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Economic Costs of Intimate Partner Violence in Ethiopia

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Abstract

Reduction of intimate partner violence (IPV) against women is a recognised public health goal worldwide. However, the negative economic impacts of IPV against women, households and the economy are not well studied, especially in African countries. Based on a primary quantitative survey of 2,095 women, this study addresses this gap by estimating the economics costs of IPV against women in Ethiopia, focusing on out-of-pocket (OOP) costs, lost productivity and poverty. According to our study, the lifetime prevalence of intimate partner violence (IPV) is approximately 36%, while the prevalence of IPV within the past year is around 21%. In terms of lost productivity, women missed an average of 19 care workdays due to IPV and husbands (perpetrators) missed 11 care workdays. In addition, working women had a productivity loss of about 17 days due to violence experienced in lifetime. OOP costs were also substantial. In nearly a third of incidents (34%), women reported incurring an average expense of 2,934 Birr, which represents roughly 10% of their annual earnings. Furthermore, using Propensity Score Matching (PSM) analysis, it was found that intimate partner violence (IPV) resulted in a reduction of 372.83 Birr in women's income, 929.90 Birr in household income, and 332.95 Birr in household spending. The consequences of intimate partner violence (IPV) for women and their families entail substantial financial instability and negative effects on social well-being. These results stress the importance of integrating IPV prevention and response measures into national policies and budgets, as well as strongly improving current initiatives to prevent and combat IPV.

Key Words: Economic costs of violence, intimate partner violence, lost productivity, income insecurity; poverty, PSM, Ethiopia

JEL Classification: C10, D74, O40, J16.

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1. Introduction

Violence against women and girls (VAWG) represents a major issue globally, impacting society, the economy, and public health, and transcending cultural and religious boundaries. Globally, almost one-third of women (30%) have experienced physical and/or sexual intimate partner violence (IPV) or non-partner sexual violence (NPSV) or both in their lifetime (WHO, 2021). The prevalence of IPV is higher in Sub-Saharan Africa (SSA), where approximately 45.6% of women have been subjected to at least one form of IPV in their lifetime (Muleneh et al., 2021).

In the most recent Ethiopia Demographic and Health Survey (EDHS), 34% of ever-married women aged 15-49 reported ever experiencing emotional, physical or sexual violence by their current or most recent husband/partner (Central Statistical Agency (CSA) [Ethiopia] and ICF, 2016). Controlling behaviors by intimate partners, involving at least three types, were reported by 16% of ever-married women. Additionally, 28% of ever-married women between the ages of 15 and 49, have encountered physical and/or sexual intimate partner violence (IPV) at least once in their lives, with 20% experiencing such violence within the past year. A significant 81% of women who endured emotional, physical, and/or sexual violence from their spouses or partners also reported that their husbands or partners frequently consumed alcohol to the point of intoxication. Economic violence was not measured in the 2016 EDHS. Local research studies have pointed to significantly higher incidences of both physical and sexual violence. For instance, a study at Gondar Referral Hospital found that almost 59% of pregnant women experienced domestic violence, with emotional violence being the most prevalent at almost 58%, followed by physical violence at 32%, and sexual violence at 8%.

While prevalence of violence is an important estimate, it is the determinants/correlates of violence that helps researchers and policymakers in violence prevention (Chadha et al., 2020). The 2016 EDHS IPV data reported by MoWSA (2019) also provided detailed information on violence categorized by factors like women's property ownership and education levels. For example, the study revealed that increased educational opportunities for girls and young women are associated with reduced incidents of spousal violence. Additionally, the research investigated the connection between VAWG and women's empowerment, the adverse effects of VAWG, and women's tendencies to seek assistance. Notably, only 23% of women who experienced physical and/or sexual violence sought support.

1.1 Impacts of IPV

Intimate Partner Violence (IPV) significantly impacts the welfare of women and their households through a complex interplay of physical, mental, and socio-economic mechanisms. Recent studies have highlighted how economic abuse limits women's financial independence, reinforcing the economic instability that often accompanies abusive relationships (Asante et al., 2019; Elmusharaf et al., 2019; Ghaus et al., 2019). A complete understanding of these mechanisms is essential for developing effective interventions.

One key mechanism is the profound physical health impact of IPV, ranging from immediate injuries to chronic conditions as highlighted by research by Campbell (2002) and Coker et al. (2002). In addition to physical health, IPV significantly affects the mental health of IPV survivors. A crucial meta-analysis conducted by Golding (1999) highlights the significant association between IPV and mental disorders, including depression and anxiety. These psychological impacts go beyond survivors, impacting other household members who witness violence, especially children (Levendosky and Graham-Bermann, 2001).

The welfare implications of IPV will be incomplete without understanding the economic dimensions of IPV. Literature has consistently established the negative economic consequences of VAWG, including IPV and/or NPSV. For instance, a myriad of studies conducted in the US and OECD countries have identified various work-related consequences of intimate partner violence (IPV). These include issues such as unemployment, job insecurity, absenteeism, tardiness, work interruptions, and decreased job effectiveness. (Alasker, et. al, 2016, Anderson et al., 2014, Blodgett and Lanigan, 2018, Crowne et al., 2011, Kulkarni and Ross, 2016, Logan et al., 2007, Rayner-Thomas, 2013 and Wathen, et al., 2015). On the other hand, research on work-related consequences of VAWG in low and middle-income countries is scant (IFC, 2019b, IFC, 2019a, Chadha et al., 2020, Duvvury et al., 2022, Chadha et al., 2022).

Given the limited literature on the negative economic impacts of IPV in African countries, including Ethiopia, the current study fills this gap by providing reliable estimates on the economic costs of IPV in Ethiopia. Based on Duvvury et al. (2019), this study primarily uses accounting methodology to estimate direct and indirect costs of IPV. This study also employs Propensity Score Matching (PSM) to estimate the difference in productivity loss, women’s income, household income and expenditure between survivors and non-survivors.

This research establishes the substantial economic costs of Intimate Partner Violence (IPV) in Ethiopia. This study points to the significant drain of household resources due to out-of-pocket (OOP) expenses incurred by survivors and loss of care workdays. Working women demonstrate a higher prevalence of lifetime violence, suggesting work as a potential risk factor. The study points to a productivity loss of almost 17 days for working women experiencing lifetime violence. Propensity Score Matching (PSM) analysis reveals that IPV survivors have significantly lower income, contributing to income insecurity, negative social well-being, and adverse effects on the economy.

Our recommendation is for the government to integrate gender-based violence (GBV) prevention and response measures into national policies and budgets. In particular, we advocate for special emphasis on Intimate Partner Violence (IPV), within the broader GBV programs and training initiatives, as the current response predominantly centers on GBV, particularly sexual assault. Additionally, there is a crucial need to integrate the impacts of IPV into economic and social planning as well as policies for a more comprehensive approach to addressing this issue.

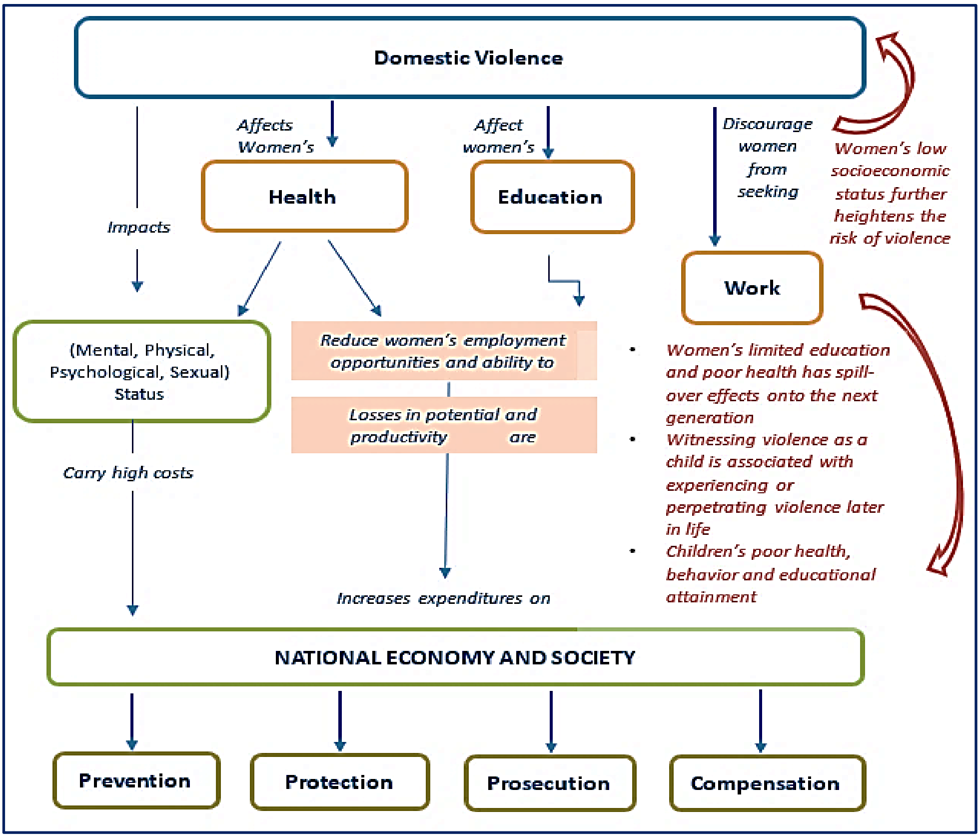
2. Research Methodology

This article draws from a larger mixed-methods study focused on estimating the economic costs of IPV in Ethiopia - estimates of the yearly direct expenses incurred by households due to intimate partner violence (IPV), the indirect costs associated with IPV, and the annual costs related to providing IPV services. (UN Women Ethiopia, 2022). This article focuses on the quantitative findings of the study in terms of OOP costs, lost productivity and poverty.

2.1. Conceptual Framework

Figure 1 below shows the conceptual framework that guides this study. It is widely understood that domestic violence has several impacts that result in losses for women, families, communities, businesses, and broader societal costs at macroeconomic level. Figure 1 depicts the pathways through which IPV affects the welfare of women and their households, which further lead to a range of economic and social costs at the individual/household level, community/business level and the government/state level.

Figure 1: Conceptual Framework



Source: Duvvury *et al*. 2017

2.2. Data Collection Method

An accurate estimation of the costs and impacts of intimate partner violence (IPV) in Ethiopia requires collection of high-quality quantitative data through a national survey. Such a survey is essential not only for identifying the incidence and prevalence, but also the economic costs of IPV, as well as its broader impacts on households, communities, and the country as a whole. Conducting a household and women's surveys involving women aged 18-59 years and household heads or other knowledgeable adult members is considered the most reliable approach to gather information on the extent of VAWG in the general population. The questionnaire used in the current study was developed and adapted to the Ethiopian context in collaboration with relevant stakeholders, drawing on insights from previous costing surveys.

The success of this particularly sensitive study hinges on the efficacy of field operations, particularly in the recruitment of essential field personnel—namely, supervisors, enumerators, and interviewers. Consequently, enough qualified and experienced enumerators, interviewers, and supervisors were enlisted, trained, and deployed to ensure the completion of the fieldwork within the predetermined timeframe. The selection criteria for field staff were primarily based on their prior experience in sensitive data collection related to IPV, sexual and reproductive health, and HIV/AIDS. Their proficiency in local languages and English, as well as their prior experience with tablet or computer-based electronic data collection, were also considered. Additionally, consideration was also given to the ability to comprehend the nuances of the questions, enthusiasm and motivation for the demanding fieldwork, full-time commitment, physical capability to travel and work in potentially challenging environments, familiarity with the study areas, teamwork aptitude, cultural sensitivity, and relevant technical skills and training in data collection.

Furthermore, a deliberate effort was made to recruit more female data collectors, recognizing their greater ease in approaching women respondents and understanding their experiences compared to male counterparts. The one-week training for field staff placed a primary focus on IPV, communication with survivors, and adherence to ethical standards ensuring survivor and interviewer safety, as well as maintaining confidentiality. WHO’s ethical and safety recommendations for intervention research on violence against women were consistently followed (WHO, 2016).

The initial sections of the questionnaire focused on gathering household information and were administered with the household head or another knowledgeable member. Once completed, subsequent sections of the survey were conducted with a selected randomly chosen woman. The primary objective of the women's survey was to gather detailed information on the selected woman's experiences with intimate partner violence (IPV) and its repercussions on herself, her spouse, and children.

Unlike data obtained through other methods such as administrative records, personal observations or in-depth interviews, population-based surveys allow us to collect data from randomly selected samples that can be generalized to the entire population. These surveys provided a more precise depiction of actual examples of victimization compared to reports filed with authorities like the police. By directly questioning women about their experience of IPV, population-based surveys offer crucial insights into the prevalence of IPV against women. Trained enumerators or interviewers conducted individual face-to-face interviews using tablet or computer-based questionnaires.

2.3. Description of the Study Area and Population

The study was conducted in three of Ethiopia's eleven regions—Oromia, Amhara, and Southern Nations, Nationalities, and Peoples' Region (SNNPR)—as well as Addis Ababa, one of the two City Administrations. Fieldwork was conducted from September 2021 to December 2021. These regions and the city administration collectively represent a significant portion of Ethiopia's population, exceeding 80% (CSA, 2013), and showcase the survey's ability to capture diverse geographic and ethnic makeup of Ethiopia. They also contribute substantially to Ethiopia's GDP, approximately 82% (Amsalu et al., 2017). The survey focussed on households and women from both rural and urban areas across Ethiopia. MoWSA provided support letters to regional and sector offices to facilitate the data collection process.

2.4. Sampling Procedure

The study used multi-stage probability sampling techniques, which included systematic, simple random, and cluster sampling methods, to choose representative households and women. This process included randomly choosing sample zones or sub-cities, woredas (districts), kebeles (wards), and households. The selection of woredas, kebeles, and households was based on their respective regions' or city's contribution to Ethiopia's GDP. According to Amsalu et al. (2017), Oromia, Amhara, SNNPR regions, and Addis Ababa city contribute 33.6%, 17.3%, 19.9%, and 11.2% to the country's GDP, respectively, totalling 82%. To allocate the 2,095 sample households proportionally among the regions and city, the sample size was distributed as follows: 41% for Oromia, 21.1% for Amhara, 24.3% for SNNPR, and 13.6% for Addis Ababa. This led to random selection of three zones from Oromia, two zones each from Amhara and SNNPR, and two sub-cities from Addis Ababa. Subsequently, three districts (two rural and one urban) were randomly selected from each zone in the three regions, and three urban districts were chosen from Addis Ababa, totalling 27 sample districts across the regions and city administration. After district selection, all kebeles within the chosen districts were listed, and three kebeles were randomly selected from each district for inclusion in the survey

A sampling frame consisting of lists of households was obtained from the kebele administration of selected kebeles. Household selection for the study was conducted randomly from this frame. An additional list of households was prepared as a backup in case the selected household did not have a woman meeting the inclusion criteria or if the selected woman declined to participate. In kebeles with clusters, about 3-4 clusters were randomly chosen from each kebele. Enumerators and supervisors were provided with addresses of both selected and alternative households. In situations where household lists were unavailable for selected kebeles, enumerators and supervisors would identify a landmark in certain areas of the kebele or cluster. From this central point, households were randomly selected in all directions (e.g., every 3rd or 4th household) based on the housing density in the kebeles.

For the selection of women participants, if there were multiple adult women in a household, one woman was chosen randomly using a KISH grid method. Furthermore, women within households in each sampled kebele were stratified by age, education level, and employment status. Eventually, a probability proportional to population size method was employed to randomly select 2,095 households from these kebeles for interviews with household heads or other knowledgeable household members, as well as with women. Table 1 below provides the sample zones, woredas, kebeles, households, and women included in the quantitative data collection process.

Table 1: Sampling households for quantitative data

Region/City	Total Zones/ Sub-Cities	Sample Zones/ Sub-Cities	Total Woredas	Sample Woredas	Sample Kebeles	Sample Households
Oromia	22	3	287	9	27	858
Amhara	11	2	169	6	18	442
SNNPR	16	2	133	6	18	508
Addis Ababa	10	2	116	6	18	286
Total	60	9	705	27	81	2,095

Source: Authors' own

2.5. Estimation of Economic Costs

Based on Duvvury et al. (2019), this study primarily uses accounting methodology to estimate direct and indirect costs of IPV. Under this methodology, the costs of services utilized by women due to intimate partner violence (IPV) are estimated by multiplying the unit cost incurred by each woman by the frequency of service utilization. This approach is also applied to estimate indirect costs, such as the economic impact of missed caregiving duties.

Accounting methodology provides a comprehensive assessment of economic costs, considering both direct and indirect costs, and providing a fine understanding of the financial implications of violence on women, society and economy. The use of quantifiable metrics assists in precise measurement and comparison across different types of violence, regions, and timeframes, providing policymakers with data-driven insights. The economic cost estimates arising out of this methodology have worked as compelling tools for advocacy, raising public awareness, and accumulating support for preventive measures. The economic costs estimated using accounting methodology can be further used for cost-benefit analysis of various interventions to reduce domestic violence.

This study also employs Propensity Score Matching (PSM) to estimate the difference in productivity loss, women's income, household income and expenditure between survivors and non-survivors. In impact evaluation studies using non-experimental or quasi-experimental designs, different approaches can be used but there are three widely used models, namely propensity score matching (PSM), two-stages least squares (2SLS), and endogenous switching regression (ESR) models. Of the three, PSM and ESR models are often used to correct for self-selection bias and heterogeneity. This study used an ESR model to control for self-selection problems and heterogeneity. To check for the robustness of the estimates, PSM was also used. ESR model is a parametric approach that uses two different estimation equations for the IPV and non-IPV women by adding the inverse mills ratio, controlling for selection bias. Inverse mills ratio is calculated through a selection equation in the first stage where the selective sample is treated as a missing data problem. Then for each regime conditioned on being victim of IPV, the outcome equations are disposed of differently, which are estimated by a probit model.

2.5.1. Prevalence of violence

This research uncovers the prevalence of violence over the past year and throughout a woman's lifetime. The prevalence rates were estimated by asking women about their experiences with specific forms of psychological, economic, physical, and sexual violence. Women who were currently partnered or had been separated, divorced, or widowed in the past year were asked about their experiences both within the last 12 months and prior to this period. Women who had been married or cohabiting before the past year were only asked about their experiences during that time. The data on violence behaviours was collected using an ordinal scale: 'never', 'rarely', 'sometimes', and 'often'. For a detailed list of the behaviours examined, refer to the Annexure. Given the gaps in current literature, this survey particularly focused on economic violence.

Following international standards (Sardinha et al., 2022), if a woman reported experiencing any form of violence at least once in the past year, she was classified as having experienced violence. If a woman reported experiencing violence either in the past year or before, she was classified as having experienced violence in lifetime. Furthermore, women were also asked about the total number of incidents they had experienced. To facilitate accurate recall, women provided details about incidents from the past year, including the nature of the incident, its impacts, any help sought, and the costs incurred. The monetary cost estimation was based on this incident-specific information.

2.5.2. Out of Pocket Expenditure

Out-of-Pocket (OOP) costs are estimated solely for incidents that occurred within the past 12 months. These costs cover expenses incurred by survivors for accessing legal services, health services, police services, shelter, mediation, and property replacement.

Health Costs

The OOP health costs include expenditures related to an incident of violence, including services from nurses, doctors, pharmacists, or technicians; visits to hospitals, clinics, or health centers; overnight hospital stays; medical tests like x-rays; medication and treatments; alternative medical treatments (such as herbal medicine); other healthcare-related expenses like drinks, food for survivor and companions; transportation; medical consultations; medical or health reports; and mental health services from counselors or psychiatrists.

Legal and Police Costs

OOP legal costs include expenses related to the incident for lawyers, court fees, litigation, consultations like visits to legal consultation centers, legal reports, online consultations, and other related costs like food, communication, transport, etc. Police costs include fees and transportation expenses.

Property Replacement Costs

OOP property replacement costs include spending on replacing items damaged due to the violence incident. These items might include tableware, plates, utensils, electronic devices (like tablets, phones, laptops, TV), electrical appliances, cars, bicycles, children’s toys, antiques, wall clocks, carpets, clothes, furniture, and other items mentioned by survivors.

Shelter and Mediation Costs

OOP shelter costs cover transportation from where the violence occurred to an informal shelter or parent's home, communication costs including cell phone bills, and other related expenses (e.g., accommodation in hotels or privately rented spaces, food, drink, housekeeping). Mediation costs include expenses such as meals for mediators, paying for their transport, etc.

Total Out of Pocket Costs

The total out of pocket costs for each incident are estimated as follows:

$$OOP\ Costs = Health\ Costs + Legal\ Costs + Police\ Costs + \\ Property\ Replacement\ Costs + Shelter\ Costs + Mediation\ Costs$$

2.5.3. Care work loss

Care work loss, including missed domestic tasks and caregiving for children and the elderly due to the incident, has also been included in this study. Husbands may also stop performing domestic and care work due to their violence against their wives or partners, so their lost days have been included as well.

Care work activities entail supporting children's education (assisting, training and reading); childcare (cleaning, feeding, bathing, changing diapers, providing medical/health care, preparing children for school); and caregiving for the elderly and/or sick (preparing food, personal care, medical care, accompanying to medical/health services).

Domestic activities include a variety of household chores, such as preparing meals, routine cleaning (bathrooms, rooms, kitchen), washing clothes, organizing household items, dusting, washing windows, polishing floors, and taking out the garbage. Shopping for household needs involves buying food products (groceries), school supplies, medical supplies, clothing, household appliances, gasoline and furniture. Additional household chores include external cleaning of the patio, garage and collecting foliage.

Survivors were asked to report the number of days they and their husbands completely or partially missed a particular activity due to the incident. If survivors indicated that an activity was partially missed on some days, the number of those days was halved.

Missed care days were therefore estimated as follows:

$$\boldsymbol{MCW} = \sum_i (\sum_t (\boldsymbol{DFS_t} * \boldsymbol{M_t}) + (\mathbf{0.5} * \boldsymbol{DPS_t} * \boldsymbol{M_t})) / å\, \boldsymbol{H_t}$$

Where MCW represents Missed Care Work, i denotes the individual woman, t the specific care activity (domestic activity, childcare, or care for elderly/sick members), DFS indicates the days fully stopped for care activity t DPS signifies the days partially stopped for care activity t, and M is the average minutes spent on care activity t in a day. The sum of the hours of care work missed for activity t is divided by the hours typically spent on care activities in a day to calculate the missed days of care work.

In the survey, survivors were asked about the approximate minutes they spend on these activities. However, there were a significant percentage of outliers in the results. For example, 129 women (6%) provided care work minutes in a day to be more than 960 (16 hours) in a day, which is way higher than the average of 7 hours. For this reason, mean time use data from the Ethiopia Time-Use Survey 2013 has been employed[6].

Within the extended System of National Accounts (SNA), the 2013 Time-Use Survey provides data on the average minutes spent on a number of unpaid caregiving services. These services include caregiving for children and adults within the household, as well as unpaid domestic services. For this study, we excluded unpaid community services due to the complexity in monetizing their economic impact.

The Time-Use Survey 2013 report categorizes time-use data for women aged 15-29 and 30-64. To derive an approximate time-use for this study, we calculated the average time spent on activities for women across these age groups. The average daily care work time for women is calculated as the sum of the average minutes spent on providing unpaid caregiving services to children (77.5 minutes), to adults (72 minutes), and on domestic tasks (282 minutes), amounting to a total of 431.5 minutes or 7.2 hours per day.

Similarly, the average daily care work time for husbands is determined by summing the average minutes spent on providing unpaid caregiving services to children (9 minutes), to adults (91.5 minutes), and on domestic tasks (181.5 minutes), resulting in a total of 282 minutes or 4.7 hours per day.

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[6] CSA. (2014). Central Statistical Agency [Ethiopia]. Ethiopia Time Use Survey 2013.

To monetize care work, we employed the median wages for both women and men. We avoided using the minimum wage due to its exceptionally low value. The wage was adjusted to reflect the earnings for a care workday, distinguishing it from a standard workday. This has been done because a care workday cannot be equal to a workday in terms of the working hours. Therefore, first the hourly wage is estimated and then the hourly wage is multiplied by the respective no of care workday hours men and women do.

2.5.4. Amalgamation of Incidents Cost

The estimation method considered the fact that reporting of costs was across incidents, rather than as a total cost for all incidents. The estimation strategy for the sample level cost is given below:

$$Aggregate\ Cost = Costs\ for\ survivors\ with\ 1\ incident + Costs\ of\ survivors\ with\ only\ 2\ incidents + Costs\ for\ survivors\ with\ more\ than\ 2\ incidents$$

$$Costs\ (Survivors\ with\ only\ 1\ incident) = \sum_{i=1}^{n} cost_i$$

Where *n* refers to the survivor who sustains various costs on the sole incident she experienced. Costs include OOP expenses and care work.

$$Cost\ (Survivors\ with\ only\ 2\ incidents) = \sum_{i=1}^{n} cost_i$$

Where *n* refers to the survivor who sustains various costs on the 2 incidents she experienced. Costs include OOP expenses and care work.

$$Cost\ (Survivors\ with\ more\ than\ 2\ incidents) = Cost\ of\ 2\ incidents + Cost\ of\ more\ than\ 2\ incidents\ (3rd\ incident, 4th\ incident\ etc.)$$

$$Cost\ of\ 3rd\ incident, 4th\ incident\ etc. = Average\ incident\ cost$$

$$Average\ incident\ cost\ of\ OOP = \frac{\sum OOP\ cost\ of\ incidents\ which\ resulted\ in\ OOP\ expenditure}{No\ of\ incidents}$$

$$Average\ incident\ cost\ of\ Care\ Work = \frac{\sum Carework\ cost\ of\ incidents\ which\ resulted\ in\ care\ work\ loss}{No\ of\ incidents}$$

2.5.5. Propensity Score Matching (PSM) & Endogenous Switching Regression (ESM): Productivity Loss, Women's Income, Household Income & Household Expenditure

Productivity loss due to violence involves absenteeism (missing work), tardiness (arriving late or leaving early), and presenteeism (working irregularly or less productively). The survey included specific questions to measure absenteeism, tardiness, and presenteeism, adapted from Vara-Horna (2013). The estimation weights were derived from Duvvury et al. (2022).

The measurement of household expenditure was done based on the following survey question: How much did your household spend approximately last month on all commodities and services (like food, clothes, electricity, water, phone etc.)? (in Birr)

For measurement of income, the survey asked the following two questions about both women and husband:

- How much income do you usually receive/earn in a month from primary economic activity?
- How much income do you usually receive/earn in a month from secondary economic activity?

The responses of women about their income were used to measure women's income; the responses of women about their and their husbands' income were used to measure households' income.

Propensity Score Matching (PSM) was employed to estimate the difference in productivity loss between survivors and non-survivors. PSM was also used to rigorously establish the impact of violence experienced by women on various outcome variables of interest such as women's income, household income and household expenditure.

Table 2: Survey Questions for Measurement of Productivity Loss

Absenteeism (In the last three months, how many days of work did you miss because…?)	You were unwell
	You had to go to a hospital or a health clinic because you were unwell
	You had to look after a child or other family member because they were unwell
	You had to attend to legal, financial or personal matters
	You did not have enough money for transport to and/or from work
Tardiness (In the last three months, how many days were you late for work by at least 1 hour because…?)	You were unwell
	You had to go to a hospital or a health clinic because you were unwell
	You had to look after a child or other family member because they were unwell
	You had to attend to legal, financial or personal matters
Presenteeism (In the last three months, for how many days...?)	Did you have difficulties concentrating on your work
	Did you work much more slowly than you normally would
	Were you exhausted at work
	Did you have to stop work because you were worried about something
	Did you have to stop work because you had an accident at work

The Propensity Score Matching (PSM) technique encompasses myriad steps aimed at controlling for selection bias in studies of lifetime intimate partner violence (IPV). Initially, factors influencing lifetime IPV and outcome variables are identified, followed by estimating propensity scores and selecting an appropriate matching method. Subsequently, the common support region is defined to ensure overlap in propensity scores between women who have experienced IPV and those who have not. A balancing test is then conducted to verify the similarity in propensity score distributions between treated (IPV-experienced) and control (non-experienced) women. Estimation of treatment effects for both groups follows, comparing outcomes exclusively attributed to IPV experience. Finally, a sensitivity analysis is performed to assess model robustness.

These measures are crucial in mitigating bias by aligning women in the sample based on propensity scores, facilitating comparisons between those who have experienced IPV and those who have not. PSM was performed in STATA 15 using the teffects psmatch command.

The Endogeneous Switching Regression (ESR) model captures the unobserved heterogeneity which is one of the limitations of PSM. ESR model was estimated using the FIML approach which derives both the selection and outcome equations jointly. The first stages of the estimation of ESR models are presented first as selection equation while the second stage of the estimation, i.e. estimation of separate outcome equations for women experiencing IPV and not experiencing IPV follows.

The second stage of the FIML shows the estimated coefficients of the correlation, between women experiencing IPV and all outcome variables, namely woman income, household income, household expenditure and productivity loss.

2.6. Limitations

There are a number of limitations to be considered while interpreting the findings of this study. Firstly, the survey's coverage of psychological violence behaviours was limited, potentially leading to an underreporting of the true prevalence of overall violence experiences. Secondly, the survey collected cost data on an incident basis in the last 12 months. While most women provided cost information for one or two incidents, a minority reported experiencing 3 or 4 incidents but did not supply information for these additional incidents. For these cases, an average incident cost was assumed. Thirdly, the data on the approximate time spent by participants on domestic and caregiving activities lacked robustness. Therefore, to estimate time use for this study, we utilized average data from the 2013 Ethiopia Time-Use Survey, aggregating time-use patterns across age groups 15-29 and 30-64.

Furthermore, accounting methodology used in this study may substantially underestimate the true economic costs of IPV due to underreporting because of fear of reporting, as well as recall bias while answering questions on service use due to violence. Furthermore, PSM, which was employed to estimate women income loss, household income loss, household expenditure loss & productivity loss, has its own limitations. PSM is very prone to bias due to omitted variables. Due to poor, or lack of, data, it was not possible to include all the relevant covariates in the model. The correct specification of the PSM is crucial, and achieving balance in observed covariates between treated and control groups can be challenging, and it may not completely address selection bias.

Respondents were queried about productivity loss over the past three months. To project annual productivity loss, the three-month estimate was multiplied by four. However, this extrapolation may overestimate the actual annual loss by assuming that respondents missed the same number of days throughout the entire year as in the recent three-month period. Despite efforts to maintain data robustness, the findings should be interpreted as approximations rather than exact estimates.

3. Results

3.1. Demographic Characteristics of Women

Table 3 displays the regional distribution of the surveyed women. Among the 2,095 sampled participants, approximately 41% were from the Oromia region and 21% from the Amhara region, making these the two largest groups. The Southern Nations, Nationalities, and Peoples' Region (SNNPR) accounted for approximately 24% of the sample. Regarding marital status, the survey found that 83% of the participating women were currently married, with 14% of these women having been married more than once.

Table 2: Individual women demographic characteristics

Variables	**Percent**	**Number**
Region		
Addis Ababa	13.65	286
Amhara	21.15	443
Oromia	40.95	858
SNNPR	24.25	508
Residence		
Rural	55.75	1,168
Urban	44.25	927
Women marital Status		
Married (once and more)	83.24	1,744
Divorced	6.21	130
Separated	4.58	96
Widowed	5.97	125
Type of residential area		
Villa and apartment	0.77	16
House	93.99	1,969
Independent Room	2.63	55
Others*	2.63	55
	Mean	**Number**
Mean duration of stay after marriage	14.13	1,744
Mean duration of stay of women in this community	18.22	2,095

*'Others' refers to those living in temporary shelters, such as a plastic shelter constructed near to a church or in a corner of a street.

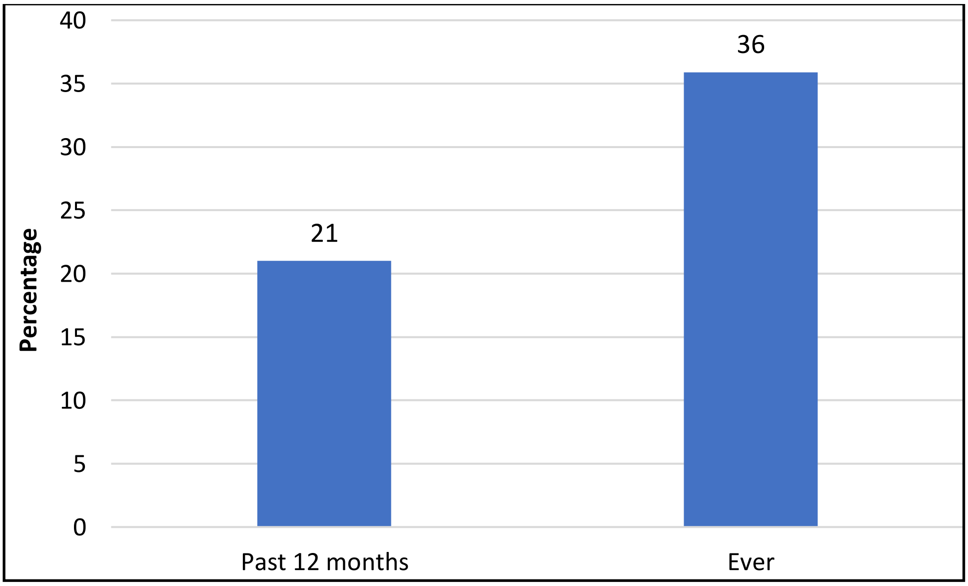
The average age of the women surveyed was 35 years. Approximately 64% of the women identified as Orthodox Christian, while around 37% identified as belonging to the Oromo ethnic group. Educational attainment among the sampled women indicated that nearly 62% had attended school at some point. Of these, 57% had completed primary education, and 29% had completed secondary education. Nearly half of the surveyed women (49.5%) were involved in various economic activities. The majority of these women were self-employed (74%), with approximately 22% being employees in different sectors.

3.2. Prevalence of Intimate Partner Violence

3.2.1. Prevalence of IPV: Past 12 Months and Ever

The prevalence of intimate partner violence (IPV) was determined based on various behaviors reported by women in the total sample surveyed, including physical, sexual, psychological, and economic forms. However, for the costing analysis, our focus was on estimating the overall prevalence, considering that the impacts of these behaviors are often interconnected. Figure 2 illustrates the percentage of women in the study who reported experiencing at least one form of violence in lifetime and in the past 12 months.

Figure 2: Prevalence of violence



Source: Authors' own calculations

Approximately 21% currently partnered[7] women experienced at least one form of violence in the past 12 months. Furthermore, about 36% of currently or previously partnered[8] women experienced violence at some point of time in their life. These prevalence rates are comparable to the findings from the 2016 Ethiopian Demographic and Health Survey (EDHS), which reported a 34% lifetime prevalence of IPV among women. Moreover, the study found that almost 26% of ever-married women had experienced physical and/or sexual violence at least once in their lifetime, a figure closely aligned with the 28% prevalence rate reported in the 2016 EDHS for ever-married women aged 15-49 experiencing physical or sexual violence.

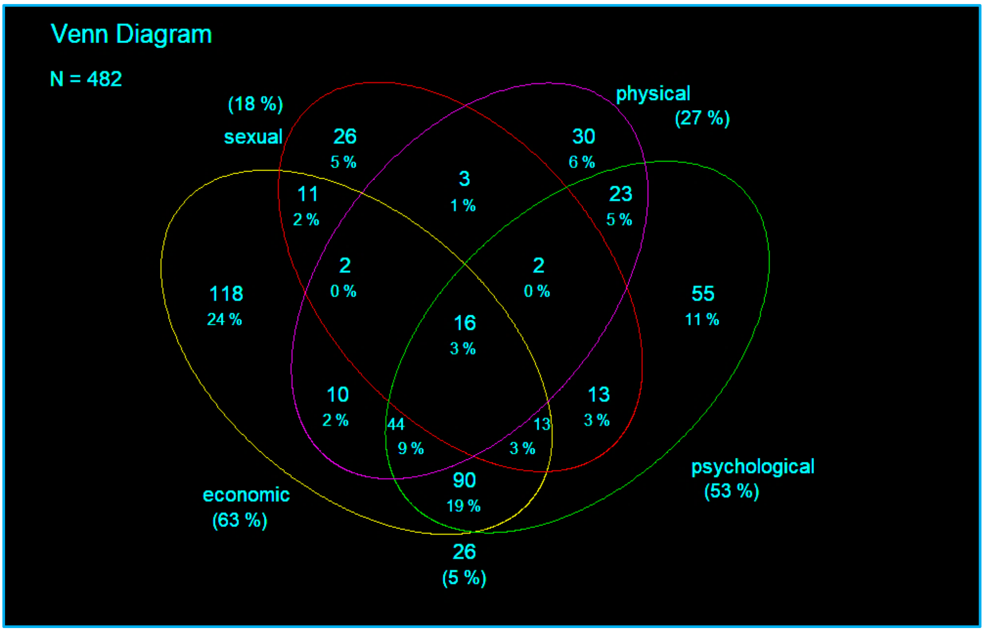
3.2.2. Incidents by Type of Violence

As discussed in the methodology, women who reported experiencing violence in the past 12 months were asked about the number of incidents they experienced during that period. On average, survivors reported experiencing 2 incidents within the past year, with a median of 1 incident. The majority (about 75%) reported experiencing one incident, while 10% reported two incidents. Additionally, around 15% of survivors reported encountering more than two incidents during the same timeframe.

Figure 3 illustrates the breakdown of incidents experienced by survivors, categorizing them into psychological, physical, sexual, and economic violence. Economic violence was involved in approximately 63% of incidents, while psychological violence accounted for about 53% of cases. It's noteworthy that the majority of incidents involved multiple forms of violence concurrently.

[7] ‘Currently partnered women’ implies women who have been married/cohabitating/living with a partner in the past 12 months.
[8] ‘Currently or previously partnered women’ implies women who have been married/cohabitating/living with a partner in the past 12 months or before the last 12 months.

Figure 3: Venn diagram of types of incidents



Source: Authors' own calculations

3.3. Economic Impacts of IPV

3.3.1. Out of Pocket Expenditures

Table 4 presents the findings on out-of-pocket (OOP) expenditures due to the incidents of violence experienced by women. Health-related expenditures, averaging 2,349 ETB (with a median cost of 620 ETB) was incurred in approximately 14% of the incidents. Shelter costs were incurred in 10% of incidents, with a median expense of 160 ETB. Property repair or replacement costs were reported in 13% of incidents, averaging 3,035 ETB. Overall, 34% of incidents resulted in some form of OOP costs, averaging 2,349 ETB (with a median cost of 500 ETB). ***This level of OOP expenditure amounts to approximately 15% of the per capita annual food expenditure in Ethiopia***, representing an important source of drain on household resources[9].

[9] Per capita food expenditure sourced from https://knoema.com/atlas/Ethiopia/topics/Food-Security/Expenditures-Spent-on-Food/Expenditure-on-food-per-capita. Using the annual growth of per capita expenditure of 5.33% between 2014 and 2018, same annual growth was assumed between 2018 and 2022, giving a per capita food expenditure of 316.8 USD.

Table 3: Out of pocket expenditures in last 12 months

	N	% of incidents	Average cost (Birr)	Average cost (USD)	Medium cost (Birr)	Medium cost (USD)
Health	67	14	1,346	27	620	12
Legal	23	5	2,270	45	650	13
Police	20	4	289	6	175	3
Property	64	13	3,035	60	300	6
Shelter	48	10	618	12	160	3
Mediation	53	11	249	5	200	4
OVERALL (Birr/USD)	**164**	**34**	**2,349**	47	**500**	10

*Assumed exchange rate of I USD to 50.59 Birr as of 7th February 2022, based on average buying and selling exchange rate of the Commercial Bank of Ethiopia (https://www.combanketh.et/en/exchange-rate/)

3.3.2. Care Work Loss

Care work loss was identified as a significant cost in the quantitative survey. Tables 5 and 6 outline the findings regarding care work loss for survivors and husbands, respectively. Approximately 19% of incidents resulted in missed days of childcare and support for children's education, during which survivors were unable to engage in these activities for an average of 12 days. When adjusted for the average time allocated by women in Ethiopia to childcare and supporting children's education, this equates to an average of almost 2 care workdays lost. In total, 25% of incidents led to an average of almost 14 missed care workdays.

Table 4: Care work loss of survivors in last 12 months

Type of Care Work	N	% of Incidents	Days Missed	Average Minutes Spent	Care Workdays Missed
Child Care and Education	91	19	12.2	77.5	2.2
Caring for Elderly and Sick	42	9	5.7	72	0.95
Domestic Activities	97	20	22.6	282	14.8
OVERALL	122	25	29	na	13.7

Additionally, almost 10% of incidents led to domestic activities being missed by survivors' husbands, leading to 12.6 care workdays missed. Husbands were also involved in care activities, with the overall loss amounting to 12.2 care workdays. Due to IPV, even husbands lose their usual contribution to care work.

Table 5: Care work loss of husbands in last 12 months

Type of Care Work	N	% of Incidents	Days Missed	Average Minutes Spent	Care Workdays Missed
Child Care and Education	43	9	12.9	9	0.41
Caring for Elderly and Sick	30	6	6.1	91.5	1.97
Domestic Activities	47	10	19.6	181.5	12.6
OVERALL	55	11	30	na	12.2

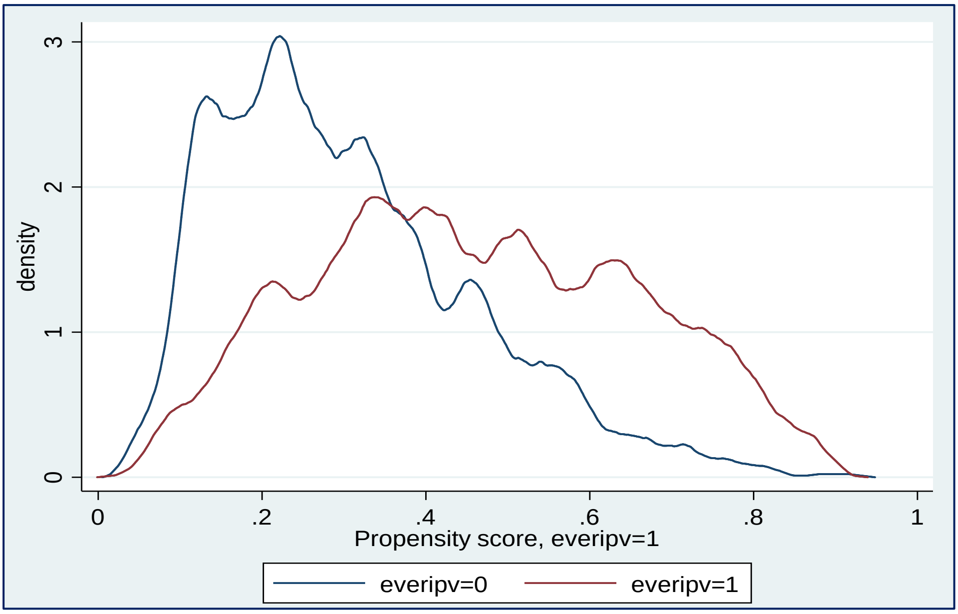
3.3.3. Propensity Score Matching & Endogenous Switching Regression: Productivity Loss, Women's Income, Household Income and Household Expenditure

As noted in the methodology, PSM & ESR analyses was done to establish the impacts of 'ever IPV' on women's income, household income, household expenditure and productivity loss to gauge the effects of IPV.

In assessing the impact of lifetime intimate partner violence (IPV) on various outcome variables using Propensity Score Matching (PSM), the analysis achieved balanced covariates between the two groups. The highest standardized bias was 0.23 and the highest variance ratio was 1.98, suggesting that after matching, the covariates are sufficiently balanced.

Another important step in investigating the validity or performance of the treatment effects estimation is verification of the common support or overlap condition. Results presented in Figure 4 show the distribution of the estimated propensity scores and the overlap between women experiencing IPV and not experiencing IPV which indicates that the common support condition is satisfied, as there is a substantial overlap in the distribution of the estimated propensity scores for the two groups.

Figure 4: Distribution of propensity scores across treatment and comparison groups



The results obtained from applying the Propensity Score Matching (PSM) algorithm with a caliper (0.25) and pstolerance (1e-50), which effectively worked with the data across all outcome variables, are summarized in Table 7. Our analysis uncovers that exposure to lifetime intimate partner violence (IPV) has statistically significant adverse effects on women's income, household income, and household expenditure. Conversely, there is a statistically significant positive impact on productivity loss associated with IPV exposure.

Table 6: Average treatment effect on the treated (ATET) of lifetime-IPV on livelihood outcomes using PSM & ESR estimator

Outcome Variable	PSM	ESR
Woman's income (n=1,035)	-372.82**	-763.8***
Household income (n= 1,905)	-929.90**	-787.4***
Household expenditure (n=2,094)	-332.95***	-737.4***
Productivity Loss (n=1,035)	16.67***	18.5***

Note: ** and *** refer to significance at 5% and 1% probability levels respectively

The Average Treatment Effect on the Treated (ATET) results suggest that women who have experienced lifetime intimate partner violence (IPV) tend to experience reductions in income, household income, and household expenditure. Specifically, on average, lifetime IPV exposure is associated with a decrease of 372.82 Birr per month in a woman's income, a reduction of 929.90 Birr per month in household income, and a decrease of 332.95 Birr per month in household expenditure. Furthermore, households with women who have been exposed to IPV generally exhibit lower levels of expenditure and income compared to households where IPV has not been reported.

Nevertheless, the result incorporating the significantly lower expenditure by households with IPV survivors should be looked at from the perspective of short-term versus long-term impact of IPV. This is because as found in this study and many previous studies (Asante et al., 2019, Chadha et al., 2020, Elmusharaf et al., 2019), violence leads to increased out of pocket costs for survivors, and therefore should increase household expenditure in the short-term. However, in the long-term, as measured by experience of IPV ‘ever’ in lifetime in this study and as expected, we are seeing a reduction in expenditure by households.

Through PSM analysis, we uncovered the overall productivity impact, including absenteeism, tardiness, and presenteeism, among employed women who have experienced intimate partner violence (IPV). The survey included detailed productivity-related questions for all employed women, akin to those posed to survivors reporting incidents in the past 12 months. Accepting the enduring effects of past violence on current circumstances, we deemed it crucial to assess the productivity impacts of women who have ever experienced violence. This approach expands the scope to include a broader group, given the stark contrast between the prevalence rates of women experiencing violence at any point in their lives (36%) versus current violence (21%). The findings from our PSM analysis point that employed women who have ever experienced violence exhibit a significantly higher number of productivity loss days compared to those who have not experienced violence. Specifically, these women face an average annual productivity loss of nearly 17 days, ranging from 9 to 24.4 days, with a 95% confidence interval.

The Average Treatment Effect on the Treated (ATT) from ESR model presented in Table 7 also indicates that women’s experience of IPV has a significant negative impact woman income, household income, household expenditure and productivity. However, compared with the ESR model estimations, the PSM model results were lower except for household income, which might be related to the fact that PSM did not account for unobservable heterogeneity. Similar inconsistencies between PSM and ESR results have been observed in the studies by Shiferaw et al. (2014) and Mojo et al. (2017), which also found insignificant PSM estimates, and significant ESR estimates. The Endogenous Switching Regression model is a more rigorous method for policy evaluation or program evaluation (Hu et al., 2021).

Using PSM, the study by Huamán-Delgado et al. (2016) found that women with violence have lower incomes by an average of $2601.82 (13.25% lower) compared with the group of women who are not victims whose income is $2999.34. Moreover, the study by IWPR (2017) found that health care costs for those experiencing abuse were 42% higher than the costs for non-abused women. The study by Asencios-Gonzalez et al. (2023) found that intimate partner violence against women negatively and significantly affects the workplace productivity. Duvvury et al. (2023) by measuring IPV's economic impact on labor productivity based on tardiness, absenteeism, and presenteeism found enormous productivity losses due to both the experience and perpetration of IPV in Africa and South America.

Balancing property measures the extent to which the distributions of propensity scores in the treatment and comparison groups. We conducted balance checks to assess whether, following matching, the distributions of the probability of experiencing lifetime intimate partner violence (IPV) were similar between women who had and had not experienced lifetime IPV (treated and control women). To evaluate the adequacy of balance achieved in the matching process, we utilized two statistics: standardized differences for continuous variables, defined as the weighted difference in means between IPV-exposed and non-exposed women divided by the standard deviation, and raw differences in proportions for categorical variables in the unadjusted sample (Kainz et al., 2017; Stuart, 2010), as well as the variance ratio, which measures the ratio of the sample variance of the logit values between those exposed to and not exposed to IPV (Kainz et al., 2017).

According to Stuart (2010), sufficient balance is indicated if matched women exposed to IPV and those not exposed to IPV exhibit standardized differences below 0.25 and a variance ratio close to 1.00, or between 0.50 and 2.00.

The results presented in Table 8 demonstrate that the covariates utilized in this study were effectively balanced between the two groups. The highest standardized bias observed was 0.11, and the highest variance ratio was 1.31, indicating that covariates are balanced after matching (Austin, 2009).

Table 8: Results of the Covariate Balance Tests

Variable	Standardized differences		Variance ratio	
	Raw	Matched	Raw	Matched
Partner education	-0.149	-0.086	0.660	0.900
Location	0.121	-0.077	1.025	1.000
Region				
Oromia	-0.285	0.047	0.639	1.108
Amhara	0.424	-0.021	1.114	1.004
SNNP	-0.224	-0.014	0.746	0.978
Women empowerment index	-0.435	-0.005	1.620	1.024
Woman employment status				
Self-employed	0.070	0.022	1.039	1.011
Unpaid family worker	-0.114	-0.029	1.007	0.999
Wealth status				
Medium	-0.341	0.005	1.157	1.000
Higher	-0.181	-0.048	0.347	0.711
Partner consumes alcohol	-0.287	0.003	1.146	1.000
Partner chews chat	-0.356	-0.033	1.691	1.034
Number of children	-0.073	-0.042	1.062	0.952
Duration of marriage	-0.020	0.076	0.971	0.987
Women education	0.086	-0.022	0.956	1.014
Number of observations	2,094	1502		
Treated observations	751	751		
Control observations	1,343	751		

3.4. Costs for Women and Households

The aggregate costs of all incidents for women and households are presented in Tables 9, 10. and 11. As Table 9 indicates, nearly 47% of survivors reported incurring an average of 2,710 Birr in costs.

Table 9: OOP Costs

	N	% of Survivors	Average Cost (Birr)*	Average Cost (USD)**	Median Cost (Birr)	Median Cost (USD)
OOP	**181**	**47**	**2,710**	**54**	**680**	**13**

*The values have been adjusted for **month-on-month** inflation until through April 2022, the latest month for which data was available. Data was sourced from https://tradingeconomics.com/ethiopia/inflation-rate-mom

**Assumed exchange rate of I USD to 50.59 Birr as of 7th February 2022, based on average buying and selling exchange rate of the Commercial Bank of Ethiopia (https://www.combanketh.et/en/exchange-rate/)

Table 10 details the results of monetised lost care work for women and their husbands/partners. Nearly 36% of survivors and 23% of survivors' husbands/partners reported missing 19 and 11 care workdays respectively.

Table 10: Loss of Care Workdays

	N	% of Survivors	Average Days	Median Days	Wage (Birr)*	Average Cost (Birr)	Average Cost (USD)	Median Cost (Birr)	Median Cost (USD)
Care Work	140	36	19	8.78	61	1159	23	536	11
Care Work-Husband	87	23	11	5.61	60	660	13	337	7

*As the minimum wage in the sample comprises of both part-time and full-time employees, median wages of women and husbands have been used to monetise care work. The monthly wage was converted to hourly wage and then multiplied by respective no of care work hours of women and men to give a care work wage day. Individual women's wages have been employed for productivity loss.

Table 11 below provides the unit cost estimates for women's income, income loss for households, expenditure loss for households and productivity loss.

Table 11: Income, Expenditure and Productivity Loss for Women and Households*

Category of Loss	Annual Unit cost (Birr)*	Annual Unit cost (USD)**
Women's Income Loss	4475	88
Income loss of Households with IPV	11,850	234
Expenditure loss of Households with IPV	3393	67
Productivity loss***	1272	25

4. Discussion

This study highlights the substantial economic implications of intimate partner violence (IPV) for women, households, and the Ethiopian economy. Initially, this study estimated that almost 36% of women have experienced IPV at some point in their lives ('ever'), with 21% experiencing IPV within the past 12 months ('current'). These figures closely align with the prevalence rates reported in the 2016 Ethiopian Demographic and Health Survey (EDHS), underscoring the persistent nature of this issue in Ethiopia. IPV is deeply intertwined with gender inequality, revealing a notable disparity despite Ethiopia's commendable economic strides towards achieving the Millennium Development Goals (MDGs). Despite being the most improved country in the 2020 Global Gender Gap Index by closing 70.5% of its gender gap, Ethiopia experienced a setback of 15 points in 2021 (World Economic Forum, 2021). This setback is evident in areas such as women's employment, where labour force participation favours men (86.7% vs. 76%), and women are underrepresented in skilled positions (29.9%) and senior roles (26.5%). Moreover, Ethiopia has yet to bridge over 50% of its gender gap concerning income and wages. These challenges point to the ongoing and consistent barriers women face in achieving economic parity and highlight the urgent need for targeted interventions to address IPV and gender inequality effectively. Unless IPV in Ethiopia is comprehensively addressed, gender inequality will continue to pose substantial problems for women's empowerment and status in society.

However, we also found that working women had a greater prevalence rate of lifetime violence at almost 38%, which like other studies suggests that work may indeed be a risk factor for violence (Alzahrani et al., 2016; Deribe et al., 2012; Hjort and Villanger, 2012). This is an area in need of further examination, as the literature is inconclusive, with some studies establishing the opposite trend (Gebrewahd, et al., 2020; Gelles, 1997; Bhattacharya et al., 2011). It would seem that the complexity involved stems from the influence of additional factors, such as the man's working status and his adherence to traditional gender norms (Macmillan and Gartner, 1999; Atkinson et al., 2005).

Moreover, the negative impact of IPV on women's work, both paid an unpaid, is clear. One of the most significant costs established by this study is the cost of unpaid domestic household and care work. On average, survivors missed 19 care workdays due to IPV and husbands/partners of survivors missed 11 care workdays. Previous research has also established a similar loss of household and care work (Chadha et al., 2020; ESCWA, NUI-Galway and MOWA, 2021). However, few studies have focused on the impact of IPV perpetrated by men against their wives on the unpaid domestic household and care work of these men. By establishing an estimate of such loss, the current study expands our knowledge base. Working women experiencing lifetime violence had a productivity loss of almost 17 days. While some previous studies (Asante et al., 2019; Elmusharaf et al., 2019; Ghaus et al., 2019) have attempted to estimate productivity loss for survivors, we believe this study's results to be more robust due to the PSM analysis.

Furthermore, utilizing Propensity Score Matching (PSM) analysis, backed by ESR analysis, we identified that women who have survived intimate partner violence (IPV) experience notably lower income compared to their counterparts. This finding aligns with previous studies conducted by Morrison and Orlando (2004) and Duvvury et al. (2012). Our research also reveals that IPV contributes to reductions in both household income and household expenditure. These outcomes collectively result in diminished social well-being, heightened income insecurity, and negative ripple effects for the economy at large.

The study also points to a significant drain of household resources due to OOP expenses which survivors incur. Nearly, one in three incidents led to some form of OOP costs, with an average cost of 2,349 ETB, which approximates to **15% of the per capita annual food expenditure in Ethiopia**. Previous studies in other African countries, Ghana (Asante et al., 2019) and South Sudan (Elmusharaf et al., 2019) have also established a similar significant drain on household resources. Given Ethiopia's goal of eradicating poverty, this finding provides an important insight into measures to be taken concerning the prevention and response to IPV.

Both community-based activism interventions, with the goal of shifting harmful gender attitudes, roles, and social norms, as well as interventions focusing on gender transformation and economic empowerment, could be implemented in Ethiopia. Some examples of evidence-based community activism interventions include Indashyikirwa in Rwanda (Chatterji et al., 2020) and the Rural Response System (RRS) in Ghana (Ogum Alangea et al., 2022). Similarly, evidence-based gender transformation and economic empowerment interventions encompass programs such as Stepping Stones and Creating Futures in South Africa (Gibbs et al., 2019) and Zindagii Shoista in Tajikistan (Mastonshoeva et al., 2022),

5. Conclusions and Recommendations

This study highlights the substantial costs of IPV for women, households, and the economy of Ethiopia. While there is no doubt that IPV is a violation of human rights; however, as this study highlights, it is also an economic problem. By monetising the impact of IPV, this study points to the need of expanding efforts to avert IPV to safeguard the economic health of Ethiopia. This is especially true in the current vulnerable economic environment, where we are still coping with the after-effects of COVID-19 as well as the ongoing Russia-Ukraine war. We recommend that the government builds gender-based violence (GBV) prevention and response into national policies and budgets and increase the efforts to address and prevent gender-based violence, including by mainstreaming evidence-based violence prevention and response approaches into health, education, social protection and other sectors. We also strongly recommend devoting particular attention to IPV in overall GBV programming and training, as the present response is largely focused on GBV, and in particular, sexual assault. Finally, there is also a need to integrate the impacts of IPV into macroeconomic and social planning and policies.

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Annexure

Table 1: Different Violence Behaviors Covered in Ethiopia Violence Survey 2021

Refuses to give you enough money for household expenses even though he has enough money to spend on other things
Asks for details about how you spent your money
Withdraws money from your account or credit card without your permission
Forces you to work
Forces you to quit your work
Prevents you from working
Tries to exploit properties (use properties/ sell and use the income from the sale of properties) you inherited from your family without your permission?
Disposes of your belongings without your permission
Restricts your connections/relations with your first-degree relatives
Prohibits you from going out with your female neighbors
Try to prevent you from meeting your female friends
Throws something at you, which can be harmful
Twists your arm or pull your hair
Assaults you, causing bruises, scratches, minor wounds and/or joint pain
Pushes you hard
Hits you with less dangerous tools, i.e. belt, stick …etc
Suffocates you or try to suffocate you
Holds you tight while attacking you
Tries to attack you with a knife, axe, shovel or any other dangerous tool
Hits you on the head, leading to unconsciousness
Slaps your face
Attacks you, resulting in you breaking one or more of your bones
Burns your skin on purpose
Physically forces you to have sexual intercourse when you do not want to
Use threats or intimidation to get you to have sexual intercourse when you did not want to
Physically forces you to do other sexual acts that you do not want to do
Uses threats or intimidation to get you to do other sexual acts that you do not want to do

Table 2 below shows the items used to measure productivity loss for survivors, with the respective weights. A weight of 1, for example, implies that the workday is counted as a full day, whereas a weight of 0.125 implies that one day is measured as one-eighth of a workday.

Table 2: Productivity Loss Items for Survivors

Type	**Weights**
Absenteeism	
Missed work because you had to seek medical treatment	1
Missed work because you had to attend legal services (e.g, family counselling)	1
Missed work because you had to visit police stations	1
Missed work because you were unwell	1
Missed work because you had to take care of your child/children	1
Missed work because you stayed with friends or family	1
Presenteeism	
Was not as productive at work as you normally would be	0.25
Had difficulties dealing with clients and/or customers	0.25
Had to stop working because you were worried	1
Had to stop working because you had an accident at work	2
Tardiness	
Late for work by 1 hour or more	0.125
Left work early by 1 hour or more	0.125

Source: Authors' own based on Ethiopia Violence Survey 2021 & Duvvury et al. 2020

Mixed Farming System for Crop Yield Improvement and Adaptation to Climate Change: Evidence from Smallholder Farmers in Ethiopia

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Abstract

Adverse weather appears to compel smallholders in Ethiopia to shift increasingly towards a mixed-farming system. Nearly 90% of the smallholders practiced the shift. However, unless carefully dealt with, the shift could lower crop yield because of the potential disincentive from livestock income. Thus, there is an interesting reason to investigate whether yield declines with livestock size and the increasing adoption of mixed farming. To investigate, we used 'Resilience to Climate Change' data collected in 2021 from 2000 households. Descriptive analysis and econometric models, specifically the Generalized Method of Moments and logit, are employed for the estimations. The findings pointed out: (1) households beyond livestock quartile II, who own 60% of the cropland, produce lower average yields. (2) Major yield factors do not hugely vary between GMM estimations. Mainly high-value crops, the number of equines owned, and renting land out, increased yields, whereas age, dummies of drought frequencies, inter-cropping, and drought-resistant crops decreased yields. The mixed-farming dummy resulted in higher yields only for the

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bottom livestock groups. (3) The transformative investment in thresher increased yields. (4) Agricultural Growth Program increased yield in the land-abundant quartile IV. (5) The estimated logit model shows that higher age, family and landholding sizes, social capital, cooler agro-ecologies, more hot days, the use of modern feed, and fewer drought shocks affected the adoption of mixed farming. The findings offered several policy options. Among others, designing extension services to improve yields in households owning larger livestock sizes requires attention. Moreover, the frequent drought years urge adaptation measures to climate change.

Keywords: Mixed Farming, Yield, Climate change, GMM, Ethiopia
JEL Classification: Q12, Q54

1. Introduction

The increasingly challenging climate conditions appear to be driving smallholder farmers in Ethiopia towards adopting mixed farming as an adaptation strategy. An evidence indicates that 90 percent of smallholders in Ethiopia have embraced the mixed farming system due to its benefits in terms of income generation, food security, availability of manure, access to draught power (e.g., Belay et al., 2022; Mekuria and Mekonnen, 2018), and consumption smoothening (Danso-Abbeam et al., 2021; Tesfaye and Tirivayi, 2020; Thornton and Herrero, 2014). The increasing adoption could also be due to the development of increasing demands for dairy processing (Franzluebbers et al., 2021; Gil et al., 2016). However, from the perspective of its advantage in adaptation to climate change, Berhe et al. (2020) discussed that livestock ownership increases GHG emissions, but other studies advocate that mixed farming increases yield, rehabilitates degraded pastures, and grows forage while mitigating emissions (Shiferaw, 2020; Descheemaeker et al., 2016). This debatable issue calls for further investigation.

In Ethiopia, it is possible that smallholders are increasingly transitioning towards mixed farming as a means to improve their food security and income, while also mitigating the impact of climate change. This trend is observed in other African countries as well (Mekuria and Mekonnen, 2018). However, from the perspective of its advantage in increasing yield and as an adaptation mechanism to climate change (Muchuru and Nhamo, 2019), the mixed-farming system in Ethiopia and globally is not adequately dealt with (Thornton and Herrero, 2014). Previous studies on the mixed-farming system in Ethiopia focused on issues such as farmers' perception of climate change and choice of adaptation strategies (Eshetu et al., 2021; Bedeke et al., 2019), manure and yield advantages in specific crops such as maize (Shiferaw, 2020), and climate-smart agriculture and the yield of individual crops (Wakwoya et al., 2022; Bedeke et al., 2019). Most of those studies carried out on the impact of climate change and adaptation measures use the changes in temperature and rainfall data to investigate the impact of climate change on individual crop yields (e.g., Kassaye et al., 2021; Eshetu et al., 2021). However, the studies neglect the role of households' resource endowment. In order to account for the influence of households' resource endowment on adaptation, it is crucial to aggregate yields at the household level, rather than solely focusing on adaptation measures at the individual crop and plot level, as argued and attempted in this study. In addition to this argument, several previous studies have also suggested the adoption of mixed farming systems as a means of adapting to climate change (Eshetu et al., 2021; Bedeke et al., 2019). However, the increasing number of livestock may not guarantee better yields to ensure food security and adapt to climate change. This could be because, first, the increased income from crop production may simply lead to livestock rearing to consume dairy products (Tesfaye and Tirivayi, 2020; Mellor, 2014). Second, instead of serving as an adaptation option, the free choice of mixed farming could lead to decreasing crop yields because of the potential disincentive effect of livestock income on crop yields. Therefore, it is compelling to examine yield with increased livestock size in the mixed farming system at household levels rather than merely testing the impact of climate variables such as temperature and rainfall on individual crop yield as in previous studies (Wakwoya et al., 2022; Waktola et al., 2014) and rather than boldly recommending the mixed farming system as an adaptation strategy (Eshetu et al., 2021; Bedeke et al., 2019). It is compelling because households in the larger quartile occupy nearly 60 percent of the total land occupied by smallholders.

Theoretical and empirical studies have demonstrated that crop yield is influenced by various household socio-economic, technological, and climatic factors (Zhengfei et al., 2006; de Wit, 1992). Factors such as family labour and effective farm management play a crucial role in optimizing the use of inputs such as seeds, water, and soil nutrients (Zhengfei et al., 2006). The availability of inputs such as water and soil nutrients is influenced by climatic factors such as temperature, precipitation, and agro-ecological diversities (Kassaye et al., 2021; Abate et al., 2015). According to Thornton and Gerber (2011), climate change has a direct impact on crops through extreme weather, drought, and flooding. Descheemaeker et al. (2016) discussed that climate change increases the incidence and severity of pests, weeds, and diseases, which in turn decreases yields. Location also matters in adaptation, which influences yield (Stark et al., 2018; Mendelsohn, 2012), and in a very diverse geography of 18 agro-ecologies in Ethiopia, the role of agro-ecology and location differences could be immense. Also, Teklewold et al. (2019) and Di Falco and Veronesi (2013) stress that the adaptation strategies have positive impact on crop yield and farmers' return when implemented complementarily, not in isolation. The impacts of climate change on yield have been assessed in numerous other studies (Sardar et al., 2021; Ojumu et al., 2020; Clay and Zimmerer, 2020). Ariom et al. (2022) summarized that in African countries, smallholder farmers use adaptation strategies such as drought-resistant varieties, crop diversification, changes in cropping pattern, calendar of planting, conserving soil moisture with appropriate tillage methods, afforestation, and agro-forestry. The adaptation options discussed in IPCC (2007) also include technological, behavioral, investment, and policy-related approaches (Shuai et al., 2018). Muchuru and Nhamo (2019) and Thronton and Gerber (2011) suggested that post-harvest food storage systems, water harvesting (e.g., Wakeyo and Gardebroek, 2017), and road and market infrastructure matter in adaptation.

In mixed farming, the drivers of the increasing adoption of mixed farming by smallholders are interesting too, to get insights for possible interventions. If we assume the adoption of mixed farming practices is climate-smart, the adoption is affected by several direct and indirect factors (Owen, 2020; Thornton and Gerber, 2011), such as technology, environmental, socioeconomic, demographic, and policy design. Mekuria and Mekonnen (2018) found that livestock holding, irrigation, and extension contact significantly influence the adoption of mixed farming, whereas rented-out land, improved seed, and soil fertility status decrease it. In countries with diverse agro-ecologies, such as Brazil, the crop-livestock system is influenced by biophysical, socioeconomic, and institutional factors (Gil et al., 2016). Gil et al. (2016) concluded that education and supply-chain infrastructure play a role in the early adoption of crop-livestock systems, as they are more common in areas closer to research centers and processing facilities for grains and cattle.

Building upon the preceding discussions, it is necessary to raise questions regarding the potential impact of the growing adoption of mixed-crop livestock farming systems on crop yield. Specifically, it is important to investigate whether this adoption could lead to an increase or decrease in crop yield, considering the potential disincentive effect of livestock income. Additionally, it is relevant to explore why certain households continue to focus solely on crop cultivation or livestock keeping, despite the numerous advantages associated with mixed farming. This means that the factors driving the adoption of mixed farming in diverse agro-ecological contexts have to be understood. Thus, this study specifically attempts to (1) look into the crop yield differences by livestock size (quartile), farming system, and agro-ecology; (2) investigate factors of yield differences between households by livestock quartiles; and (3) investigate factors driving households to shift to a crop-livestock system under varying agro-ecology, institutional, climatic, and regional variations.

The rest of the study is organized as follows: In Section 2, conceptual framework of crop yields and climatic linkage is discussed, followed by the discussion of methodology and data in Section 3. In Section 4, the descriptive statistics and estimation results are discussed. Section 5 concludes and reflects on recommendations.

2. Conceptual Framework

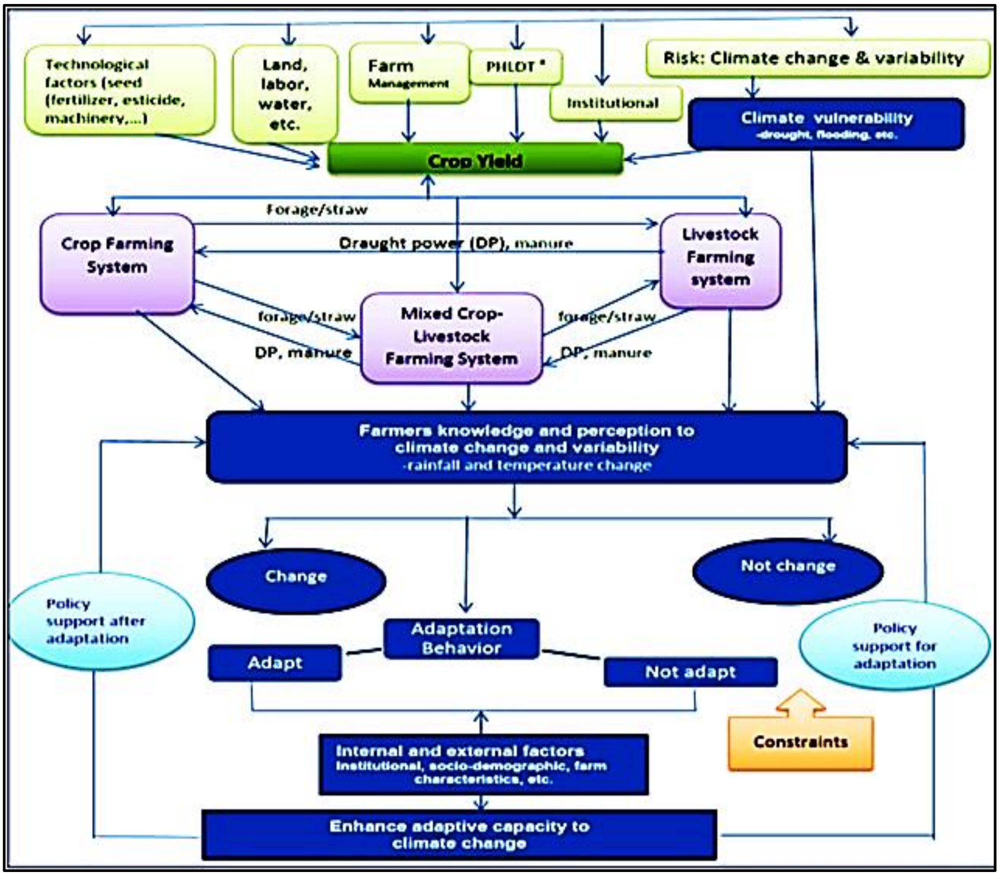
Population pressure and climatic, economic, social, and institutional changes are transforming into mixed farming systems rather than being restricted to either crop-only or livestock-only production as studies, show (e.g. Gil et al., 2016; Thornton and Herrero, 2014). These studies underline that the move to a mixed farming system involves a move to a more intensively managed crop-livestock system. For example, when farmers move from a fully pastoral to an agro-pastoral system, it infers the settlement of pastoral households and the use of cropping technologies. The household decision to move to an agro-pastoral farming system is enhanced by discussions, farmers' training, declining land size, longer distance to water points for humans and livestock, shorter distance to market, and more income from off-farm sources (e.g., Bebe et al., 2012). Similarly, the move from a crop-only to a crop-livestock system occurs as a mechanism for reducing the risk of crop failure (Sertse et al., 2021; Tesfaye and Tirivayi, 2020) and the ease of access to water for livestock. Of course, the risk-coping strategy of the crop-livestock system in Africa is widely recognized as an adaptation mechanism to climate change.

The theoretical link between yield, farming system, and the perception and knowledge of farmers about climate change is illustrated in Figure 1. The figure shows that yield depends on internal and external factors such as technology, resource endowments, farm management, institutional factors, and weather risk (climate change) factors, among others. The technologies influencing crop yield include improved seed, fertilizer, pesticides, herbicides, manure or compost, and machinery such as tractors and harvesters. The institutional factors of yield include policies, access to extension services and information, market and financial conditions, and socio-cultural conditions. The post-harvest loss-decreasing technologies, farm management, risk factors, and portfolio between crop production and livestock rearing challenges are also relevant. Note that the influential theoretical approach to productivity of de Wit (1992) suggests that yield depends on the level of the most constraining input factors, such as water and nutrients, for example, and they cannot be neglected in the link. In the link, yields could also be suboptimal following the resource constraints of the households that diversified into mixed crop-livestock system.

Figure 1: Conceptual Framework

Source: Adopted from Belay et al. (2022) and Stark et al. (2018).

Note: PHLDT stands for Postharvest loss decreasing technologies.



In the conceptual framework, Belay et al. (2022) employed the theory of planned behavior to conceptualize rural farmers' perceptions and behaviors of rural farmers regarding current climate change and variability. Following the framework, the link between the livestock-only (pastoral), the crop-only, and the mixed farming systems is facilitated by the advantage and exchange of draught power and manure, as illustrated in Figure 1. In the same context, the perception and knowledge of farmers about climate change and variability determines their adaptation behavior and choices of adaptation strategies, which can be influenced by policy. The farming system and the adaptation behavior, therefore, affect crop yields. Thus, from the theoretical linkage between yield and farming system presented in Figure1, increasing livestock size could affect yields through input technologies, climate change and variability, institutions, and the significance of these factors could vary with livestock size.

3. Methodology

3.1. Approach to Empirical Estimation

In this study, there is an opportunity to utilize plot-level household's data to examine yield variations within both crop-only and mixed farming systems across livestock quartiles. The analysis of household data by livestock quartiles involves both descriptive and econometric estimations. It is important to note that the conventional measure of 'per hectare output' does not adequately capture the factors driving yield at the household level, prompting the need for alternative approaches. Measuring yield in this way has the limitation of neglecting the area share of the crops, as it has implications of households' resource endowment and yields. To overcome this limitation, standardizing the 'yield by crop-yield index' is ideal, and we discuss in this section the crop-yield index.

In the computation of the crop yield index, for all crop categories in cereals, pulses and oilseeds, and fruits and vegetables, the crop yield index is calculated as a weighted sum of the yields of the crops. The weight attached to each crop is the proportion of land area allocated to the crop out of the total land of the household allocated to the crops. Then, the weight of the crop area is multiplied by the crop yield to obtain the crop yield index (refer to Equation 1).

$$YI_i = \sum_{i=1}^{n} y_{ij} * \frac{a_{ij}}{A_{ij}} \quad \textbf{(1)}$$

where Y_i is the overall crop yield of household i, and $i = 1, 2, \ldots, n$; y_{ij} is the per hectare yield of crop j, and $j = 1, 2, \ldots, M$ in household i; a_{ij} is the area of crop j of household i; and, A_{ij} is the total cropping area of household i. The computation of the crop yield index for households' as utilized in Abdisa et al., (2024), is subsequently followed by the estimation of factors for the weighted yield index across both the aggregated and individual livestock quartiles.

Econometric regression employing the method of moments is utilized to estimate and identify the factors that contribute to the yield, aggregated at the household level. The method allows a general moment condition $E\{\boldsymbol{z_i} u_i(\beta)\} = 0$, where $\boldsymbol{z_i}$ is the vector of instruments and $\boldsymbol{u_i(\beta)}$ is an additive regression error term. In modeling the yield index, the GMM is stated as:

$$YI_i = \sum_n^i \boldsymbol{\beta_i X_i} + u_i. \qquad \textbf{(2)}$$

where, $\boldsymbol{X_i}$ is a vector of observable variables; β_i is a vector of unknown coefficients; and u_i is an additive error term with the property $E\{\boldsymbol{z_i} u_i(\beta)\} = 0$, which allows that some variables are endogenous. The key advantage of the model lies in its ability to calculate a heteroskedasticity-robust weight matrix prior to the primary estimation. It also addresses the endogeneity concerns by employing instrumental variables and effectively captures the non-linearities in yields to overcome any potential limitations. The estimation process tests the impact of variables on yield, which are selected based on both theoretical and empirical justifications.

The methods of analysis, therefore, include descriptive and quantitative estimations using econometrics. To see the yield differences, the use of descriptive analysis by quartiles of livestock is used, followed by the econometric estimations of the Generalized Method of Moments (Verbeek, 2008) by livestock quartiles, to find out the factors driving the yield differences. Many of the previous studies such as Belay et. al. (2017), have relied on localized small sample-size data, which restricts the capacity to examine yield differences across various agro-ecologies, regions, and other sources of diversity.

The preliminary analysis of the data shows that more than 81 percent of the households increasingly shifted to the crop-livestock system seeking its various advantages. Belay et al. (2022) discussed that farmers' response to adaptation decisions may be driven by internal and external factors and these factors could be a constraint for farmers to participate in the adaptation process. Thus, the hypothesized factors driving the adoption decision include household characteristics, socioeconomic, technological, agro-ecological, and regional variables. The factors influencing the decision to adapt adaptation mechanisms, including technologies and practices, in both crop-livestock systems and crop-only or livestock-only (primarily pastoral) systems are examined using probit model estimation, following the approach of Belay et al. (2017). Belay et al. (2017) employed probit model to identify the driving factors. Similarly, Mekuria and Mekonnen (2018) estimated the tobit model to test whether water scarcity, livestock holding, agro-ecology, and other socioeconomic factors influence crop–livestock diversification, in the Ethiopian agriculture. But different from what they estimated, in this study, the aim is to test the factors driving adoption rather than diversification.

Both probit and logit models are viable options for this type of estimation. However, the criterion for selecting between the two is that in large sample-size data, the estimation of logit model tends to perform better than the probit model (Cakmakyapan and Goktas, 2013). Verbeek (2008) underlines that in large-size data, logit has several advantages compared to probit. The cumulative distribution function of the logit model is:

$$\Pr(Y = 1/X)e^{-x'\beta} \quad \textbf{(3)}$$

where Y is the dichotomous dependent variable that represents the choice of mixed farming or not; $\Pr(Y = 1/X)$is the probability of choosing mixed farming given the vector of explanatory variables X; β is vector of coefficient of explanatory variables; and e is the base of natural logarithm. Following this, equation (3) leads to the estimation of the most simplified form of the probability of choosing mixed farming an individual variable keeping the influence of all other variables constant:

$$\Pr(Y = 1/X) = \frac{e^{\beta_o + \sum_i^k \beta_i x_i}}{1 + e^{\beta_o + \sum_i^k \beta_i x_i}} \quad \textbf{(4)}$$

Note that Equation (4) is equivalent to estimating the marginal effect of each exogenous variable (Cameron and Trivedi, 2009: 479).

3.2. Data

The data utilized for this study is derived the nationally representative plot-level survey on Resilience to Climate Change, conducted in 2021. The data encompasses a wide range of agro-ecologies and administrative regions across Ethiopia. The study's sample size consists of 2000 households, and a multistage stratified sampling approach was employed for the sampling strategy. Woredas (administrative divisions) were randomly selected from six regions, namely Amhara, Oromia, SNNPR, Somali, Gambela, and Dire Dawa Administrations. Subsequently, farmers' associations were selected from each woreda, and a random selection of sample households was conducted for the purpose of interview.

4. Results

4.1. Descriptive Analysis

The findings regarding the impact of livestock size, agro-ecology, and farming systems on crop yield index are presented in Table 1.

4.1.1. Livestock quartile vis-à-vis yield index

The livestock quartiles computed, based on the number of livestock owned by households, have cut points of 0-3, 4-7, 8-14, and 15 and above heads of livestock from quartiles I to IV. The number of households in each of these livestock quartiles is 546, 509, 483, and 462, respectively. In per capita terms, livestock ownership is increasing smoothly across all categories livestock quartiles.

The total land occupied by all households in each quartile and the mean landholding of the sample households in each livestock quartiles are both increasing successively. This implies that proportionately larger cropland is occupied by owners of large livestock sizes. For example, 35 percent of the total land in the study area is occupied by livestock quartile IV, and 60 percent is occupied by livestock quartiles III and IV. The per capita landholding of the sample households in each livestock quartile tells the same story of high per capita landholding. Specifically, the per capita landholding of households in quartile IV is more than double that of the households in quartile I.

The mean yields computed for the aggregate households decline successively from livestock quartile I to IV. The average decline rate of the aggregated yield is 23 percent, with a maximum of 25 percent between QII and QIII and a minimum of 19.5 percent between QI and QII. The decline in yield affects 81 percent of the land occupied by the sample households. However, when we control for outlier yields, the story changes and the decline is from QI to QII and from QIII to QIV, at a 17.2 percent average decline rate.

Table 1: Number of households, average livestock size, per capita livestock ownership, and land occupied (in ha), by livestock quartile

Livestock quartiles	Quartile-I	Quartile-II	Quartile-III	Quartile-IV	Total
Range of heads of livestock in each quartile	0-3	4-7	8-14	15-105	0-105
Number of households in each quartile	546	509	437	462	1954
Total number of livestock by livestock category					
Cattle	466	1,265	1,949	3,745	7,425
Shoats (sheep & goat)	150	578	1198	3537	5,463
Equines	96	232	426	597	1,351
Chicken	114	686	1,570	4,135	6,505
Total number of Livestock	826	2,761	5,143	12,014	20,744
Average per capita ownership					
Cattle	0.33	0.53	0.76	1.41	0.82
Shoats (sheep & goat)	0.32	0.42	0.63	1.49	0.90
Equines	0.17	0.21	0.24	0.29	0.25
Chicken	0.30	0.47	0.75	1.74	1.03
Average per capita livestock	0.28	0.41	0.60	1.23	0.75
Landholding and average yield					
Total land (ha) occupied	593.40 (30.10)	663.50 (28.70)	802.70 (34.80)	1084.40 (44.20)	3144.00 (72.50)
Average land size (ha)*	1.12 (1.29)	1.33 (1.27)	1.67 (1.58)	2.37 (2.10)	1.66 (1.63)
Average crop yield (all households)	42.00 (405.20)	33.80 (275.30)	25.40 (53.10)	19.20 (40.20)	30.50 (252.80)
Average crop yield (all households) with outliers controlled	24.6 (89.9)	21.6 (47.8)	25.4 (53.1)	19.6 (40.2)	22.8 (61.2)
Average crop yield (crop-only producing households)	29.5 (118.9)	19.6 (47.7)	18.3 (22.3)	16.9 (22.2)	26.5 (103.0)
Average crop yield (mixed crop-livestock households)	19.7 (44.3)	21.9 (47.9)	25.6 (54.4)	19.4 (41.0)	22.0 (47.6)

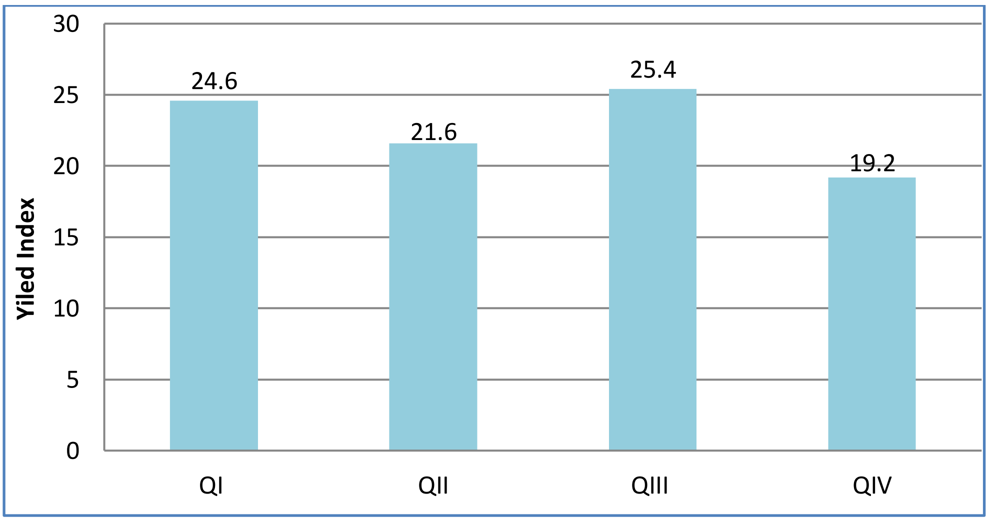
Source: Authors' computation. Notes: In brackets are standard errors; * the average excludes zero ha.

Similarly, in the regions of Amhara, Oromia, Gambella, and Dire Dawa, the mean yield declines after quartile II or III. In all regions except SNNPR, the computed yields of quartile IV decline compared to those of quartiles II and III. This might indicate the role of the disincentive of owning larger livestock size or possibly the yield-decreasing factors such as farm management, technology, and economic and non-economic factors that constrain the yield of households in quartile IV. Contrary to this declining trend, in the SNNP region, the largest proportion of households compared to all other regions (more than 71%) use high-value crops and yield is successively increasing from quartile II to IV.

The lower average yield in the last quartile indicates that the larger landholdings occupied by the fourth quartile households, which account for nearly 35 percent of the cropland, are not efficiently utilized. When considering the average yield in the last two quartiles, the proportion of land occupied by these households increases to 60 percent of the total land occupied by all the households, highlighting the extent of inefficient land used.

The control of outliers of the highest reported yield in the computation, however, changes the figures, but the yield of the last quartile is yet the lowest of all yields by livestock quartile (Figure 2). In this case, yield declined from quartile III to IV by 24 percent.

Figure 2: Average crop yield by livestock quartiles



Source: Author computation. Note that the outliers are sugarcane yields.

4.1.2. Crop yield by farming system

The farming system in the survey has six classifications. However, only the ‘crop only’ and the’ mixed farming’ systems of these classifications have adequate sample sizes for comparison of yields. In the classifications, however, only the absolute number of livestock owned is considered. Some households use their livestock as a capital good rather than owning livestock for dairy products, and this approach gives room for adequate samples in the classification. In this approach, beyond the 155 households that own no livestock, 133 own one or two oxen, bulls or young bulls, one or two horses, or one or two donkeys. The number of these households considered in this study as crop-only producers increased from 189 to 375. This means that almost half of the 375 households own some livestock used not for dairy products, like in the case of mixed farming households, but rather as a capital good for draught power and means of transport.

The yield index computed for the two farming systems indicates that crop-only households have a superior average yield of 26.5 quintals per hectare over mixed farming households, which have an average crop yield of nearly 22.0 quintals per hectare. The average yield difference between the two household groups is statistically significant at the one percent level of significance. So, the average yield of crop-only producers is greater than that of mixed farming households. This means that the average yield of mixed farming households is lower than the former by 17 percent. Also, the average yield of the third and fourth quartiles in the crop-only and mixed farming systems is 18.3 and 16.9 and 25.8 and 19.4, respectively. The difference between the average yield of quartiles III and IV in mixed farming is 24.8 percent, which is higher than that of the crop-only farming system (7.7%) and statistically significant at a five percent level of significance. Thus, similar to the cases of the average yield computed for all households (and regions), the average crop yield of mixed farming households also declines in the last quartile, and the difference is significant at five percent.

By gender, the average yield of male and female-headed households of crop-only households and mixed crop-livestock farming households is 25.6 and 29.0 and 22.0 and 21.7, respectively. However, the yield difference by gender is not statistically significant, even at a 10 percent level, in both cases. Thus, on average, differences in the farming system cause little difference in yield by gender computed for all households.

4.1.3. Yield by agro-ecology

The yield index computed by agro-ecology and livestock quartile is indicated in Table 2. . The scientific classification of the agro-ecologies depends on the elevation of locations in meters above sea level (masl from now on), with desert, hot, moderate, cool, and frost elevating differently in masl, successively from desert to frost. The mid-altitude areas of woyina dega dominate the land coverage, accounting for more than half of the total area (nearly 52.3%) of the sample households.

Table 2: Average crop yield by agro-ecology and livestock quartile

Agro-ecology /altitude in masl	Aggregated		QI		QII		QIII		QIV	
	N	Yield	N	Yield	N	Yield	N	Yield	N	Yield
Frost (> 3200)	21	13.9(16.3)	5	7.7(9.2)	4	8.0(4.0)	5	9.9(3.9)	7	22.4(24.1)
Cool (3200-2300)	538	26.4(65.0)	101	32.4(113.4)	125	28.3(64.1)	159	29.6(50.2)	153	17.4(19.2)
Moderate (2300-15	1046	22.2(67.2)	302	23.2(94.2)	290	20.1(43.7)	242	23.9(59.0)	212	21.8(55.7)
Hot (1500-500)	271	20.9(35.1)	83	23.5(43.7)	68	16.9(29.2)	58	25.7(41.3)	62	17.2(17.0)
Desert (< 500)	70	13.3(25.1)	24	17.1(39.7)	9	17.7(20.1)	15	8.9(7.9)	22	10.2(9.7)

Source: authors' computation. NB. In the brackets are standard errors; N signifies frequency

The survey data shows that each farming system has the highest representation in the mid-altitude, similar to the case of other developing countries (Thornton and Herrero, 2011). In the mid-altitude, 47.6 percent, 66.7 percent, 53.4 percent, and 100 percent of the crop-only, livestock-only, mixed farming, and agro-pastoral farming systems are practiced, respectively. Of the total plots, 52.9 percent are located in the moderate agro-ecology, followed by 27 percent in the high-altitude cool areas, showing a dominant crop growing in Ethiopia in the mid-altitude than in the extreme weather. However, the highest average yield is observed in moderately cool agro-ecology. The moderately cool condition has adequate moisture to increase yield relative to other agro-ecological conditions. The yield difference between the cool and moderate highlands by livestock quartile is statistically significant only in the third quartile at the 10 percent level. In the other quartiles, the yield difference is statistically insignificant.

This table also shows that the average yields in the mid-altitude (moderate) and hot agro-ecologies are almost comparable in all quartiles. The mean-tests show that the difference in yield between the mid-altitude (moderate) and lowlands (hot) quartiles is statistically insignificant. Thus, in agro-ecology, if farmers invest to increase moisture in moist agro-ecology, there is potential to increase yield, and this could also work for lowland hot agro-ecology.

In the case of the highest elevation areas of frost agro-ecology, the experience is that crop yield increased in livestock quartile IV, unlike many other cases. In a relatively small number of observations of only seven households, it could be difficult to conclude this, but surprisingly, even though the number of livestock falls within quartile IV, the numbers of livestock are relatively lower, and they are found at the bottom of quartile IV with 15 to 27 livestock when the data is scrutinized. The lower number of livestock in the quartile seems to have a relatively lower disincentive role, unlike households that own larger livestock sizes up to 105. Note that the number of livestock in moderately cold, mid-altitude, lowland, and desert agro-ecologies ranges from 15-68, 15-103, 15-105, and 15-66, respectively, which is by far greater than that of the highest elevation or frost agro-ecology, that is, 15-27 heads of livestock. Another interesting point is that the average yield of the frost and that of the cold seem to be mirror images of each other and that of hot and desert has also the same pattern, which requires further study.

4.2. Factors of Crop Yield by Livestock Quartiles

The estimation results of the generalized method of moments (GMM) are presented in Table 3. In the estimated result, age, area proportion of high-value crops in the cropping area, the dummies of years of drought frequencies in the last five years, the use of thresher, rented-out cropland, intercropping, and drought-resistant crops, not participating in any of the flagship programs, increasing the number of livestock as an adaptation strategy, migration of at least a member of the household, shift from livestock to crop, and regional and agro-ecological dummies have significantly explained the households' crop yields in at least three of the five estimations. Of course, some of the estimations are weakly significant, and in others, they carry mixed (positive and negative) signs. Many other variables explained yield less than once or twice. However, variables such as household size (proxy to family labour), use of fertilizer and seed dummies, whether the households currently use irrigation or not, owning a tractor or not, shifting from livestock to crop, and also being in Dire Dawa (except weakly in the aggregated estimation) have no significant influence on households average yield on any of the estimations, and those variables are not reported in Table 3.

Among these variables which explain yield, age and the area proportion of high-value crops strongly explained it. The other variables that consistently and strongly explained yield are climatic variables. Those include dummies of climate change noticed as hotter days, four years drought frequency in the last five years. Moreover, practicing intercropping and drought resistant crops, using thresher, increasing the number of livestock as an adaptation strategy to climate change, not participating in flagship programs, and being in Gambela region consistently and significantly explained the yields in at least three of the estimations. Among these yield influencing variables, the signs of the coefficients in the frequency of drought dummy show mixed coefficients. This means that in the aggregated and livestock quartiles I, II, and III, they carry consistently negative and strongly significant signs, whereas in the livestock quartile IV, they carry positive sign though weakly significant. Furthermore, of these variables, age, frequency of the number of years of drought in the last five years, dummies of practicing intercropping, and drought resistant crops decreased households' average yield, whereas the rest of the variables increased it. The advantages of intercropping could also be greater in individual crop yield than in the case where household yield is aggregated. The individual crop yield advantage of intercropping is found in Bedeke et al. (2019), but the disadvantages are discussed in Waktola et al. (2014).

Table 3: Factors Affecting the Household Yield-index

Dependent variable: ln of yield- index	**Aggregated households**	**Livestock Q-I**	**Livestock Q-II**	**Livestock Q-III**	**Livestock Q-IV**
	Robust coefficients (in brackets are their standard errors)				
Ln of the age of household head	-0.26***	-0.35*	-0.15	-0.43**	-0.11
	(0.11)	(0.22)	(0.16)	(0.22)	(0.18)
Gender dummy, (male =1)	0.12	0.19	0.31**	-0.08	0.24*
	(0.11)	(0.15)	(0.15)	(0.25)	(0.15)
Education dummy, grade 8-12=1, 0 otherwise	0.13*	0.36*	-0.02	0.02	0.06
	(0.08)	(0.25)	(0.15)	(0.15)	(0.12)
Are you a widow? (yes=1), 0 otherwise	0.30**		0.56***	0.09	
	(0.16)		(0.20)	(0.36)	
Number of equines owned	0.09**	0.01	0.01	0.09	0.13***
	(0.04)	(0.16)	(0.07)	(0.06)	(0.03)
Proportion of high value crops (in terms of area)	1.44***	1.29***	0.66**	1.43***	0.96**
	(0.19)	(0.37)	(0.29)	(0.39)	(0.45)
Dummy, did you earn off-farm/ nonfarm income? yes =1	-0.42	0.81	0.34	0.11	1.17***
	(0.75)	(1.09)	(0.39)	(0.37)	(0.43)
Do you use info for agricultural forecasting? Dummy. Yes =1	0.06	-0.27	0.45***	-0.22	0.25**
	(0.11)	(0.26)	(0.16)	(0.18)	(0.12)
No. of drought frequency in the last 5 years dummy, once	-0.36***	-0.79***	-0.12	-0.13	0.62**
	(0.13)	(0.26)	(0.22)	(0.26)	(0.24)
No. of drought freq. in the last 5 years dummy, 1 if twice	-0.56***	-1.25***	-0.35	-0.67***	0.75*
	(0.16)	(0.35)	(0.38)	(0.27)	(0.39)
No. of drought freq. in the last 5 years dummy, 1 if thrice...	-1.00***	-1.66***	-0.97**	-0.25	0.90**
	(0.22)	(0.44)	(0.41)	(0.49)	(0.42)
No. of drought frequency in the last 5 years dummy, 1 if 4 times and 0 otherwise	-0.94**	-1.78***	-0.91*		
	(0.31)	(0.48)	(0.62)		
Did you sell livestock? Yes = 1, 0 otherwise.		0.29	0.08	-0.09	-0.46*
		(0.31)	(0.48)	(0.29)	(0.24)
Have you rented out cropland? dummy, yes =1, 0 otherwise	0.30**	0.64**	0.39*	0.01	-0.93***
	(0.15)	(0.27)	(0.22)	(0.01)	(0.32)
Number of relatives that you rely on for critical time	0.02**	-0.02	0.01	0.01	0.01*
	(0.01)	(0.04)	(0.02)	(0.01)	(0.02)
Faced crop loss in the last five years? Dummy, yes =1				-0.87**	-0.21
				(0.38)	(0.19)
Climate change noticed as hotter days? Dummy, yes =1	0.14*	0.22*	0.35***	0.05	-0.10
	(0.08)	(0.15)	(0.11)	(0.13)	(0.11)

Dependent variable: ln of yield- index	**Aggregated households**	**Livestock Q-I**	**Livestock Q-II**	**Livestock Q-III**	**Livestock Q-IV**
	Robust coefficients (in brackets are their standard errors)				
Dummy, diversify crop?	-0.01	-0.34*	-0.17*	-0.08	-0.01
yes=1	(0.09)	(0.18)	(0.12)	(0.14)	(0.13)
Dummy, intercropped? Yes	-0.15**	-0.01	0.08	-0.21*	-0.29***
=1	(0.08)	(0.15)	(0.11)	(0.12)	(0.10)
Dummy, minimum tillage?	-0.28***	-0.06	-0.56***	0.14	0.06
Yes =1	(0.11)	(0.21)	(0.12)	(0.15)	(0.17)
Dummy, drought resistant	-0.22***	-0.30*	-0.16*	-0.21*	-0.13
crop? Yes =1	(0.08)	(0.18)	(0.11)	(0.13)	(0.12)
Dummy, used thresher?	0.54***	1.38***	0.28	0.75**	0.37**
yes=1	(0.13	(0.50)	(0.20)	(0.32)	(0.16)
Dummy, increase number of	0.23**	0.36*	-0.18	0.25*	0.36*
livestock? yes=1	(0.10)	(0.21)	(0.16)	(0.17)	(0.21)
Dummy, mixed crop-	0.48**	1.06**	0.08	0.01	0.27
livestock? yes=1	(0.23	(0.45)	(0.28)	(0.41	(0.28)
Dummy, shift crop to	-0.74***	0.03	-0.70***	-0.67**	-0.23
livestock? Yes = 1	(0.22)	(0.25)	(0.26)	(0.34)	(0.33)
Dummy migrated? Yes =1	0.31*	0.77**	0.02	-0.04	0.41***
	(0.16)	(0.30)	(0.32)	(0.34)	(0.21)
Quantity of manure used in kg	0.00	-0.07	0.02	0.03***	0.04
	(0.02)	(0.19)	(0.06)	(0.01)	(0.03)
PSNP_dummy, 1 if	-0.07	1.70**	-0.52*	1.21**	0.42
beneficiary	(0.74)	(0.74)	(0.28)	(0.56)	(0.46)
AGP_dummy, 1 if beneficiary	-0.38	-0.07	0.25	0.12	1.06**
	(0.41)	(0.71)	(0.28)	(0.36)	(0.44)
Non-program_dummy, 1 if	0.17	1.45***	0.56**	0.95***	0.74***
non-beneficiary	(0.67)	(0.54)	(0.23)	(0.35)	(0.28)
Amhara region dummy	0.87*	1.09***	-0.82***	1.89**	1.32**
	(0.47)	(0.45)	(0.24)	(0.96)	(0.65)
Oromia region, dummy	0.70*	0.39	-0.48*	1.54*	0.96*
	(0.41)	(0.57)	(0.27)	(0.92)	(0.60)
Somali region, dummy			-1.33***		
			(0.50)		
SNNP region, dummy	0.33	-0.55	-0.88***	1.33*	1.87***
	(0.27)	(0.62)	0.28	(0.88)	(0.62)
Gambela region, dummy	1.09			2.67**	2.77***
	(0.79)			(1.07)	(0.78)
Dire Dawa region, dummy	0.62*	-1.03		1.68	0.52

Dependent variable: ln of yield- index	Aggregated households	Livestock Q-I	Livestock Q-II	Livestock Q-III	Livestock Q-IV
	Robust coefficients (in brackets are their standard errors)				
	(0.41)	(0.90)		(1.79)	(0.79)
Agro-ecology frost	-0.11	-1.55*	1.31***	-0.39	0.86*
(highest altitude), dummy	(0.35)	(0.92)	(0.48)	(0.85)	(0.59)
Agro-ecology cold, dummy	0.12	-1.44**	0.75**	1.00***	1.09***
	(0.22)	(0.62)	(0.32)	(0.35)	(0.39)
Agro-ecology moderate (mid-	0.28	-1.06*	-0.74*	0.94***	0.71**
altitude), dummy	(0.22)	(0.59)	(0.32)	(0.32)	(0.35)
Agro-ecology hot	0.29*	-0.84*	0.46***	1.00***	0.96***
(low altitude), dummy	(0.20)	(0.64)	(0.31)	(0.33)	(0.36)
Dummy, livestock quartiles I	-0.35				
	(0.29)				
Dummy, livestock quartiles II	0.77**				
	(0.38)				
Dummy, livestock quartiles III	0.20				
	(0.41)				
Constant term	1.90**	2.32**	2.40***	0.47	0.12
	(0.93)	(0.92)	(0.72)	(1.34)	(0.98)
Number of observation (N)	1948	516	497	479	456
GMM Weight matrix	Robust	Robust	Robust	Robust	Robust
	Chi^2 (11)	Chi^2 (16)	Chi^2 (23)	Chi^2 (17)	Chi^2 (16)
Hansen's J chi2 (.)	14.79***	9.04***	25.20***	11.50***	14.90***
	(p=0.1923)	(p= 0.916)	(p=0.3414)	(p=0.8285)	(p=0.5357)

Note: ***p < 0.01, **p < 0.05 and *p < 0.1. Note that variables with no significance coefficient at all are dropped.

In the aggregated estimation, 18 of the 44 variables strongly explained households' average yield (Table 3). In this estimation, consistent with our expectation, a higher age by one year of household head on average decreases yield by 0.25 percent (Table 3). Similarly, a move to one, two, three, and four years of drought frequencies from no drought frequency consistently decreases yield by 0.36, 0.56, 1.00, and 0.94 percent, respectively. In addition, the use of intercropping, minimum tillage, and drought-resistant crops significantly decreased yield by 0.15, 0.28, and 0.22 percent, respectively, all significant at least at a five percent level. The fact that minimum tillage frequently produces no gain in yield is consistent with Cock et al. (2022). In the case of the variable 'shifting from and to livestock' as an adaptation strategy to climate change, lower yield could be the factor for the lower shift to livestock (123 households, or only 6%), compared to the shift from livestock to crop (211 households, or nearly 11%), contrary to the finding of Descheemaeke et al. (2016). The shift from livestock to crop also significantly decreased yield in the aggregate estimation at a one percent level.

On the other hand, in the aggregated estimation, several variables increase yield, including number of equines owned, the proportion of high-value crops, the dummies of being a widow, social capital, the use of threshers, the mixed farming system, the increase in the number of livestock as an adaptation strategy (relatively higher increase in Quartile I and III), being in livestock Quartile II, and whether anyone in the household migrated, significantly increasing yield at least at the 5% level of significance. Those yield-increasing variables on average increased yield by 0.46 percent (at least by 0.02% due to social capital and at most doubling yield due to the proportion of high-value crops with 1.44%) for the aggregated households. It is not surprising to see the highest yield increase for being in Gambela, the most fertile region, relative to being in the often drought-hit Somali region. On the top of the variables, dummies of secondary education, climate change noticed as hotter days, and being in Amhara, Oromia, and Dire Dawa regions and moderately hot agro-ecology, all increase households yield, but weakly significantly at 10%.

Importantly, the variables of interest of the livestock quartiles I, II, and III entered in the aggregated estimation as dummy variables; only livestock quartile II strongly and significantly increased yield. The significant coefficient of quartile II shows better yield in the relatively lower livestock quartile than in the higher quartiles III and IV, consistent with the descriptive analysis.

Related to the households' average yield in quartile IV, the number of equines owned, the proportion of high value crops, dummies of earning off-farm income are variables of household characteristics. Similarly, the use of information for agricultural forecast, once to three times drought frequency in the last five years are climate related variables that explained yield in Quartile IV. Moreover, participating in Agricultural Growth Program (AGP from now onwards), not participating in the flagship programs, the use of thresher, out-migration explained yield in Quartile IV. Also, the regional variables of being in Amhara, SNNP, and Gambela regions, as well as being in relatively cooler highlands (dega), moderate highlands, and hot lowlands, all strongly and significantly increase yield in quartile IV. Other variables such as dummies of renting out cropland and intercropping strongly and significantly decrease yield at least at 5 percent level of significance. The renting out of cropland does not seem to be consistent with the argument that livestock income is disincentive unless the size and proportion of the land rented out are possibly small. In this livestock quartile, surprisingly, the frequency of drought years of once, twice, and three times increases yield, whereas in the other quartiles, they decrease yield, though weakly significant in the case of twice drought frequency (Table 3). This yield-increasing effect might be related to the fact that the number of drought frequency-reporting households is the lowest in quartile IV compared to that of other quartiles. For example, the number of households that reported draught frequency once, twice, three times, and four times is 43, 15, 9, and 1, respectively, in quartile IV, whereas they are 58, 34, 9, and 1 in quartile III. The cases of quartile IV are lower than those in quartile III, and this lower number of households reporting each drought frequency might contribute to the change in the sign of the coefficient. Last is the strong and significant influence of participating on AGP in increasing yield in quartile IV, unlike in the other quartiles. This could be consistent with the inception of AGP that land and abundant resources are beneficiaries of the project, which supports the significance of the quartile IV estimate. Note that in livestock quartile IV, nearly 24.3 percent of households are beneficiaries of AGP.

On the other hand, the dummies of information used for agricultural forecasting and PSNP significantly influence yield in other quartiles but not in quartile IV, contrary to the case of the number of equines owned, off-farm income, and intercropping, where they are significantly influencing yield in quartile IV but not in other quartiles. Other explanatory variables are significantly affecting yield in all the quartiles, including quartile IV. Those explanatory variables include dummies of the use of a thresher, increased number of livestock (but significant only at 10%), out-migration, not participating in any flagship program, relatively cold, moderate, and hot agro-ecologies, owning a thresher (except quartile II), regional dummies, and renting out cropland (Table 3).

Overall, most of the variables significantly influencing the yield by livestock quartiles are common to many of the quartile estimations. Moreover, for the aggregated households and the livestock quartiles I, the variable 'mixed farming' consistently and significantly increases yield. This means that mixed farming increases yield in the relatively lower livestock quartile, whereas its income-disincentive role could be formidable in the upper livestock quartile, which is evident from the yield-decreasing effect of increasing livestock size mainly in the descriptive analysis. The influence of gender (quartiles II and IV), being widowed (quartile II), education (aggregated and quartile I), facing crop loss due to drought (quartile II), diversifying crops (livestock quartiles I and II, but weakly significant), and quantity of manure used (quartile III) are significant only in a few quartiles rather than a consistent role in many of the quartiles.

4.3. Effects of Climate Change Variables and Crop Yield

The need for adaptation to climate change is critical in developing countries like Ethiopia. Let alone neglecting them, even a high level of adaptation in the agricultural sector does not prevent the negative effect of climate change on yield (for example, Shuai et al., 2018; Mendelsohn, 2012). Among the adaptation measures found to not significantly influence yields is irrigation. However, the dummies of irrigation use carry positive coefficients in all estimations by quartiles, though they are insignificant. In addition, as a means of adaptation to climate change, households engage in non-farm activities, but the variable has a positive influence on yield only in the estimation of quartile IV. Its yield-increasing role in quartile IV could be surprising because households slash their farm management time to work off-farm, but still, it contributes to increasing yield. Also, households that noticed hotter days due to climate change have positive and significant coefficients in the aggregate estimations, quartile I, and II estimations though weakly significant in the latter two. This shows that in the African context, where there is evidence that land surface temperatures are rising faster than on any other continent and that climate variability is increasing (Akinnagbe and Irohibe, 2014), the increasing yield on more hot days varies across countries (Mendelsohn, 2012). The dummy variable of whether households use the information for the agricultural forecast is strongly and significantly increasing yield in quartiles II and IV. Nearly 16 percent of households use the information for agricultural forecasting, and their proportion increases over the livestock quartiles, which might have contributed to significantly increasing yield in quartiles II and IV. The dummies of drought frequency in the last five years of once, twice, three, and four times all decrease yield consistent with expectations except in quartile IV, but significantly increase yield in quartile IV. The descriptive analysis of the frequencies shows that in quartile IV, the proportion of households that reported the frequency of drought once to five times is only 14.7 percent, whereas it is 30.6, 26.7, and 22.0 percent in quartiles I, II, and III, respectively, and the lower proportion in quartile IV might be one of the factors for the change in sign. In the descriptive statistics, 60 percent of the sample households are those living in mid-altitude agro-ecology, followed by those living in the cold highlands (20%) and in the hot lowlands (15%). The data shows that, at least with strong significance in quartile II and weak significance in the aggregate and quartile I estimations, more hot days consistently increase yield.

The crop diversification dummy has negative coefficients throughout the estimation. It decreases yield in quartiles I and II, but weakly significantly. In Ethiopian agriculture, low-income farmers are risk-averse, and they tend to diversify their crops, which makes yields sub optimal, as the evidence shows. The fact that the variable is at least weakly significant in the lower livestock quartiles and has no effect in the upper quartiles is consistent with expectations. The other variables of resilience to climate change, such as intercropping, minimum tillage, and the use of drought-resistant crop dummies, decrease yield rather than increase it (Table 3). The role of those variables is mixed, as the evidence in the literature shows. On the other hand, as resilience to climate change increases, the dummies of the use of tractor and thresher increase yield consistent with expectations, but the former has insignificant coefficients unlike the latter, that has a strongly significant coefficient. The insignificance of tractor use, despite its positive coefficient throughout the estimations, could be because the proportion of tractor users is low, that is, only five percent of the farmers use it. The users of modern threshers have the advantage of decreasing harvest losses during threshing, and on average, seven percent of households use them. However, the dummies of improved seed and chemical fertilizer have no significant influence on yield, possibly because the application rate of these inputs is extremely low in contrast to the number of crops grown. The descriptive statistics show nearly 55 and 73 percent of the sample households use improved seed and chemical fertilizer, respectively, but this is mainly to limited cereal crops such as wheat and teff than to all the crops produced used for the estimation of the yield index.

Other four variables of resilience to climate change include increasing the number of livestock dummies and mixed crop-livestock dummies, as well as shifting from livestock to crop and crop to livestock dummies. Of those variables, the first increases yield in the quartiles I, III, and IV, but weakly significantly. The second variable increases yield in the aggregate and quartiles. On the other hand, the shift from crop to livestock consistently decreases yield, but the shift from livestock to crop has no significant effect on yield in any of the estimations. As a resilience factor, the dummy of outmigration and quantity of manure used both increase yields in some of the quartiles and the aggregated estimations, but remittance has no role in increasing yield. Households receiving remittances could use the incoming resource to purchase or pay for yield-increasing input and services as an advantage, but there is no strong evidence to support this claim. Contrarily, outmigration of at least one member of a household contributes to increasing yield in some of the estimations by transferring finance to smallholder households for the purchase of inputs. In the descriptive statistics, less than one percent of the sample households migrate, and they are fairly distributed across the livestock quartiles.

In the end, the tests of the GMM estimations are worth discussing. In all five GMM estimations, the over-identifying restriction test (Hansen's J chi2 (2)) shows that the null that the instruments used are fulfilling the orthogonality condition of no correlation to the error term fails to be rejected even at 10% statistical significance. Therefore, the estimated model is robust. On top of this, the weight matrix, which is robust in all five estimations, has heteroskedasticity and robust standard errors.

4.4. Factors Driving the Adoption of Mixed Farming System

A logit model is estimated to identify the factors influencing the adoption of the crop-livestock farming system. The use of logit is because the data is large, and in large-size data, logit has several advantages compared to probit (Verbeek, 2008). The preliminary analysis of the data shows that more than 81 percent of households have increasingly shifted to the crop-livestock system, seeking its various advantages. Belay et al. (2022) discussed that farmers' responses to adaptation decisions may be driven by internal and external factors, and these factors could be a constraint for farmers to participate in the adaptation process. Thus, the hypothesized factors driving the adoption decision include household characteristics, socio-economic, technological, agro-ecological, and regional variables. The estimated results summarized in Table 4 indicate that 12 variables strongly explain the adoption of mixed farming, while only six of them weakly explain the adoption. This conclusion is based on a robust estimation of the model from the Wald test.

Table 4: Factors driving the adoption of mixed farming system (RCC): Logit Model

Dependent variable: crop-livestock mixed farming dummy (1 if mixed farming, 0 otherwise)	Coefficient	Stand Error
Gender dummy, 0= Female, 1= male	0.127	0.163
Education dummy, Grade 8-12 is 1	0.136	0.182
Household size (proxy to family labour)	0.156***	0.033
Non-farm income dummy, 1 if yes	-0.190	0.132
Climate change noticed? 1 if yes	0.229	0.201
Information on rainfall & temp, 1 if yes	0.196	0.167
Rented-out crop land, 1 if yes	0.652**	0.314
Climate change, hot days? 1 if yes	-0.383**	0.181
Mobile ownership, 1 if yes	0.267**	0.121
Use modern (improved) feed? 1 if yes	1.035***	0.276
AGP Dummy, 1 if beneficiary,	-0.299	0.200
PSNP dummy, 1 if participants	-0.186	0.190
Non-program Dummy, 1 if not a member to programs	-0.212	0.211
Total land size of crop production	0.198***	0.075
Drought shock in the last 5 years? 1 if yes	-0.328*	0.174
Ease of access to land, water & feed for livestock? 1 if yes	0.453***	0.132
Any remittance? dummy, 1 if yes	0.224	0.199
# of relatives that you rely on for a critical time	0.052*	0.094
Divorce dummy, 1 if yes	-0.460	0.332
Number of crops produced	0.163***	0.051
Amhara region, dummy	0.480**	0.189
SNNPR region, dummy	0.101	0.197
Somale region, dummy	-1.083***	0.348
Gambela region, dummy	-0.621*	0.363
Dire Dawa Admi. region, dummy	3.061***	1.025
Frost lands, dummy	0.644	0.364
Cold highlands, dummy	0.664***	0.233
Desert lands, dummy	-0.538	0.372
Mid-highlands (moderate), dummy	0.109	0.204
Constant term	-0.546	0.372
Wald chi2(29) = 204.63 (P=0.0000) **N = 1990**	**Pseudo R2 = 13.2%**	
Log pseudo likelihood = -849.924		

Note: ***p < 0.01, **p < 0.05 and *p < 0.1.

Among the factors that strongly explained the adoption of mixed farming, household size (family labour), ownership of mobile telephone, use of modern feed, total landholding, whether leased out land, ease of access to land, water, and feed, level of crop diversification, being found in Dire Dawa relative to Oromia, and being in the relatively cold highland increase the probability of adopting mixed farming, whereas more hot days due to climate change and being in Amhara and Somali regions relative to being in Oromia decrease the probability of adopting mixed farming. More crop-diversifying households tend to diversify into livestock too, compared to fewer crop-diversifying households. The variables that weakly explained the dependent variables are the number of drought shocks in the last five years, and being in Gambela relative to being in Oromia decreases the probability of adopting, whereas social capital increases the probability of adopting mixed farming.

4.5. Discussion

One of the fears in estimating aggregated crop-yield models is that the aggregation masks the role of explanatory variables. In such a case, it is advisable to run the estimations by quartiles of livestock ownership. In this study, we have estimated the yield factors in aggregation and by quartiles. From the estimation, a number of climatic and adaptation variables influencing yield are captured. Among others, the frequency of drought shocks, variables of climate-smart agriculture, long-run adaptive investments, and technologies significantly influence yield, and this is supported by the descriptive analysis of yield. The estimation also helped to identify the adaptation mechanisms, though in this kind of yield estimation, the role of intercropping and minimum tillage, which increased yield in individual crops (for example, Bedeke et al., 2019), is found to contrarily decrease yield in the household yield index, consistent with Waktola et al. (2014). Nevertheless, the econometric estimation is consistent with the descriptive statistics of the yield-index variations by livestock quartiles.

In the crop yield index, controlling the proportion of high-value crops was critical. This is because even though their proportion in crop diversification is low, the weight of the high-value crop is high, and this could increase the yield index, even when the household is less efficient. Therefore, it is not surprising to find the significant influence of the variable on yield, similar to the case of AGP II, similar crop-yield index was computed for the sample households for a baseline study in 63 AGP II woredas (Wakeyo et al., 2017). In Wakeyo et al. (2017), the average weighted yield of selected cereals and pulses for aggregated households was 16.2, whereas that of fruits and vegetables was 18.6, which shows that fruits and vegetables (high-value crops) have higher contributions to the weighted yield index used in the estimation.

The fact that moisture stress and drought decrease yield at the time of climate change is supported both in theory and empirical evidence (Mendelsohn, 2012; de Wit, 1992). Mendelsohn (2012) remarked that with no insurance, climate variability limits households from using expensive inputs, such as improved seeds and fertilizer. Similarly, de Wit (1992) underlined that yield is low to the extent that one of the inputs, such as water or rainfall, is under stress, which largely happens to crop production at the time of drought. As the estimation result shows, increasing drought frequencies in the last five years, which exacerbate moisture stress, have strongly, significantly, and consistently decreased yield because of the constraining effect of rainfall shortages. Other studies found that with drought frequency due to climate change, yield shrinks, and this varies with locations (Shuai et al., 2018; Mendelsohn, 2012). Consistent with those findings, the findings in this study show that yield varies by regions and agro-ecologies.

In the estimations, the number of equines owned by households increases the quantity of manure that can be used for increasing soil fertility (Belay et al., 2022), beyond the advantage in drought power and transportation. With an adequate number of equines, farmers can use manure. Farmers can transport their harvest in time from the field to threshing centers and storage, and this decreases post-harvest loss. Similarly, the use of a thresher has consistently and significantly increased yield in almost all estimations, consistent with the finding in Abraham (2015). Threshers increase yield by minimizing crop losses during harvesting and threshing; it increases time efficiency to overcome crop overstaying on fields to escape crop susceptibility to damages from rainfall, temperature, wind, and animals, consistent with Thornton and Herrero (2014). In Ethiopia, where threshing is manually done, 20-30 percent post-harvest losses have been common (Hengsdijk and de Boer, 2017).

Studies show that yield is negatively affected by climate change due to its impact on the reduction of soil moisture, faster depletion of soil organic matter, premature drying of grains, increased heat stress, and limited irrigation (Pequeno et al., 2021; Descheemaeker et al., 2016). Climate change studies that focus on individual crops in many cases found that warming decreases yield (Descheemaeker et al., 2016), which is consistent with the finding that the perception that hotter days by farmers increases yield. The perception of hotter days increase yield is consistent with Di Falco and Veronesi (2013). On the other hand, minimum tillage is found to decrease yield consistently in many of the estimates in this study, consistent with the findings of Mihretie et al. (2022) and Rusu et al. (2009), but contrary to the findings of Mupangwa et al. (2007) in Zambia for maize yield. In many of the previous studies, the soil water conservation advantages of the minimum tillage practices were more positive and significant than their yield advantages (Mihretie et al., 2022; Rusu et al., 2009). Other studies underline that minimum tillage increases soil acidity, which in turn decreases yield (Wakwoya et al., 2022), and this shows that minimum tillage has to be complemented with other farming practices and technologies (for example, liming to decrease soil acidity) to enhance yield. In addition to the minimum tillage, the finding shows that intercropping also significantly decreases yield, at least in some of the estimations by quartiles. Intercropping decreases yield, as estimated by Bekele et al. (2016) for maize and soybean, which is consistent with these findings. However, this contradicts the result of Waktola et al. (2014), although it is important to note that these studies focus on individual crop yields obtained from different locations. Farmers' experience in intercropping at various locations could result in a yield advantage, though this could be altered with climate change and input use traditions. The other climate-smart practice is the use of drought-resistant crops, a dummy variable. The finding shows that the dummy significantly decreases yield. It is expected that those crops have the advantage of overcoming moisture stress, but the extent of research in Ethiopia on their viability in diverse locations is limited, except for sorghum.

The result also shows that households that rent out their land score higher in aggregated households and quartiles I and II, and their yield decreases in quartile IV. Households often rent out their land because of labour and other resource constraints (for example, Descheemaeke et al., 2016). The finding that household size, a proxy for family labour (Wakeyo and Gardebroek, 2017), increases yield at least in the aggregated estimation matches with the logic that those who rent out land score higher yield, but this may not always be the case. The finding related to the role of land tenure, climate shocks, and social capital is consistent with the finding of Teklewold et al. (2019).

The finding also shows that the dummy for participation in the flagship program of AGP significantly increases yield in the land-abundant quartile IV. This is consistent with the finding of Weldesilassie et al. (2020) that yield increased in the AGP woredas compared to the non-AGP woredas. The AGP intervention woredas have a number of advantages compared to those of non-AGP woredas, for example, yield-increasing training and demonstration, encouragement of irrigation schemes, and climate-smart agriculture. Those AGP interventions increased crop yields (Weldesilassie et al., 2020).

Agro-ecology dummies are found to influence yield significantly. Altitude differences mark the agro-ecologies classified into five. The influence of agro-ecologies is mixed, but often, contrary to Descheemaeker et al. (2016), hotter agro-ecologies do not always decrease yields. In this connection, the finding shows that hot agro-ecologies increase yield consistently and significantly in quartiles II, III, and IV, and consistent with the summary of Thornton and Herrero (2014), cooler agro-ecologies increase yield in quartiles II, III, and IV too. As the descriptive analysis shows, the average yield in the cool highlands is the highest of all the average yields in other agro-ecologies. The findings also indicate that regional variations in yield may attributed to the level of commitment by administrations in the implementation regional development plans, consistent with the findings of Assefa et al. (2020), Shuai et al. (2018), and Abate et al. (2015).

Importantly, in the aggregated estimations the quartile II dummy increased yield, though weakly significantly, but there is no evidence that livestock quartile III increases yield. This reinforces the finding in the descriptive statistics that household-level yield falls in the upper livestock quartiles.

The yield factors estimation is followed by the factor driving the adoption of mixed farming. Among others, household size (family labour) and the use of modern feed increase the probability of adopting a mixed farming system. In addition, previous livestock ownership matters in the adoption. For example, Mekuria and Mekonnen (2018) indicated that the ownership of livestock positively and significantly influences the adoption of crop-livestock diversification. However, they did not provide any indication as to whether this influence is driven by increased land ownership or increased livestock ownership. Rather than previous livestock ownership, the use of modern feed and the ease of accessing land and water for livestock significantly influence the adoption of crop-livestock systems. Previous studies somehow found similar findings. For example, Descheemaeker et al. (2016) underlined that numerous adaptation measures exist, but smallholders face constraints of small farm sizes, poor access to markets and relevant knowledge, land tenure insecurity, and the common property status of grazing resources, which are relevant to the case of Ethiopia.

The increasing adoption of the crop-livestock system by smallholder farmers could result from either the maximization of return or from the upcoming programs that encourage and add to the livestock sector. Interventions such as AGP and the Sustainable Land Management Program (SLMP) might have also contributed to the increased crop-livestock system among smallholders. In this study, the likely adaptation strategy of households in the future can be better understood. This means that households could tend to continue with cropping or adding livestock rearing as an adaptation strategy to climate change, such as more severe water scarcity and labour shortages, and upcoming opportunities in investments (for example, agro-processing). In both cases, smallholders could likely be more resilient to climate change, be it due to lower crop productivity or due to labour and technological factors.

One can understand the influence of micro-water-use practices on starting livestock. Since the early 2000s, these technologies and practices have been encouraged, and their role is substantial in starting livestock on top of using them for the production of high-value crops (Bekele and Ayele, 2008). An optimal livestock size and combination of species would provide policy insight into the freely increasing livestock size in the mixed crop-livestock system.

5. Conclusion and Recommendations

5.1. Conclusion

In a country facing significant challenges of food insecurity due to droughts and climate change, reducing livestock yield by quartile poses a considerable challenge. This is because relatively more land is in the hands of livestock quartile-III and quartile-IV households. The disincentives for higher yield by livestock quartile have to be addressed rather than paying attention only to the poor who have limited land. The finding mainly shows that though mixed farming contributes to increased yield in the lower quartiles, its yield-decreasing effect in the upper quartiles sparks concern.

Drought shocks decrease the probability of adopting mixed farming, and information on rainfall, temperature, and land abundance improves the move to a mixed farming system. On the contrary, the findings show that difficulty accessing water and land decreases the probability of adopting mixed farming. Relative to SNNPR, most regions tend to stay in crop-only farming systems. This means that households tend to continue with cropping or adding livestock rearing, either as an adaptation strategy to climate change with severe water scarcity and labour shortages or as an upcoming investment (for example, agro-processing).

The finding strongly supports that climatic shocks in the frequency of drought in the last five years in the sample areas play a predominant role in decreasing crop yield. Surprisingly, the rate of the influence of the shocks on yield increases with the frequency of the drought, which is most likely to happen. This requires the attention of policymakers to improve the adaptation mechanisms of smallholder farmers. Currently, investment in irrigation and water management technologies has gotten the attention of the government. This is an encouraging strategy to increase the irrigated land to decrease the risk of climate change or drought shocks. Moreover, in line with the findings, the use of threshers improves yield because of their advantages in decreasing harvest losses.

5.2. Recommendations

The study found that increasing livestock size creates a disincentive to increase crop yield. Given that nearly 60 percent of the cropland is occupied by upper livestock quartile households, it urges attention to accommodate the extension and other support services to the upper livestock quartile households. In other words, there is a need to expand current agricultural interventions by designing appropriate strategies that specifically address the challenges faced by the most affluent farmers.

The finding shows that drought frequency over several years significantly decreases yield. This has an essential implication. In the relatively surface water-abundant Ethiopia, it is essential to understand that irrigation and water technologies and practices need to be encouraged as adaptation strategies. In the estimations, the coefficient of irrigation is positive but insignificant in many of the estimations, possibly because of the limited number of users of irrigation (only 15%), but investment in irrigation has to be further encouraged.

Drought-resistant crops are only second best relative to the crops that farmers would grow under non-drought-normal conditions, and the finding shows this practice decreases yield. Research institutes on crop varieties need to work on these varieties to improve their yield contributions as options in drought years, which is a critical assignment in the Ethiopian context.

The agricultural information helps farmers forecast, and the findings show that this increases yield. This implies the need to enhance information sharing with farmers through digital and non-digital mechanisms to increase yield.

The finding strongly supports transformative investments, such as the implementation of threshers to increase yield. This highlights the need for affordable threshers that either available for purchase or for rental, as the current expensive options pose a barrier. Exploring the reasons behind the low adoption rate of threshers and their profitability could be areas of further research.

The fact that outmigration increases yield shows that labour productivity could be low and has the potential to increase labour productivity, which transforms agriculture. This is consistent with the prediction of the Lewis model. The path to influencing crop yield per hectare is that those outmigrantors could transfer financial resources to household to purchase yield-increasing inputs.

Last but not least, the finding that yield varies with agro-ecologies and administrative regions magnifies the need to avoid a one-fits-all type of recommendations and emphasizes the importance of considering agro-ecologies and regional variations to increase crop yields. Several studies, such as Mendolson (2012) highlight this crucial issue in agricultural transformation.

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Impact of Climate Change on Agricultural Output and Adaptation Measures in Ethiopia

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Abstract

Part of the literature informs that different regions of the world contribute to greenhouse gas emissions in varying degrees, in global warming. It also highlights that these regions influence different influences from the warming effects, ranging from extreme net loss to net gain. Importantly, it emphasizes that countries in the tropical regions, such as Ethiopia, are particularly vulnerable to these changes. This study utilized a production function approach that considers the physiology of plants and animals to assess the long-term economic impacts of rainfall variability on the agricultural output. The analysis is based on time-series data covering the period from 1961 to 2012. The results of the econometric analysis confirmed the existence of an optimal volume of rainfall. When this optimal threshold is exceeded, the benefits of rainfall diminish indicating that the country experiences short-lived and negligible gains from climate change, while enduring comparatively higher economic loses in the long run. Furthermore, there is a probable trend of excessive rainfall during the rainy seasons, surpassing the optimal amount. In order to delay the onset of diminishing benefits of rainfall, it is crucial to undertake mitigation and adaptation efforts promptly

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and resolutely. Among others, too much rainfall, which is catastrophic, can also be an opportunity to use rainwater harvesting to fill the moisture-stress gap that can be created due to the early stoppage of rainfall. Most importantly, since the adverse impacts are caused mainly by global negative externalities, the findings suggest a need to complement the global approach with the local adaptations of smallholder farmers to address the negative impact of climate change.

Keywords: Impact, Climate Change, Agriculture, Output, Time-series data, VECM
JEL Classification: E23, Q15, Q54

1. Introduction

History tells us that climate change has been hitting this planet at irregular intervals of time since antiquity. Whenever it occurred, it caused great changes in life and socio-economic performances (for example, Acemoglu and Robinson, 2012, p. 152; World Bank, 2010:39). In recent years as well, our planet has been facing another climate change. According to the IPCC (2021), the global average surface temperature has been increasing since 1861 without moving back to its mid-nineteenth century level, rather increasing over the twentieth century by about 0.6°C, but taking a different trend since 1950, showing a 0.10°C rise per decade (IPCC, 2001:2), and continuing to increase (IPCC, 2021). The vast majority of scientists agree that the average surface temperature on the planet has already warmed by about 1°C since the mid-eighteenth century, and unless reductions in GHG emissions occur, the global warming of 1.5°C and 2°C will be exceeded during the 21st century (IPCC, 2021). The global concentration of carbon or emitted GHG in the atmosphere influences the natural climate (Althor et al., 2016; Weyant, 1993).

Just like the past climate changes, the present warming has several prolonged effects. Melting of snow and ice causing rising sea levels, increasing frequency of warmer days and nights and heavy-flood causing rainfalls are some major effects. IPCC (2021:5) puts the effects as increase in global average sea level by 0.20 (0.15 to 0.25) meters between 1901 and 2018, decrease in snow cover of about 10 percent since 1960s, twentieth century increase in precipitation by 0.5 to one percent per decade (IPCC, 2001:2).

With no doubt, agricultural outputs are mainly vulnerable to the indicated change. Some writers estimate the effect of such changes at a two to 50 percent yield decline in major cereal crops (Serdeczny et al., 2017; Rosenzweig et al., 2014) and a 20 to 30 percent reduction in grain production globally (Darwin et al., 1995). Burke et al. (2018) estimated a cumulative $20 trillion in global damages avoided by 2100 if global warming is limited to 1.5 degrees Celsius rather than two degrees Celsius. Reilly et al. (1994), assuming no adaptations, estimated the global welfare losses in the agricultural sector at US$61.2 billion and the likely welfare gains at US$0.1 billion. Many writers argue that the highest losses occur in tropical regions (Uribe et al., 2023; Mendelsohn et al., 2000), which may cause production to retreat from the tropics to temperate regions. Several studies projected that due to climate change, output agricultural reduction falls between 1.2 and 4.5 percent for Eastern Africa (Kahsay and Hansen, 2016) to 10 percent of GDP in Africa (Hernes et al., 1995). A large number of these studies conducted on the impact of climate change are, however, crop-specific rather than macro-level estimations (Carr et al., 2022; Pereira, 2017; Serdeczny et al., 2017; Schlenker and Lobell, 2010). Those studies estimated the yield fall due to climate change in specific crops by about 50 percent (for example, Serdeczny et al., 2017). Similarly, Thomas et al. (2019) assumed increasing rainfall and temperature in the future in Ethiopia and found a less than one percent yield decline of two major crops (sorghum and wheat) but a possible yield increase of maize by about 1.2 to 4.2 percent in 2035 and 2085. In the case of Ethiopia, Rettie et al. (2022) found a similar result of a limited decline in maize yield but a fall in wheat yield of 36 to 40 percent by 2050.

Reducing the adverse effects of the change and making optimal use of its likely gains requires an adequate and clear understanding of the relationship between climate change and a country’s economic performance, however. This understanding may include knowledge of the magnitude of the changes in temperature and precipitation, the frequency and intensity of floods, a more precise functional relationship between climate variables and socio-economic variables like agricultural production and labour productivity, the feasibility and costs of factor reallocations offsetting adverse effects and reap optimally from available opportunities.

To reduce the vulnerability of its population, environment, and economy to the adverse effects of climate change, Ethiopia is undertaking adaptation and mitigation initiatives, following its Climate Resilient Green Economy Strategy/CRGE (FDRE, 2012), to at least sustain the encouraging performance of the agricultural sector since 2004. The sectoral GDP was growing with an average growth rate of seven percent annually between 2004/05 and 2013/14 (Schmidt and Thomas, 2018). The question is, despite the strategic approach to gradually addressing the issue of climate change, how far does climate change affect the agricultural output in Ethiopia? In line with the CRGE strategy, the study investigates agricultural water management in the context of climate change, aiming at assessing the impact of climate change on agricultural output. It could inform policymakers regarding policy measures that help overcome undesired effects and harness gains from the change.

To assess the impact of climate change on agricultural output, studies employ different models. They estimated a model focusing on assessing the effects of the change on the production of specific crops (Carr et al., 2022; De Salvo et al., 2013). Others employ non-crop-specific production functions (Rosenzweig et al., 2014), the Ricardian approach (Deressa et al., 2007; Mendelsohn et al., 1994), and the Integrated Assessment model (Peng and Guan, 2021; Nordhaus, 1993). Each approach has its own merits and limitations, however. This study employs a production function approach to look into the impact of climate change on agricultural output. The contribution of this study is that, among others, it estimated the optimal level of rainfall to understand the impact of deviation of the volume of rainfall from its optimal level, which is not attempted in many other studies (Solomon et al., 2021; Ketema and Negeso, 2020) rather than conventional estimations in time series analysis (Ketema and Negeso, 2020). In addition, the study used the quarterly dummies to check the impact of quarterly (crop-growing season) shocks on agricultural output. This study used more than 50 years of data, unlike similar studies (Ketema and Negeso, 2020), which is advantageous to adequately capture the long-run effects.

In the remaining part of the study, Section 2 reviews the literature on models employed and reported impacts. Section 3 presents the framework of the analysis. Empirical analysis employs alternative estimators and results and conclusions are presented in sections 4 and 5, respectively.

2. Literature Review

In the literature, various authors constructed several models to assess the impacts of climate change, very likely due to the multidisciplinary nature of the problem. De Salvo et al. (2013) listed crop simulation models, production function approaches, Rechardian models, mathematical programming, integrated assessment models and general equilibrium models (GEM). The crop simulation model concentrates on plant physiology and considers the biological and ecological consequences of climate change (Torriani et al., 2007), but criticised for ignoring the adaptive behaviour of producers and for its crop and site specificity. To improve its weakness, other authors prefer to employ a production function approach that considers producer behaviour (Rosenzweig et al., 2014). The approach is also praised for its suitability to both short and long-terms time-scale. However, its application to cross-section data is reproached for its likely biased results arising from omitting the possibility of farmers' adaptation. On this issue, Dell et al. (2014) underlines that the long-run effect estimate derived from cross-sectional data is larger in intensification or smaller in adaptation than the short-run. To address these issues, others employ Ricardian approach-developed by Mendelsohn et al. (1994) to capture farmers' adaptation in some sense. This approach specifies farmland prices as a function of climate and other variables. Unlike the production function approach the model aims at capturing the farmers' adaptation strategies based on land values or net revenues on normal climate situations and other control variables. Most often the normal situation is calculated as averages of long-term circumstances. This model is praised for it well assesses the effects climate change in the whole of agricultural, sub-sector or crop (Nguyen et al., 2022; De Salvo et al., 2013; Seo and Mendelsohn, 2008; Deressa, 2007), but difficult to apply when farmland prices are unavailable. Besides, it neglects irrigation except that Nguyen et al. (2022) took the proportion of irrigated land. All the above models assume agriculture is self-reliant while actually not. To bypass this limitation, other writers employ GEM, which considers the interdependence of economic sectors and provides information on the effect of climate change by regions and sectors. However, this model is criticised for it treats production factors, including irrigation water, undifferentiated inputs, and for the difficulty to analyse farmers' adaptation strategies (De salvo et al., 2013).

Peng and Guan (2021) and Nordhaus (1993) employed the integrated assessment model to address the limitations. However, the main obstacle to this model is the uncertainty about future economic growth and technological change that is associated with GHG emissions, the actual relationship between emitted GHG per unit of time and the accumulated GHG, the rate at which heat is transferred into the ocean, and the reverse causation from warming to atmospheric GHG concentrations (Allen and Frame, 2007). But, often, each difficulty could be improved as human understanding of the underlying mechanisms and relevant technology improves. Zerayehu et.al. (2020) applied a recursive dynamic computable general equilibrium (CGE) model to investigate CO2 emissions' impact on agricultural performance and household welfare.

Building upon these models and different types of datasets, several authors have assessed the impact of climate change and documented varying impacts depending on the relative global locations. Dell et al. (2012) employed a 1950-2003 panel dataset to examine how annual variation in temperature and precipitation affects per capita income throughout the world. They reported that being 1°C warmer annually reduces per capita income by 1.4 percent, but only in poor countries. Hsiang and Narita (2010) employed panel data (233 countries over 1950-2008) to examine the effect of windstorms on income and found higher wind speeds cause economic losses. Lobell et al. (2011) also conducted a global study focusing on the impact of weather on agricultural output and found a statistically significant and nonlinear effect. Though these studies are comprehensive, to the extent they are global, one expects to learn more about feedback effects. That is the extent of changes in warming due to the suppressed output, either through the impacted outputs exerted on GHG emissions or reflections of the sun's heat arising from the accumulation of GHG, which is beyond the scope of this paper.

The literature focusing on Africa reveals a similar effect. Emediegwu et al. (2022) developed a spatio-temporal model and estimated the effects of climate change on crop yield and found that the effect varies depending on whether the countries are poor or rich. Pickson and Boateng (2022) employed the pooled mean group technique and the Dumitrescu–Hurlin panel causality test to investigate the effect of climate change on food security in 15 African countries between 1970 and 2016 and found a significant role for rainfall and temperature. Bruckner and Ciccone (2011) and Exenberger and Pondorfer (2011), employing panel data on sub-Saharan Africa, examined the effects of climate change and observed that the effects are quite adverse. Following a similar technique, Schlenker and Lobell (2010) estimated the yield response in sub-Saharan Africa to weather changes. They found that higher temperatures reduce yields. Miguel et al. (2004) dealt differently, employing datasets of 41 African economies to examine the relationship of civil conflicts, income, and rainfall. They reported that the per capita income growth was positively predicted by the current and lagged rainfall growth. However, the researchers assumed a monotonic relationship between climate variables and economic variables. But one could ask whether the finding would remain unchanged had they relaxed their assumption about the possibility of non-monotonic relationship.

For Ethiopia, Solomon et al. (2021) employed the dynamic computable general equilibrium (CGE) model and simulated up to 2050 to see the impacts of climate change on the agriculture sector of Ethiopia, and their results suggest that crop production will be continuously adversely affected over time, suggesting the need for adaptation mechanisms. Also, Ketema and Negeso (2020) employed time series data from 1980-2016 to see the long-run and short-run effects of climate change on agricultural output in Ethiopia and found that climate changes have an important long-run effect on agricultural output and an estimated 73.8 percent annual adjustment towards long-run equilibrium. In the short run, mean annual rainfall has a significant effect, but the average temperature has an insignificant effect on output. However, the study does not consider, among others, the optimal level of rainfall and temperature in the analysis of the impacts of the variations.

Robinson et al. (2013) employed global circulation models and found that by 2050, climate change could cause GDP to be 8-10 percent smaller than under a no-climate change baseline. In identifying important elements of a climate-resilient development strategy, they recommend rapidly developing hydro-potential, upgrading road design, and gradually diversifying the economy. Wakeyo and Gardebroek (2013) found that growing perennial crops increases the probability of using rainwater irrigation to adapt to climate change, similar to the adaptation mechanisms of households in other developing countries (Williams et al., 2016). Tesso et al. (2012), employing time-series data, examined the effect on crop production. They documented that 90 percent of the variation in productivity was explained by area under irrigation, manure, improved variety, seasonal rains (Meher and Belg), and temperature. Demeke et al. (2011) investigated the effect of rainfall shocks on smallholders' food security. They found that the level and variability of rainfall determine persistent food insecurity. Shang et al. (2011) examined whether a long-term increase in extreme precipitation exists and reported no increasing trend in extreme precipitation. These studies clearly document the fact that Ethiopia's economy is influenced by climate change. But the issue of the non-monotonic relationship between climate variables and economic variables needs further investigation. From the reviewed models, cross-sectional studies may not capture the farmers' adaptive behaviour and hence bias the estimated marginal effects. According to Dell et al. (2014), panel data could also have limitations in reflecting medium- and long-run situations. This condition necessitates the use of time series to get clearer picture of the effects of climate change on Ethiopia's agriculture in the long run.

3. Empirical Methods and Data

3.1. Empirical Methods

To assess the impact of rainfall variation in the agricultural production function approach, one needs to know factors of production and the type of functional relationship that links them to the considered output. From the literature, one observes that the common factors used in production functions are capital, labour, and land. These factors can be modified into more suitable forms like substituting produced capital with livestock or splitting land into arable land, irrigated area, and investment like fertilizer.

Conventionally, it is assumed that maximizing behaviour of producers coupled with market forces leads to the stability of the product of the ratio of the marginal product of each factor to its unit price, and the share of output invested in the acquisition of that factor is constant, but this assumption may not hold true for rainfall since optimization is not so feasible.

This is because the decision on the amount of this ‘factor’ to enter the production is not in the hands of the producers. Besides, even one can assume that at the global level rainfall quantity depends on the extent to which people take environmental care, and hence, at the global level, human races can have some influence on the amount of rainfall. At the country level, the amount of this ‘factor’s supply seems exogenous. However, the implicit assumption in using rainfall as a factor of production could be that the cost of reducing GHG emissions that a country bears could represent the cost of getting the required amount of rainfall. In fact, the view is more plausible at the global level than at the country level or for a hypothetical closed economy. Bearing this in mind, the production function $f(.)$ that determine agricultural output, $Y(t)$ at time t is,

$$Y(t) = f\left(R(t), L(t), K(t), Z(t)\right) \tag{1}$$

Where $R(t)$, $L(t)$, $K(t)$ and $Z(t)$ represent the amount of rainfall, labour, capital and land, all registered and entered production at time point t, respectively. After taking total derivative of both sides of equation [1], and dividing both sides through by $Y(t)$ and then taking the integral of both sides one can switch to explicit function as

$$Y(t) = AR(t)^{\alpha_1} L(t)^{\alpha_2} K(t)^{\alpha_3} Z(t)^{\alpha_4} \tag{2}$$

Where $\alpha_1, \alpha_2, \alpha_3 \text{ and } \alpha_4$ are elasticities.

Usually, the Cobb-Douglas production function can be seen as the first-order Taylor's series expansion of the natural logarithm of the output in the natural logarithm of the factors. Under the expectation of interaction effects among the factors or non-unity elasticity of substitution, however, one may take the second-order Taylor's series expansion that results in the translog production function. Even if the interactions of agricultural inputs are very likely, as in, for example, Wakeyo and Gardebroek (2013), who reported the interaction effect of water-harvesting irrigation and fertilizer use, in our case we confined ourselves to first-order expansion since the estimation of the function demands much more observation than we have.

Expressing equation [2] in log form

$$lnY(t) = lnA + \alpha_1 lnR(t) + \alpha_2 lnL(t) + \alpha_3 lnK(t) + \alpha_4 lnZ(t) \tag{3}$$

Equation [3] helps to assess the effect of rainfall on the output of a hypothetically closed agricultural economy that avails no external economy to others or faces the same from others. For a country that fulfills such a scenario or is at least close to it, the equation may help to estimate parameters like the marginal effects of rainfall on output, the effect of a percent increase or decrease in rainfall on output, and the share of rainfall from total output as compared to other factors. As pointed out above, the equation may also serve to assess the global-level impacts of climate change, in which external economies are internalised, disregarding country-or regional-level impacts.

However, application of the model at country level, particularly to low-income economies, could give a misleading result. This is primarily because of the weak relationship between the assumed 'unit cost' and the amount of 'factor'. Under this condition, parameter estimates of the equation could be spurious, which as is clearly seen from the prediction of equation [3], which implies that for $\alpha_1 > 0$ there is persistent growth gain from a continuous increase in rainfall quantity, which is inconsistent with reality. From the physiology of plants and animals, one understands that scarcity and excessiveness of rainfall hamper their growth and reproduction, and at the extreme, threaten their lives. Despite this fact, the equation suggests that increases in rainfall at extremely high rainfall amounts, which are catastrophic, are associated with output growth just as they are associated with output growth at optimal rainfall levels. With a slight difference, the same is true for cases of scarcity. The equation implies that increases in rainfall from an extremely meager level are associated with output growth exactly the way they are associated with output growth at an optimal level. In real cases, a given amount of increase from an inadequate level is related to better performance than increases from an optimal level.

The interest of this paper is neither global-level assessment nor ignoring external economies, which is equivalent to assuming a closed economy since it is not realistic. As a result, even if equation [3] is a very common type, we need to modify it so that it serves our interests at best. To overcome the limitations of the equation, instead of treating rainfall as a factor of production, we treated it as a part of the general structure within which the production process takes place, just as the effects of the progress of industry on the progress of a firm are treated, that is, as a systematic deviation of the volume of rainfall from its optimal level that arises in the form of external economies.

In emphasizing that external economies play roles just like internal economies in determining the progress of production volume, Marshall (1890: 152) wrote, “We may divide the economies arising from an increase in the scale of production...into two classes: (1) those dependent on the general development of the industry; and (2) those dependent on the resources of the individual houses of business engaged in it, on their organization, and on the efficiency of their management. We may call the former external economies and the latter internal economies.” Regarding the size of the effects of external economies in comparison to internal economies, He (1890:255) wrote, “Those internal economies that each establishment has to arrange for itself are frequently very small compared to those external economies that result from the general progress of the industrial environment....”.

In our case, to express both forms of economies mathematically, we relied on the damage function, in which part of the output is damaged due to the external economies manifested in the deviation of rainfall from its optimal level. Before the introduction of the external economies, let’s first suppose that the economy gets an optimal volume of rainfall and employs traditional production factors. Following equation [1] and equation [2],

$Y(t) = A\mathrm{L(t)}^{\beta_1}\,\mathrm{K(t)}^{\beta_2}\,\mathrm{Z(t)}^{\beta_3}$ Where $\beta_1,\ \beta_2$ and β_3 are elasticities. Now to introduce the external economy, let's suppose that at time t, some part of the output is damaged by some percent $D(t)$ as a result of scarcity, or excessiveness of rainfall, or deviation of rainfall from its optimal level. The actual output in this situation is that

$$Y(t) = A(1 - D(t))L(t)^{\beta_1}\,K(t)^{\beta_2}\,Z(t)^{\beta_3} \tag{4}$$

Since the damage is assumed to be due to a deviation of rainfall from its optimal level, we set $ln(1-D(t))$ as an implicit function $H(R(t))$, where $H(.)$ is some function of the amount of rainfall. Using Taylor's polynomial approximation for $H(R(t))$ and substituting it in equation [4] and taking the natural logarithm,

$$lnY(t) = ln\,A + \sum_{i=0}^{\infty} \pi_i R(t)^i + \beta_1 lnL(t) + \beta_2 lnK(t) + \beta_3 lnZ(t) \tag{5}$$

Where $\pi_i{}'s$ are parameters.

Based on the physiology of plants and animals, which indicates the existence of some optimal level of moisture for their growth and reproduction and that both scarcity and excessiveness of rainfall hamper their growth and reproduction, one can truncate the Taylor series in second order. That is, using only quadratic approximation and setting the theoretically expected signs of the parameters as $\pi_2 \leq 0$. Accordingly, the theoretical model that takes the physiology of plants and animals into account will be

$$\ln Y(t) = \ln A + \sum_{i=0}^{2} \pi_i R(t)^i + \beta_1 \mathrm{lnL(t)} + \beta_2 \mathrm{lnK(t)} + \beta_3 \mathrm{lnZ(t)} \tag{6}$$

Equation [6] suggests that the log of agricultural output is linearly related to the log of traditional factors of production and quadratically related to the amount of rainfall.

To compare the implications of equations [6] and [3], take the derivatives with respect to time. The result gives contribution of growth by rainfall amount plus other factors to the percent growth of agricultural output. After differentiating equation [6] and rearranging,

$$dY(t)\Big/Y(t) = \left[\left(-2\pi_2 R(t)\right)\left(-\pi_1\Big/2\pi_2 - R(t)\right)\right] dR(t)\Big/R(t) + \beta_1\, \mathrm{dL(t)}\Big/\mathrm{L(t)} + \beta_2\, \mathrm{dK(t)}\Big/\mathrm{K(t)} + \beta_3\, \mathrm{dZ(t)}\Big/\mathrm{Z(t)} \qquad \textbf{[7]}$$

Under the secular amount of increase in rainfall, equation [3] implies that a percentage increase in rainfall is associated with a fixed percent increase or decrease in output growth depending on the sign of the parameter, α_1 irrespective of rainfall. This is a very unlikely prediction, for $\alpha_1 > 0$. It ignores the possibility that too much rainfall damages crops and the output in general, and in case of $\alpha_1 < 0$, it ignores the likely gains when the country is getting rainfall below optimal. Unlike equation [3], equation [7] suggests that a percent increase in rainfall depends on the previous time record of rainfall and the extent to which it deviated from the optimal level $\left(-\pi_1\Big/2\pi_2\right)$. If $R(t)$ is below optimal level $-\pi_1\Big/2\pi_2 - R(t) > 0$ and the coefficient of $dR(t)\Big/R(t)$ will be positive since $-2\pi_2$ is expected to be positive based on the indicated physiology, and hence increase in the amount of rainfall contributes to the growth of output positively. A close look at the equation reveals that the contribution declines as the amount of rainfall approaches the optimal level. But, if the observed level is already above the optimal, the second term will be negative and the first term remains positive, i. e. $-\pi_1\Big/2\pi_2 - R(t) < 0$ and $(-2\pi_2 R(t)) > 0$, implying the term in the big bracket will carry a negative sign, which suggests an increase in rainfall reduces the contributions of other factors of production to output growth. Thus, whether an increase in rainfall contributes to output growth depends on whether the nation is already getting below or above the optimal rainfall, and the size depends on the gap between the observed and the optimal, with a larger gap being associated with a bigger loss or gain and vice versa.

Following the same route of analysis, one can deduce that if rainfall follows a secular decline, it contributes to output growth adversely if the amount is below the optimal level. Similarly, under this context, one can conclude that it contributes favourably to output growth if the observed amount of rainfall is above the optimal level.

In the context of global warming, it is expected that a persistent increase in temperature will cause a persistent increase in rainfall, with some random fluctuations. Under this circumstance, the equation predicts that nations that are getting inadequate rainfall or are below the optimal level may enjoy some gains in their output growth up to the point when the optimal level is reached. Then after, they start to face suppressed output growth that may lead to stagnation or even economic crash if the warming continues to raise rainfall. Additionally, nations already getting above optimal would face suppressed output growth from the very beginning because of rising rainfall. In the long run, if warming is not mitigated and its effect on rainfall is unrelenting, nations depending on rain-fed agriculture may lose production. However, in the short and medium terms, whether the nation will be a net gainer or net loser will be the subject of empirical work.

From the perspective of reaping the likely gains and struggling against the likely losses arising from climate change, equation [7] has some additional information. In the context of the secular rise of rainfall, it implies that the nations already getting rainfall above optimal need to do their best on their own and with international cooperation to halt rising rainfall by limiting the forces that contribute to global warming. In terms of equation [7] this implies attempting to have lower $R(t)$ if possible, in the short run, otherwise in the medium or long run. This corresponds to mitigation activities related to stumbling rainfall from not exceeding the optimum level. At the same time, they need to alter the parametric optimal level in the direction of rainfall's secular trend. In terms of equation [7], this means rising $-\pi_1 / 2\pi_2$, which corresponds to adaptation -related to innovations associated with drought/wet resistant new varieties and other related activities.

From the set-up of equation [7], part of the inefficiencies in agricultural production could be attributed to the variations of rainfall around some optimal level. The next question is whether the deviation explains all of the inefficiencies involved or not. This question will be left to empirical analysis.

Turning back to the likely situation in Ethiopia, the three possibilities are: the country has been getting rainfall below the optimal level, exceeding its optimal level, and at about its optimal level. In the first case, one may expect some degree of economic benefit from the secular increase in rainfall, and in the later case, some degree of economic loss. However, as long as the increase in rainfall is continuous, it is likely that, soon or later, the economy will start to experience suppressed growth in its agricultural output. But if the second case is consistent with the country's reality (getting rainfall above the optimal level already), one can think that the diminishing benefit has already been set in the production system.

A look at Ethiopia's geographic location reveals that it lies within the tropical latitudes. From this location, living plants and animals have already adapted to tropical rainfall that suits their growth and reproduction. However, the increase in global warming may initially reduce rainfall to some degree, since it limits the process of condensation of water vapour to form rain drops. But after some degree of warming, when mountain glaciers, snowpack, and ice melt more and more, the country may experience more rainfall. Accordingly, keeping the effects of the annual erratic fluctuation of rainfall aside, the country has been getting rainfall below some optimal level, which may lead one to expect the first scenario to hold.

3.2. Data

The variables used for the empirical analysis include value added in agricultural output expressed in constant price in (million Birr[5]), annual rainfall (in millimetres), arable land (in hectares ha), area equipped for irrigation (in 1000 ha), fertilizer consumption (in kilograms per ha), livestock (in TLU) and labour[6] (in head counts). The time series constructed for them ranges from 1961 to2012.

Data for value added in agricultural output were taken from the Ministry of Finance and Economic Development (MoFED), whereas rainfall, arable land, and fertilizer consumption data were taken from the World Bank (2016). Similarly, data on land equipped for irrigation and livestock were taken from FAO (2017), and labour data from the World Penn Table.

4. Results and Discussion

4.1. Descriptive Statistics

The descriptive statistics is presented in Table 1. The table reports that the annual average temperature was 23^{o}C and 23.91^{o}C during 1981-1985 and 2006-2010 respectively. If we assume that the 5 year average can smooth out random

[5] One Ethiopian Birr was equivalent of 0.441 US$ on March 31, 2017.

[6] The variables series taken from Penn was adjusted for agricultural sector, using the fraction of rural population from the total.

fluctuations and that temperature follows a linear trend, we can think that the countries annual average has been rising by 0.37°C per decade over the past 25 years. However, there is no reason to rule out the possibility of a non-linear trend. The rising trend and the possibility of non-linearity can be seen in Figure 1. The figure indicates that if one fits a linear trend to the temperature 1961-2010 data, the fitted line shows that temperature exhibits a rising trend during the considered five decades. But if one allows the data to choose between a linear and non-linear trend by employing fractional polynomial-fit that gives the data both chances, there is a tendency toward non-linearity. The non-linearity and convexity to the origin are signs of rising marginal changes per unit of time, besides the rising trend. Thus, the temperature shows a tendency to rise with time.

Table 1: Descriptive statistics

Variables a	1981-1985		2006-2010	
	Mean	St. dev	Mean	St. dev
Annual rainfall (in mm)	673.17	83.80	745.51	44.02
Arable land (ha per person)	0.32	0.03	0.17	0.004
Arable land (ha per person) growth	-0.05	0.01	-0.001	0.03
Fertilizer in kg/ha	1.91	0.25	16.78	3.84
Fertilizer (in kg/ha) growth	0.07	0.01	0.17	0.16
Total irrigated area (1000ha)	180.97	5.19	304.86	10.43
Total irrigated area (1000ha) growth	0.02	0.001	0.02	0.00
Agriculture value-added per-person (birr)	669.51	105.37	743.43	59.58
Agriculture value-added per-person (birr) growth	-0.09	0.14	0.06	0.02
Rural labour growth	0.03	0.02	0.03	0.002
Rural population growth	0.03	0.004	0.02	0.002
Annual average temperature (°C)	23.00	0.12	23.72	0.53
TLU per-person	0.84	0.02	0.66	0.01
Livestock in TLU per-person growth	-0.001	0.03	0.02	0.04
Quarter-1 (December-February)	22.70	11.83	37.82	9.68
Quarter-2 (March-May)	211.76	38.53	183.50	32.28
Quarter-3 (June-August)	283.27	27.82	331.52	12.51
Quarter-4 (September-November)	155.44	29.72	192.67	11.38

Likewise, Table1 reports that the country's average annual rainfall was 673.172 mm during 1981-1985 which rose to 745.507mm during 2006-2010. Again, if there is reasonable ground to assume rainfall follows a linear secular trend, the statistics imply that during the study period, the country's rainfall was increasing by 2.893mm [(745.507-673.172)/25] per year, or 4 percent per decade. This general tendency is consistent with what the IPCC documented (2001:2) and is cited in section 1. But in a broader span (1961-2010), the linear trend suggests that annual rainfall was declining. However, if the restriction on linearity is relaxed, one can observe that the declining trend is limited to the period before the 1980s. Figure 2, which reports the fractional polynomial fit besides the linear prediction, indicates a clear tendency toward non-linearity in the rainfall. The non-linear curve indicates that the volume of rainfall was following a declining trend in the 1960s and 1970s but a rising trend 'after the 1990s'. Moreover, on average, the least amount of rainfall is during the first quarter (December to February) and the highest during the third (June to August), as shown in Table 1. Furthermore, Table 1 indicates a tendency to decrease in rainfall variability over time, with a coefficient of variation of 0.12 for 1981-1985 and 0.06 for 2006-2010. A similar situation is seen when the reference time is quarters of a year.

Figure 1: Trend of Temperature [1961-2010]

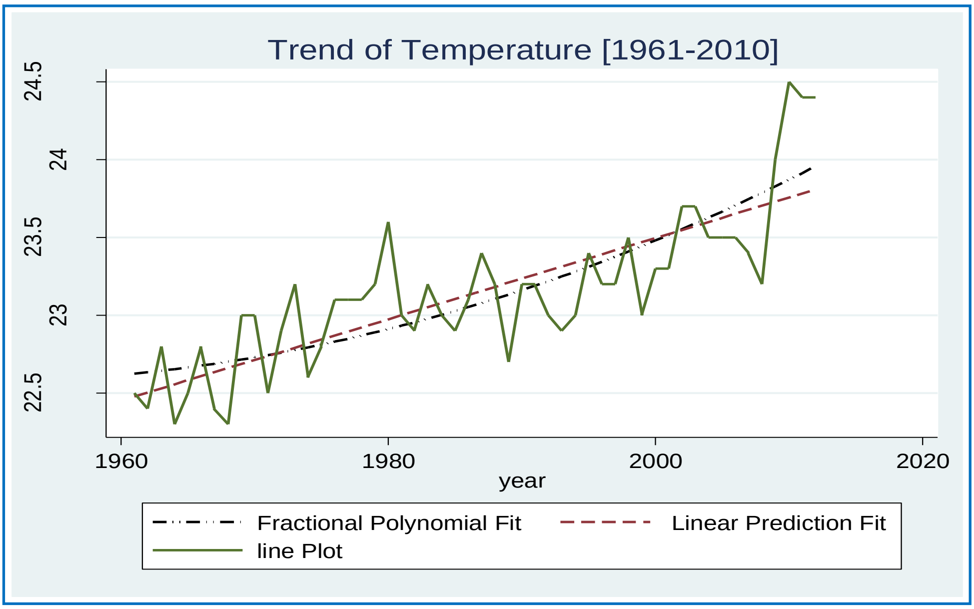
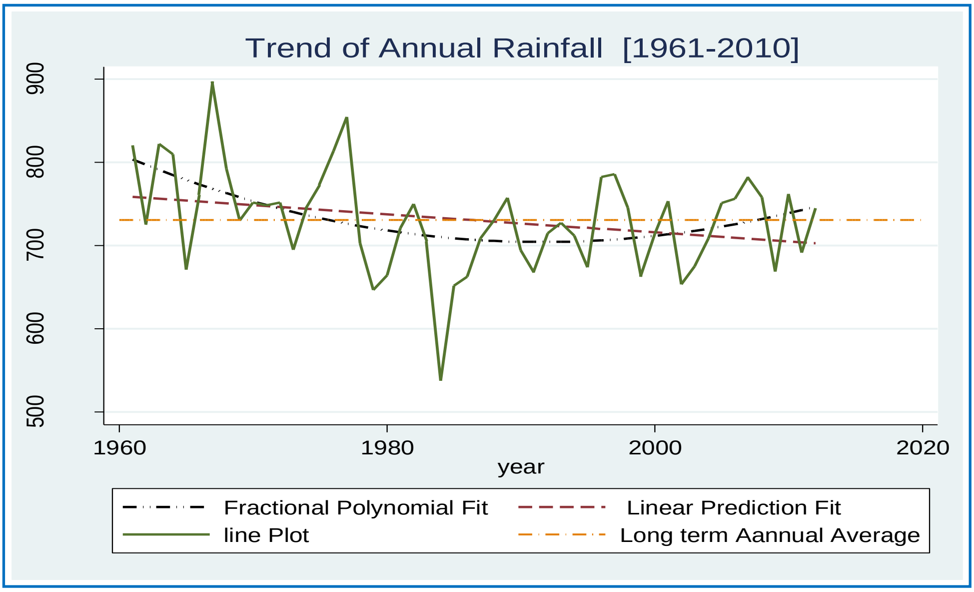


Figure 2: Trend of Rainfall [1961-2010]



In short, from the statistics of temperature and rainfall, we can understand that the variables are exhibiting some secular changes, be they in linear or non-linear form, instead of the common expectation of stable levels with some random variations. We can think that, besides the erratic fluctuations, such secular changes could have some effects on agricultural production. To see the temporal variations, rainfall anomalies were calculated as standardised rainfall units, the deviation of annual rainfall from its mean divided by its standard deviation. Table 1 reports that during the former period, the country was getting less rainfall than its long-term volume of 730.57mm, but during the latter, it was getting above its long-term average, with the difference getting higher over time. Figure 2 also confirms this point.

Besides, Table 1 indicates that during 1981-1985 the country was facing a decline in agricultural value-added per capita of -8.5 percent per year, a catastrophic decline. Most likely, it happened during a war and an extensive drought period. After 25 years, however, the economy exhibited swift progress as proxied by this variable. The table indicates that during 2006-2010 the average growth rate in agricultural value-added per capita was 5.7 percent.

Figure 3: Trend of agricultural value added per person growth

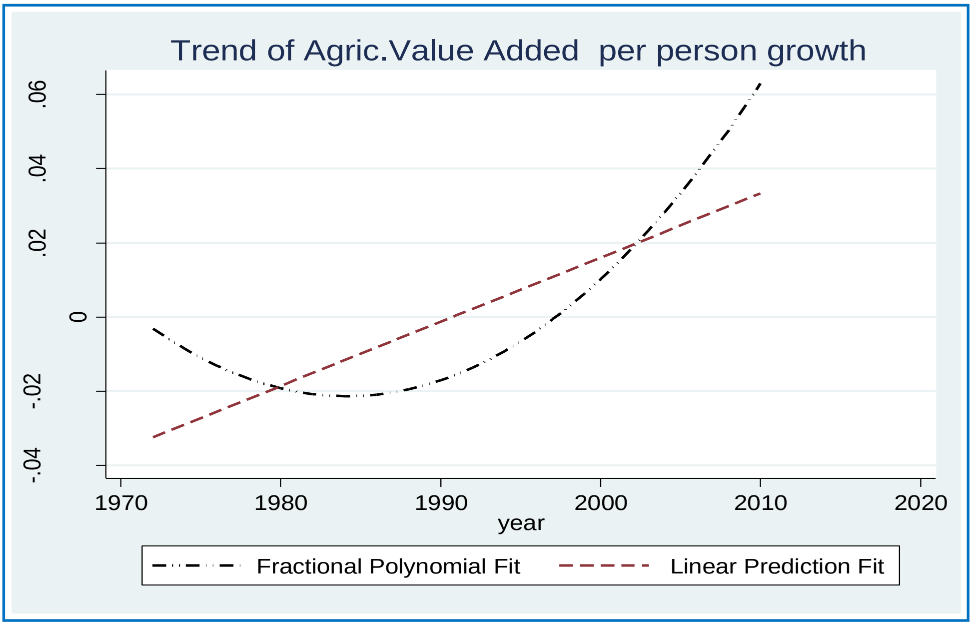
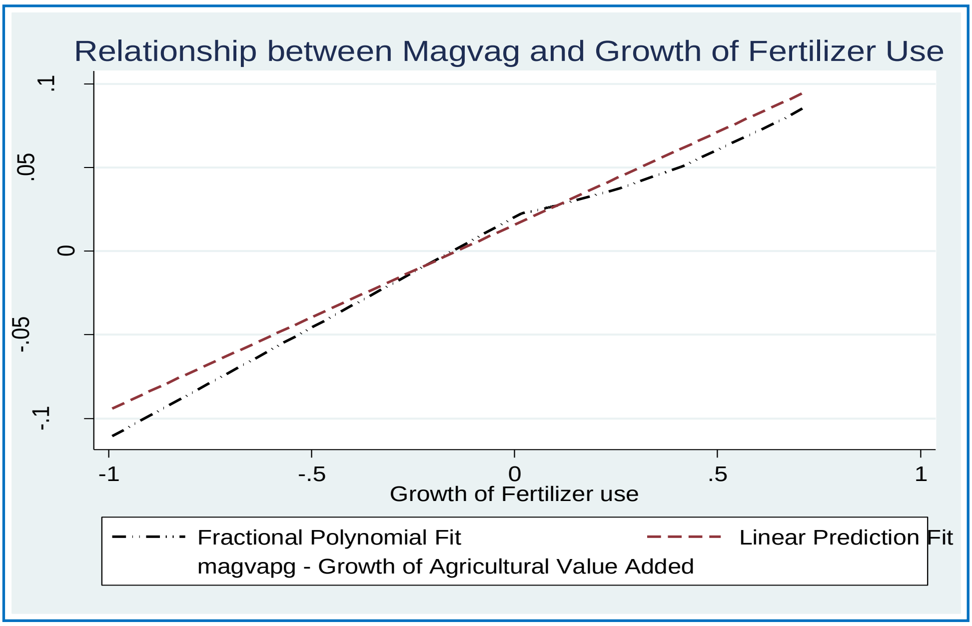


Figure 4: Relationship between agricultural value-added (magvag) and growth of fertilizer use



From the table, one can understand that the likely reasons behind such swift progress are improvements in the factor of production - fertiliser use that increased from 1.91 kg/ha in the first period to 20.12 kg/ha in the second, and land equipped for irrigation that increased from 180,965 to 311650 hectares. Figure 4 indicates a positive and nearly linear relationship between growth in agricultural value added and growth in fertiliser use, suggesting improvement in farm management could be among the likely factors behind the observed progress in the performance of the sector.

But these two factors alone may not bring such remarkable performances. Arable land per person has declined from 0.32 ha in the first period to 0.17 ha in the second, most likely due to rapid growth in rural population relative to the expansion of arable lands. Even if one cannot state this with certainty in our case, there is a possibility that land scarcity may induce technological progress. Besides, the growth of labour force has been close to stability, as the rate in both periods stood at 2.5 percent. Just like arable land, livestock per capita also declined from its level in the first period to the second. The scarcity of land and rapid growth of the rural population are likely reasons for the decline. However, the increase in aggregate livestock could be positively associated with aggregate-level output progress.

Figure 5: Relationship of rainfall and Temperature [1961-2010]

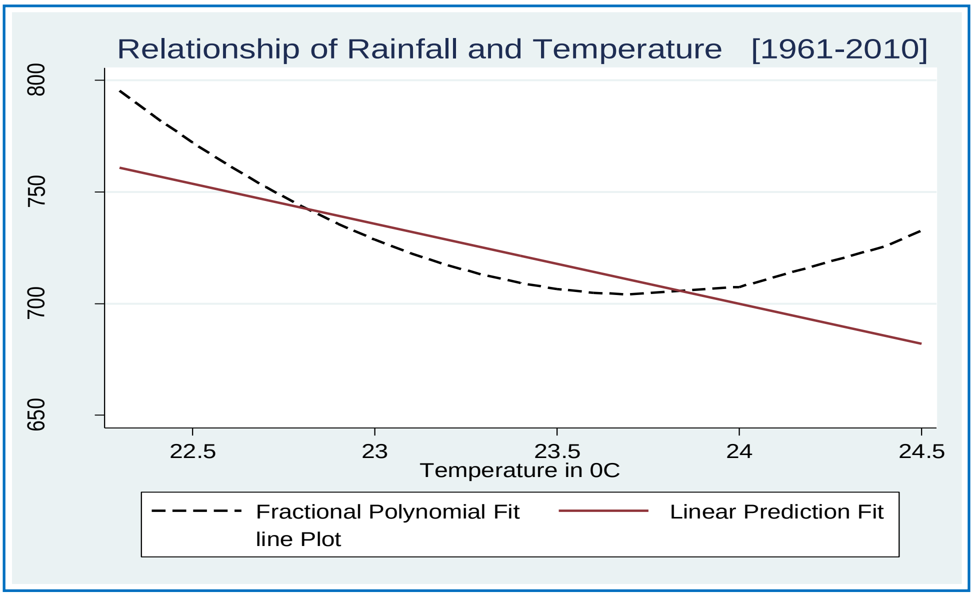
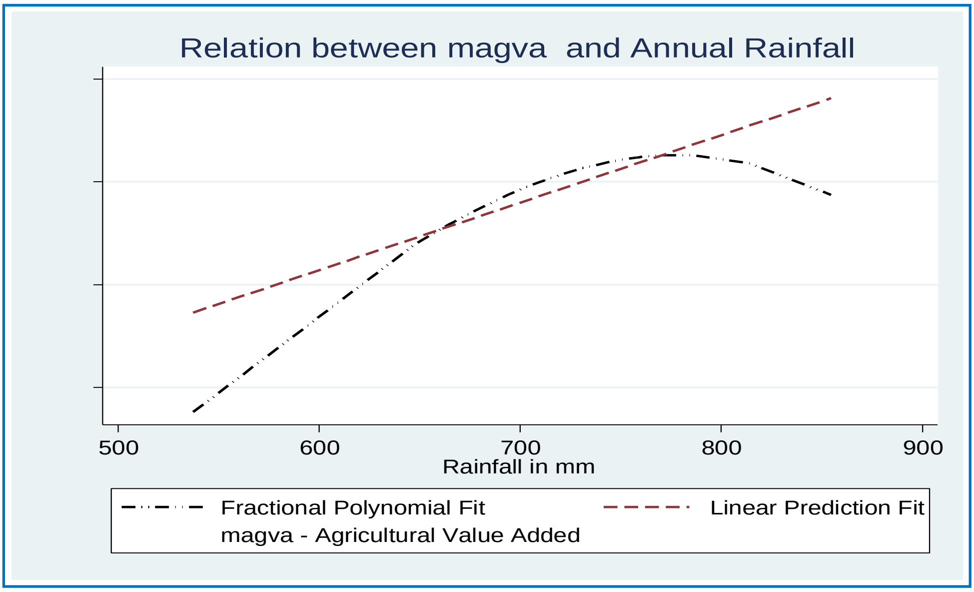


Figure 6: Relationship of agricultural value-added (magva) and annual rainfall



But the crucial point is how the secular change in temperature related to the secular volume of rainfall and how rainfall influenced the performance of the sector to bring about the results presented in Table 1 and Figure 2. Roughly one can imagine that if the secular trend in rainfall is below the optimal level, the rising secular trend might have been contributing favourably to the sectoral performance. This possibility can be observed in Figure 6. But if the trend has exceeded the optimal level, say at some point in time, it is likely that the rising trend has been adversely affecting the performance from that time on.

Figures 7 and 8 show curves with similar shapes. Roughly, Figure 7 suggests that for the growth of agricultural value-added per capita, there is an optimum temperature slightly below 24oC. Temperatures above or below such levels are associated with a lower rate of growth. Similarly, Figure 8 roughly suggests that the maximum growth of value-added in agriculture is associated with zero change in rainfall. In short, from the figures, it seems that the relationship between growth in agricultural value-added and temperature and growth in agricultural value-added and change in rainfall follows an inverted U-shape, which, if happed to be true, is compatible with plants and animals' physiology. To refine these points and related issues, we believe that econometric analysis is an indispensable tool.

Figure 7: Relationship between agricultural value added growth (magvapg) and annual temperature

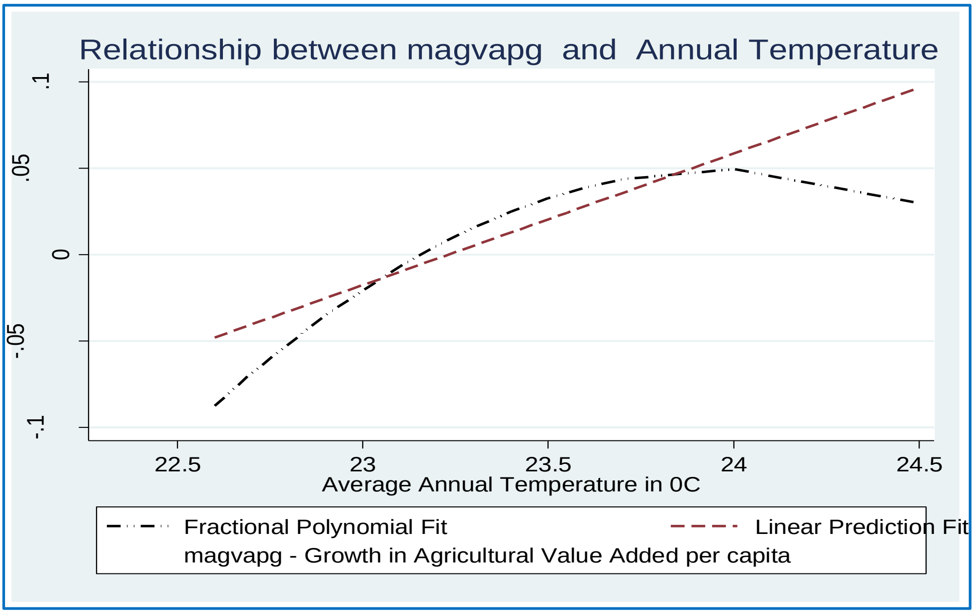
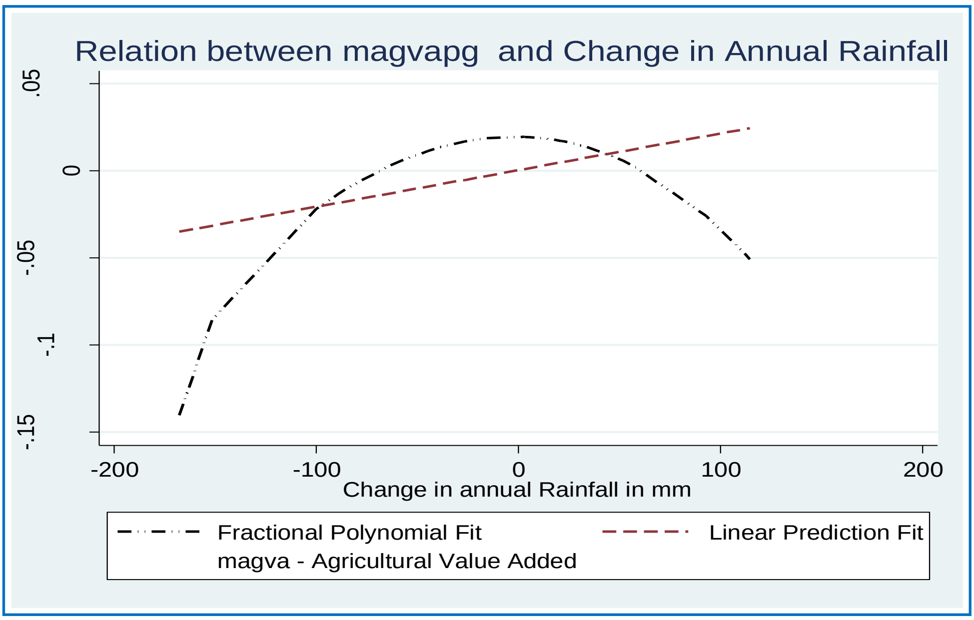


Figure 8: Relation between agricultural value added growth (magvapg) and change in annual rainfall



4.2. Econometric Analysis

To estimate equations [3] and [6], we used the national time series dataset described in Section 4.1. The analysis of agricultural time-series data requires taking care of the problems of non-stationarity (Granger, 1986) and technical inefficiency (Farrell, 1957; Aigner et al., 1977). Application of the Vector Error Correction Model (VECM from now onwards) to our dataset requires one to assume away the possibility of technical inefficiency while it is there in the actual case. Similarly, applicating the Frontier model to our dataset requires one to assume away the possibility of non-stationarity, while it is there too. Both assumptions are too costly to be the basis of our analysis. Rather, we followed an indirect approach that helps to avoid spurious regression.

Green (2003:852) notes that macroeconomic variables almost always exhibit non-stationarity or trending. Obviously, the application of traditional regression methods to such non-stationary variables leads to spurious results. To avoid spurious results, either one needs to have stationary variables or has to reduce them to stationary forms either through differencing or through the application of functional transformation. However, this could lead to the loss of some of the information needed for the analysis. On the problem associated with differencing the non-stationary but cointegrated variables with the aim of reducing them to stationary form, Green (2003: 852) notes, "...differencing would be counterproductive since it would obscure the long-run relationship....". The development of the concept of cointegration has simplified the problem to some extent. According to this approach, if some non-stationary variables are cointegrated even without transformation, the cointegrating parameters and t-tests and F-tests are not spurious, but they are economically meaningful (Gujarati, 2003: 822). This implies that to apply traditional regression methods, we need to undertake a cointegration test. On this point, Granger (1986) notes, 'a test for cointegration can be thought of as a pre-test to avoid spurious regression.' In the literature, one can find two approaches to testing for the cointegration of variables. The Engle and Granger (1987) method is based on assessing whether the equilibrium errors are stationary or not, and the Johansen (1988) and Stock and Watson (1988) approaches, which are indeed similar, are based on vector auto-regression. The second approach employed here tests the null hypothesis that there are r-number of linearly independent cointegrating vectors or fewer cointegrating vectors using the trace statistic.

Accordingly, to estimate equations [3] and [6], we first conducted cointegration test to confirm if the variables in our specified model are cointegrated or not. After confirming that the variables are cointegrated, the common step is to employ traditional regressions, or VECM, to get sample estimates of the cointegrating vectors. In our case here, proceeding with this step requires assuming the absence of technical inefficiency, while it could be there. Therefore, after fitting VECM, we tested the null hypothesis of no-technical inefficiency using the Frontier model before reporting the results from VECM. In the presence of technical inefficiency, since the cointegration test result legitimatises the application of traditional regression methods, we report the results from the Frontier model.

In the theoretical framework, it is indicated that two candidate models were suggested. To identify the model that fits the data better, both models were estimated using the VECM and Frontier, and their predicted values were compared with the actual. To start with equation [2], first, to employ VECM, we have to identify how many lags are to be included. The appropriate lag order was identified using Akaike's information criterion (AIC), final prediction error (FPE), Hannan and Quinn information criterion (HQIC), Schwarz's Bayesian information criterion (SBIC), and the sequence of likelihood ratio (LR) tests. Except for the statistic from SBIC that selects a model with lag(1), all the remaining three information criteria as well as LR tests suggest selecting a model with lag(2), not depicted here but found in the supplementary material.

Next, we conducted tests for cointegration based on the Johansen method. This test determines if the considered variables have a long-run relationship or not. After applying the method, we found that the trace statistic value (61.51) falls below the critical value (68.52) at the maximum rank of two, strongly rejecting the null hypothesis of one and failing to reject the null of at most two cointegrating equations. After determining variables are cointegrated, we estimated the parameters of our equation that can serve as estimates of parameters of a long-run relationship after making necessary rearrangements. The estimation results are presented in Table 2. However, bear in mind that these parameter estimates assume the absence of technical inefficiency and no physiological constraint on the rainfall-output relationship.

Table 2: Estimation Results of Equation [3] a

Estimator	Variable b	Coefficient	St. err	Z	P>|z|
VECM	Ln of agricultural value added	1.00	.	.	.
	Ln of annual rainfall	-0.46	0.12	-3.66***	0.000
	Ln of rural labour	0.75	0.26	2.84**	0.004
	Ln of TLU per person	-0.86	0.18	-4.81***	0.000
	Ln of arable land	-0.49	0.07	-6.70***	0.000
	Ln of total irrigated area (1000a)	-0.19	0.12	-1.62	0.106
	Ln of fertilizer in kg/ha	-0.36	0.11	-3.27***	0.001
	constant term	-6.68	.	.	.
	Number of obs=36; AIC = -21.03; HQIC= -19.98 , SBIC =-18.06				
	Cointegrating equations - chi2 = 1261.48 P>chi2=0.0000				
Frontier	Ln of Annual Rainfall	0.27	0.17	1.60	0.110
	Ln of labour	-0.36	0.19	-1.91	0.056
	Ln of TLU per person	0.29	0.15	1.90	0.057
	Ln of arable land	0.24	0.01	44.10***	0.000
	Ln of total irrigated area (1000a)	0.42	0.09	4.49***	0.000
	Ln of fertilizer in kg/ha	0.34	0.06	5.84***	0.000
	_constant term	9.52	.	.	.
	/lnsig2v	-26.45	47.19	-0.56	0.580
	/lnsig2u	-4.42	0.22	-19.76***	0.000
	sigma_v	0.000002	0.00004		
	sigma_u	0.110	0.012		
	sigma2	0.012	0.003		
	Lambda	60782.61	0.012		
Likelihood-ratio test of sigma_u = 0: chibar2(01) = 19.96 Prob>=chibar2 = 0.000					

*P <0.05, **P <0.01 and ***P <0.001.

TLU: Total livestock unit

The output from this estimator indicates that, under the considered assumption, the model robustly fits the data, P>chi2=0.000. The statistically significant coefficients of ln of annual rainfall suggest that the share of rain from the country's agricultural output is about 45.5 percent, or it suggests that a percent increase (decrease) in the volume of rainfall results in a 0.46 percent increase (decrease) in agricultural output. Likewise, the table reports that the coefficients of the natural logarithms of livestock in total TLU, irrigated land, fertilizer, and rural labour, the last variable with an unexpected sign, are also statistically significant.

As indicated above, these estimation results are based on the assumptions of the absences of technical inefficiency and the absence of no physiological constraint in rainfall-output relation. Keeping the issue for a while, next we dealt with the assumption of absence of technical inefficiency. In sober fact, the estimation results obtained from VECM and reported in Table 2 could be reliable only if the production system shows no technical inefficiency. That is the situation existing in the economic system is consistent with the assumption we made in applying the estimator.

However, since we are dealing with agricultural production, the issues of economic rigidity and uncertainty arising from imperfect foresight cannot be undermined. Therefore, after ensuring that the considered variables have a long-term relationship, the issue of technical inefficiency is examined.

The second half of Table 2 reports the estimation results from the Frontier model, which considered the issue of technical inefficiency. The table reports the parameter estimates together with their statistical tests. Besides, at the bottom of the table, it reports the test results of the null hypothesis of no technical inefficiency in the model. The output shows LR = 19.96 (p-value = 0.000), suggesting significant technical inefficiency existed.

Hence, we preferred the estimation results of Frontier instead of the ones obtained from VECM. Here, unlike the results of VECM, the coefficient of rural labour, with an unexpected sign, and annual rainfall are not statistically significant. Moreover, if the assumption that no physiological constraint is convincing, or at least the data were taken from the period when the actual secular trend of rain has not exceeded the optimal level, then one can estimate the share of rainfall from the entire agricultural output at about 27.1 percent. This shows a difference from the estimate obtained from VECM, which estimates the share of rainfall at 45.5 percent. Besides, the estimation results from Frontier suggest that the share of arable land, irrigation, and fertilizer is 24.4 percent, 41.7 percent, and 33.5 percent, respectively. Moreover, the results suggest that the share of livestock is 28.9 percent, which is weakly significant. There can be possible reasons for the wrong sign of the natural logarithm of labour, but besides the functional form under consideration, the negative marginal productivity of labour resulting from the abundance labour in rural areas is certainly a leading candidate among possible reasons.

In fact, the estimation results reported in Table 2 could be reliable as long as the dataset was taken from an environment with no secular trend in the rainfall or as long as the trend of rainfall did not exceed the optimal level. However, since the secular increase is underway, the inferences from the estimation results may not be reliable.

Equation [6] relaxes the assumption of the absence of physiological constraint. We estimated this equation following the procedure used for the estimation of equation [3]. To identify the number of lags, test results from AIC, FPE, HQIC, SBIC, and LR are used. Except for the statistics from SBIC and HQIC that select a model with lag(1), all the remaining three information criteria and LR tests suggest a model with lag(2) (Annex-3 test results depicted in the supplementary material). After identifying the lag order, we tested if the considered variables were cointegrated.

The trace statistics exceed the critical value at zero maximum rank, which implies no cointegrating equation, but the value 121.4 becomes less than the critical value 124.24 at a maximum rank or number of cointegrating equations of one (Annex-4 depicted in supplementary material). Hence, we rejected the null of no cointegrating equation and failed to reject the null of at most one cointegrating equation, showing the variables are cointegrated or have one cointegrating equation. Next, we estimated the parameters to get estimates of the long-run parameters (Table 3). Here again, we keep in mind that this estimation procedure is based on the assumption of no technical inefficiency.

Table 3 reports that the output from the VECM estimator indicates that under the no-technical inefficiency assumption, the model fits out time-series data well, chi2 = 2987 (P > chi2 = 0.0000). The coefficients of the natural logarithms of livestock in TLU (Total Livestock Unit), total irrigated land, arable land, and fertilizer in kg/ha carry the expected signs and are statistically significant. But the coefficient of the natural logarithm of labour carries wrong sign and is statistically significant (p>|z| = 0.011). The likely reason for the wrong sign could be excessive labour use, causing a negative marginal product.

Table 3: Estimation Results of Equation [6] a

Estimator	Variable	Coeff.	St.error	Z	P>|z|
VECM	Ln of agricultural value added	1.000	.	.	.
	Annual rainfall(mm)	-0.012	0.002	-6.18***	0.000
	ln of rainfall anomaly calculated as standardized rainfall	8.39e-06	1.41e-06	5.94***	0.000
	Ln of rural labour	0.49	0.193	2.53*	0.011
	Ln of TLU per person	-0.57	0.131	-4.40***	0.000
	Ln of arable land	-0.46	0.053	-8.66***	0.000
	Ln of irrigated land (1000ha)	-0.45	0.087	-5.16***	0.000
	Ln of fertilizer (kg/a)	-0.30	0.080	-3.72***	0.000
	_constant term	-2.84	.	.	.
	Number of observations = 38; AIC = 12.30; HQIC= 13.63 , 16.05				
	Cointegrating equations: chi2 = 2480.711 P > chi2 = 0.0000				
Frontier	Ln of annual rainfall(mm)	0.01	0.002	3.31**	0.001
	ln of rainfall anomaly calculated as standardized rainfall	-3.44E-06	1.25E-06	-2.75*	0.006
	Ln of rural labour	-0.37	0.002	-211.03***	0.000
	Ln of TLU per person	0.33	0.039	8.40***	0.000
	Ln of arable land	0.28	0.026	10.79***	0.000
	Ln of irrigation land	0.39	0.005	84.57***	0.000
	Ln of fertilizer (kg/a)	0.32	0.000	850.84***	0.000
	_constant term	9.31	.	.	.
	/lnsig2v	-24.91	33.403	-0.75	0.46
	/lnsig2u	-4.49	0.224	-20.08***	0.000
	sigma_v	0.00	0.000		
	sigma_u	0.11	0.012		
	sigma2	0.01	0.003		
	Lambda	27225.89	0.012		
Likelihood-ratio test of sigma_u=0: chibar2(01) = 22.79 Prob>=chibar2 = 0.000					

*P <0.05, **P <0.01 and ***P <0.001.

A shock to one of the variables, like rainfall, directly affects this variable. But it is expected that the effect is also transmitted to all other variables through the dynamic structure. An impulse response function traces the effect of a one-time shock to one of the innovations on current and future values (Figure 9).

Figure 9: Impulse-Response function

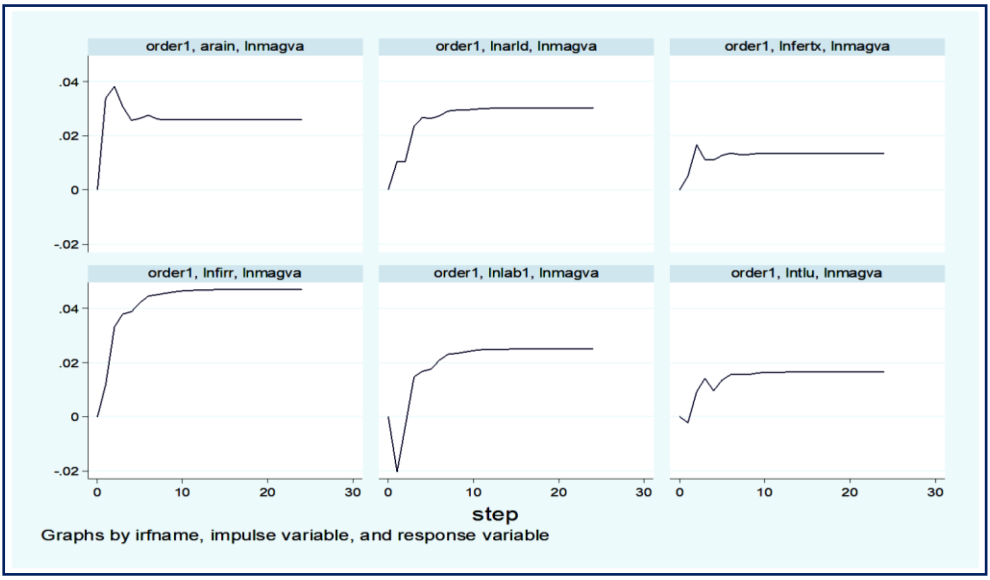
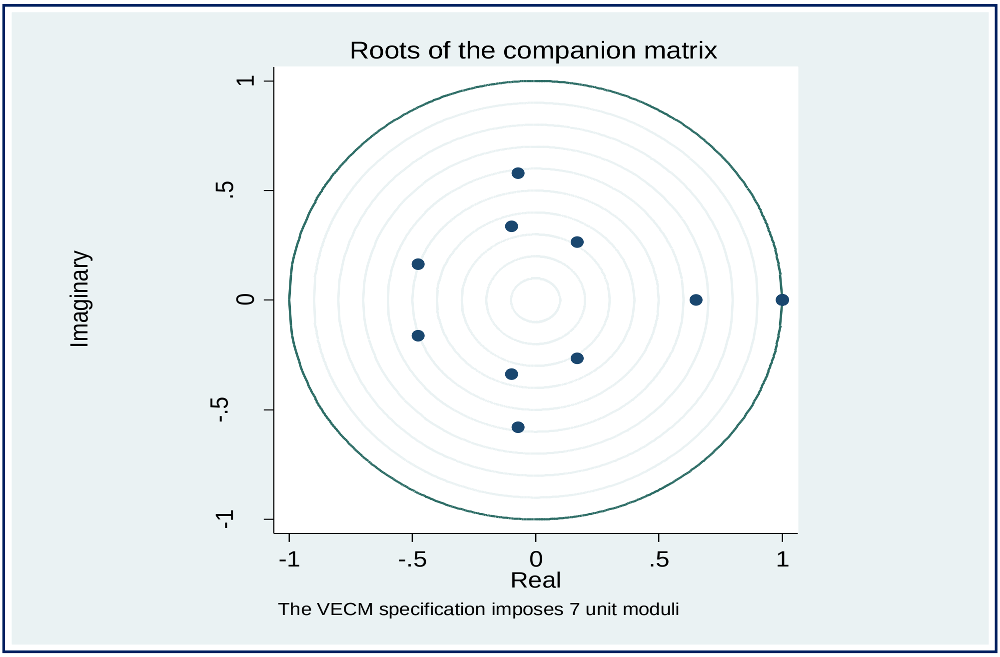


Figure 10: Roots of Companion Matrix



The trajectories of the impulse-response functions are almost similar, except for a shock to annual rainfall that shows an initial narrow, sharp point. The shocks to the rest variables cause temporary variations in the natural logarithm of agricultural value added (lnmagva) up to a period of 10 years and then end with a permanent effect on the natural logarithm of agricultural value added, which implies that the system exhibits long-memory processes. Making inferences after fitting VECM requires that the cointegrating equations be stationary. This requires a post-estimation test determine whether the cointegrating equations are stationary or not. Figure 10 presents the plots of the eigenvalues of the companion matrix, with the real component on the x-axis and the imaginary component on the y-axis. The graph shows that none of the remaining eigenvalues appear close to the unit circle, implying the stationarity of the cointegrating equation. In other words, the stability check does not indicate that our model is misspecified.

Turning back to the variables of interest, rainfall, the estimation results indicated that the coefficients of the natural logarithm of the annual rainfall (-0.012625) and of the rainfall anomaly calculated as standardized rainfall (8.39e-06) carry the expected signs and are statistically significant. These results confirm the hypothesis that the relationship between rainfall and output is not monotonic rather follows an inverted U-shape, indicating an optimal volume of annual average rainfall determined by the physiology of plants and animals. The parameter estimates suggest that this optimal level is about 752.4mm (-.0126252/(2 x 8.39e-06). From the shape of rainfall and output relation, the implication of this result is that when the rising trend of rainfall exceeds this optimal level, the diminishing benefit will set in the economy’s performance.

However, since this result assumes no technical inefficiency, having the estimate after relaxing the assumption would be more important. Based on the cointegration test results that confirm the variables are cointegrated, we employed the frontier model, considers the possibility of technical inefficiency. The test result is presented in the second half of Table 3.

Just like the results of VECM, the coefficient of the natural logarithm of rural labour lnrlab1 carries unexpected sign-negative and is statistically significant. This result suggests that an increase in labour would suppress the growth of agricultural output. Besides this, the remaining factors of production carry an expected sign, and estimates are statistically significant. Moreover, the coefficients of the natural log of annual rainfall and rainfall anomalies calculated as standardized rainfall carry the expected signs and have statistical significance. In agreement with the VECM estimate, this result also confirms the rainfall-output relationship has an inverted U-shape. This parabolic shape implies the existence of an optimal level of rainfall determined by the physiology of plants and animals. The coefficient estimates suggest this optimal level is about 742.15mm (0.005106/(2*-3.44e-06)), suggesting some economic gain from an increase in rainfall up to this optimal level and some economic loss from an increase beyond it. If an increase in temperature is associated with an increase in rainfall, as in recent times, then the result is consistent with Hope (2006) and Tol (2009), who inform initial benefits from a modest increase in temperature, followed by losses as temperatures increase further. The estimate of the optimal level is less than the estimate obtained from VECM by 10.25mm. We believe that the difference arises because VECM assumes the absence of inefficiency, and hence the level of rainfall and the time at which the diminishing benefits set in will be delayed. Putting it in other terms, had the production system been efficient, the time at which the economy starts facing the adverse effects of the secular increase in rainfall would have been delayed by some years until the indicated optimal level was reached. After considering physiological constraints and technical inefficiency, we were interested in seeing which quarter's rainfall is most important to production to examine the possibility of intra-annual water allocation.

Following the World Bank (2011), we divided and used from quarter 1 (December to February) to quarter 4 (September to November). We employed both the VECM and the Frontier model and presented the results in Table 4.

Table 4: Estimation Results of Equation [6] with Quarterly Rainfall a, b

Estimator	Variable	Coeff.	St.err	Za	P>|z|
VECM	Ln of agricultural value-added	1.00	. .	.	
	Quarter-1 (Dec-Feb)	-0.01	0.002	-7.74***	0.000
	Quarter-2 (Mar.-May)	-0.01	0.002	-7.11***	0.000
	Quarter-3 (Jun.-Aug.)	-0.01	0.002	-7.24***	0.000
	Quarter-4 (Sept.- Nov.)	-0.01	0.002	-6.59***	0.000
	Ln of rainfall anomaly calculated as standardized rainfall	7.79e-06	1.22e-06	6.39***	0.000
	Ln of rural labour	1.21	0.17	6.97***	0.000
	Ln of TLU	-0.78	0.11	-6.90***	0.000
	Ln of irrigated land (1000ha)	-0.37	0.06	-5.96***	0.000
	Ln of arable land (ha)	-0.17	0.08	-2.27*	0.024
	Ln of fertilizer (kg/ha)	-0.62	0.08	-8.05***	0.000
	_constant term	-10.59	.	. .	
	Number of obs=38; AIC = 38.10; HQIC= 40.45 , SBIC = 44.69				
	Cointegrating equations - chi2 = 4637.33 P>chi2=0.0000				
Frontier	Quarter-1 (Dec-Feb)	0.004	0.001	3.88***	0.000
	Quarter-2 (Mar.-May)	0.003	0.001	3.63***	0.000
	Quarter-3 (Jun.-Aug.)	0.003	0.001	3.99***	0.000
	Quarter-4 (Sept. - Nov.)	0.003	0.001	4.45***	0.000
	Ln of rainfall anomaly calculated as standardized rainfall	-1.92e-06	5.19e-07	-3.70***	0.000
	Ln of rural labour	-0.48	0.02	-33.02***	0.000
	Ln of TLU	0.37	0.01	80.03***	0.000
	Ln of irrigated land (1000ha)	0.26	0.06	4.22***	0.000
	Ln of arable land (ha)	0.36	0.02	21.02***	0.000
	Ln of fertilizer (kg/ha)	0.36	0.03	11.81***	0.000
	_constant term	11.00	.	.	.
	/lnsig2v	-26.30	44.603	-0.59	0.555
	/lnsig2u	-4.54	0.224	-20.29***	0.000
	sigma_v	1.95e-06	0.00004		
	sigma_u	0.10	0.012		
	sigma2	0.01	0.002		
	Lambda	53035.65	0.012		
Likelihood-ratio test sigma_u=0: chibar2(01) = 23.44Prob>= chibar2 = 0.000					

*P <0.05, **P <0.01 and ***P <0.001.

VECM, which assumes the absence of technical inefficiency, indicates that the marginal effects of the four quarters are more or less similar. But the marginal effects of quarter-1 (-0.014), that is, the marginal effect of the long dry season occurring from December to February, are slightly greater than those of the remaining quarters, with quarter 4 having the least marginal effects (-0.012).

Estimates of the marginal effects obtained from the Frontier estimator convey a similar message to that of VECM regarding the differences among the quarters. The parameter estimates of each quarter are more or less equal, though that of quarter 1 is slightly more important. The equality of the parameter estimates has some implications for the attempts made to adapt to climate change. For example, a nation can encourage rainwater harvesting practices at the individual household or community level as an adaptation strategy (Wakeyo and Gardebroek, 2017) of the third and fourth quarters (Korecha and Barnston, 2007), as it has been encouraged since the early 2000s (Wakeyo and Gardebroek, 2017). In the third and fourth quarters, the rainfall volume gets above the mean quarterly average (see Table 1) and can make use of the harvested water during the first and second quarters (the meagere-rainfall quarters). Since the marginal effects are more or less the same, it is possible to postpone the period at which the diminishing effect of rainfall sets in the production system. In other words. stepping on the observed empirical evidence, one can reduce the adverse impact of climate change on agricultural output through employing moisture stress gap filling technologies such as rainwater harvesting. From the literature, one can expect that technology gets additional benefit that come from inducing farmers to use fertilizers (Wakeyo and Gardebroek, 2013).

In general, the frontier estimation results presented in Tables 3 and4 indicate the likelihood that the country enjoys short-lived and negligible gains from climate change and suffers relatively higher economic losses in the long run. This result is consistent with Hope (2006) and Tol (2009), who documented initial gains from global warming and then economic losses. Tol (2009) indicated that the loss may go up to 25 percent of income in low-income countries. Thus, the effect of climate change on Ethiopian agriculture could not be different. Primarily, as the country exists closer to the equator, the region is expected to face more warming than the rest, and the effect may not be similar. Secondly, as a low income country, it may take time for policies designed to counter the effects. Thirdly, as in many low-income countries, measures to reduce the loss could be constrained by resource scarcity. Hence, the countermeasures need to be taken more determinedly on time and have to be supported financially and technically from the sources that generate the negative externalities.

5. Conclusion

The literature informs us that different parts of the world contribute quite differently to climate change. Also, they are affected differently, with effects ranging from extreme net economic losses to net gains. Different research results indicate that countries in tropical regions, like Ethiopia, are particularly vulnerable to the effect.

To investigate the impact of one form of climate change-rainfall variability-on agricultural output in Ethiopia, we compared two possible production functions. The first treats volume of rainfall as a production factor along with labour, capital, and land. The facts that it is an unpaid factor and that the amount of the factor that enters the production function is not under the control of the producers were considered. Besides these, the case that it implies the relationship between volume of rainfall and amount of output is monotonic, while the actual case could be non-monotonic, was considered critically. As an alternative approach, we employed a modified production function derived from a damage function where the damage is caused by a deviation of rainfall from its optimal level. Since the optimal is determined by the physiology of plants and animals, this approach takes into account a production function that considers physiology.

The empirical analysis is grounded in time-series data ranging from 1961-2012. Results from the econometric analysis indicate that it is very likely that the presently increasing trend of rainfall exceeds the optimal level of rainfall determined by the physiology of plants and animals in the near future. Such excess is associated with suppression of economic performance, which later, if left unchecked, leads to economic stagnation. In other terms, the analytic results indicate that the country enjoys very short-lived and negligible growth gains from climate change and the possibility that it may suffer relatively higher economic losses in the long run, unless satisfactory adaptation measures are taken. Among adaptation measures, the excessive rainfall that is very likely in the future can be an exploitable opportunity. The opportunity is that smallholder farmers can use rainwater harvesting to fill the moisture-stress gap created due to the early stoppage of rainfall in some areas. Most often, the winter rainfall in Ethiopia stops during mid- or early- September, when most of the crops of the major cropping season are in the critical ripening period. If a portion of the excess rainfall is harvested into ponds, shallow wells, and flood diversion structures, which require relatively low investment expenditure by households, the harvested water can be used to fill the moisture stress gap during the ripening period of crops. Note that under the increasing volume of rainfall that is expected, rainwater harvesting can be encouraged in rural areas and small towns to overcome the increasing shortage of potable water too, which is currently missing in several parts of Ethiopia. Because of this missing practice, we are losing this natural rainfall water in front of our eyes. Similarly, investment in conventional irrigation helps to overcome the effect of rainfall shortages in crop growing seasons. Also, dry-season irrigation can be cautiously encouraged, like in the case of irrigated wheat, in the production of food crops. In the dry season, wheat has the double advantage of increasing the supply of food crops while simultaneously reducing GHG emissions. These adaptations and transformative measures help to boost agricultural production and build climate-resilient agriculture.

In addition to the local measures, effective global-level mitigation measures could also help reduce the degree of economic loss. The paper concludes that, since the adverse impacts are caused mainly in the form of negative externality, the adaptation and mitigation efforts of the country need financial as well as technical support from the rest of the world.

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Agricultural Technological Change and Technical Efficiency of Crop Production in Ethiopia

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Abstract

Proper utilization of agricultural technology and enhancing the technical efficiency of crop production are key factors for agricultural output growth in Ethiopia. However, the lack of studies that assess the broad set of agricultural technological change and efficiency of multiple crop production together using longitudinal datasets poses major challenges in identifying crop production impediments in Ethiopia. This study explores agricultural technological changes (specifically fertilizer, improved seed, pesticides, irrigation, and extension services) and the factors contributing to technical inefficiency in crop production in Ethiopia. National-level representative longitudinal data sets from 2004/05 to 2018/19 were obtained from the Central Statistics Authority and the Ethiopian Meteorology Agency-(EMA) as data sources in Ethiopia. A panel stochastic frontier model using a true fixed-effect econometrics model was applied to estimate the coefficients of the elasticity production coefficients, identify technical inefficiency factors, and estimate the level of technical efficiency scores for multiple aggregate crops at the national and regional levels. This study assessed the trends in agricultural technology use from 2004/05 to 2018/19 in Ethiopia. In response to the increased utilization of land, labor and inputs such as chemical fertilizer, pesticides, improved seeds and improved practices through expanded extension coverage, the use of irrigation, and the availability of rainfall and temperature, good progress in agricultural production and productivity was observed from 2004/05 to 2018/19. However, there is a less adequate supply of agricultural production input

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technologies and the intensive utilization of irrigation is highly insufficient. Furthermore, the elasticity coefficient estimates with respect to labor, cultivated area, chemical fertilizer, and pesticide have positive and significant effects on crop output, indicating the importance of these inputs. However, the use of capital and local seed had negative and statistically significant impacts on crop output from 2004/05 to 2018/19 in different regions of Ethiopia. The overall technical efficiency value of 73.84% at the national level shows room for further increasing yield using existing technologies by working on inefficiency factors. Additionally, the room for further boosting yield is wide and differs across major regions in Ethiopia. The future crop output growth will be driven by a combination of enhancing the use of agriculture technologies and efficiency of crop production through promoting the use of suitable, reliable and affordable modern agriculture technologies, revitalized agricultural advisory services, mechanization services, providing targeted affordable credit services, land consolidation by cluster farming, deployment of a labor force, and the intensive use of irrigation systems over the coming years.

Keywords: Agriculture technologies, technical inefficiency, Panel stochastic frontier, Ethiopia.

JEL Classification: Q13, Q33, O4, O47

1. Introduction

Agriculture is the most dominant sector and plays a crucial role in the life and livelihood of most Ethiopians, accounting for 32.4% of the country’s GDP, 75% of export earnings, 73% of employment opportunities, and 70% of sources of raw materials for agro-processing industries. It also serves as a market for industrial outputs. The country has favorable agro-ecological zones suitable for growing a wide range of temperature and tropical cereals, root crops, oil crops, pulses, fruits and vegetables (NBE, 2022; MOA, 2020). Recognizing this, the Ethiopian government has given attention to and adopted a broad agricultural-led industrial development policy and strategy to guide rural and agricultural development. It has also implemented successive development plans policies, strategies and programs over the last few years to enhance the performance of the agriculture sector and contribute to food security, poverty reduction and the production of exportable agricultural products.

The agriculture sector is considered one of the major sectors driving growth in the current ten-year development plan for the period from 2020/21 to 2029/30. The plan for the agriculture sector focuses on freeing agriculture from rain dependence, increasing the use of agricultural mechanization services; encouraging contract farming, deploying land consolidation through a cluster approach, developing livestock, animal feed and animal health, paying attention to horticulture development including in urban areas (irrigation and urban farming), leveraging private sector participation, providing all-round institutional implementation capacity, and implementing a climate-resilient sustainable agricultural development system. All of these are assumed to help Ethiopia realize its vision of becoming a lower-middle-income country by 2025 and aspire to become an African beacon of prosperity by 2030 (PDC, 2020).

However, agriculture in Ethiopia is characterized by low input-low output, largely based on smallholder producers, low-tech, and rain-fed crop production systems for the majority of farmers. The low technology uptake by the sector has retarded the growth of agricultural productivity, limited the total volume of production and even threatened national food security for decades (Zerssa et al., 2021). The slow pace of transitioning from low to high productivity in agriculture has led to a lack of market-led agriculture to expansion and has seriously challenged the pace towards successful agricultural transformation. Due to over-reliance on rain-fed production by smallholding farmers, the use of traditional subsistence production methods, and the lack of irrigation and modern water management systems, the agriculture sector is still struggling with cycles of drought. The frequent droughts and climate change are not only affecting the rural poor but also posing further challenges to the country’s economy (Getachew, 2018 and 2020). Additionally, the sector’s poor performance can be attributed to limited private sector investment in recent years (Sisay and Semeneh, 2022). Consequently, a significant number of people are suffering from malnutrition and depend on daily assistance and developmental safety nets.

Previous studies on agricultural technological changes in Ethiopia such as Admassie and Ayele (2010), Aynalem et al. (2018), Shita et al. (2018), Gebru et al. (2021), and Diro et al. (2022) attempted to examine the determinants, challenges and opportunities at the national level. There are also some other micro-level studies that extensively addressed the effect of agricultural technology on welfare outcomes over recent decades in Ethiopia. For example, Bekele et al. (2014) assessed the effect of agricultural technology on food security, Mesele et al. (2022) studied its impact on food consumption expenditure, Wordofa et al. (2021) analyzed its effect on household income, Ayenew et al. (2020) and Araya and Lee (2022) investigated its effect on the welfare of smallholder farmers, Shita et al. (2020) examined its effect on income inequality, and Biru et al. (2020), and Sebsibie et al. (2015) explored its effect on poverty and vulnerability of smallholders in Ethiopia. Further, there are only few empirical studies on efficiency analysis of crops using longitudinal datasets at the national level. These studies were conducted by Bachewe (2009 and 2012) and Bachewe et al., (2011 and 2015), Sisay et al. 2022). On the contrary, there is limited number of studies in Ethiopia that assess the broad set of agricultural technologies change and efficiency of crop production together using longitudinal datasets. Although, there are a few empirical studies such as Abebayehu et al. (2019) and Arega and Manfred (2005) that were conducted using cross-sectional datasets in different parts of the country, which are pertinent for developing policy recommendations for specific study areas. However, these types of studies may provide less assistance in developing strategies and policy implications for improving agricultural production at the national and/or regional levels for multiple cropping systems in Ethiopia. Hence, this study aims to assess the status and performance of a broader set of agricultural technological changes, including technology adoption (such as chemical fertilizers, improved seeds, and pesticides) and recommended agronomic or farm practices (such as the use of irrigation and extension services). The study also aims to estimate the technical efficiency score and its determinants of aggregate crops using longitudinal zone-level data sets from 2004/05 to 2018/19 at the national and regional levels in Ethiopia.

2. Methods

Data types and sources: The study employed mainly secondary data obtained from the Central Statistics Authority (CSA) of Ethiopia covering the period from 2004/05 to 2018/19. The dataset included all rural areas of the country except for the non-sedentary population, and provided detailed information on agriculture, such as total crop area, crop production volume, and the use of agricultural technologies such as chemical fertilizer, improved seed, pesticides, extension services, and irrigation (CSA, 2004/05 to 2018/19).

In order to select the sample, a two-stage sampling technique using a combination of stratified and cluster sample designs was implemented in the rural parts of the country. The Annual Agricultural Sample Survey covered the entire rural parts of the country. Census Enumeration Areas (EAs) were taken to be the primary sampling units and the secondary sampling units were agricultural households. EAs from each stratum were selected systematically using the probability proportional to size sampling technique, with size being the number of agricultural households selected based on the Ethiopian population and housing census cartographic frame. Using the fresh list of households prepared at the beginning of the survey, 20 agricultural households within each sample EA were selected using systematic random sampling technique. Each EA was further classified into three agro-ecologies namely “kolla”, “Dega” and “Weyna Dega” for Tigray, Amhara, Oromiya and SNNPs regions. A total of 2,371 EAs (85.66%) in 52 zones throughout the regions were included in the study. The sample survey was conducted based on 20 agricultural households selected from each EA. A total of 47,420 agricultural households were covered by the survey. The raw datasets of the Agricultural Sample Survey were obtained from the Central Statistics Authority (CSA) of Ethiopia.

The dataset covered detailed agricultural information on cereals, pulses and oilseeds, as well as the most grown vegetables, root crops (including tuber crops), and fruits. However, it does not include spices, herbs, Enset, coffee, sugarcane, cotton and other medicinal and essential oil products (CSA, 2004/05 to 2018/19). Additionally, the study also utilized meteorological datasets, such as rainfall, minimum and maximum, temperatures, corresponding to each year and crop growing period obtained from the Ethiopian Meteorology Agency (EMA). The Agricultural Sample Survey datasets of CSA for each EAs were merged with the meteorology datasets by estimating the average meteorological datasets of the Meher season. The Meher season is the main crop growing period in Ethiopia, which is linked to the long rainy season from June to September. It accounts for 95.5 percent of the total annual production (CSA, 2004/05 to 2018/19). A total of 47,420 agricultural households were included in 2,371 EAs Agriculture Sample Survey datasets, which were then combined again into the 52 zones across the country. These datasets were then merged with meteorological data for all periods. The analysis is carried out at the zone-level using panel datasets that cover a time period from 2004/05 to 2018/19.

Methods of data analysis

In order to analyze agricultural technological change and farm practices (chemical fertilizers, improved seed, pesticides, irrigation, extension services) simple descriptive statistics were applied. Meanwhile, stochastic frontier panel using the True Random Effects (TRE) econometrics model was applied to estimate the coefficients of the production function, as well as the level of technical inefficiency and its factors.

The TRE model of Green's uses nationally representative longitudinal panel data set from 2004/2005 to 2018/2019, both at the national level and separately for the Amhara, Oromia, South Nation Nationality and People (SNNP), and Tigray regions of Ethiopia. In contrast to the Random Effect (RE) model of Battese and Coelli (1992), the TRE model captures time-varying technical inefficiency resulting from time-invariant unobserved firm heterogeneity which is inherent in farming (Green 2005 a, b). The Cobb-Douglas production function is specified in log-linear form using zone-level longitudinal crop output and inputs data. The True-Fixed Effect model has been specified for us:

$$lnY_{it} = (\alpha + \theta_i) + lnf(x_{it}; \beta) + v_{it} - \mu_{it} \quad \textbf{(1)}$$

$$v_{it} \sim N(0, \delta_v^2), \theta_{it} \sim N(0, \delta_\theta^2), \mu_{it} \sim N(0, \mu_\mu^2), \epsilon_{it} = v_{it} - \mu_{it} \quad \textbf{(2)}$$

Where lnY_{it} is the logarithm of output for farm household in period from 2004/5 to 2018/19 of aggregate crops (cereals, pulse, oilseeds, vegetables, and root crops in kg) for zone i and at time t, where i ϵ (1, 2, 3, ….52) in period t ϵ (2004/5 to 2018/19); x_{it} is the matrix of logarithm of production inputs (such as land in hectare, labor in number of holders, capital (number of livestock used for plowing the land) in oxen days, fertilizer in kilogram, improved seed in kilogram, local seed in kilogram, and pesticides in liter) for zone i and at time t, where i ϵ (1, 2, 3, ….52) in period t ϵ (2004/5 to 2018/19); v_{it} is a random error that is normally distributed with mean zero and variance of δ_v^2; $\mu_{it}$is a non-negative inefficiency term that changes over time; the term θ_i is random term that is time-invariant and normally distributed with mean zero and variance of δ_θ^2 accounts unobserved firm heterogeneity; ϵ_{it} is composite error term; and α is a common intercept for all the production units; β are technology parameters to be estimated.

Based on the above Cobb-Douglas production function in logarithmic specification, a one-step procedure was applied to identify determinants of technical inefficiency in which estimated simultaneously along with production function (Green 2005 a, b), TE of zone i is defined as:

$$\tau_{it} = e^{\mu_{it}} \quad \textbf{(3)}$$

is ranked a $\mu_{N,t} \leq \ldots \leq \mu_{2,t} \leq \mu_{1,t}$ Zone N produces with maximum TE of the total sampled zone's.

$$\mu_{it} = \varphi_0 + lnf(x_{it}; \varphi) + \delta_{it} \quad \textbf{(4)}$$

Where υ_{it} are technical inefficiency effects in the stochastic frontier model that are assumed to be independently but not identically distributed, φ is vector of variables which influence technical efficiencies (irrigation in hectare, agriculture extension service coverage in hectare, average temperature in degrees Celsius (centigrade), and amount of precipitation of rainfall during Meher cropping seasons measured using a rain gauge, and agro-ecologies (measured as dummy variables; moisture sufficient highlands, moisture sufficient midlands, and drought prone highlands, and δ_{it} is a random variable distributed as a truncated normal distribution with zero mean and variance σ_{μ}^{2}, consistent with the assumption of the inefficiency terms being distributed as truncated normal distribution.

3. Result and Discussions

This section begins with an assessment of agricultural technological changes, followed by an assessment of the inefficiency of crop production and its determinants over a long period.

3.1. Agricultural Technological Changes

Following the definition of technology adoption by Rogers (1962) and Feder et al. (1985), agricultural technology adoption refers to the use of agricultural technologies such as improved seeds, fertilizers and pesticides. Meanwhile, the use of recommended agronomic or farm practices, such as irrigation and extension services for crop production, helps farmers with the adoption of agricultural technology. In this study, an agricultural technological change refers to the uses of agricultural technologies, recommended agronomic practices and the technical efficiency of production in agriculture. Agricultural technological change might refer to the replacement of traditional varieties with improved cultivars and the increased use of chemical fertilizers pesticides, often aided by better agronomic practices through improved irrigation and agricultural extension services.

Improved seeds

A greater number of improved varieties have been developed and released in Ethiopia in the period since 2004/05-2018/19 than at any other time. Improved variety release has been particularly dynamic for maize, barley and wheat. Table 1 shows using CSA statistics, how the share of farmers that reported using improved seeds in the cereal domain has increased over the last decade.

One of the most successful dissemination of improved seed technologies can be seen in maize production, where the adoptions of improved seeds have grown fourfold from 12% to close to 40%. The participation of private seed sector in hybrid technology is relatively very high. However, the above-mentioned rate based on the CSA mostly underestimates the actual use of improved seeds at the national level. This has been recently documented through a DNA fingerprinting-based study by Moti et al. (2020). The CSA survey methods do not sufficiently capture whether farmers are or were re-using (recycling) improved seeds in subsequent generations. Improved seed adoption monitored through DNA fingerprinting in wheat and maize in Ethiopia indicated that a higher proportion of farmers use improved varieties and the proportion of the area covered with improved seeds is much higher than what the CSA data shows (Moti et al., 2020). DNA fingerprinting analysis showed a much wider adoption in wheat, ranging from 61-73% in sampled areas (Moti et al., 2020). The result shows that apart from wheat, the improvement and dissemination of released varieties of indigenous cereals like teff is remarkably higher than what is shown in Table 1.

Table 1: Proportion of improved seed applying farm holders (%)

Crop	2004/05	2009/10	2013/14	2016/17	2017/18
Barley	0.8	1.2	0.8	1.4	1.5
Maize	11.6	15.7	27.6	34.0	36.9
Sorghum	0.9	1.8	0.4	0.4	1.3
Tef	1.0	2.4	4.6	4.3	2.0
Wheat	4.5	4.1	7.7	1.5	4.6
Cereals	10.1	11.3	21.5	27.3	23.7

Source: CSA, Agricultural Sample Surveys, 2004/05-2018/19

While the overall adoption rates of varieties are low in most crops, there have been significant improvements in maize, wheat, and teff over the last decade. The share of cereal producers using improved varieties increased from 10 percent of cereal producers in 2004/5 to 24 percent in 2017/18 (Table 1). This increase seems to be driven primarily by the rapid adoption of improved seeds in maize, wheat, and teff with the private sector playing a role, such as Corteva (Pioneer Seed) in maize.

Consequently, the use of improved seed appears to be higher than what has been previously reported by CSA or other sources in Ethiopia.

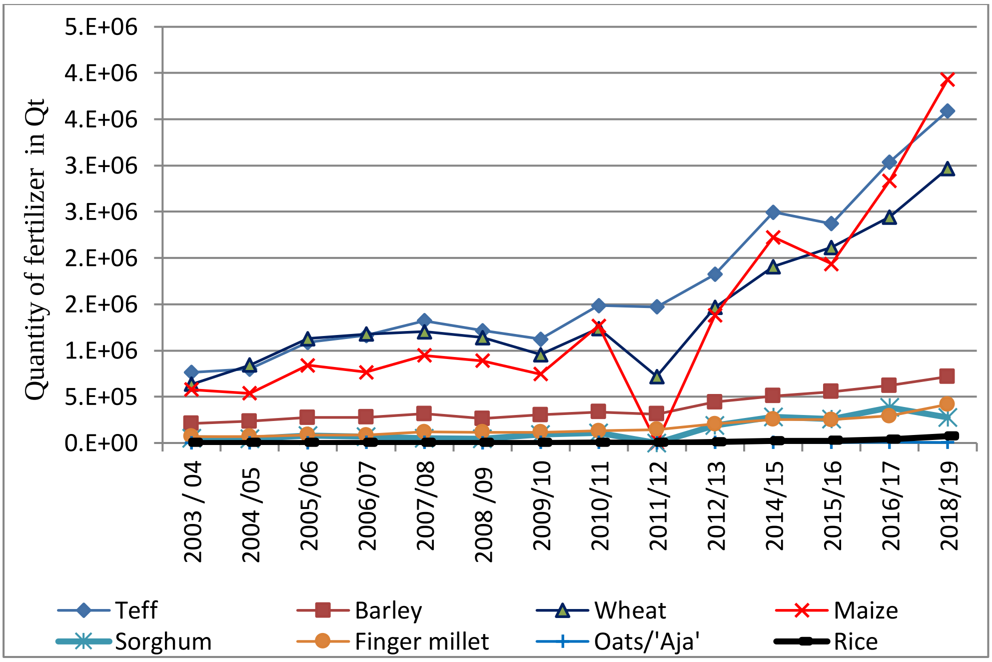
Chemical fertilizers

Soil fertility is among the key constraints of agricultural productivity in Ethiopia due to severe soil degradation caused by natural and man-made factors. As a result, the use of chemical fertilizer has become increasingly critical in order to maintain production. Therefore, chemical fertilizer has gained growing importance as one of the major agricultural inputs that help farmers increase their land productivity. In the highlands, where fertility depletion is particularly high in farmlands due to reduced organic matter, low nutrient content and degraded soil structure resulting from intensive and continuous cultivation for centuries, the situation is in degraded, deforested land, leading to further aggravated soil and nutrient losses. This calls for a more programmatic, science-based fertilizer input intervention program. However, most smallholder farmers in the highland still use lower rates of chemical fertilizer compared to rates even in sub-Saharan Africa. Urea and DAP (Di-Ammonium Phosphate) are the dominant fertilizer sources used in Ethiopia, based on some experimental results in the past (Tilahun et al., 2022). However, the use of nitrogen (N) and phosphorous (P) has not changed over decades despite considerable changes in soil conditions in the highland areas across the country. The agricultural crop area planted with cereals and applied with fertilizer has grown from 2.7 to 7.8 million hectares from 2004/2005 to 2018/2019, a nearly three-fold growth in fifteen years in cereal production. This figure for multiple crops shows a growth from 4.6 to 9.6 million hectares (CSA report, 2018/19). The declining soil fertility and increasing need for chemical fertilizer might be a clear indication of growing sustainability challenges in the near future that need to be taken into account.

The use of chemical fertilizers like potassium, sulfur and zinc has shown a considerable response in different parts of the country (MoA, 2020). This has triggered a national-scale use of blended fertilizer to supply deficient nutrients based on soil fertility mapping done by the same institutions. Fertilizers help to increase yield and product quality but require prior knowledge of soil nutrient information. The increase in crop productivity observed in the country is believed to have been positively impacted by the increased use of chemical fertilizer, in conjunction with improved seed, and increased pesticide use (Robe and Sisay 2021).

As a land-augmenting input, intensive use of fertilizer is supposed to substitute for land as a capital input that smallholders do not have in abundance, by increasing yields per hectare. Therefore, it also provides an option for declining farm sizes in the highland areas of the country. Farmers combine land with labor, seed, fertilizer, and other inputs to produce food and other commodities. Therefore, fertilizers and seeds are important means towards the intensification of production, and smallholders appear to use both more intensively than large-scale farmers (Gebeyanesh et al., 2021).

Figure 1: Trends in quantity of fertilizer use (in quintals) for specific Cereals (from 2003/2004-2018/2019)



Due partly to the attention given to cereal production to achieve food security in Ethiopia, most fertilizer use has been focused on cereals (Sisay et al. 2022; Endale et al., 2023). According to the CSA repot in 2004/05, 2.1 million holders (46 percent) growing cereals used fertilizer, and this number increased to 5.5 million holders (76 percent) in 2013/2014. The cereal area applied with fertilizer nearly doubled during the same period from 2.7 to 5.2 million hectares or increased from 36 to 53 percent of the total cereal area. In 2014/2015 about 82 percent of smallholders applied fertilizer and showed a decline thereafter until 2017/2018. Fertilizer use on other crops has also shown significant increases over the same period. The intensity of fertilizer uses in cereals has also increased from 92 kg/ha in 2003/04 to 122kg/ha in 2013/14.

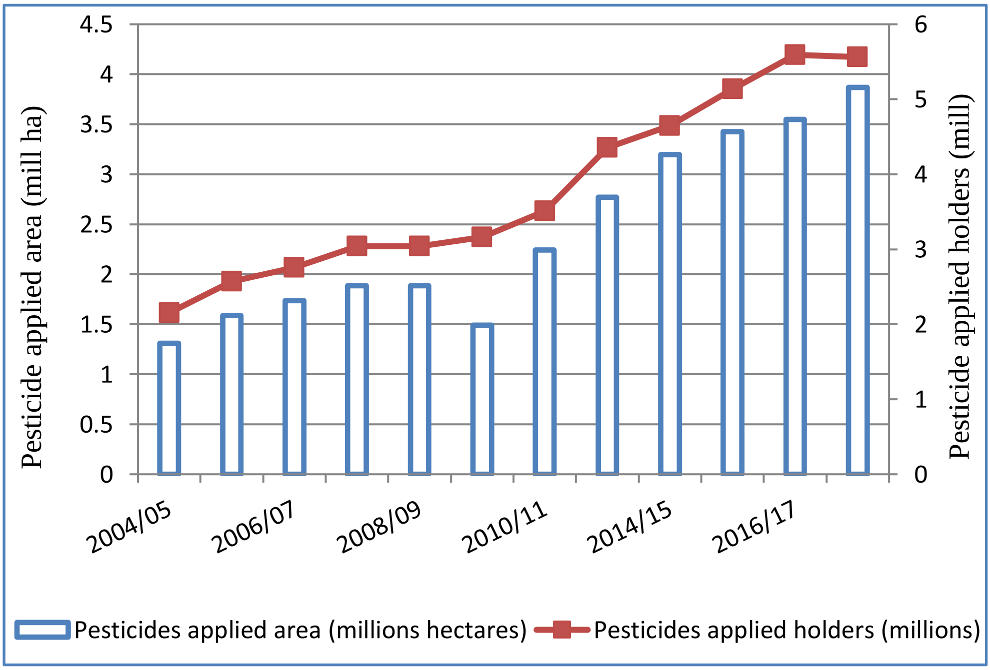
For wheat, maize and tef, fertilizer use has dramatically increased since 2011/2012 while for sorghum, rice and finger millet the increment is far lower (Figure 1). Grain price, crop response to added fertilizer and lower acreage in the case of millet are some of the factors affecting the wider use of fertilizer.

Pesticides

In areas where crop damages caused by pests and weeds are high and difficult to counteract by human labor, the application of pesticides is indispensable. According to CSA data, there has been a considerable increase in the number of farmers who have applied pesticides over time (Figure 2). In 2004/2005, 13 percent of the crop area was exposed to pesticides and this number rose to 24 percent in 2016/2017. Particularly, the proportion of the total area on which pesticides were applied grew rapidly during 2009/10 - 2016/17. A slight decline in the imported pesticide volume was observed in 2018/2019 compared to the previous year.

Figure 2: Area under pesticide application and total number of holders applied (in millions)

There was a two-fold increase in pesticide application in multiple crops as shown in Table 2. However, the increase in pulses, oilseeds and horticultural crops was more dramatic than in cereals. The commercial nature of these crops has been



very encouraging for farmers to intensify inputs to maximize yield per unit area. Nevertheless, the intensity of research is more focused on cereals and the development of production packages for these groups of crops is rather low in comparison. This has slowed down production intensification and growth in productivity over the period. The area where pesticides were applied for the above groups grew from 26,000 hectares (7%) in 2004/05 to 352,936 hectares (42%) of the total holder area in 2018/2019, representing greater than 13-fold increase. However, compared to the total holder area under these crops, the amount pesticide applied shows the low level of input being used in Ethiopia.

Table 2: Area growth under pesticide application of the 2004/05 and 2018/19

Groups of Commodities	Total holder area (ha)		Area (ha) under pesticides		Proportion (%) of the total	
	2004/05	2018/19	2004/05	2018/19	2004/05	2018/19
Multiple crops	10,887,953	14,966,916	1,312,290	3,870,302	12.05	25.86
Cereals	7,633,802	10,358,891	1,278,139	3,440,647	16.74	33.21
Pulses	1,349,116	1,618,095	10,268	241,718	0.76	14.94
Oilseeds	824,430	745,191	8,757	71,370	1.06	9.58
Vegetables	94,334	240,464	2,188	*	2.32	
Root crops	156,205	229,627	4,735	39,848	3.03	17.35

Source: Computed based on CSA annual reports (2004/05–20118/19)

Irrigation

The use of irrigation is very important for a farming system that is fully dependent on less reliable rain every year. Ethiopia's failure to sustain food security in the past many decades seems to be its strategic failure to develop its irrigation sector. Irrigated areas did not grow significantly in the study period and cereals have been the least benefiting sector. Given the frequent El Niño-caused droughts, which make Ethiopia's agriculture vulnerable to these various shocks and often make it a highly risky business for millions of smallholders, investment in and development of knowledge-based irrigation use is becoming extremely compelling in Ethiopia (Mekonen, 2021). The country has rich unexploited water resources that can be tapped for this purpose.

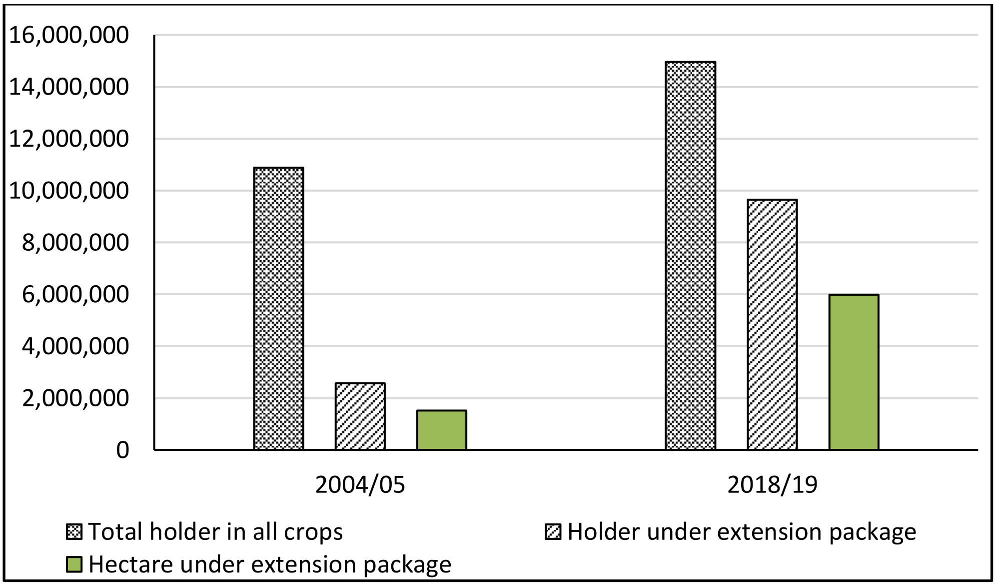
Future agricultural growth is impossible to comprehend without judicious development and more intensive use of irrigation systems. It needs to pay special attention to expanding irrigation development and continuously improving its use to ensure sustainable and rapid agricultural growth. Several big rivers that originate from the highlands cross the terrain and lowland plains and flow and cross the borders without use. Ethiopia's total potential irrigable area is estimated to be around 3.7 to 4.2 million hectares (Awulachew et al. 2007). However, some estimates show quite a higher value i.e. up to 40 million hectares if slopes up to 30 percent are irrigated using modern systems. The country has developed only about 4% of its traditional potential estimate (of 3.7 million ha). Even the performance of the existing irrigation schemes is on average 30% below their design estimation. This indicates that both inadequate irrigation infrastructure and operational problems are major features of the Small-Scale Irrigation Development (SSID) in the country. Because of such a low level of irrigated agriculture development, Ethiopia could not maximize the benefits for its sustainable development.

Irrigation schemes developed with good planning are expected to be fully operational and impactful. In the country many irrigation systems have been built in the past and more are currently being developed. Although it is difficult to obtain precise data, most of the developed systems do not meet the required quality of service. Evidence from the survey indicates that irrigated farms, which are supposed to be in service, have only been able to cultivate a fraction of the expected irrigable land. For example, in the Awash basin, about 741 irrigation schemes are cultivating an average of 79% of their total irrigable land. Among the factors causing the underperformance are, damage to the irrigation systems (42.5%), a low level of river flow and use water shortages due to use by farmers in the upper course of the river (24%). ; Both problems contribute to the underperformance (28%) and for unknown reasons (13%) (PSI, 2019). According to a survey of 75 irrigation schemes in the Oromia region, 65% are able to cultivate their land using the irrigation water.

Agricultural extension

Since 1992, the GoE has made significant investments in an agricultural extension system that focuses on providing of advisory and training services through frontline development agents (DAs). As a result, Ethiopia has achieved one of the highest DA-to-farmer ratios in the world, estimated at approximately 1 DA for every 476 farmers or 21 DAs per 10,000 farmers. This ratio is significantly higher than in other countries such as China, Indonesia, and Tanzania, where the ratio is 16, 6, and 4, respectively (PSI, 2019).

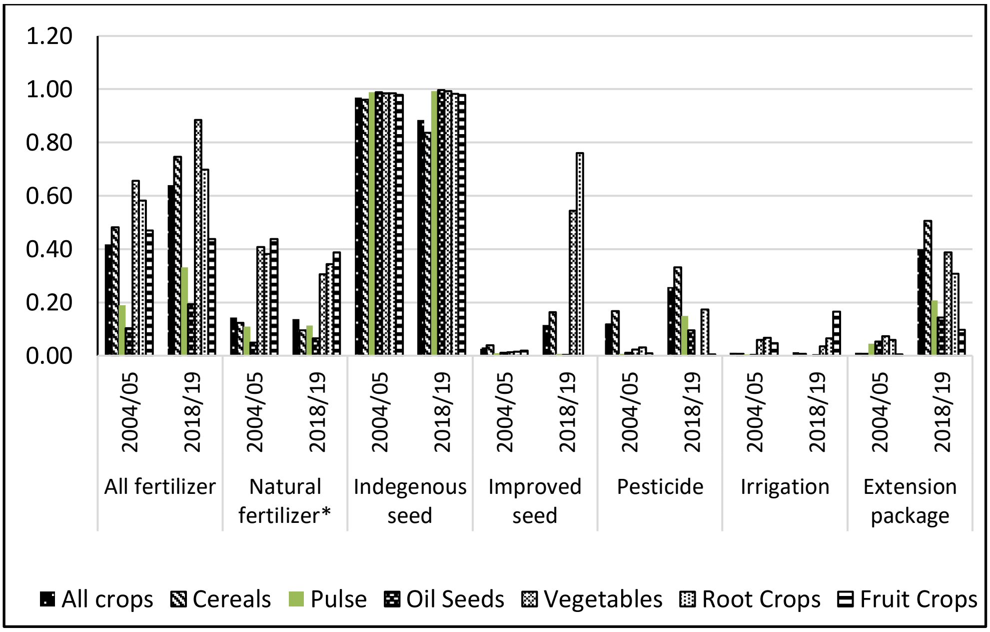
Figure 3: Area covered through the public extension system (package), 2004/2005 and 2018/2019



Source: CSA data (CSA, 2005b–2018/2019).

CSA data allow us to track changes in the number of farmers with access to extension advice. Figure 3 clearly confirms the increasing presence of extension agents over the last decade. The number of smallholders who reported using different crop extension packages quadrupled from 2.6 million in 2004/2005 to 9.6 million in 2018/2019, an average growth of 18.4 percent each year from 24.0 percent of all smallholders to 65 percent. In the same period, the cultivated areas covered by the extension package program increased from 1.5 million hectares in 2004/2005 to 5.98 million hectares in 2018/2019. Figure 4 shows further detailed dynamics of changes that took place in the crop sector. Among the different package components, the least change observed was in irrigation application, which showed no improvement at all except in root crops from about 5 percent in 2004/2005 to 17 percent in 2018/2019. On the other hand, a huge increase was recorded in comparison for improved seed use in 2018/2019 from 4 percent to 16 percent on average for multiple crops. Highest increment was recorded in root (74 %) and fruit crops (54%) from one and two percent respectively. Fertilizer use has increased from 48 percent in 2004/2005 to 64 percent in 2018/2019.

Figure 4: Progress of various recommended agronomic practices covered (hectares), 2004/2005 and 2018/2019



For wheat, maize and teff, fertilizer use has dramatically increased since 2011/2012 while for sorghum, rice and finger millet the increment is far lower (Figure 1). Grain price, crop response to added fertilizer and lower acreage in the case of millet are some of the factors that might contribute to the wider utilization of fertilizer.

3.2. Efficiency Analysis of Crop Across Regions

In the first part, the stochastic frontier is estimated using a Panel fixed-effect model with zone-level data from 2004/2005 to 2018/2019. In the subsequent section, the results of parametric stochastic frontier analysis of aggregate crops across regions are presented focusing on determinants of inefficiencies, and technical efficiency score.

Parameter estimates of the Stochastic Frontier Panel True-Fixed Effect Model applying a Cobb-Douglas production function is given in Table 3. The results indicate that growth in the size of cultivated land and labor are among the factors that make the largest contribution to changes in output at the national level. Land is significant in all specifications except in the Tigray region. The elasticity of output with respect to the cultivated area is about 0.28 at the national level. The contribution of the cultivated area was most important in SNNP (0.43), slightly less so in Oromia (0.26), and the Amhara region (0.21). Similarly, the elasticity of output with respect to labor is about 0.41 at the national level. Labor's contribution was most important in Tigray (0.78) and SNNP (0.51), and slightly less so in the Oromia region (0.06). Labor did not affect output in Amhara. Moreover, the estimated elasticity of labor at the national level from 2004/2005 to 2018/2019 in the aggregate production function indicates that a one percent increase in the labor force and cultivated land accounted for 0.41 percent and 0.28 percent increase in agricultural output growth, respectively. Both results are statistically significant at a one present significance level.

The elasticity of output with respect to chemical fertilizer is about 0.02 at the national level, which is the third largest estimate next to land. While the use of chemical fertilizer positively and significantly influences the total output in all regions at a 1% significance level, but negatively and significantly affects the total output at a 5 % statistical significance level in the SNNP region. The elasticity of chemical fertilizer is positive and relatively higher in Oromia (0.64) and relatively lower importance in both Tigray (0.20) and Amhara (0.19) regions. While it negatively contributed to the SNNP region with an elasticity value of 0.04. The plausible explanation for the negative results in SNNP might be due to the problem related to the untimely distribution of fertilizer to the farmer and/or less responsiveness of land to fertilizer in the region. Moreover, the estimated elasticity of chemical fertilizer in the aggregate production function result implies that one percent increase area covered by chemical fertilizer was accounted by 0.02 percent increase in output growth at the national level from 2004/2005 to 2018/2019 and the result is statistically significant at five present significance levels.

Table 3: Stochastic Frontier using true-fixed panel model result for multiple crops, across regions- 2004-2019

Variables in log	National		Amhara		Oromia		SNNP		Tigray	
	Coef.	**St.E**	**Coef.**	**St. E**	**Coef.**	**St. E**	**Coef.**	**St. E**	**Coef.**	**St. E**
Land	0.28*	0.025	0.21*	0.064	0.26*	0.041	0.43*	0.050	0.12	0.087
Labor	1.41*	0.040	0.19	0.200	1.06*	0.819	1.51*	0.064	0.78*	0.158
Capital	-0.03*	0.021	0.21	0.211	0.04	0.024	-0.19*	0.047	0.47**	0.276
Fertilizer	0.02**	0.010	0.19*	0.267	0.64*	0.178	-0.04**	0.017	0.20*	0.031
Imp. seed	-0.02***	0.009	-0.02	0.018	0.01	0.015	-0.02	0.016	0.03	0.024
Local seed	-0.12*	0.011	0.12*	0.025	-0.08*	0.018	-0.21*	0.022	-0.09**	0.043
Pesticides	0.02*	0.007	0.08*	0.016	0.01	0.017	-0.02**	0.012	0.04**	0.021
Constant	0.18	0.046	-4.86***	2.696	3.06	7.55	3.58*	0.132	6.34*	0.829
Sigma_u	14.59*	2.084	0.09	0.119	4.91**	2.316	5.20*	0.396	23.86**	9.889
Sigma_v	1.09*	0.025	1.54*	0.053	1.18*	0.48	0.91*	0.050	0.71*	0.061
Lambada	13.34*	2.086	40.06	0.117	4.15***	2.315	6.59*	0.408	33.66*	9.890
# Observation	3642		750		1230		1287		375	
Wald chi2	4257.67*		644.35*		583.75*		3316.25*		521.49*	

Note: *, ** and *** represents statistically significant at 1%, 5% and 10% levels, respectively.

Source: CSA, 2004/05 to 2018/19

The elasticity of output with respect to the area covered by pesticide is positive 0.02 at the national level, which is the third larger estimate with equal value to chemical fertilizer. While the area covered by pesticide positively and significantly influences the output change in Amhara and Tigray regions. However, it negatively affects and significantly output change in the SNNP region with an elasticity value of 0.02 from 2004/2005 to 2018/2019. The elasticity of pesticide is positive in Amhara (0.08) and Tigray (0.04) regions. Meanwhile, it has a negative effect in the SNNP region (0.02) which might be due to the unaffordable higher price, untimely distribution of pesticide, and less responsiveness of land to pesticide in the region. Moreover, the estimated elasticity of pesticide in the aggregate production function result implies that a one percent increase in the area covered by pesticide accounted for a 0.02 percent increase in output growth at the national level from 2004/2005 to 2018/2019, and the result is statistically significant at a one percent significance level.

The elasticity of output with respect to capital which is proxied by the number of livestock used to plow the land is about 0.03 at the national-level from 2004/2005 to 2018/2019. The effect of change in the number of livestock used to plow land has a negative and statistically significant effect on output at the national level (0.03) and in the SNNP region (0.19) from 2004/2005 to 2018/2019. However, it has a positive and significant effect on the output in the Tigray region (0.47). The negative result might indicate that there is less contribution from draft cattle to the plowing power and hence seems a less tendency to use tractors and other divisible technologies from 2004/05 to 2018/2019. The elasticity of output with respect to the area covered by improved seed is negative and statistically significant with a value of 0.02 at the national level. Similarly, the elasticity of output with respect to the area covered by local seed is negative at National, SNNP, Tigray, and Oromia regions with elasticity values of 0.12, 0.21, 0.09, and 0.08, respectively. However, it has a positive effect with an elasticity value of 0.12 in the Amhara region from 2004/05 to 2018/19. The negative results might be due to problems related to timely supply, low utilization of recommended packages as most farmers use improved varieties by mixing with local varieties, and untimely distribution of improved seed in the regions.

Determinants of inefficiency factors across regions

Parameter estimates of the inefficiency of an equation using the single-stage estimation technique in Cobb-Douglas production function estimated by the Stochastic Frontier Panel-Fixed Effect model result is given in Table 4. The result implies that inefficiency declines with an increase in irrigated areas with an estimated coefficient of 6.85 and 0.19 both at the national and Amhara region from 2004/2005 to 2018/2019, respectively. However, the proportion of area curved by irrigation does not affect technical efficiency in other regions. Besides, none of the inefficiency factors used in the equation for Tigray explains technical inefficiency. Similarly, with an estimated coefficient of 7.39, inefficiency declined with the proportion of area cultivated using the Ministry of Agriculture's recommended agricultural extension services at the national level from 2004/2005 to 2018/2019. This result was also found in SNNP with an estimated coefficient of 1.05 implying that efficiency improved with more users of agricultural advisory services. Similarly, the inefficiency declines with an increase in the average temperature during Mehir cropping seasons with an estimated coefficient of 1.38 at the national level and 0.21 in SNNP from 2004/2005 to 2018/2019. Moreover, the finding further attested the availabilities of adequate rainfall during Mehir cropping season's decreases inefficiency with an estimated coefficient of 0.42 at national and with a value of 0.06 in the SNNP region from 2004/2005 to 2018/2019. Besides, none of the inefficiency factors associated with various agro-ecologies used in the equation affected technical inefficiency variation both at the national level and in all regions from 2004/2005 to 2018/2019.

The result in Table 4 shows that the overall level of Technical Efficiency (TE) for multiple crops is 73.84%. For Amhara, it is 78.42%, for Oromia, it is 79.64%, for SNNP, it is 63.34%, and for Tigray, it is 61.84%. These figures indicate the existence of substantial levels of inefficiencies from 2004/05 to 2018/19. The results suggest that there is potential for further increasing the output level without the need for additional inputs or the use of modern agricultural technologies by addressing the inefficiency factors.

Table 4: Stochastic Frontier using true-fixed panel model inefficiency factors for multiple crops, 2004-2019.

Variables	National		Amhara		Oromia		SNNP		Tigray	
	Coef.	St.E	Coef.	St. E	Coef.	St. E	Coef.	St. E	Coef.	St. E
Irrigation	-6.85**	2.715	-0.19**	0.087	-2.21	1.929	0.24	0.395	5.82	9.396
Extension	-7.39*	2.435	0.04	0.045	-1.371	1.212	-1.05*	0.299	-26.83	23.30
Rain fall	0.42*	0.134	0.0001	0.002	0.047	0.048	0.06*	0.016	1.02	0.997
Temp.	-1.38*	0.510	-0.0001	0.003	-0.252	0.311	-0.21*	0.065	-0.46	0.785
Agro.02	-16.20	29.54	0.66	-	-10.09	9.042	-198.94	329.03	-	-
Agro.03	10.35	27.56	-	-	3.67	12.52	2.72	4.07	-	-
Agro.04	42.40	30.48	-		-	-	-		-192.11	242.86
_Cons	-147.08*	51.015	-0.69*	0.171	-3.06	7.549	-20.21	5.171	-124.57	227.75
TE	0.7384		0.7842		0.7964		0.6334		0.6184	

Note: *, ** and *** represent statistically significant at 1%, 5% and 10% levels, respectively.

Agro.02 – moisture sufficient highlands, Agro.03- moisture sufficient midlands & Agro.04- drought prone highlands

Source: CSA, 2004/05 to 2018/19

4. Conclusion and Policy Implications

This study assessed the trends of agricultural technological change in the form of chemical fertilizer, improved seed, pesticides, irrigation, extension services, and analyzed the factors influencing technical inefficiency of crop production using panel data from 2004/2005 to 2018/2019 in Ethiopia. Panel stochastic frontier using a true fixed-effect econometrics model employing Cobb-Douglas production function was applied to estimate the elasticity coefficients of production, determinants of technical inefficiency, and their scores using national-level agricultural field survey and meteorology data sets in four major-crop producing regions of Ethiopia.

In response to increased utilization of land, labor and inputs such as chemical fertilizer, pesticides and improved seeds, as well as improved practices through expanded extension coverage, good progress in agricultural production was observed from 2004/05 to 2018/19. However, agricultural technological change through agricultural investment has not been well coordinated and the institutional support system to appraise commercial farmers and ensure sustainability was nearly lacking. Besides, the adequate supply of agricultural production input technologies (such as good quality seeds and chemical fertilizer) and their timely distribution in different regions, as well as intensive use of irrigation and extension services, have contributed to lower productivity over the last years. The desired changes in the use of improved technologies and farm practices need to be critically viewed from a sustainability point of view in order to maintain the increasing productivity trend of farm lands in the most exploited part of agricultural lands in the country.

The results of the true-fixed panel econometrics model imply that the elasticity of output with respect to cultivated area, labor, area covered by chemical fertilizer and pesticides has a positive and statistically significant effect on crop output. This indicates the importance of these inputs in crop production. However, the elasticity of output with respect to capital (proxied by the number of livestock used to plow the land) and local seed has a negative and statistically significant effect on crop output at the national level from 2004/05 to 2018/19. Similarly, the result of disaggregation of the national data across regions implies that the elasticity of all inputs with respect to crop output is different in the Amhara, Oromia, SNNPR, and Tigray regions. The important policy implication of this finding is that policies aimed at enhancing agricultural crop output at the national and regional levels should be specific in order to enhance the proper utilization of production input resources. This can be done through, the wise use of limited land, deployment of the labor force, and providing targeted affordable credit service for adopting technologies that facilitate divisible farming at the national and Tigray region levels. It is also important to strengthen the dissemination of improved seeds, as the local seed is often used in combination with improved seed, which hinders the proper utilization of improved seed both at the national and Oromia, SNNP and Tigray regions. Additionally, the use of pesticide and soil deficient chemical fertilizer input utilization should be particularly addressed at SNNP region.

The overall technical efficiency of crop output value at the national level shows that there is room for further increase using existing technologies and addressing inefficiency factors. Furthermore, there is significant potential to boost yield, with TE values ranging between 62% and 80% across different regions. Technical efficiency has been observed to improve with the expansion of irrigated areas and the implementation of agriculture extension packages or services. However, it can decline due to insufficient rainfall and higher temperatures during cropping seasons.

The future expansion of crop areas in the highlands is already severely limited and boosting crop production will only be driven by a combination of both enhancing the use of agricultural technological change and efficiency of crop production. The use of suitable, reliable and affordable modern agriculture technologies such as more intensive use of improved varieties and high-quality seeds replacing traditional varieties and optimizing crop management through aggressive promotion of packages for fertilizers with better and efficient water management and irrigation is required. Besides, the providing revitalized agricultural extension and advisory services and mechanization services. In this regard, the role of agricultural Research and Development (R&D) and innovative systems and advanced sciences for faster information generation, retrieval, and analysis will be critically important. Research skills and facilities that use and integrate state-of-the-art technologies are becoming increasingly important for the development of superior varieties (in terms of yield and quality) and promotion of hybrid technologies in future agricultural development in Ethiopia.

Policy that aims to enhance agricultural crop output at national and regional levels should be specific to enhance the proper utilization of production input resources. This can be done through, the wise use of limited land through cluster farming (land consolidation) and expansion of mechanization service, deployment of labor force, and providing targeted affordable credit service for adopting production technologies at national and Tigray region. It is also important to strengthen the dissemination of improved seed since the local seed is applied in combination with improved seed that hinders the proper utilization of improved seed both at national and Oromia, SNNP and Tigray regions. Additionally, the use of pesticide and soil deficient chemical fertilizer inputs should be particularly addressed at SNNP region.

The results of determinants of technical inefficiency show that technical efficiency improved with the increase in irrigated area and improvements in the agriculture extension package or agriculture extension services. It also improved with an increase of the average temperature during Mehir cropping seasons. However, technical efficiency declines due to a lack of adequate rainfall during Mehir cropping seasons at the national level. Similarly, the regional disaggregated model also yielded similar results in Amhara and SNNP regions. The key policy implication therefore is that expanding irrigated areas and rectifying the shortage of rainfall by allocating an adequate public budget for the construction of irrigation schemes, strengthening the existing agricultural extension service provision through providing short and long-term training, upgrading education, and providing non-overlapping and congruent responsibilities to extension workers.

Abbreviations

CSA: Central Statistical Authority; DAP: Di-Ammonium Phosphate; EMA Ethiopian Meteorology

Agency: GDP: Growth Domestic Project; MOA: Ministry of Agriculture; NBE: National Bank of Ethiopia; PDC: Plan Development Commission; PSI: Policy Study Institute; RE: Random Effect; SNNP: South Nation Nationality and People; SSID: Small-Scale Irrigation Development; TRE True Random Effects.

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The Effect of Access to Primary School on the Timing of School Enrollment: Analysis of the Ethiopian Education Reform

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Abstract

This paper offers empirical evidence on whether access to primary school induces children to enroll in primary school at the legal enrollment age using household survey data from Ethiopia. We exploit the variation in the intensity of the impact of the education reform across districts in Ethiopia to identify the effect of access to school on the timing of enrollment. Using pre-reform enrollment rate in primary school to measure the variation in the intensity of the impact of the reform, we estimate difference-in-differences models. The results suggest that the reform has substantially increased the probability the child enrolls in grade 1 by age 7. It is also found out that the reform has decreased age at enrollment in grade 1 by about 4 months. These estimates highlight the important role access to school plays in inducing parents to enroll their kids in primary school at the legal enrollment age.

Keywords: school enrollment age, education, Ethiopia
JEL Classification: I25, O10, O12

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1. Introduction

One of the main features of the education system in developing countries is that the majority of students enroll in primary school long after the legal enrollment age, which is usually around 6 or 7 years. Barro and Lee (2001) find out that at least 50 percent of the students enrolled in grade 1 in 31 countries are older than the legal enrollment age. In Ethiopia, a country where the data for this study come from, the 2004 Welfare Monitoring Survey data show that more than 80 percent of children in rural areas enrolled in grade 1 after the legal enrollment age of 7. A number of other studies documented delayed primary school enrollment throughout the developing world (Bommier and Lambert, 2000; Glewwe and Jacoby, 1995; Wils, 2004; Moyi, 2010; Todd and Winters, 2011).

The standard human capital investment models fail to explain the widely observed delayed primary school enrollment as they predict that an individual invests in education in the early period of his/her life and reaps its benefits later in life. Besides, in communities where child labor is a common practice and most of the work children are expected to perform are physically demanding, it is optimal for parents to enroll the child as early as possible since the value of the child's time is lower when the child is younger. There is growing evidence that suggests delaying primary school enrollment is costly. In Ghana, for example, Glewwe and Jacoby (1995) calculated that delaying primary school enrollment by 2 years beyond 6 years, the legal enrollment age, costs an individual about 6 percent of his/her lifetime wealth. Also, children who enroll in school late have higher grade repetition and school dropout rates, and complete fewer years of schooling than those who enroll at the legal enrollment age (Wils, 2004). Given the high cost associated with delaying primary school enrollment, it is not well understood why most parents in developing countries enroll their children long after the prescribed age.

The bulk of the literature in this area focuses on the probability of enrollment, without considering age at enrollment. However, delayed enrollment cannot be tackled by general policies that are designed to increase enrollment rates since delayed enrollment is not confined to countries that have lower enrollment rates (Moyi, 2010; Lloyd and Blanc, 1996). Very few studies analyzed why students in developing countries delay primary school enrollment. Loosely speaking, the explanations these studies provided can be grouped into three: poor child health, liquidity constraint, and limited (or lack of) access to school.

Poor child health slows down the child's development process and renders the child less ready to attend school at the legal enrollment age. Hence, at legal enrollment age, say, a malnourished child would be too weak to be able to walk the (typically longer) distance to school (Bommier and Lambert, 2000; Partnership, 1999). Besides, poor child health lowers the learning ability of the child and thus it is optimal to delay enrollment until the negative effect of poor child health on mental readiness decreases after a few years when the child gets older (Glewwe and Jacoby, 1995). A liquidity constraint explanation, on the other hand, suggests that resource constrained families might need to employ the child in family activities until the family accumulates sufficient saving to finance the child's schooling (Jacoby, 1994). Finally, if there is limited access to schooling, school officials may ration enrollment in primary school, and the rationing tends to favor older children who are typically on the waiting line for a relatively longer time (Bommier and Lambert, 2000). Note that shortage of schools means schools are widely dispersed and we expect children to walk for a relatively longer distance. Since malnourished children are too weak to walk for longer distance to school, school shortage may interact with child health and have differential impact across children on the health distribution.

Most families in developing countries, particularly those in rural areas, do not have access to primary schools. In recent years, however, many developing countries have made primary schools more accessible. There is evidence that suggests making schools more accessible has increased primary school enrollment, but we know little about the effect of access to school on the timing of enrollment. This paper, thus, attempts to bridge this gap in the literature by offering empirical evidence on the effect of access to school on the timing of primary school enrollment using a household survey data from Ethiopia.

One of the empirical challenges of assessing the effect of access to school on the timing of enrollment is endogeneity of access to school; that is, families that live closer to school may be inherently different and their children may enroll in school on time regardless of their proximity to school. In situations like these, most researchers attempt to mitigate the bias by either finding appropriate instrumental variable or using a "natural experiment" that affects the endogenous variable but not the outcome variable. Some prior studies exploit government programs as exogenous source of variation in economic variables. For example, Todd and Winters (2011) and McEwan (2013), respectively, exploit the government programs in Mexico (called Oportunidades) and Chile as exogenous source of variation in child health to investigate the effect of child health on the timing of school enrollment. This study employs a similar approach and uses an education policy shock that happened in Ethiopia between the mid-1990s and mid-2000s as exogenous source of variation in access to primary school.

The Ethiopian government has launched a series of five-year Education Sector Development Programs (ESDPs) since 1997 with a prime objective of achieving universal primary education by 2015. To date, 6 five-year ESDPs have been implemented. During the first two ESDPs that covered 8 academic years between 1997/98 and 2004/05, 2,398 new primary schools were built (World Bank, 2005). The program has substantially decreased distance to primary school at a national level from its average of 2.73 Km in 1996 to that of 1.25 Km in 2004. Though such a large number of primary schools were built in a short period of time and the program has substantially decreased distance to primary school at a national level, the decrease in distance to primary school vary widely across states and zones.[23] For example, distance to primary school has decreased by 100 percent in East Wellega zone while the decrease was only 2.81 percent in South Gondar zone during the same period.

We exploit the variation in the intensity of the impact of the program across states to identify the causal effect of access to primary school on the probability of enrollment in grade 1 by age 7, the legal enrollment age. Narrowing down education inequalities across states by building more schools in rural and under-served areas was at the core of the program's objective. In fact, the program explicitly targeted increasing primary school enrollment from its 30 percent national average at the beginning of the program to at least 50 percent by the end of the program. Thus, we should expect more schools to be built in areas that had lower primary school enrollment rate in the pre-program period. Accordingly, states that had pre-program primary school enrollment rate below 30 percent are assigned into treatment group, whereas those states above 30 percent enrollment rate are assigned into control group. Then, difference-in-differences models are estimated where the dependent variable is a binary indicator for enrollment in grade 1 by age 7. To estimate the models, we use household survey data - called Welfare Monitoring Survey (WMS) data - administered by Ethiopia's Central Statistical Agency during the periods 1996 and 2004. The main advantage of using datasets from these survey rounds is that they have information on important variables just before the beginning of the program (i.e., 1996) and around the end of the program (i.e., 2004). Moreover, this is a period where the Ethiopian government has started mass building primary schools across the country, focusing primarily on under-served communities.

[23] Ethiopia is a federal country with three levels of governments: federal, state (or regional), and local governments. Zones are mid-level administrative unit of the government that are equivalent to US counties.

The results from the difference-in-differences models reveal that the education program has increased the probability the child enrolls in grade 1 by age 7 by more than 35 percentage points. The results also suggest that the reform has decreased age at enrollment in grade 1 by about 4 months. These estimates highlight an important role access to school plays in inducing parents to enroll their kids in primary school at the legal enrollment age.

The remainder of the paper is organized as follows. The following section briefly reviews the literature, and Section 3 describes the education reform in Ethiopia. Section 4 explains the data and presents descriptive statistics. The impact of the education program on both access to school and primary school enrollment is discussed in Section 5. Section 6 presents the evidence on the impact of the education program on the timing of enrollment. While doing so, Section 6 discusses the identification strategy and presents the econometric results. The final section concludes.

2. Literature Review

Delayed primary school enrollment is observed in a number of developing countries. For instance, it has been documented in most Sub-Saharan African countries (Barro and Lee, 2001), in Tanzania (Bommier and Lambert, 2000), Ghana (Glewwe and Jacoby, 1995; Seshie-Nasser and Oduro, 2016)), Mozambique (Wils, 2004), Malawi (Moyi, 2010), Mexico (Todd and Winters, 2011), and rural China (Chen, 2015). Contrary to the fact that delayed enrollment is common in most developing countries, we have limited understanding of its causes.

Prior studies on the topic suggest various explanations on why parents delay their children's enrollment in primary school. First, malnutrition could cause delayed primary school enrollment. This is because malnutrition lowers children's learning ability and hence it is optimal to delay enrollment until the negative effect of malnutrition decreases after a few years when the child gets older (Glewwe and Jacoby, 1995). Using a policy intervention that improved child health in Mexico as exogenous source of variation in child health, Todd and Winters (2011) find out that early health and nutrition intervention has increased the probability a child enrolls on time in primary school. On the contrary, McEwan (2013) finds out that a similar policy intervention that made higher calorie meal available to vulnerable children in Chile has no effect on enrollment in grade 1 at the legal enrollment age. The author attributes this to the lower incidence of child malnutrition in Chile, and high proportion of children in Chile being enrolled in school on time. On the other hand, in Ghana and Tanzania, Partnership (1999) found out that malnutrition, measured by height-for-age, delays enrollment in primary school.

Second, De Vreyer et al. (1999) model a household behavior, where households diversify their investment among three assets: physical assets, general human capital acquired through schooling, and specific human capital acquired through child labor. If the return to specific human capital at younger age is higher than that of general human capital, then parents do not send their children to school at the legal school enrollment age. Third, delayed school enrollment could be the result of liquidity constraints. When households are resource constrained, a child might need to be employed in family activities until the family accumulates sufficient saving to finance the child's schooling (Jacoby, 1994).

Finally, delayed school enrollment could be the result of supply side problems. If there is shortage of school, school officials may ration enrollment in primary school, and the rationing tends to favor older children who are typically on the waiting line for a relatively longer time. On the other hand, shortage of school may mean students have to walk longer distance to school. In this case, delayed enrollment could be due to the fact that children may not be mature enough to walk the distance to school at the legal enrollment age (Bommier and Lambert, 2000). In societies where there is high incidence of child malnutrition, shortage of schools exacerbates the problem of delayed enrollment since developmentally stunted children take relatively longer time to be physically strong and be able to walk the longer distance to school. On the other hand, walking longer distance to school increases the propensity a child walks through unsafe neighborhoods. Thus, parents that are concerned about the safety of their children may refrain from sending their children, especially their daughters, to school at the legal enrollment age.

Though access to school is one of the most important factors that determine the timing of enrollment, identifying its effect on the timing of enrollment is complicated by the relationship between school proximity, socioeconomic status, parental taste for education, and other characteristics that affect the timing of enrollment. For instance, being economically disadvantaged is correlated with poor taste for education and living further away from schools. All these factors affect the timing of enrollment, but they cannot be perfectly controlled in the regression framework. A credible identification of the effect of access to school on the timing of enrollment, thus, requires exogenous source of variation in access to school that does not affect the timing of enrollment.

In situations like these, government programs can be used as exogenous source of variation in the independent variable. For example, to test the hypothesis that malnutrition delays school enrollment, Todd and Winters (2011) used the government program in Mexico called Oportunidades as exogenous source of variation in child health. McEwan (2013) also used a similar intervention in Chile as exogenous source of variation in the amount of calorie intake among children to identify the causal effect of child health on the timing of enrollment. We follow a similar approach and use the education reform that happened in Ethiopia between 1996 and 2004 as exogenous source of variation in proximity to school to identify the causal effect of access to primary school on the timing of enrollment.

3. The Education Reform in Ethiopia

Following the change in government in May 1991, Ethiopia has undergone a number of policy changes in almost all sectors of the economy. The education sector is one of the sectors that has gained the attention of the government since then. Consequently, it has undergone many policy changes and received a large and increasing budget share of the government. Among the many changes the sector experienced recently, the implementation of a series of five-year Education Sector Development Programs (ESDPs) is the major one. We exploit the variation in the intensity of the impact of the education program across districts to identify the causal effect of access to primary school on the timing of enrollment in grade 1.

The ESDPs started in 1997 with the objective of achieving universal primary education by 2015. Reducing educational inequalities by increasing access to primary school, mainly in rural and under-served areas, was at the core of the ESDPs. To date, 6 five-year ESDPs have been implemented. We will focus on the first two ESDPs in this paper as their duration aligns with the survey years of the data used in this paper and this is the period where Ethiopia has begun building a large number of schools to substantially increase access to primary education, albeit from a very low base.

The first ESDP covered five academic years between 1997/98 and 2001/02. Over the five years period of the first ESDP, it was planned to build 2,423 new primary schools, to upgrade 1,814 primary schools, and to renovate 1,220 primary schools in order to accommodate 3.9 million additional students (World Bank, 1998). The expected outcomes were substantial increase in access to primary school especially in rural areas where the majority of newly built schools were to be located. Moreover, it was expected to increase gross primary school enrollment rate from its 30 percent level by the beginning of the first ESDP to 50 percent by the end of the first ESDP.

The second ESDP also covered five academic years between 2000/01 to 2004/05. The first two years of the second ESDP overlapped with the last two years of the first ESDP. Thus, in effect, the second ESDP had covered three unique academic years between 2002/03 and 2004/05. The reason for the overlap in the duration of the first and second ESDPs is to align the second and consecutive ESDPs with the political election cycle and the five-year term of the elected government in office. Though it was planned to build 2,423 primary schools during the first ESDP alone, a total of 2,398 new primary schools were built during the first two ESDPs, and, in line with the focus of the program, 86 percent of the new schools were built in rural areas (World Bank, 2005).

As the first two ESDPs covered 8 academic years between 1997/98 and 2004/05, household survey data collected in 1996 and 2004 are used in this paper so that the 1996 and 2004 data are, respectively, used as pre and post program data. The next section discusses the data used in this paper and presents descriptive statistics.

4. Data

The analysis in this paper is based on the Ethiopian Welfare Monitoring Survey (WMS) data, which was administered by the Ethiopia's Central Statistical Agency in 1996 and 2004. The WMS is a cluster-based nationally representative repeated cross section household survey. The 1996 and 2004 WMS covered 11,569 and 36,303 households, respectively, and the surveys contain a wide range of information on household demographics, household assets, availability and use of different facilities (including schools), and other important economic variables.

For each household member aged five and above, we observe whether an individual was attending school during the survey years and a year prior to the survey years. We also observe the grade in which an individual was registered in these two consecutive years. Using this information, we restricted the sample to first time grade 1 enrollee in the two survey years. Since grade repetition is common in Ethiopia as it is in most developing countries, it is important to mention that one of the advantages of these data is that they allow us to observe first time grade 1 enrollees. Hence, bias from measurement error of age at enrollment, which can be caused by grade repetition, is not a serious concern here.

Table 1 presents descriptive statistics for a sample of 2,368 children used in the econometric analysis. Detailed definition of variables is given in Table A.1 of the Appendix. The table shows that children in rural areas, on average, enroll in grade 1 at least 2.5 years after the legal enrollment age of 7. The extent of delayed enrollment in rural area is also reflected by the small proportion of children that were enrolled in grade 1 by age 7, which was 11 percent in 1996 and 18 percent in 2004. Although delayed enrollment in urban areas is less common as compared to rural areas, a non-trivial number of children in urban areas enroll in grade 1 after the legal enrollment age. For instance, Table 1 depicts that only about 50 percent and 53 percent of children in urban areas were enrolled in grade 1 by age 7 in 1996 and 2004, respectively. Moreover, children in urban areas delay enrollment in grade 1 by about a year in 1996 and 10 months in 2004. To summarize, a sizable proportion of children enroll in grade 1 few years after the legal enrollment age of 7 years. However, children in rural areas are more likely to delay enrollment, and when they do, they delay enrollment by more years than their urban counterparts.

The enrollment rate for girls has been disproportionately lower than for boys for a long time, particularly in rural Ethiopia. Table 1, however, shows that the proportion of girls enrolled in grade 1 has been increasing during the period of analysis, both in rural and urban areas. Given narrowing down gender gap in primary school enrollment was one of the objectives of the program, it is interesting to see increasing proportion of girls were enrolled in grade 1 during this period.

Generally, parents in Ethiopia are less educated, with the highest average years of schooling being 5 years for fathers and 3 years for mothers. As expected, parents in urban areas are more educated than their rural counterparts. Parental years of schooling has slightly increased in rural areas between 1996 and 2004. Though it is not clear why this is the case, it could be partly because of ongoing adult education in Ethiopia.

Table 1: Descriptive statistics for a sample of children who were enrolled in grade 1 by year and location

1996 2004	Rural	Urban	Rural	Urban
Enrolled in grade 1 by age 7 (yes=1)	0.111	0.498	0.176	0.528
	(0.314)	(0.501)	(0.381)	(0.500)
Age at enrollment	10.203	7.967	9.635	7.752
	(2.128)	(1.760)	(2.151)	(1.587)
Girl (yes=1)	0.304	0.474	0.452	0.534
	(0.461)	(0.501)	(0.498)	(0.500)
Birth order	2.538	3.414	2.509	2.859
	(1.334)	(1.936)	(1.414)	(1.646)
Household size	7.184	7.395	7.032	6.662
	(1.895)	(2.409)	(1.896)	(2.110)
Dad's years of schooling	1.108	5.107	1.629	5.041
	(2.165)	(3.687)	(2.580)	(3.679)
Mom's years of schooling	0.149	3.386	0.570	3.248
	(0.768)	(3.642)	(1.635)	(3.756)
Dad's age	45.364	45.558	44.803	43.931
	(9.725)	(11.411)	(10.615)	(10.798)
Mom's age	37.038	36.293	35.867	34.614
	(7.840)	(7.353)	(7.809)	(7.710)
HH has piped water (yes=1)	0.044	0.716	0.151	0.783
	(0.206)	(0.452)	(0.358)	(0.413)
HH has electricity (yes=1)	0.013	0.847	0.020	0.707
	(0.11	(0.361)	(0.140)	(0.456)
HH has pit latrine (yes=1)	0.092	0.758	0.253	0.741
	(0.289)	(0.439)		
HH owns land (yes=1)	0.997	0.703		
	(0.056)	(0.458)		
HH owns farm animal (yes=1)	0.633	0.655		
	(0.483)	(0.476)		
Proportion of hhs with piped water	0.035	0.819		
	(0.137)	(0.301)		
Proportion of hhs with electricity	0.016	0.677		
	(0.087)	(0.361)		
Proportion of hhs with pit latrine	0.083	0.705		
	(0.204)	(0.267)		
Proportion of hhs with land	0.974	0.547		
	(0.048)	(0.269)		
Proportion of hhs with farm animal	0.493	0.515		
	(0.300)	(0.295)		
State-level unemployment rate*	2.479	5.109		
	(4.743)	(6.068)		
Observations	316	290		

Standard deviations are in parentheses.
*Source: The 1994 and 2007 Ethiopian Census.
Proportion of households is defined over the locality of the child's residence which is roughly equivalent to a village or an urban neighborhood.

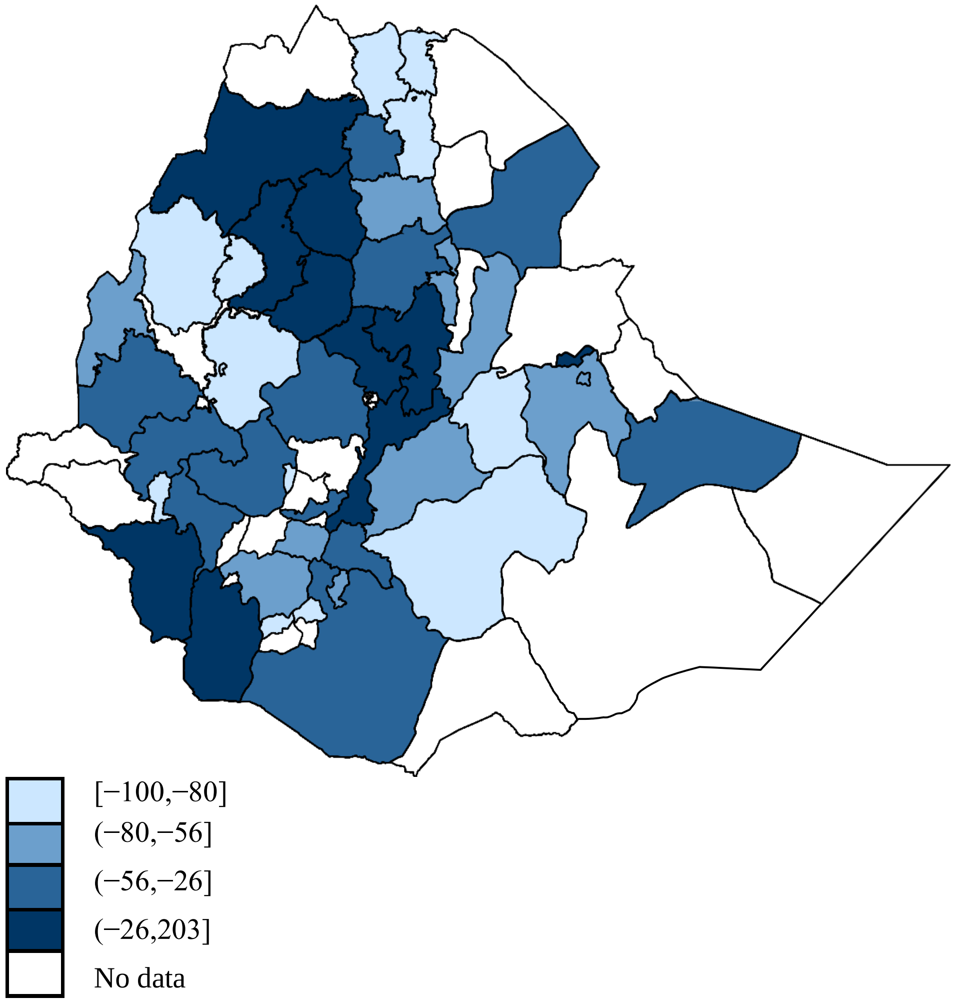
Household assets and amenities variables depicted in Table 1 show that families in rural areas have fewer household assets and live in poor housing conditions compared to those in urban areas. However, household assets and housing condition have improved during the period of analysis for households in both rural and urban areas. To control for the economic condition of the locality of the child's residence, we control for the proportion of households that owns different types of household assets and amenities in the locality of the child's residence; that is, enumeration area which is used as primary sampling unit in the survey design and is roughly equivalent to a village or an urban neighborhood. As expected, the table shows that rural localities are relatively poorer than their urban counterparts. Finally, Table 1 also shows that unemployment rate varies by location of residence, with urban unemployment rate higher than rural unemployment rate.

5. The Impact of the Education Program on Access to School and Primary School Enrollment

The education program substantially increased access to school in Ethiopia. As mentioned earlier, 2,398 new primary schools were built over a period of 8 years as a result of the program (World Bank, 2005). Besides, data from the 1996 and 2004 Ethiopian Welfare Monitoring Survey show that the average distance to primary school had decreased at a national level by 1.48 kilometers (Km) between 1996 and 2004, which is more than a 50 percent decrease from its average of 2.73 Km in 1996 to that of 1.25 Km in 2004.

Although the program has substantially decreased distance at the national level, Figure 1 shows that the change in distance to primary school during this period vary widely across zones. Of the total 52 zones surveyed both in 1996 and 2004, distance to primary school decreased in 43 zones, ranging from a 100 percent decrease to that of 2.81 percent decrease. On the other hand, distance to primary school increased in 9 zones during the same period, ranging from a 1.13 percent increase to that of 203 percent increase.

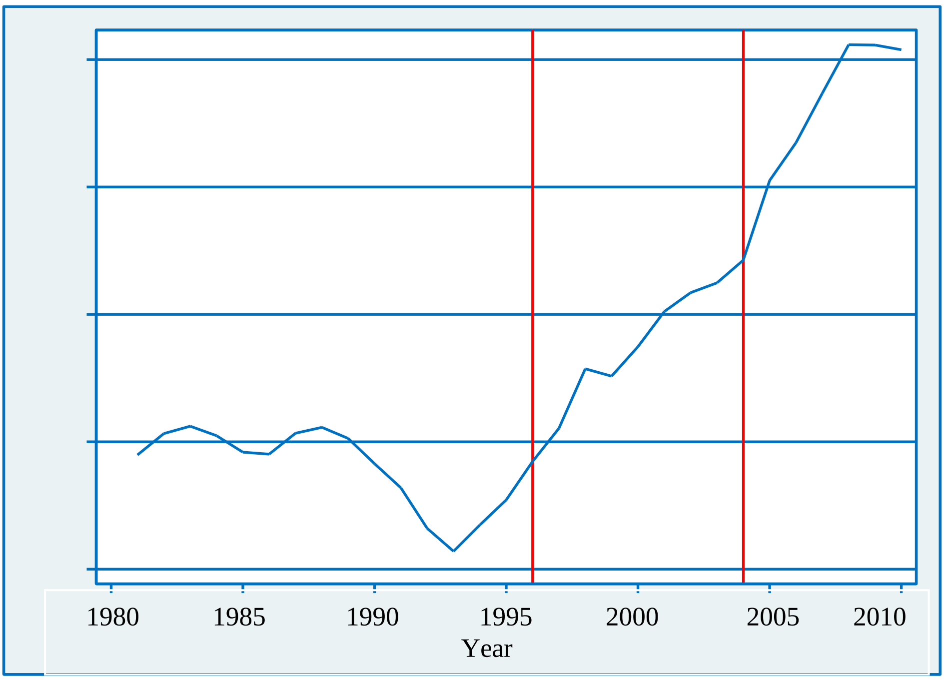
Figure 1: Percentage change in distance to primary school between 1996 and 2004 by zones in Ethiopia



Similarly, enrollment in primary school has increased substantially in recent years. Figure 2 depicts the trend in enrollment rate in primary school in the last three decades using data from the World Bank. For the most part of the 1980s, enrollment rate was stable around 40 percent, except in the late 1980s where it started to decline. The decline is mainly because of the aggravated civil war between the military government in power at that time and the rebellion group that finally threw the military government out of power in 1991.

Starting the early 1990s, enrollment rate has started to increase and reached its 1980s level around 1997. Enrollment rate has been continuously increasing since then. The increase in enrollment rate during the period of analysis (which is marked between the two vertical lines in Figure 2) is attributed to the education program that has been in place. Even if the focus of this paper is on the education program that was implemented between 1996 and 2004 (more specifically, the first and second Education Sector Development Programs), the next phase of the program (the third Education Sector Development Program) has been implemented by the end of the second phase of the program. Therefore, we should not expect the growth in enrollment rate to decrease or plateau after 2004. That is why the curve in Figure 2 continuously increases even after 2004.

Figure 2: Primary School Enrollment Rate Trend in Ethiopia



Source: World Bank

One feature of the education program is narrowing down educational inequalities across states and between rural and urban residents. This is reflected in the allocation of the newly built schools where 86 percent of them were built in rural areas (World Bank, 2005). The program also explicitly targeted increasing primary school enrollment from its 30 percent national average at the beginning of the program to at least 50 percent by the end of the program. We should, therefore, expect more schools to be built in states that had less than 30 percent enrollment rate before the program. Accordingly, we assign states with less than 30 percent enrollment rate before the program in the treated group and those above 30 percent in the control group.

Using the 1994 Ethiopian census data, Table 2 presents the primary school enrollment rate before the program by state and treatment status. Three states had enrollment rate above 30 percent before the program. These three states are assigned into a control group and all the remaining states are assigned to a treatment group. It is crucial to mention that the three states in the control group are largely urban in nature and lead primarily non-agrarian economies. But note that all the other states also have major urban areas[24] although the majority of their residents live in rural areas. Given the program focused on building the majority of the schools in rural areas, it is expected states in the control group to be predominantly urban in nature.

Table 2: Enrollment Rate in Primary School (Grades 1-8) During the Year before the Education Program

State/Region	Enrollment Rate	Treated State?
Tigray	15.2	Yes
Afar	2.96	Yes
Amhara	7.64	Yes
Oromiya	9.52	Yes
Somali	2.03	Yes
Benishangul Gumuz	9.94	Yes
SNNP	10.9	Yes
Harari	31	No
Addis Ababa	62	No
Dire Dawa	31.6	No

Source: The 1994 Ethiopian Census

[24] Central Statistical Agency of Ethiopia defines two types of urban areas: *major urban areas* and *other urban areas*. This classification depends on the nature of economic activity and the number of residents. All state capitals are considered as major urban areas, and they are typically more developed and have larger population size relative to other urban areas.

6. Estimation Strategy and Identification

6.1. Econometric Method

Let us denote enrollment status of child *i* residing in state's in year *t* by $enroll_{ist}$. Taking into account individual differences in observable characteristics, the probability that the child enrolls on time it can be written in a generic form

$$Pr(enroll_{ist} = 1|d_{it}, \mathbf{X}_{ist}) = G(\gamma d_{it} + \mathbf{X}_{ist}\boldsymbol{\beta}), \quad (1)$$

where d denotes distance to primary school, X_{ist} represents a vector of explanatory variables, and G is a known function of covariates.

If access to primary school (d_{it}) is endogenous in equation (1), estimating equation (1) provides biased estimate of γ and hence it cannot be interpreted as the causal effect of access to school on the probability of enrollment on time. There are a number of reasons why we expect access to primary school to be endogenous in equation (1), including unobserved parental taste for education. Generally, families that live closer to schools may be inherently different and their children may enroll in school on time regardless of their proximity to school. If there is exogenous source of variation in proximity to school that does not affect the outcome variable, the causal effect of access to school on the timing of enrollment can be identified. We exploit the variation in the intensity of the impact of the education program across states in Ethiopia to identify the causal effect of access to school on the timing of enrollment.

Difference-in-Differences Approach

Ideally, we would compare the probability of enrollment in grade 1 by age 7 ($enroll_i$) for the same set of children when they are exposed to the education program ($enroll_i$ |education program) and when they are not ($enroll_i$ |no education program). In this ideal case, the average treatment effect would be the differences in the expected values under the two scenarios.

However, the same set of children cannot be observed under both scenarios since the child is either exposed to the program or not. Hence, to estimate the average treatment effect, data on two groups of randomly assigned children where one group is exposed to the program (treatment group) while the other is not exposed to the program (control group) are required. As long as assignment of children to treatment

(Treated = 1) and control (Treated = 0) groups are random, the average treatment effect can be obtained by first difference model.

If, however, children in the two groups differ initially and have different timing of enrollment in the absence of the program, we have to control for the pre-existing difference between the two groups. If we have information on observations both before the education program occurred (After = 0) and after the program occurred (After = 1), then a difference in differences approach can be used to separate the pre-existing difference from that of the treatment effect. Specifically, we can estimate:

$$P\,r(enroll_{it} = 1) = G(\alpha_0 + \eta_0\, Treated_{it} + \tau_0 After_{it} + \gamma_0\, Treated_{it} * After_{it}) \quad \textbf{(2)}$$

In linear probability model, η_0 in equation (2) estimates the pre-existing difference between children in the two groups, τ_0 estimates the change in the outcome that occurred over time due to other factors, and γ_0 estimates the impact of the education program. Estimating γ_0 in equation (2) assumes children in the two groups would experience the same time trend (τ_0) in the absence of the program, so that once initial difference (η_0) and time trend are controlled for, the remaining difference between children in the treatment and control groups can be attributed to the program.

As mentioned earlier, state level pre-program enrollment rate in primary school is used to group states (and hence students) into treatment and control groups. Specifically, students that live in states that had pre-program primary school enrollment rate below 30 percent are assigned into treatment group, whereas students that live in states with pre-program primary school enrollment rate above 30 percent are assigned into control group. The argument is that relatively more schools should be built in areas where the pre-program enrollment rate in primary school is lower since the program explicitly targeted narrowing down education inequalities across states by building more primary schools in areas where primary school enrollment rate was lower before the education program. Hence, if proximity to primary school induces children to enroll on time, in the post-program period, we expect to see children in the treated states to be more likely to enroll in primary school on time relative to those that live in control states.

The basic identification strategy can easily be demonstrated by a simple difference- in-differences table. Table 3 presents the difference in differences in age at enrollment in grade 1 between children in the treated and control states before and after the education program. The first column of Table 3 displays that, before the program, children in the treated group enrolled in grade 1 at age 9.5 on average while those in the control group enrolled at mean age of 8.0, a difference of 1.6 years. The difference, however, narrowed down to 0.6 years after the program. Thus, the difference in the differences in mean age at enrollment in grade 1 is about −0.992 years with a standard error of 0.339. This indicates that the unadjusted treatment effect is about -1 year, implying that the educational reform program has reduced age at enrollment in first grade by age 7 by about 1 year.[25]

Table 3: Age at Enrollment by Treatment Group Before and After the Program (Observations 2368)

Group	Before the Change	After the Change	Time Difference
Treated	9.546*** (0.103)	9.372*** (0.053)	-0.174 (0.116)
Untreated	7.976*** (0.238)	8.794*** (0.211)	0.818*** (0.318)
Group Difference	1.570*** (0.260)	0.577*** (0.218)	-0.992*** (0.339)

Notes: Standard errors are given in parentheses. The standard error associated with the treatment effect (highlighted) is clustered by enumeration area, the primary sampling unit. Statistical significance: * p <0.10, ** p < 0.05, and *** p < 0.01

The difference in differences can be interpreted as the causal effect of the program under the assumption that in the absence of the program the decrease in age at enrollment would not have been systematically different in treated and control states. If this assumption is not satisfied, the difference in differences presented here cannot be interpreted as the "true" treatment effect. In the paragraphs below, we present a difference-in-differences model that adjusts for observable differences between individuals in the treated and control groups in the regression framework.

Using observations sampled from 10 states in Ethiopia and controlling for individual, household, and community-level characteristics; state fixed effects; and state-by-year fixed effects to improve precision, we estimate:

$$Pr(enroll_{ist} = 1) = G(\alpha + \eta Treated_s + \tau After_{it} + \gamma Treated_s * After_{it} + \boldsymbol{\beta}_1\mathbf{X}_{it} + \boldsymbol{\beta}_2\mathbf{W}_{ht} + \boldsymbol{\beta}_3\mathbf{C}_t + \boldsymbol{\beta}_4\mathbf{S} + \boldsymbol{\beta}_5\mathbf{S} * \mathbf{Y}) \quad \textbf{(3)}$$

[25] A counterpart of Table 3 which uses means of enrollment dummy is presented in Table A.2 in Appendix A. Table A.2 shows that the unadjusted treatment effect is 0.107, suggesting the program has increased the probability of enrollment in grade 1 by age 7 by 10.7 percentage points. Note that the same result can be obtained from OLS regression of equation (2).

where $enroll_{ist}$ is a dummy variable which takes a value of 1 if child i in state s in year t is enrolled in grade 1 by age 7; $Treated_s$ is a binary indicator for states that had pre-program primary school enrollment rate below 30 percent; $After_{it}$ is a dummy variable equal to 1 if the child is being observed after the program, and zero otherwise; $\mathbf{X}_{it}$, $\mathbf{W}_{ht}$, and $\mathbf{C}_t$ are vectors of individual, household, and community level characteristics, respectively; **S** is a vector of state dummies to control for (time invariant) state fixed effect; and ($\mathbf{S} * \mathbf{Y}$) is a vector of binary indicators for the interaction of state and year dummies to control for state-specific shocks over this period which are correlated with the education program.[26]

The primary (explanatory) variable of interest is the interaction term, $Treated_s *$

$After_{it}$, and γ captures the treatment effect, i.e., the effect on the probability a child enrolls in grade 1 by age 7 due to the child lives in the treated states (relative to those that live in the control states) after the program has occurred. While estimating equation (3), the standard errors are clustered by enumeration area, a primary sampling unit, to account for correlation in the error terms within enumeration area over time. For the most part, we assume **G** is standard normal cumulative distribution function and estimate a probit model, in which case the estimate of the average treatment effect and its standard error are computed as suggested by Puhani (2012).

6.2. Econometric Results

Table 4 presents Probit estimates of the average treatment effects (effect of education reform on on-time primary school enrollment) for various specifications depending on the control groups used in equation (3). The dependent variable is a binary indicator for enrollment in grade 1 by age 7. All specifications include state and state-by-year fixed effects to the extent possible due to potential collinearity between these effects and post-treatment and treatment dummy variables. Table A3 in the appendix provides Linear Probability Model (LPM) treatment effect estimates

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[26] A slightly different version of the model presented in equation (3) is the one that replaces the dummy variable for treated group, Treated_S, by a continuous pre-program state level primary school enrollment rate variable, EnrolRates, i.e.,

$$Pr(enroll_{ist} = 1) = G(\alpha + \eta EnrolRates_S + \tau After_{it} + \gamma EnrolRates_S * After_{it} + \boldsymbol{\beta}_1 \mathbf{X}_{it} + \boldsymbol{\beta}_2 \mathbf{W}_{ht} + \boldsymbol{\beta}_3 \mathbf{C}_t + \boldsymbol{\beta}_4 \mathbf{S} + \boldsymbol{\beta}_5 \mathbf{S} * \mathbf{Y})$$

Results from this specification are presented in column 1 of Table 6.

of equation (3) for specifications analogous to those used in binary Probit. The treatment effects are significant at conventional levels of significance except the effect from LPM in specification A1 is not tightly estimated (p-value of 0.139).

Focusing on preferred specification in column 4, the Probit model indicates that children in the treated states are 21 percentage points less likely to enroll in grade 1 by age 7 relative to children in the control states during the pre-program period, and the effect is statistically significant at 1 percent level. This evidence supports the argument that there was pre-existing difference in the timing of enrollment in primary school between children in the treated and control states prior to the education program, where children in the treated states were less likely to enroll in primary school at the legal enrollment age relative to those in the control states.

Table 4: Probit DID estimates of the effect of education reform on on-time school enrollment (Observations 2368)

Dependent Variable: Binary Indicator for Enrollment in Grade 1 by Age 7

Variables	(1)	(2)	(3)	(4)	(5)
Treated*After	0.1887***	0.2146***	0.2197***	0.2133***	0.2305***
	(0.068)	(0.060)	(0.065)	(0.065)	(0.064)
State fixed effects	Yes	Yes	Yes	Yes	Yes
State-by-year fixed effects	Yes	Yes	Yes	Yes	Yes
Individual characteristics	No	Yes	Yes	Yes	Yes
Household characteristics	No	No	Yes	Yes	Yes
Locality & related Characteristics	No	No	No	Yes	Yes
Unemployment rate	No	No	No	No	Yes
Minus Log Likelihood	1273	1100	1012	1001	1001
AIC	2584	2250	2086	2075	2075

Statistical significance: *** p < 0.01, ** p<0.05, * p<0.10

Probit estimates of the treatment effect are based on standard errors clustered by enumeration area, the primary sampling units.

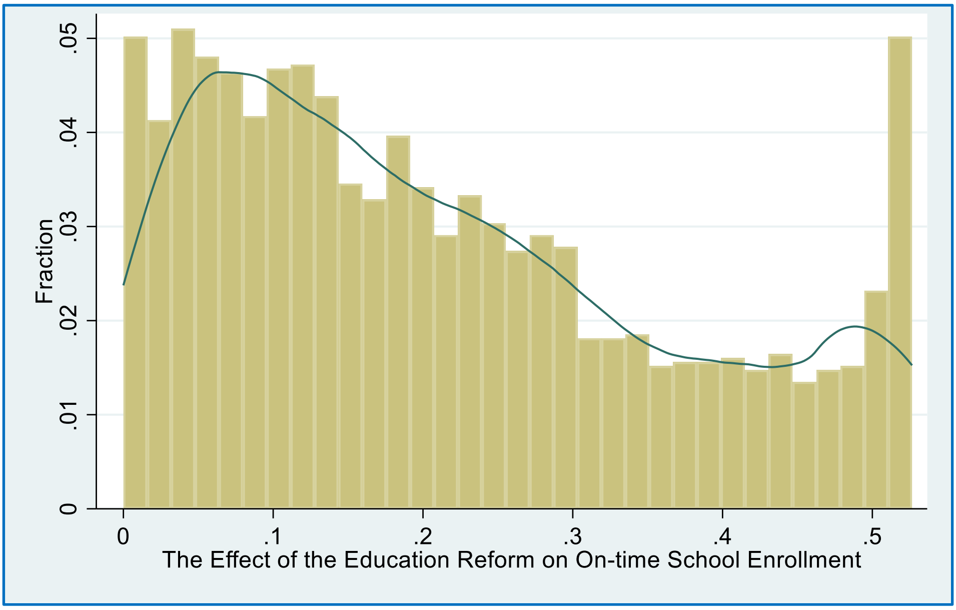
The control groups are individual-level characteristics (a binary indicator for gender, birth order, mother’s and father’s age and years of schooling), household-level characteristics (household size, binary indicators for whether a household has piped water, electricity, pit latrine, land, and farm animal), and locality-level and related characteristics (i.e., proportion

of households with piped water, electricity, pit latrine, land, farm animal, and urban dummy for location of residence), and state unemployment rate.
The post treatment year dummy (After) and the treatment variable (treated) are also included in each specification.
AIC denotes Akaike Information Criterion.

The average treatment effect of the interaction term is about 0.21 in Probit model and 0.35 in LPM (specification in column 4 of Table A3 in the Appendix). This suggests children in the treated state are 21 and 35 percentage points more likely to enroll on time relative to those who live in the control state after the program has occurred. Since the data set for the analysis is available only for two years, we are unable to formally test for common trend assumption. However, the specifications control for pre-existing differences in the timing of enrollment between children in the treated and control states; the time trend, i.e., the change in the timing of enrollment overtime due to other factors; observable individual, household, and community-level characteristics; state fixed effect; and state-by-year fixed effect. Hence, this effect is attributed to the education program, and it can be interpreted as the “true” average treatment effect.

Even if Table 4 documents positive and significant average treatment effect, it is crucial to examine the distribution of the treatment effect in non-linear models such as Probit since marginal effect is not constant in non-linear models. Figure 3, hence, presents the histogram and kernel density of the treatment effect based on the results reported in column 4 of Table 4 with average treatment effect of 0.21. The figure clearly shows that the estimated treatment effect is always non-negative and goes up well above 40 percentage points, suggesting large and positive treatment effect. The histogram and kernel density of the treatment effect is also plotted separately for rural and urban samples (see Figures B.1 and B.2 in Appendix B) to see if there is any difference in the treatment effect between rural and urban samples. The figures show strong and positive treatment effect both for urban and rural samples. However, the distribution for rural sample is right skewed while that for the urban sample is left skewed.

Figure 3: Historgram and Kernel Density Estimate of the Treatment Effect



Alternative specifications and robustness check

The specifications presented in Tables 4 and A3 do not control for family income. This is because information on family income is not collected in the WMS data. Fortunately, however, detailed information on family income and expenditure is gathered in a supplementary survey called Household Income, Consumption, and Expenditure Survey (HICES), which is also administered by the Ethiopian Central Statistical Agency. HICES collects information on a subset of households that are surveyed in WMS, and it is usually conducted in the same year as the WMS. Using households sampled both in the HICES and WMS, we re-estimate equation (3) both by including and excluding household expenditure in the regression model.

Table 5 presents the results from different specifications using the restricted sample (i.e., households observed both in the HICES and WMS), and hence has relatively smaller sample size.

Table 5: Probit DID estimates of the effect of education reform on on-time school enrollment (Restricted Sample, Observation 1435)

Dependent Variable: Binary Indicator for Enrollment in Grade 1 by Age 7

Variables	**(1)**	**(2)**	**(3)**
Treated*After	0.2781***	0.2760***	0.2776***
	(0.090)	(0.090)	(0.090)
Log of HH expenditure	No	Yes	No
Log of community expenditure	No	No	Yes
State fixed effects	Yes	Yes	Yes
State-by-year fixed effects	Yes	Yes	Yes
Individual characteristics	Yes	Yes	Yes
Household characteristics	Yes	Yes	Yes
Locality & related Characteristics	Yes	Yes	Yes
Minus Log Likelihood	632	632	632
AIC	1337	1338	1339

Statistical significance: *** $p < 0.01$, ** $p<0.05$, * $p<0.10$

Probit estimates of the treatment effect are based on standard errors clustered by enumeration area, the primary sampling units.

The control groups are individual-level characteristics (a binary indicator for gender, birth order, mother's and father's age and years of schooling), household-level characteristics (household size, binary indicators for whether a household has piped water, electricity, pit latrine, land, and farm animal), and locality-level and related characteristics (i.e., proportion of households with piped water, electricity, pit latrine, land, farm animal, and urban dummy for location of residence).

The post treatment year dummy (After) and the treatment variable (treated) are also included in each specification.

To make comparison of results from different specifications (that control for household expenditure and that do not) straight forward, column 4 of Table 4 is re-estimated for the restricted sample, and the results are presented in column 1 of Table 5. Column 2 of Table 5 presents the results from a specification that controls for household expenditure. Controlling for household expenditure changes neither the magnitude nor the significance of the average treatment effect of the interaction term.

The coefficient estimate (not reported here) of the household expenditure itself, on the other hand, is positive, but not significant. It is insignificant may be because the specification controls for parental years of schooling and household assets and amenities, which are generally good controls for families' socioeconomic status.

If higher income families self-select themselves to live at closer proximity to schools and they are more likely to enroll their children in primary school on time regardless of their proximity to school, then household income or expenditure is endogenous and bias the results. The program was explicitly designed to make primary schools more accessible to households in rural areas and underserved localities. In this setting, bias from this type of selection is less likely since the program exogenously allocates new schools across households. If higher income families somehow managed to influence policy makers to build more schools in their locality or higher income families move to areas that received more school construction, then household expenditure is endogenous and biases the results. To mitigate potential endogeneity of household expenditure, we aggregated household expenditure at enumeration area a primary sampling unit which is typically equivalent to a village or urban neighborhood level and estimated equation (3). The results are depicted in column 3 of Table 5. The average treatment effect under this specification is again similar to those presented in columns 1 and 2 both in magnitude and significance. The similarity of the results reinforces the argument that relatively rich communities were less likely to influence policy makers to build more schools in their communities. It also suggests there is no evidence that high income families moved to areas that received more school allocation.

One of the identifying assumptions in the difference-in-differences model is the economic growth rate in the treated and control states do not vary systematically over time. In reality, however, states in the two groups may experience different growth rates. Thus, the estimates could potentially confound the effect of the program with the effect of the differential growth rate on the timing of enrollment that would have been observed even in the absence of the program. Thus, we present a specification that controls for state level unemployment rate in column 5 of Table 4. Information on unemployment rate is obtained from the 1994 and 2007 Ethiopian census. In this specification, the average treatment effect has increased by about 4 percentage points relative to the basic specification.

If we expect states with relatively higher growth rate (or lower unemployment rate) make schools relatively more accessible to their residents in the absence of the program, and if we assume the program targets building more schools in states with lower growth rate, then comparison of the average treatment effect in the basic specification and the one that controls for differences in economic growth rate implies that the program help children who live in lower-growth-rate states to catch up with those in high-growth-rate states in terms of enrolling in primary school on time.

Table 6 gives results from specifications that involve alternative outcomes and treatment status as appropriate. Column 1 of Table 6 presents results from a model that replaces a binary indicator (for treated states) by a continuous measure of pre-program state level primary school enrollment rate. One advantage of using a continuous primary school enrollment rate variable, rather than a binary indicator, is it makes use of all the available information and hence the treatment effect is more precisely estimated. Besides, it is more robust to the risk of arbitrarily grouping states into treatment and control groups. Prior studies employ a similar strategy to estimate treatment effect. For instance, Miller (2012) used pre-reform insurance rate to investigate the effect of the 2006 Massachusetts health reform on emergency room visits. In this continuous treatment specification, Treateds in equation (3) is replaced by pre-program state level primary school enrollment rate, say EnrolRates.

The dependent variable for specifications 1 through 3 is a binary indicator for enrollment in grade 1 by age 7. The response variable for Spec 4 is the logarithm of age at enrollment in grade 1. Estimates were obtained using probit (specs 1-3) and OLS (Spec 4).

The control groups are individual-level characteristics (a binary indicator for gender, birth order, mother's and father's age and years of schooling), household-level characteristics (household size, binary indicators for whether a household has piped water, electricity, pit latrine, land, and farm animal), and locality-level and related characteristics (proportion of households with piped water, electricity, pit latrine, land, farm animal, and urban dummy for location of residence).

Table 6: DID estimates of the effect of education reform on school enrollment: continuous and binary treatments (N = 2368)

Variable	Dependent variable: Enrollment Status			ln(AgEnrollment)
	(1)	**(2)**	**(3)**	**(4)**
Enrollment rate*After	-0.0246**			
	(0.012)			
School distance*After		0.0383		
		(0.048)		
Planned # schools*After			0.0005	
			(0.0003)	
Treated*After				-0.1973***
				(0.069)
State fixed effects	Yes	Yes	Yes	Yes
State-by-year fixed effects	Yes	Yes	Yes	Yes
Individual Characteristics	Yes	Yes	Yes	Yes
Household characteristics	Yes	Yes	Yes	Yes
Locality & related covariates	Yes	Yes	Yes	Yes
R-squared				0.382
Minus log-likelihood	1001	1001	1001	
AIC	2075	2075	2075	

Statistical significance: *** $p < 0.01$, ** $p < 0.05$, * $p < 0.10$
Standard errors in parentheses are clustered by enumeration area, the primary sampling unit.
The dependent variable for specifications 1 through 3 is a binary indicator for enrollment in grade 1 by age 7. The response variable for Spec 4 is the logarithm of age at enrollment in grade 1. Estimates were obtained using probit (specs 1-3) and OLS (Spec 4).
The control groups are individual-level characteristics (a binary indicator for gender, birth order, mother's and father's age and years of schooling), household-level characteristics (household size, binary indicators for whether a household has piped water, electricity, pit latrine, land, and farm animal), and locality-level and related characteristics (proportion of households with piped water, electricity, pit latrine, land, farm animal, and urban dummy for location of residence).
The post treatment year dummy (After) and the relevant treatment variable are also included in each specification.

In this model, the estimate of the average marginal effect of *EnrolRates* can be interpreted as the change in the probability of enrollment in grade 1 by age 7 for a one percent change in the pre-program enrollment rate. We find that children who lived in states with one percent higher pre-program primary school enrollment rate were about 1.9 percentage points (not reported in Table 6) more likely to enroll in school on time, reaffirming the pre-existing difference on the timing of enrollment across children that live in states with different pre-program primary school enrollment rate. On the other hand, the average treatment effect is estimated to be -0.025. This suggests that, on average, children that lived in a state with one percent higher pre-program enrollment rate were 2.5 percentage points less likely to enroll in primary school on time. Thus, the program has caused children that live in states with lower pre- program enrollment rate to enroll in school on time.

One of the potential concerns of our identification strategy is that the variable we chose (i.e., pre-program primary school enrollment rate) to measure the variation in the intensity of the impact of the program across districts could be arbitrary. As discussed above, we chose pre-program primary school enrollment rate because the program's major objective was to increase primary school enrollment rate from its pre-program level of 30 percent to at least 50 percent. However, we want to check if our results are sensitive to the choice of alternative variables. Columns 2 and 3 of Table 6 present the results from this exercise.

In column 2 of Table 6, we present results from a specification where we use continuous measure of state-level pre-program distance to primary school (instead of pre-program primary school enrollment rate with its result reported in column 1 of Table 6). Since the program intends to make schools more accessible to previously neglected areas, we should expect children who lived in states with longer average distance to primary school before the program to more likely enroll on time relative to those that lived in states with shorter distance to primary school. The magnitude of the average treatment effect of 0.038 can be interpreted as children that lived in a state with an average of 1 km longer pre-program distance to primary school were about 3.8 percentage points more likely to enroll in primary school on time as a result of the intervention/program. However, the estimate is not statistically significant.

Alternatively, we used the number of schools that the federal government has planned to build in each state as part of the program.27 Again, the government has planned to build more schools in underserved areas and hence we should expect the impact of the program to be stronger in areas where the government has planned to build more schools. Under this specification (which is reported in column 3 of Table 6), the average treatment effect is estimated to be 0.0005. This treatment effect

[27] Ideally, we would want to use the variation in the actual number of schools built across districts as a result of the program. Since we do not observe the actual number of schools built in each state, we resort to using the number of schools the government has planned to build in each state.

suggests that building additional 100 primary schools have, on average, increased the probability of on-time enrollment by about 5 percentage points. This effect is not tightly estimated.

Overall, the results reported in Table 6 show that our results are largely not sensitive to the choice of different measures of the variation in the intensity of the impact of the program across districts in Ethiopia.

By how much has the program decreased age at enrollment?

The results presented above support the argument that the program has increased the probability of enrollment in grade 1 at the legal enrollment age. It is, therefore, interesting to investigate by how much the program has decreased age at enrollment. Column 4 of Table 6 presents the estimates of this experiment where the dependent variable is the natural logarithm of age at enrollment. Again, results from the basic specification of the probability model are reported in column 4 of Table 4 with the estimated average treatment effect of 0.213. As discussed earlier, this suggests that children in the treated state are 21.3 percentage points more likely to enroll in primary school on time. Column 4 of Table 6, on the other hand, depicts the results of the log duration regression, where the dependent variable is the natural logarithm of age at enrollment. The results reported in column 4 of Table 6 show that the average treatment effect is -0.197, implying that the difference in age at enrollment between children in the treated and control states has decreased by 19.7 percent as a result of the education program. Remember that children in the treated states, on average, enroll in primary school 1.57 years later than those in the control states before the education program (see Table 3). Hence, the program has decreased age at enrollment in grade 1 by 0.31 ($1.57 * 0.197$) years or 3.72 months.

6. Conclusion

In recent years, many governments in developing countries have attempted to achieve universal primary education through a largescale construction of primary schools. The majority of the studies on primary education in developing countries focus on enrollment rates, without considering the timing of enrollment. Delaying primary school enrollment beyond the legal enrollment age, however, is more of a norm than an exception in these countries. Prior studies have documented that delaying enrollment is costly as it, for instance, decreases an individual's lifetime wealth (Glewwe and Jacoby, 1995), and it increases both school dropout and grade repetition rates (Wils, 2004). Though delayed enrollment is widely observed in developing countries and there is a high cost associated with it, the literature on the topic is limited, and we have a limited understanding of why children delay enrollment in primary school. This paper attempts to fill the gap in the literature by investigating the effect of access to primary school on the timing of enrollment in primary school.

Identifying the causal effect of access to primary school on the timing of enrollment is complicated by endogeneity of access to primary school. For instance, parents who choose to live at closer proximity to school may have strong taste for education and enroll their children in school on time regardless of proximity to school. To mitigate biases due to endogeneity of access to school, we exploit the education reform in Ethiopia as exogenous source of variation in access to primary school. Then, we estimated difference-in-differences model where the dependent variable is a binary indicator for enrollment in primary school by age 7, the legal enrollment age in Ethiopia, and the natural logarithm of age at enrollment in primary school.

The average treatment effect is estimated to be between 0.21 and 0.35, suggesting the probability the child enrolls in primary school on time has increased by between 21 and 35 percentage points as a result of the education reform. The log duration DID regression (where the dependent variable is the natural logarithm of age at enrollment), on the other hand, suggests that the reform has decreased age at enrollment in grade 1 by about 4 months. These estimates highlight the important role access to school plays in inducing parents to enroll their kids in primary school at the legal enrollment age.

The findings reported here are important as they show that, in Ethiopia, education intervention has been effective in decreasing age at enrollment in primary school. The intervention was meant to increase primary school enrollment, but it also induced households to enroll their children in primary school at a relatively younger age. The Ethiopian government provides free primary education. Thus, households do not have to pay for tuition. Households, however, still have to incur other costs related to school attendance, including the child's opportunity cost of time in terms of forgone family income from child labor.

Making schools accessible to poor households would decrease the time the child spends walking to school, and hence decreases the opportunity cost of school attendance. Moreover, accessibility induces physically weaker children to attend school since it decreases the physical strength needed to walk the distance to school. Policy makers, thus, should also consider improving communication networks and public transport as alternative/additional ways to encourage households to enroll their kids in primary school on time. At this point, it is worth mentioning that there is inequality in access and on-time enrollment in Ethiopia where girls, kids with disabilities, and kids from rural areas and emerging states are at disadvantage. Thus, policy choices that focus on narrowing down inequalities across groups should be given a priority.

Providing quality education has increasingly become a challenge in Ethiopia given the scale of expansion and increased access in the last couple of decades. However, the data still show that kids in Ethiopia do not enroll on-time at their legal school starting age. This has recently been exacerbated by COVID-19 and the on-going conflict throughout the country where thousands of schools have been destroyed and millions of kids are forced to be out of school at the moment, see, for example, Ministry of Education (2022). A country like Ethiopia should still need to work on both improving access and quality; of course, along with improving equity and finding sustainable ways of financing the education sector. We, thus, believe this study will inform not only Ethiopian policymakers but also other policymakers in similarly resource-constrained countries.

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Appendix

Appendix A. Additional Tables

Table A.1: List and Description of Variables Used in Estimation

Variable	Description
Dependent variables	
Enrolled in grade 1 by age 7 (yes=1)	=1 if a child is enrolled in grade 1 at age ≤ 7; 0 otherwise
Age at enrollment	Age in years by the time a child enrolled in grade 1
Independent variables	
Treated	=1 if state level primary school enrollment rate is ≤ 30; 0 otherwise
After	=1 if year=2004; 0 otherwise
Girl	=1 if a child is a girl; 0 otherwise
Birth order	=1 for a first-born child, =2 for a second-born child, etc
Household size	Total number of people who live in the household
Dad’s years of schooling	Highest grade completed by the father
Mom’s years of schooling	Highest grade completed by the mother
Dad’s age	Father’s age in years
Mom’s age	Mother’s age in years
HH has piped water	=1 if the household has piped water; 0 otherwise
HH has electricity	=1 if the household has electricity; 0 otherwise
HH has pit latrine	=1 if the household has pit latrine; 0 otherwise
HH owns land	=1 if any member of the household owns any land holdings regardless of how the land is used; 0 otherwise
HH owns farm animal	=1 if the household owns farm animals 0 otherwise
Proportion of hhs with piped water	Proportion of households with piped water
Proportion of hhs with electricity	Proportion of households with electricity
Proportion of hhs with pit latrine	Proportion of households with pit latrine
Proportion of hhs with land	Proportion of households that owns land
Proportion of hhs with farm animal	Proportion of households that owns farm animal
Log (Household expenditure)	Log of annual total household expenditure in 2005 prices
Unemployment rate	State level unemployment rate
Urban area (yes=1)	=1 if the household is located in urban area; 0 otherwise

Table A.2: Fraction of Children Enrolled in Grade 1 by Age 7 by Treatment Group and Time (Observations 2368)

Group	Before the Change	After the Change	Time Difference
Treated	0.228***	0.224***	-0.004
	(0.020)	(0.010)	(0.022)
Untreated	0.476***	0.365***	0.112*
	(0.046)	(0.041)	(0.062)
Group Difference	-0.248***	-0.141***	0.107
	(0.050)	(0.042)	(0.081)

Notes: Standard errors are given within parentheses. The standard error associated with the treatment effect (highlighted) is clustered by enumeration area, the primary sampling unit.
Statistical significance: *** p < 0.01, ** p < 0.05, * p < 0.10

Table A3: LPM DID Estimates of the Effect of Education Reform on On-time School Enrollment (Observations 2368)

Dependent Variable: Binary Indicator for Enrollment in Grade 1 by Age 7

Variables	(1)	(2)	(3)	(4)	(5)
Treated*After	0.3449	0.3519**	0.3469**	0.3514**	0.3253*
	(0.233)	(0.165)	(0.176)	(0.173)	(0.169)
State fixed effects	Yes	Yes	Yes	Yes	Yes
State-by-year fixed effects	Yes	Yes	Yes	Yes	Yes
Individual characteristics	No	Yes	Yes	Yes	Yes
Household characteristics	No	No	Yes	Yes	Yes
Locality & related Characteristics	No	No	No	Yes	Yes
Unemployment rate	No	No	No	No	Yes
R-squared	0.030	0.171	0.230	0.239	0.239

Statistical significance: *** p < 0.01, ** p<0.05, * p<0.10
LPM/OLS estimates of the treatment effect are based on standard errors clustered by enumeration area, the primary sampling unit.

The control groups are individual-level characteristics (a binary indicator for gender, birth order, mother's and father's age and years of schooling), household-level characteristics (household size, binary indicators for whether a household has piped water, electricity, pit latrine, land, and farm animal), and locality-level and related characteristics (i.e., proportion of households with piped water, electricity, pit latrine, land, farm animal, and urban dummy for location of residence), and state unemployment rate.

Appendix B. Additional Figures

Figure B.1: Histogram and Kernel Density Estimate of the Treatment Effect, Rural Sample

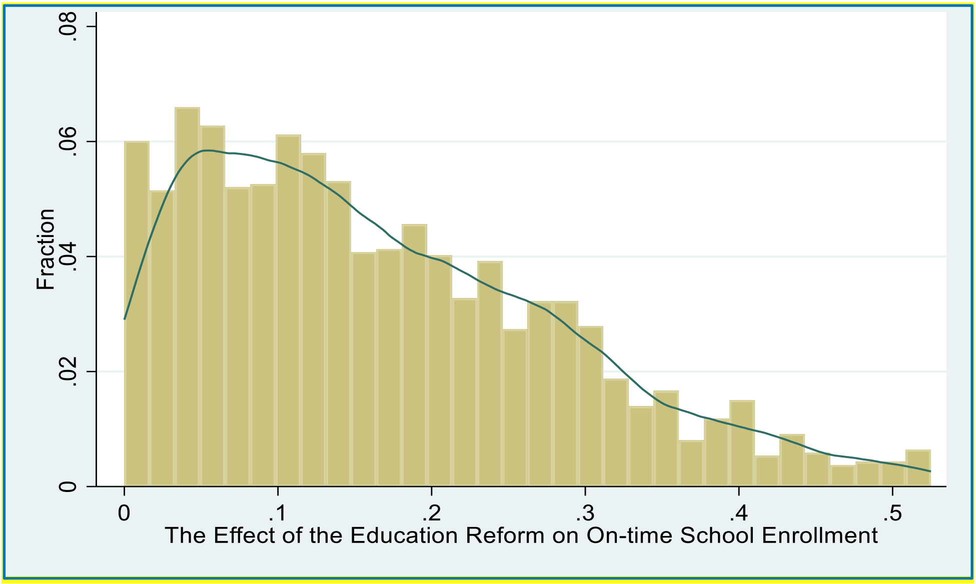
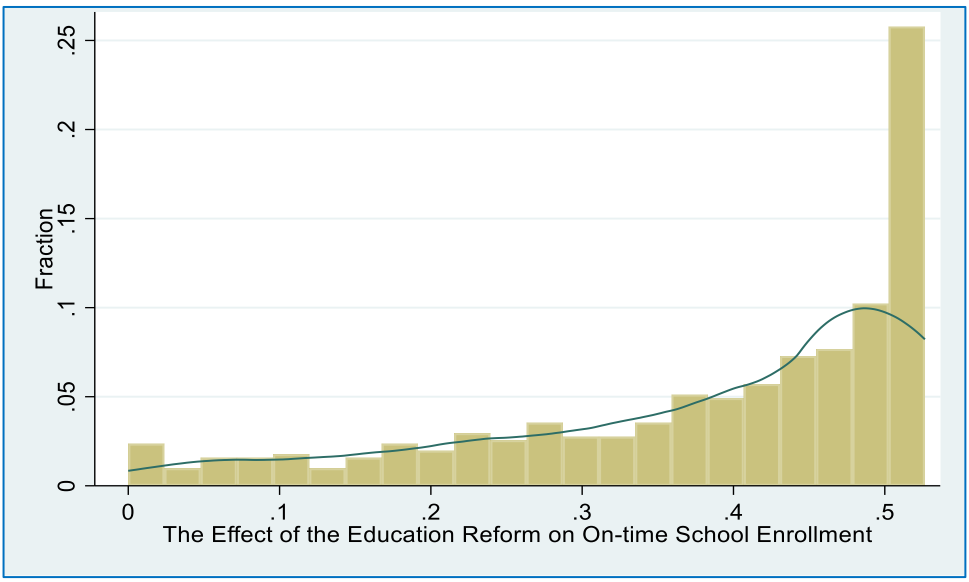


Figure B.2: Histogram and Kernel Density Estimate of the Treatment Effect, Urban Sample



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