating a potential enabling effect of electrification on livelihood diversification. This may be because of difference in production and productivity, income, market linkage, and entry barriers. A vast majority of households without access (82.39%) do not participate in nonfarm enterprise activities. This positive association between grid electricity access and nonfarm enterprise participation supports the hypothesis that access to grid electricity may facilitate rural households' participation in nonfarm enterprise activities by enabling home-based enterprises, extending working hours, or powering tools and equipment.

Table 4.6: Descriptive summary statistics by years

Variable	2011	2013	2015	2019	2021	Total
Grid electricity (Access)	0.25 (0.43)	0.23 (0.42)	0.22 (0.41)	0.15 (0.36)	0.25 (0.43)	0.22 (0.41)
Household size (number)	3.34 (2.28)	4.11 (2.53)	4.48 (2.63)	3.61 (2.29)	4.33 (2.37)	3.97 (2.47)
Gender (Dummy)	0.63 (0.48)	0.62 (0.49)	0.62 (0.49)	0.61 (0.49)	0.67 (0.47)	0.63 (0.48)
Age (number)	44.93 (17.99)	46.64 (17.08)	48.75 (16.70)	45.51 (17.93)	46.50 (16.75)	46.51 (17.35)

Variable	2011	2013	2015	2019	2021	Total
Education (years)	0.41 (2.23)	0.40 (2.28)	0.26 (1.82)	0.18 (0.92)	0.16 (1.36)	0.29 (1.84)
Off-farm income (dummy)	0.32 (0.47)	0.27 (0.44)	0.29 (0.45)	0.22 (0.42)	0.25 (0.43)	0.27 (0.44)
Total expenditure (number)	30,716 (46,403)	31,941 (29,088)	35,817 (30,146)	79,915 (67,360)	191,781 (167,681)	64,388 (91,897)
Road access (dummy)	0.75 (0.43)	0.74 (0.44)	0.75 (0.43)	0.62 (0.48)	0.63 (0.48)	0.70 (0.46)
Credit access (dummy)	0.22 (0.41)	0.23 (0.42)	0.21 (0.40)	0.12 (0.32)	0.17 (0.38)	0.19 (0.39)
Distance to urban (km)	88.7 (93.1)	68.7 (62.6)	79.4 (105)	68.7 (74.0)	60.6 (85.6)	73.5 (84.6)
MFI availability (dummy)	0.31 (0.46)	0.28 (0.45)	0.29 (0.45)	0.18 (0.39)	0.10 (0.30)	0.24 (0.43)

Note: Values are means, with standard deviations in parentheses.

Source: Authors computation based on Ethiopian socio-economic survey data, 2025

Table 4.6 shows the proportion of households with grid electricity access and other socioeconomic characteristics over the years. The result indicates a fluctuation in access to grid electricity over time in rural Ethiopia. This may be due to sample differences across years or nonlinear expansion of the grid electricity. Surprisingly, access in 2021 is no higher than in 2011, suggesting limited progress in electrification coverage over a decade or possible survey location shifts. This variation could reflect changes in electrification efforts, possibly influenced by infrastructure projects, rural electrification programs, or sample composition changes. Moreover, key explanatory variables like grid electricity access, education, and financial services access declined or stagnated, but household expenditure and proximity to urban centers improved over time. This result underlines the need to critically assess the influence of access grid

electrification on nonfarm enterprise participation using econometric controls for year effects and confounders. In addition, the result highlights a structural constraint in rural development.

4.2. CRE Probit Model Estimation Results

Table 4.7: Estimation result of average marginal effect (AME)

Variable	dy/dx	Std. Error	z-stat	p-value
Grid Electricity (Access)	0.0728	0.0357	2.04	0.041**
Household size	0.0063	0.0094	0.67	0.506
Gender (Male=1)	0.0367	0.0205	1.79	0.073*
Age	-0.0031	0.0008	-3.91	0.000***
Education (Years)	-0.0238	0.0053	-4.45	0.000***
Marital Status (Married)	0.0037	0.0339	0.11	0.912
¹⁹ Marital Status (Others)	0.0199	0.0436	0.46	0.649
Off-farm Income (Yes)	0.0068	0.0190	0.36	0.721
Total Expenditure	0.000	0.000	1.89	0.058*
Road Access (yes=1)	-0.0411	0.0214	-1.92	0.054*
Credit Access (yes=1)	0.0243	0.0203	1.20	0.232
Distance to Urban Center	-0.000	0.000	-0.23	0.815
MFI Availability (Yes)	0.0513	0.0161	3.19	0.001***
Grid Electricity (mean)	0.1304	0.0411	3.17	0.002***
Household Size (mean)	0.0098	0.0100	0.98	0.326
Age (mean)	-0.0005	0.0009	-0.55	0.582
Marital Status (mean)	0.0310	0.0226	1.37	0.170

¹⁹ To capture differences in household risk preferences, coping strategies, availability of labor and resources, which may have an impact on participation in nonfarm enterprises, we categorized the variable marital status as married, unmarried, and other (divorced, separated, widowed, or informal unions) in the correlated random effect estimation. Moreover, multiple categories may provide more accurate representation of rural household characteristics.

Variable	dy/dx	Std. Error	z-stat	p-value
Off-farm Income (mean)	-0.0111	0.0301	-0.37	0.712
Total Expenditure (mean)	0.000	0.000	0.29	0.771
Road Access (mean)	0.0608	0.0305	1.99	0.046**
Credit Access (mean)	0.0547	0.0322	1.70	0.089*
Year 2013	0.0245	0.0201	1.22	0.222
Year 2015	0.0096	0.0220	0.44	0.663
Year 2019	-0.0722	0.0231	-3.12	0.002***
Year 2021	-0.0913	0.0267	-3.42	0.001***

*** $p < 0.01$; ** $p < 0.05$; and * $p < 0.10$

Source: Authors computation based on Ethiopian socio-economic survey data, 2025

Table 4.7 presents the average marginal effect of access to grid electricity and other socio-economic characteristics on non-farm enterprise participation in Ethiopia²⁰. As compared to households without access to grid electricity, households with access are 7.3 % more likely to engage in non-farm enterprise activities in rural Ethiopia. Community-wide access to electricity has a stronger impact (13%). This between household effect shows that households in more electrified areas are 13 % more likely to participate in NFEs indicating a strong contextual effect of electricity beyond individual access. This may be due to network effects, and better functioning of local enterprises. This result supports the main hypothesis that electricity access facilitates rural non-farm enterprise participation.

Our study result is consistent with those of (Fried et al., 2021; Hassan et al., 2022; Tirkaso, 2023). They come to a conclusion that having access to grid electricity transforms economies of rural villages and facilitates the creation and growth of non-farm business enterprises in Ethiopia. But our finding is inconsistent with the finding of (Lenz et al., 2017; Pelz, 2020). The results of their analysis in the contexts of rural Ethiopia, Nigeria, and Rwanda indicate that household electrification alone was insufficient to trigger shifts in non-farm entrepreneurship for 2-4 years following grid connection and suggests consideration of necessary complementary

²⁰ The estimation results of the Base model (Correlated random effect probit model) are available in the appendix section.

infrastructures in order to improve identification of the causal effects of access to grid electrification.

Older household heads are less likely to participate in non-farm activities. Each additional year in age reduces the likelihood of NFEs participation by 0.31%, indicating that younger heads are more entrepreneurial. Gender has a borderline effect, with men slightly more likely to participate. Even though effect is weakly significant, males are 3.7% more likely to participate in NFIs, as compared to female household heads. Women may face financial constraints, which preclude them from using electricity for productive purposes. Women may have limited access to credit. Women's decision-making ability on electricity use may also be affected by social norms and mobility restrictions. This gender gap may have greater implications on rural household income diversification and poverty reduction. This finding is consistent with prior studies (Kabeer, 2021; Osabohien et al., 2025; Samandar et al., 2025).

Each year of education reduces the probability of NFEs participation by 2.4%, which is contrary to the intuition. Higher education is negatively associated with non-farm enterprise participation. This may be due to the fact that more educated individuals exit rural area toward wage jobs or migrate, not necessarily into NFEs. This unexpected result may from the fact that more educated household heads may have better access to formal employment, formal jobs that are stable and not risky, which reduces their likelihood of joining in NFEs. Moreover, some rural nonfarm enterprises may require manual labor, which may not be suitable for educated individuals. Fields (2019) and Gindling et al. (2014) documented that higher educational attainment often increases the probability of engaging in wage employment rather than low-return self-employment. Furthermore, higher education is associated with a lower probability of self-employment (Nagler et al., 2017; Tamvada et al., 2022).

At the individual household level, road access shows a negative effect, which may be due to out-migration to better jobs, but it has a positive effect at the community level, indicating an infrastructure spillover effect. Households with road access are 4.1% less likely to engage in NFEs. Being in a community with access to roads increases participation probability by 6.1%, which reinforces the role of complementary infrastructure. MFIs availability has a strong and positive effect. Access to MFIs increases NFEs participation by 5.1 percent, underlining the role of financial inclusion in enabling enterprise activity. Living in areas with more access to credit increases NFEs participation probability, but marginally, suggesting a contextual effect of credit

access. These findings are consistent with the findings of previous studies (Asher et al., 2020; Fiorini et al., 2022; Gibson et al., 2010; Nagler et al., 2014; Tirkaso, 2023). They conclude that the availability of complementary infrastructures, such as roads, markets, and financial institutions, has a significant impact on the probability of non-farm business enterprise ownership, particularly for those with access to electricity.

The year dummies for 2019 and 2021 are substantially negative, showing how shock to the economy as a whole affects non-farm enterprises in rural areas. NFEs participation in 2019 and in 2021 was 7.2 and 9.1 percentage points, respectively, lower than in the base year (2011), potentially due to COVID-19 disruptions, political instability, and macroeconomic or inflationary pressures.

4.3. Robustness Check

4.3.1. Fixed effect (linear probability model) and test of heterogeneous effects

To strengthen our analysis and interpretation, we run a fixed-effect linear probability model for comparison and as a robustness check²¹. Since the outcome is binary and fixed-effect probit/logit drops all households with no variation in the outcome, we use a linear probability model (LPM). This estimation method automatically drops time-invariant variables and only uses within-household variation. The coefficient of access to grid electricity is positive and statistically significant. This reinforces the correlated random effect (CRE) probit estimation result, which also shows a significant and positive marginal effect. The consistency of results across both CRE and fixed-effect models supports the robustness of the main finding: access to grid electricity increases the likelihood of non-farm enterprise participation in rural Ethiopia. Moreover, education is also significantly and negatively associated with non-farm enterprise participation across both models. This may be due to the fact that more educated individuals may opt for other livelihood options, such as migration or formal sector jobs, instead of engaging in rural enterprises.

To explore the interaction effects, we also test for heterogeneous effects using distance to urban center as an interaction variable with access to grid electricity. The coefficient of the interaction term access to grid electricity and distance to the urban center is statistically significant and positive. The implication is that the further a household is from the urban center, the stronger and

²¹ The estimation results of the fixed effect (linear probability model) and the interaction effects are available in the appendix section.

more positive the effect of grid access on nonfarm enterprise participation. This supports spatial heterogeneity in electrification impacts. In addition, contrary to intuition, years of education is negative and significant. Therefore, grid electricity access alone doesn't have a significant average effect, but its interaction with remoteness matters, suggesting policies targeting remote rural areas may yield better outcomes.

4.4. How grid electricity access translates into enterprise creation, and the risks of over-reliance on electrification without complementary investments: implications for rural industrial policy and employment creation.

Grid electrification influences rural non-farm enterprise participation through several interrelated mechanisms. First, electricity reduces production costs by substituting traditional energy sources and enabling the use of electric equipment, thereby increasing productivity and profitability. Second, electrification expands the range of feasible economic activities, particularly in agro-processing, small-scale manufacturing, and service provision. Third, electricity improves market integration by facilitating communication, information access, and product preservation. Finally, improved household welfare and educational outcomes associated with electrification may enhance entrepreneurial capacity. These channels suggest that electrification operates not only as a direct input into production but also as an enabling infrastructure that supports rural economic diversification.

The positive association observed in this study therefore reflects improved feasibility of enterprise creation rather than electricity acting as a standalone driver. The complementary roles of road access, market proximity, and financial services further suggest that electrification operates within a broader infrastructure ecosystem. However, the stronger association between electrification and enterprise participation in areas with better road access and financial services suggests that electricity is more likely to support economically viable enterprises when complementary infrastructure and institutional support are present. The findings also highlight potential risks associated with over-reliance on electrification as a standalone rural development strategy. Access to electricity does not automatically translate into enterprise creation or expansion if complementary constraints such as limited access to roads, finance, skills, and markets remain binding. In such contexts, electrification investments may primarily improve household welfare rather than stimulate productive economic transformation. Therefore,

electrification policies should be implemented alongside complementary investments that enable productive use of electricity.

From a rural industrial policy perspective, the results suggest that electrification should be aligned with strategies that promote productive employment rather than solely expanding household connections. Policies encouraging agro-processing, small-scale manufacturing, and service enterprises can enhance the employment effects of electrification. The findings also support a coordinated infrastructure approach, where electrification is complemented by road connectivity, financial services, and skills development programs to stimulate sustainable rural industrialization.

5. Conclusion and Policy Implications

Access to grid electrification has the potential to diversify rural economies, as evidenced by a significantly higher link between and rural non-farm enterprise activities. There is a clear similarity between the proportion of households with grid electricity access (21.7%) and those participating in non-farm enterprises (22.6%) in rural Ethiopia. Moreover, access to grid electricity significantly facilitates NFEs participation, both at the household and community level, though it is low and fluctuates, indicating continuous challenges in rural electrification. Inadequate access to electrification may limit productivity, educational opportunities, and quality of life. Household demographic characteristics (like household size, age, and gender) are relatively stable, reflecting consistent household structures. The extremely low years of education raises concerns for long-term economic development and the ability to diversify rural livelihoods. Economic indicators like total expenditure increase consistently, possibly reflecting inflation or growing inequality.

Access to rural infrastructure like roads and financial services is inconsistent, pointing to challenges in rural development and inclusion. Access to electricity alone may not be enough, and access to roads, markets, and finance are also necessary to unlock the potential of rural non-farm enterprise. That is, financial services and infrastructure (MFIs, road networks) are essential complements to electricity. The declining of NFEs participation in recent years (2019–2021) suggests internal and external shocks must be considered in policy design.

Electrifying rural areas with high potential for nonfarm enterprise development, particularly those close to markets and roads and with access to credit or microfinance institutions should be

a top prioritize for the Ethiopian electric power and the ministry of water and energy. To unlock the potential of rural non-farm enterprises, the government should complement electrification programs with targeted infrastructure development (such as roads and electricity) and financial services (credit access and MFIs). With such low average years of schooling, targeting skill development and adult education by the Ministry of labor and skill might also complement electrification to promote NFEs participation. In addition, local governments should encourage the uses of electricity beyond lighting like agro-processing, refrigeration, and manufacturing, and promote solar mini-grids and other systems for productive use.

6. Limitations

This study acknowledged the existence of potential endogeneity due to the non-random grid electrification rollout. To address this, feasible identification strategies such as distance to the nearest substation and historical electrification expansion patterns can be used as potential instruments. But instrument availability in ESS is limited. Moreover, studies focusing on quality, reliability, and equity in infrastructure provision would deepen understanding of long-term development impacts. But due to data limitations in ESS, which captures only access status, we could not construct a direct measure of quality or reliability (like hours of supply, power outage frequency, voltage fluctuation, or electricity expenditure relative to income).

7. Area for Further Study

Future studies should look beyond household-level electrification using geospatial data to recover variation in local electrification infrastructure improvement over longer periods of time in order to improve identification of the causal effects of access to this infrastructure.

Synthesis of Findings and Integrated Policy Implications

This section elaborates on the broader implications of access to three basic physical infrastructures for livelihood improvement in rural Ethiopia, drawing insights from the study's findings.

This dissertation examined how different types of physical infrastructure affect rural livelihoods in Ethiopia, focusing on small-scale irrigation, rural road transport, and grid electrification, with three different but interconnected empirical studies. Each paper addressed a distinct dimension of infrastructure livelihood linkages but together provide a holistic picture of how complementary investments in water, transport, and energy systems shape the pathways out of poverty for rural households. The reviewed literature demonstrates that irrigation, roads, and electrification influence rural livelihoods through interconnected mechanisms affecting production, market participation, and income diversification. However, existing studies largely analyze these infrastructures in isolation. Consequently, limited empirical evidence exists on how different types of physical infrastructure jointly shape rural livelihood outcomes. This dissertation addresses this gap by examining multiple infrastructure dimensions within a unified analytical framework using complementary empirical approaches.

Collectively, the findings reveal that access to physical infrastructure plays a transformative yet interdependent role in improving rural livelihoods through enhanced agricultural productivity, market integration, income diversification, and resilience to shocks. The findings demonstrate that each infrastructure type affects different rural livelihood strategies and outcomes, but they are highly interrelated in their effect to rural livelihoods. The positive impact is in line with more broader goals such as poverty reduction, ensuring food security, and improved rural livelihoods, all of which are central to Ethiopia's development policy and the Sustainable Development Goals (SDGs).

The three studies jointly suggest that rural infrastructure investments are mutually reinforcing rather than substitutable. Small-scale irrigation primarily enhances agricultural productivity, household income, food security, and resilience against climate variability. Households with access to small-scale irrigation achieve higher yields, greater cropping intensity, and improved dietary diversity, contributing to improved livelihood outcomes. Access to rural road

infrastructure significantly improves smallholder commercialization. Road connectivity reduces transaction costs, facilitate input and output market participation, and enhance households' ability to shift from subsistence to market-oriented agriculture. Electrification access used to facilitate rural economic diversification, particularly for the development of nonfarm enterprises. Households with grid access are more likely to participate in nonfarm businesses enterprise, which provides alternative income sources beyond agriculture. Electricity enhances productivity, enables the establishment of service-based enterprises, and contributes to employment creation in rural communities.

Based on the synthesis, several alternative policy implications can emerge. Integrating infrastructure investments within a spatial planning framework (such as development corridors and clustered villages) yields higher livelihood returns than isolated projects. Integrating roads, irrigation, and electricity investments spatially and periodically enhances synergy and cost-effectiveness. Focus infrastructure investments on regions with complementary agro-ecological and institutional capacity, while designing smart interventions for lagging regions. Establish inter-ministerial mechanisms linking the Ministry of Agriculture, Ministry of Water and Energy, and Ministry of Transport and Logistics to jointly plan and monitor rural infrastructure programs. Incorporate climate adaptation measures, community participation, and gender-sensitive designs to ensure sustainability and equity. Invest in integrated rural infrastructure monitoring systems (like geospatial platforms) to track complementarities and measure livelihood impacts over time.

Given fiscal and institutional constraints in Ethiopia, simultaneous expansion of all rural infrastructures may not be feasible. The findings of this dissertation suggest prioritizing investments that generate the largest complementary effects. Rural road expansion provides foundational benefits by facilitating market participation and enabling subsequent investments in irrigation and electrification to yield higher returns. This sequencing helps minimize opportunity costs and improves the efficiency of public infrastructure investment. Government investment should prioritize rural road connectivity in market-isolated areas as a first-stage intervention, followed by irrigation expansion in agriculturally productive zones and electrification in areas with demonstrated potential for nonfarm enterprise development. Such sequencing maximizes complementarities between infrastructure types and improves the cost-effectiveness of public investment.

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Appendix A3

Table 1-A3: Estimation result of correlated random effects probit model (base model)

Variable	Coef.	Std. Err.	Z	p-value	95% Conf. Interval
Grid Electricity (access)	0.573	0.286	2.00	0.045**	[0.012, 1.134]
Household Size	0.049	0.075	0.66	0.508	[-0.097, 0.196]
Gender (1 = Male)	0.289	0.162	1.78	0.075*	[-0.029, 0.607]
Age of HH Head	-0.024	0.006	-3.79	0.000***	[-0.037, -0.012]
Years of Education	-0.187	0.044	-4.22	0.000***	[-0.275, -0.100]
Marital Status (Married)	0.030	0.273	0.11	0.913	[-0.504, 0.564]
Marital Status (Others)	0.156	0.346	0.45	0.652	[-0.522, 0.833]
Off-farm Income (Yes)	0.053	0.150	0.36	0.721	[-0.240, 0.347]
Total Expenditure	1.71e-06	8.63e-07	1.98	0.048**	[1.63e-08, 3.40e-06]
Road Access (Yes)	-0.324	0.170	-1.90	0.057*	[-0.657, 0.010]
Credit Access (Yes)	0.191	0.161	1.19	0.235	[-0.124, 0.506]
Distance to Urban	-0.00015	0.00066	-0.23	0.815	[-0.0014, 0.0011]
MFI Availability (Yes)	0.404	0.129	3.12	0.002 ***	[0.150, 0.658]
Grid Electricity (mean)	1.026	0.334	3.07	0.002***	[0.372, 1.680]
Household Size (mean)	0.077	0.078	0.98	0.325	[-0.076, 0.231]
Age (mean)	-0.004	0.007	-0.55	0.583	[-0.017, 0.010]
Marital Status (mean)	0.244	0.179	1.36	0.173	[-0.107, 0.595]
Off-farm Income (mean)	-0.088	0.237	-0.37	0.712	[-0.553, 0.378]
Total Expenditure (mean)	2.62e-07	8.96e-07	0.29	0.770	[-1.49e-06, 2.02e-06]
Road Access (mean)	0.478	0.243	1.97	0.049**	[0.002, 0.954]
Credit Access (mean)	0.430	0.255	1.69	0.092*	[-0.070, 0.930]
Year 2013	0.177	0.146	1.21	0.225	[-0.109, 0.463]

Variable	Coef.	Std. Err.	Z	p-value	95% Conf. Interval
Year 2015	0.070	0.161	0.44	0.662	[-0.245, 0.386]
Year 2019	-0.590	0.197	-3.00	0.003***	[-0.976, -0.205]
Year 2021	-0.772	0.243	-3.17	0.002***	[-1.249, -0.295]

*** p < 0.01; **p < 0.05; and * p < 0.10

Source: Authors computation based on Ethiopian socio-economic survey data, 2025

Table 2-A3: Fixed effects regression (LPM) result for robustness

Variables	FE Coefficient	Robust Std. Error	t-stat	p-value	95% Confidence Interval
Grid electricity (access)	0.1010 **	0.0412	2.45	0.014	[0.0202, 0.1818]
Household size	0.0227	0.0229	0.99	0.323	[-0.0223, 0.0676]
Gender	0.0506	0.0838	0.60	0.546	[-0.1137, 0.2149]
Age	-0.0001	0.0018	-0.05	0.959	[-0.0037, 0.0035]
Education level	-0.0114 **	0.0046	-2.51	0.012	[-0.0204, -0.0025]
Married (vs single)	-0.0163	0.0603	-0.27	0.787	[-0.1346, 0.1020]
Others (vs single)	0.0400	0.0699	0.57	0.567	[-0.0970, 0.1770]
Off-farm income	0.0288	0.0234	1.23	0.219	[-0.0171, 0.0747]
Total expenditure	0.000	0.000	0.59	0.558	[-0.000617, 0.00114]
Road access (yes)	-0.0500 *	0.0260	-1.92	0.055	[-0.1009, 0.0010]
Credit access (yes)	0.0549	0.0394	1.39	0.164	[-0.0224, 0.1321]
Distance to urban	0.00013	0.00015	0.92	0.357	[-0.00015, 0.00042]
MFI availability (yes)	0.0284	0.0327	0.87	0.386	[-0.0358, 0.0925]
Year 2013 (ref: 2011)	0.0058	0.0232	0.25	0.802	[-0.0397, 0.0514]
Year 2015	-0.0326	0.0276	-1.18	0.237	[-0.0868, 0.0215]
Year 2019	0.0223	0.0423	0.53	0.598	[-0.0606, 0.1053]

Variables	FE Coefficient	Robust Std. Error	t-stat	p-value	95% Confidence Interval
Constant	0.0703	0.1318	0.53	0.594	[-0.1881, 0.3287]
Observations = 3,415			Households (Groups) = 2,745		
R-squared (within) = 0.032			Rho (intra-class correlation) = 0.682		
* p < 0.1; ** p < 0.05; *** p < 0.01					

Source: Authors computation based on Ethiopian socio-economic survey data, 2025

Table 3-A3: Estimation result of heterogeneous effect by distance to urban (interaction)

Variables	Coefficient	Robust Std. Error	z-stat	p-value	95% Confidence Interval
Grid electricity (access)	0.1490	0.3357	0.44	0.657	[-0.5089, 0.8070]
Household size	0.0468	0.0753	0.62	0.534	[-0.1008, 0.1943]
Gender	0.2921 *	0.1651	1.77	0.077	[-0.0315, 0.6156]
Age	-0.0241 ***	0.0065	-3.73	0.000	[-0.0367, -0.0114]
Education level	-0.1953 ***	0.0461	-4.24	0.000	[-0.2857, -0.1050]
Married (vs single)	0.0186	0.2763	0.07	0.946	[-0.5229, 0.5601]
Others (vs single)	0.1426	0.3503	0.41	0.684	[-0.5439, 0.8291]
Off-farm income	0.0555	0.1512	0.37	0.713	[-0.2408, 0.3519]
Total expenditure	0.00177 **	0.00879	2.01	0.044	[0.00043, 0.00349]
Road access (yes)	-0.3035 *	0.1721	-1.76	0.078	[-0.6407, 0.0338]
Credit access (yes)	0.1762	0.1627	1.08	0.279	[-0.1427, 0.4952]
Distance to urban	-0.0007	0.0007	-1.00	0.316	[-0.0022, 0.0007]
MFI availability (yes)	0.3803 ***	0.1325	2.87	0.004	[0.1205, 0.6400]
Grid × Distance	0.0065 **	0.0032	2.05	0.040	[0.0003, 0.0128]
Grid Electricity (Mean)	1.2371 ***	0.4003	3.09	0.002	[0.4526, 2.0217]
Household Size (Mean)	0.0822	0.0791	1.04	0.299	[-0.0730, 0.2373]
Age (Mean)	-0.0041	0.0069	-0.60	0.552	[-0.0176, 0.0094]

Variables	Coefficient	Robust Std. Error	z-stat	p-value	95% Confidence Interval
Marital Status (Mean)	0.2622	0.1819	1.44	0.149	[−0.0942, 0.6186]
Off-farm income (Mean)	−0.1006	0.2405	−0.42	0.676	[−0.5719, 0.3707]
Total Expenditure (Mean)	0.000253	0.000925	0.27	0.784	[−0.00156, 0.00207]
Road Access (Mean)	0.4484 *	0.2456	1.83	0.068	[−0.0330, 0.9298]
Credit Access (Mean)	0.4607 *	0.2588	1.78	0.075	[−0.0466, 0.9680]
Grid × Distance (Mean)	−0.0017	0.0043	−0.40	0.690	[−0.0101, 0.0067]
Year 2013 (ref: 2011)	0.1893	0.1478	1.28	0.200	[−0.1003, 0.4789]
Year 2015	0.0870	0.1629	0.53	0.593	[−0.2322, 0.4062]
Year 2019	−0.5707 ***	0.2004	−2.85	0.004	[−0.9634, −0.1780]
Year 2021	−0.7429 ***	0.2462	−3.02	0.003	[−1.2254, −0.2603]
Constant	−2.5697 ***	0.4842	−5.31	0.000	[−3.5187, −1.6206]
Observations: 3,415		Households (Groups): 2,745			
Wald chi² (27): 109.71		Prob > chi²: 0.0000			
Sigma_u: 1.877		Rho (Intra-class correlation): 0.779			
LR Test of rho = 0: χ^2 (1) = 163.15, p < 0.001					

*p < 0.1; **p < 0.05; ***p < 0.01

Source: Authors computation based on Ethiopian socio-economic survey data, 2025