Agricultural Technologies and Women's Empowerment in Rural Ethiopia: Do Improved Agricultural Technologies Matter?

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Abstract

Improved agriculture technologies are key factors for increasing welfare, especially in agriculture sector where most of the population in developing countries must deal with high workloads and little returns. Several empirical studies show that adoption of agricultural technologies can affect welfare positively in general, but because of its complex and multidimensional nature women's empowerment has not been brought to the agenda in the context of program evaluations. This study uses a panel data analysis using differences-in-differences and propensity score matching techniques. The objective of the study is evaluating the impact of adopting fertilizers with extension services on women's empowerment. The study links women's empowerment in a program evaluation setting where the issue is new to the sector. The results show that empowerment levels for both males and females are lower in Ethiopia as compared to some sub-Saharan countries. The findings also show that A-WEAI [1] is 0.50. Adopting technologies has improved empowerment in five domains (5DE), but there have been no improvements in the gender parity index (GPI). Domain-wise, income contributes most to women's disempowerment followed by lack of control over resources. The results of both propensity score matching, and differences-in-differences methods show that adoption of technologies has a positive impact on 5DE while they have mixed results for GPI. Sex-wise, the 5DE for females increases more than that for males. Finally, it is noted that a change in A-WEAI is derived more by 5DE than GPI.

Keywords: Women's empowerment; five domains; gender parity; technology adoption; Ethiopia

JEL Classification Codes: D13; I31; J16; M54; O33; Q12

[1] Abbreviated Women's Empowerment in Agriculture Index.

1. Introduction

1.1 Background

Several studies use empowerment to represent a wide range of concepts and for describing multiple ranges of outcomes. The word has been used more often to advocate for certain types of policies and intervention strategies than for analyzing empowerment itself.

Growing concerns indicate that women's empowerment is increasingly being viewed as one of the key elements of poverty reduction strategies. It is not only seen as a development objective in itself but as a means of promoting growth, reducing poverty, and promoting better governance (King and Mason, 2001). Women's empowerment and its analyses have received a growing amount of attention in research, especially since its inclusion in the third Millennium Development Goal (MDG) of promoting gender equality and empowering women.

The third MDG is not only a goal but it also contributes to improving productivity and increasing women's efficiency (Alkire et al., 2013). Women's empowerment was a priority embedded in the Sustainable Development Goals (SDGs) in 2012 (United Nations, 2015): one of the 17 SDG 5 states, 'Achieve gender equality and empower all women and girls.'

Evidence also shows that women's role in agriculture is significant as they produce over 50 percent of the world's food (FAO, 2011) and comprise about 43 percent of the agricultural labor force, both globally and in developing countries (Doss, 2014). Additionally, women invest as much as 10 times more of their earnings than men do on their family's well-being in areas including child health, education, and nutrition (Duflo, 2012; Quisumbing 2003; Quisumbing and Hallman 2003; Quisumbing and Maluccio, 2000, 2003; Skoufias 2005). Women's empowerment thus has a direct impact on agricultural productivity and household food security (Harper et al., 2013; Sraboni et al., 2014), and as a result it remains at the core of agricultural research and outreach practices in developing countries (Gates, 2014). Therefore, gender related policy interventions that improve women's status and reduce gender inequalities are expected to improve women and children's well-being, owing to women's important role in childcare and managing complex household activities including being children's caretakers and preparing food.

The agriculture sector is connected to food security as it is a source of food and nutrients, a broad-based source of income, and it directly affects food prices (Arimond et al., 2010). As women account for a dominant portion of the agricultural labor force in developing countries, supporting and empowering women leads to an increase in agricultural production (FAO, 2011a). But still there are considerable gender inequalities in the agriculture sector. Poor women or women who live in poor households and those who are more vulnerable to food-insecurity are more likely to get involved in the agriculture sector particularly as wage laborers, because women's earnings are important for their families' subsistence.

The process of empowering women in the agriculture sector to produce more food for local consumption and/or local markets is one of the right ways of reducing vulnerability to poverty and food insecurity as it can help increase income generated from the sector and increase food consumption (Baiphethi and Jacobs, 2009) because women play greater roles in achieving all pillars of food security: food availability, access, utilization, and stability in their households (Bob, 2002; Galie, 2013).

Women in rural areas are producers of food, income earners, and caretakers of households and their nutrition security. Evidence shows that investments in women's empowerment related projects contributes to improving broader development outcomes including health, education, poverty reduction, reducing vulnerability to food insecurity, and economic growth (Mayoux, 2006; Quisumbing 2003; Quisumbing and Maluccio, 2000). Evidence also shows that empowering women in the agriculture sector can provide sustainable ways for them to feed themselves leading to greater income improvements from the surplus produced, which in turn makes them less vulnerable to both poverty and food insecurity.

1.2 Rationale and Motivation

In the last few decades there has been growing interest in the agriculture sector as an engine of growth and development, and parallelly a greater recognition of the important role that women play in the sector (Alkire et al., 2013; FAO, 2011a). Women in rural societies are often responsible for managing complex household activities and they also pursue multiple livelihood strategies including producing agricultural crops, tending to the animals, processing and preparing food, working for wages in agricultural or other rural enterprises, collecting fuel and water, engaging in trade and marketing, caring for family members, and looking after their homes.

Apart from recognizing women's role in agriculture, it is also important to develop indicators for measuring women's empowerment, and examining its relationship with various welfare outcomes or indicators and effectively monitoring the impact of interventions in agriculture related sectors for empowering girls and women. The complex and multidimensional nature of empowerment makes its measurement more difficult, and this is especially true in the context of agriculture, where the concept is relatively new. If we fail to measure empowerment effectively, the impact of an intervention on empowerment is more likely to receive much less attention than income or other more measurable outcomes. In addition, most available indicators of women's empowerment in agriculture are not appropriate for the agriculture sector in program evaluation context.

The nature, form (characteristics), and extent of gender disparities and means of empowering women vary across countries, communities, and regions in general. In some communities, women may enjoy considerable power in some groups of indicators while they may be disempowered in others (Alkire et al., 2013). To design effective gender intervention frameworks, it is also important to recognize the context and domain specific heterogeneity in the empowerment indicators.

Nowadays the status of women in agriculture is receiving attention in literature even though a research gap exists regarding the specific impact of agriculture related technologies on empowering women. However, a large body of empirical literature has documented that adopting agricultural technologies improves social welfare besides leading to women's empowerment. As most of the indices and indicators used in monitoring programs on gender equality have little coverage of the agriculture sector and many agriculture-related indicators are gender-blind, there is a clear need for a tool to measure and monitor the impact of agricultural interventions on women's empowerment in the agriculture sector.

To the best of our knowledge, there are gaps in literature on which dimensions of women's empowerment in agriculture drive the process of empowerment/disempowerment due to the adoption of improved agricultural technologies. Therefore, the main objective of this research is identifying the impact of improved agricultural technology adoption on women's empowerment in rural Ethiopia. The study also identifies the indicators and dimensions of women's empowerment that are most affected by the adoption of the technology under study. Thus, to fill these methodological gaps and limitations in measuring women's empowerment in the agriculture sector, there is a clear need to conduct research that focuses on the adoption-empowerment linkages. We hope our new methodology will help promote further development of impact evaluation settings for studying women's empowerment in the agriculture sector.

The rest of this paper is organized as follows. Section 2 presents a literature review in the areas of technology adoption and women's empowerment while Section 3 describes the methodology used for estimating the impact of the stated technology. Sections 4, 5, and 6 discuss the findings, concluding remarks, and policy implications respectively.

2. Literature Review

2.1 A Brief Overview of Women's Empowerment

The notion and concept of empowerment is related to issues like agency, autonomy, self-direction, self-determination, liberation, participation, mobilization, and self-confidence (Ibrahim and Alkire, 2007; Narayan, 2005). There is large and growing documentation and literature on the concepts and measurements of empowerment (see Alsop and Heinsohn 2005; Alsop et al., 2006; Kabeer 1999, 2001; Narayan 2005). Most of the recent studies develop multiple indicators as empowerment is a multidimensional issue and a complex process by its very nature that can be conceived and interpreted differently by different people (for example, Malhotra et al., 2002; Mosedale, 2005).

There are many different definitions of empowerment, but most of these emphasize on agency and gaining the ability to make meaningful choices (Kabeer 2001). Many of the definitions are drawn from Sen's (1989) concept of an agent. Kabeer's 'resources, agency, and achievements' framework also provide a practical intuition for measuring empowerment, which involves three inter-related dimensions: resources (pre-conditions), agency (process), and achievements (outcomes) (Kabeer 1999, p.437). Kabeer conceived of empowerment as a process that enables individuals/groups to exercise a range of available choices.

Reflecting on the multiple experiences and views of empowerment, there are many definitions of empowerment used in literature (see Ibrahim and Alkire 2007, p.380-82 for a wide-ranging review of related works on empowerment). Three definitions of empowerment that are commonly cited are found in Alsop et al. (2006); Kabeer (2001); and Narayan (2002). Kabeer (2001, p.19) defines empowerment as "expanding people's ability to make strategic life choices, particularly in conditions where this ability had been denied to them." Alsop et al. (2006, p. 10) describe empowerment as "a group's or individual's capacity to make effective choices, that is, to make choices and then to transform those choices into desired actions and outcomes." This specific definition has two parts -- the component related to Sen's concept of agency (the ability to act on behalf of what people value and have reason to value or make purposeful choices) and the part related to the institutional environment, which offers people the ability to exert agency fruitfully or in which actors operate on the assumption that they can influence and have the ability to transform agency into action (Alkire, 2008 ; Ibrahim and Alkire, 2007). The second component focuses on the opportunity structure that provides people what might be considered pre-conditions for effectively achieving their agency. However, these are not mutually exclusive; such that the shift is one of focus, not the only factor. It is true that the process of women's empowerment is incomplete unless it attends to people's abilities to act, the institutional structure, and the various non-institutional changes that are instrumental in their increased agency.

Narayan (2002, p. 14) defines empowerment as "the expansion of assets and capabilities of poor people to participate in, negotiate with, influence, control, and hold accountable institutions that affect their lives." His definition focuses on four main elements of empowerment: access to information, inclusion and participation, accountability, and local organizational capacity. A focus on individual choices can limit the definition of empowerment, especially in cultural contexts where community and mutuality are valued. Several studies show that the definition of empowerment varies across disciplinary traditions, domains, and contexts. Most definitions of empowerment focus on issues of gaining power and control over decisions and resources that determine one's quality of life. In their definition, both Kabeer and Alsop also include agency and capacity - the ability to act on one's choices. In comparison, Narayan's definition is broader than Alsop's as it also includes the interactions between people and institutions.

When dealing with the concept of women's empowerment, it is necessary to distinguish two aspects. First, empowerment as a field of operation, its dimensions, its inter-linkages, as well as its inter-sectionalities with other fields of power relations such as those of race/ethnicity and class (as empowerment is a multidimensional phenomenon). Second, women's empowerment as a process in which the following elements need to be considered: awareness/ consciousness, choice/alternatives, resources, voice, agency, and participation. The second dimension of women's empowerment is linked to enhancing their abilities to make choices in areas of their lives that matter to them, both the 'strategic life choices' that Kabeer (1999, 2001) discusses and choices related to their daily lives.

The existing empirical studies on 'gender in agriculture' consistently show that women lack access to and control over resources such as farmland and capital as well as varieties of agricultural inputs and technologies such as improved crop varieties, training, information, and marketing services (Fletschner and Kenney, 2014). Evidence also shows that women have an unmanageable workload, they lack access to credit or have no decision-making powers over credit and are poorly represented in agricultural and non-agricultural groups and organizations (Alkire et al., 2013; Akter et al., 2016b).

2.2 Adoption literature

2.3 Linkages Between Agricultural Technologies and Women's Empowerment

Very little is known about the connections between women's empowerment and the impact of improved agricultural technology adoption in rural societies. No research has systematically examined the possible relationships between farm related technologies and the participation rates and status of women and their level of empowerment relative to men, specifically in the context of the agriculture sector.

However, several studies have been conducted in the area of agricultural technology adoption and its related impact on social welfare indicators, other than empowerment. These welfare indicators include income, food security, poverty, production, employment, access to market participation, and child nutrition (Adekambi et al., 2009; Asfaw and Shiferaw, 2010; Asfaw et al., 2010, 2012; Ferede et al., 2003; Hundie and Admassie, 2016; Kassie et al., 2010; Khonje et al.,2015; Mendola,2003, 2007; Mulugeta and Hundie, 2012; Shiferaw et al., 2014; Asfaw et al., 2012; Wu et al., 2010; Zeng et al., 2014). A number of these studies evaluate the connection between causes and impacts using different estimation techniques and find that adopting modern agricultural technologies and practices improves household welfare in general.

Even if the issue of empowerment in agriculture is much less studied, due to women's remarkable role in the development process in the agriculture sector, there are several reasons to hypothesize why women's empowerment and agricultural technologies may be inter-connected. Women who are empowered tend to be more educated and have greater decision-making powers within their households. Some studies have found that women are more likely than men to invest in goods that will benefit their children and households, especially the health and education of their families (Quisumbing and Hallman, 2003; Skoufias, 2005).

Yilma et al. (2012) investigated the impact of irrigation technology adoption on empowering women in northern Ghana and found that adoption of irrigation technology positively contributed to overall poverty alleviation and empowerment of women. Their study also states that as irrigation is a labor-intensive technology, it can create employment opportunities for both the growing population and women in the agriculture sector. But the effectiveness of the technology depends on some basic factors like the operations of the input and output markets and other institutional factors such as access to credit services and provision of advisory and extension services in the sector.

Closing the gap between access and availability of technology between women and men requires that the necessary technologies exist to satisfy the priority needs of female farmers, given that women are aware of their usefulness and have the means to acquire the technologies (FAO, 2011a). If equal access to a broad range of technologies is available to women, it could help them free their time for more productive activities, enhancing their agricultural productivity, improving market returns, and empowering them to make choices that are better for themselves and their families. It has also been shown that improved crops with higher yields which are better adapted to pests and diseases can save women time spent on cropping activities. Additionally, improved practices like integrated pest management can also reduce labor requirements and costs of pesticide applications, reduce female farmers' exposure to hazardous chemicals, and increase yields.

Njuki et al. (2014) in their study in Kenya and Tanzania found that women can benefit from adoption of a technology even if they do not recognize their ownership in their households. Their study shows that in Tanzania, most adopters of irrigation pumps were men, but still women were able to use the pumps and influence decisions on how to use them like whether to irrigate the crops grown on plots they managed or not. Njuki et al. (2014) also report that the time required to fetch water for domestic and livestock uses reduced due to adoption of irrigation pumps. Again, increased incomes from the sale of irrigated farm outputs helped women make contributions to women's groups and increased their access to social capital. The study also showed that income increases enabled women to take basic personal and household decisions without consulting their husbands.

Doss (2012) in his study on women's economic empowerment in agriculture, states that improved technologies or new inputs that can save or free up women's time and improve working methods in the agriculture sector allow women to increase incomes, enable them to invest in new business ventures, lead to increased agricultural production, and help reduce their drudgery. Doss' study also argues that certain technologies that are relevant for women must be identified. Some technologies that work well for women, usually technologies that do not require much land, labor, or time must be focus areas for empowering women.

In addition, the study's results show that when available land is limited, "women can use small-scale silage-making technologies, or plastic storage tubes and boxes, to collect grasses from surrounding public lands to use as cattle feed, freeing up their own limited land to grow other vegetables. Such technologies can increase nutrition and income by both improving livestock's health and by allowing women to diversify their incomes and diets with vegetables" (Doss, 2012, p.16).

A study by Paris and Chi (2005) in Vietnam on the impact of row seeder technology on women labor, showed that the impact was based on the women's initial living status. In the case of landless and poor women who engaged in low wage paying activities and used hand-weeding practices it led to substantial income losses. Landless and poor women need to engage in off-farm activities in other villages and districts which leads to neglecting their regular tasks in their fields and the impact of row seeding becomes less.

In a study on closing the gender gap in agriculture, Huyer (2016) notes that technologies could empower women under certain circumstances including pre-conditions like correct implementation in a framework of mutually reinforcing resources, women's control over assets, equitable decision-making between women and men, and strengthened women's capacity. The study also states that technology is not sufficient in itself and it needs to be considered in the context of local knowledge, culture, gender relations, capacities, and ecosystems.

Some interventions discuss reaching women with technology without monitoring if or how this happens. Instead, identifying the distribution of rights can shed light on both the potential benefits and costs that adopting a technology confers on women and men within a household (Theis et al., 2018). This evidence will help ensure that adoption of technology strategically advances development objectives such as food and nutritional security, resilience, and women's empowerment, rather than taking technology adoption as an end in and of itself.

From this literature review it can be argued that the impact of different agricultural technologies on women's empowerment are less studied and the existing results are mixed and vary according to conditions and circumstances.

3. Methodology

3.1 Conceptual Framework of Adoption Decisions and Impact Evaluation

In the context of technology adoption, farmer households face outcomes that are uncertain (Rahm and Huffman, 1984). In such a setting, farmer households are assumed to take adoption decisions based on the motives of utility maximization.

Based on the available options (to use chemical fertilizers jointly with extension services or not) households decide to adopt a technology if it will lead to an increase in utility levels.

Following this condition, the difference between the utility from adoption (U_{1iA}) and non-adoption (U_{0iN}) of the technology is given as T* such that the utility maximizing farm household i will choose to adopt the technology if the utility gained from adopting it is greater than the utility of not adopting the technology given by$(T^* = U_{1iA} - U_{0iN} > 0)$. The common challenge here is that the two utilities are unobservable, so they need to be expressed as a function of observable components in the latent variable model:

(1) $$T_{it}^* = \beta X_{it} + \varepsilon_{it}, with \;\; T_i = \begin{cases} 1 & if \; T_i^* > 0 \\ 0 & otherwise \end{cases}$$

where T is a binary 0 or 1 dummy variable that indicates use of technology; T=1 if the technology is adopted and T = 0 otherwise. β is a vector of the parameters to be estimated, X is a vector that represents household characteristics, t is time (year dummies), and ε is the random error term with mean zero and constant variance.

Due to the unobservable problem of the two utilities at a time, this study uses the differences-in-differences (DID) method that can control for systematic differences between the households in the treated and control groups (Bucheli et al., 2016). The DID framework assumes that both groups, treated and control, have common pre-intervention trends. But it is less efficient when the two groups may not share similar profiles. In such cases DID fails to correctly account for heterogeneity factors. Thus, under these limitations, DID fails to produce consistent estimates.

To address this limitation, we also used the propensity score matching (PSM) technique to compare the outcomes between households with similar probabilities of being treated given a set of characteristics, X. This is a two-step procedure where we first estimated a probability model for adoption to calculate the probability (or propensity scores) of adoption for each observation. Second, we matched each adopter to a non-adopter with similar propensity score values to estimate the average treatment effect on the treated (ATT).

3.2 Measuring Women's Empowerment

Linking women's empowerment and welfare is not a straightforward task and the initial challenge starts with measuring empowerment as a variable of interest and it has linkages between women's empowerment and welfare measures which are more difficult to quantify. Several studies show that measuring women's empowerment is difficult due to the variety of definitions of empowerment.

Available literature shows that empowerment in agriculture is generally defined as one's ability to take decisions on matters related to agricultural activities as well as one's access to material and social resources needed to carry out those decisions (Alkire et al., 2013).

Women's empowerment is a multidimensional (Kabeer, 1999) and relational concept (Kabeer, 2011). Its dimensions include resources for empowerment, agency or the ability to make choices including in relation to one's gendered attitudes and beliefs; achievements in the political, economic, social and cultural realms; and the inter-generational transmission of resources and opportunities (Kabeer, 1999). Women's empowerment is contingent on social transformation across these inter-related domains (Kabeer, 2005) and it is also an individual and a collective process (Eger et al., 2018; Kabeer, 2011). Empowerment involves claims on assets and resources, as well as control over beliefs, values, and attitudes (Cornwall, 2016).

The complex and multidimensional nature of empowerment makes it difficult to measure it. This is especially true in the context of agriculture, where the concept of empowerment is relatively new (Alkire et al., 2013). Even if empowerment exists at the individual level, several existing indices of empowerment and gender are typically measured at the aggregate country level. The first and original comprehensive and more standardized approach for directly measuring women's empowerment in agriculture is the Women's Empowerment in Agriculture Index (WEAI).

WEAI is a new index used for monitoring gender gaps in agricultural production and development projects. The index consists of five domains of empowerment including women's decision-making role in agricultural production, control over income and production resources, leadership opportunities, and time availability (Alkire et al., 2013). It was originally jointly developed by USAID, IFPRI, and the Oxford Poverty and Human Development Initiative (OPHI). The index was designed as a monitoring and evaluation tool for the US government's Feed the Future initiative to directly capture the status and level of women's empowerment and inclusion levels in the agriculture sector.

WEAI uses survey level data from a self-identified primary sample of male and female adult decision makers, whose age is 18 and over in the same household which makes it easy to aggregate the index at the program level. WEAI has two sub-indices: the five domains of empowerment (5DE) and the gender parity index (GPI) that measures women's empowerment. Since its launch in February 2012, WEAI has been implemented in 19 Feed the Future focus countries (Malapit et al.,2017).

The first component of WEAI, 5DE, is constructed from individual-level empowerment scores which reflect each person's achievements in the five domains as measured by 10 indicators that show the involvement of unit i in the agriculture sector, with its corresponding weight.[2] Relative empowerment is captured by GPI, which reflects a woman's achievements in the five domains relative to the primary male in the same household. Households are classified as having gender parity if either the woman is empowered (her empowerment score is 80 percent or higher) or her score is greater than or equal to the empowerment score of the male decision maker in her household. All these indices have values ranging from 0 to 1, with higher values reflecting greater empowerment. The overall WEAI is a weighted average of 5DE and GPI, with weights 0.9 and 0.1 respectively.

WEAI builds on research to develop indicators of agency and empowerment (for example, Alsop et al., 2006; Ibrahim and Alkire 2007; Narayan 2005; Narayan and Petesch 2007) that propose domain-specific measures of empowerment obtained using questions that can be fielded in individual or household surveys.

IFPRI has released an abbreviated WEAI (A-WEAI) with six, instead of 10, indicators in the same domains (Malapit et al., 2017). A-WEAI retains the five domains and it takes about 30 percent less time to administer than the original WEAI. It also includes new autonomy vignettes, a simplified 24-hour recall time module that collects only primary activities, and streamlined sections on production decisions and resources.[3]To ensure enough coverage of relevant aspects of agriculture, it is necessary to retain all the five domains developed under WEAI so that it is possible to monitor progress and improvements in how the Feed the Future program empowers women in the agriculture sector (Alkire, 2015). Thus, the A-WEAI survey instrument reflects all five domains of empowerment in agriculture but collects only six out of the 10 original indicators. The indicators that are dropped are autonomy in production; purchase, sale, or transfer of assets; speaking in public; and leisure. Among the indicators that are retained, the definitions, cutoffs, and aggregation rules remain the same; only the indicator weights are changed (except for workload) (Malapit et al., 2017).

3.3 Model Specification

The basic assumption of DID is that there is a common trend. Even when the common trend is not violated, including additional covariates, it can increase the precision of the ATT estimation given that the model is correctly specified (Card 1992). In such a case, DID assumes the following form: a DID model with a two-ways fixed effect:

(2) $$y_{it} = \alpha_i + \varepsilon_t + \theta T_{it} + \mu_{it}$$

where y_{it} is the outcome variable (5DE and empowerment gap (EG) in our case) for household i in the adoption category at time t, T is the treatment indicator factor which equals 1 if the household is an adopter and 0 otherwise. α_i are individual fixed effects, ε_t are the year or wave fixed effects, and μ_{it} is the random error term. One possible way of relaxing the common-trend assumption is by adding further covariates to the DID regression model. This nature (feature) is a significant advantage of DID compared to other program evaluation methods. Even when the common-trend holds, including additional covariates (either time-

[2] See Alkire et al. (2013) for the details of Domain, Indicator, Definition of Indicator and Weights for WEAI.
[3] A comparison of the domains and indicators in the original WEAI and A-WEAI is presented in detail in the Appendix.

invariant or unit (individual) specific) it helps increase the precision of the estimated impacts. In such cases we have the following DID form:

(3) $$y_{it} = \alpha_i + \varepsilon_t + \theta T_{it} + \beta X_{it} + \mu_{it}$$

where X_{it} is a vector of other covariates.

An additional generalization of the DID estimator is required when T_{it} changes over time across different individuals or locations. This is a generalization of the two-time DID to multiple-time cases (Angrist and Pischke, 2008), and in such a case we need to use regression with lags and leads of the treatment variable T_{it}. Correcting for possible differences in time trends across different individuals or locations/regions is necessary for DID to remain unbiased, and we estimate the following modified version of DID:

(4) $$y_{it} = \alpha_i + \varepsilon_t + \sum_{\tau=0}^{m} T_{t-\tau}\,\theta_{-\tau} + \sum_{\tau=0}^{q} T_{t+\tau}\,\theta_{+\tau} + \beta X_{it} + \mu_{it}$$

where *m* shows the number of lags (θ_{-1}, θ_{-2}, . . ., θ_{-m}) or post-treatment effects and *q* shows the number of leads (θ_{+1}, θ_{+2}, . . . , θ_{+q}) or anticipatory effects. Note, however, that we need relatively longer periods of panel data to estimate a model of this form. Unfortunately, we cannot apply this method in the current study because of the limited rounds of the data we used.

The second method is PSM which compares the outcomes of a treated observation with the outcomes of comparable non-treated observations. It is defined as the conditional probability of receiving a treatment given pre-treatment characteristics as:

(5) $$P(X) \equiv Pr\{T_i = 1|X\} = E\{T_i|X\}$$

where T_i= {0, 1} is the indicator of exposure to treatment and X is the multidimensional vector of pre-treatment characteristics.

Rosenbaum and Rubin (1983) show that if the exposure to treatment is random within cells defined by X, it is also random within cells defined by the values of the variable $P(X)$ .Let Y_{1t} be the value of the welfare outcome variable when household *i* is subject to treatment ($T = 1$) and Y_{0t} be the same variable when the household does not adopt the technology ($T = 0$). So, given a population of units denoted by i, if the propensity score $P(X_i)$ is known ATT can be estimated as:

(6) $$\begin{aligned} ATT &= E\{Y_{1t} - Y_{0t}|T = 1\} \\ &= E(Y_{1t}|T = 1) - E(Y_{0t}|T = 1) \end{aligned}$$

For robustness of our results we used the balance of the scores and covariates using the following methods: As suggested by Rosenbaum and Rubin (1985) the standardized bias (SB) between treatment and non-treatment samples is suitable for quantifying the bias between both the groups. For each variable and propensity score, the standardized bias is computed before and after matching as:

(7) $$SB(X) = 100\frac{\bar{X}_t - \bar{X}_{nt}}{\sqrt{\frac{V_t(X)+V_{nt}(X)}{2}}}$$

where $\bar{X}_t$ and $\bar{X}_{nt}$ are the sample means for the treatment and control groups, and $V_t(X)$ and $V_{nt}(X)$ are the corresponding variances. The bias reduction (BR) can also be computed as:

(8) $$BR = 100\left(1 - \frac{B(X)_{after}}{B(X)_{before}}\right)$$

where *B*(*X*) is the proportion difference in the outcomes of the treatment and control groups

There are many important theoretical reasons (and huge empirical literature supporting the theories) why agricultural technologies can improve farm households' well-being, but how can we be sure that the better well-being of adopters compared to non-adopters is because of technology adoption (or not)? In other words, the differences between the treated and control groups could be because of the pre-treatment differences, or agricultural technology adoption may also lead to welfare deterioration. Several existing studies conclude that improved agricultural technologies act in favor of the adopters. But it should also be noted that adoption may worsen social welfare.

3.4 Modeling the Women's Empowerment in Agriculture Index (WEAI)

In measuring empowerment, the weights of the 5DE and GPI sub-indices are 90 percent and 10 percent respectively. However, the choice of weights for the two sub-indices is somewhat subjective and open to changes but focuses more on 5DE while still recognizing the importance of gender equality. This study uses A-WEAI that retains the five domains of empowerment, but the 10 indicators of WEAI are reduced to six.

The construction of WEAI is based on the Alkire-Foster (AF) (2007, 2011a) methodology which focuses on building multidimensional poverty. The measure uses a 'dual-cut-off' to identify and count poor people and aggregates based on an extension of the Foster-Greer-Thorbecke (FGT) measures to multidimensional space (Alkire et al., 2013). The AF methodology is used as it not only creates the indices, but it also enables us to put the headline figure into its individual indicators.

i) The 5DE index

The 5DE index assesses if women are empowered and the degree to which they are empowered across the five domains in agriculture. The 5DE sub-index captures women's empowerment within their households and communities and the women who are disempowered. It also shows the percentage of domains in which they meet the required thresholds and thus experience adequacy.

Even if the end objective is measuring empowerment, 5DE is constructed in such a way that disempowerment can also be analyzed, which allows us to identify the critical indicators that must be addressed for increasing women's empowerment. This is a crucial contribution for decision makers that they should focus on the most disempowered. Following Alkire et al. (2013) the disempowerment index across the five domains (M_0) was first computed and then 5DE was computed as $(1 - M_0)$.

ii) Identification of the disempowered

In the identification stage, there are two equivalent notations that can be used for describing the construction of 5DE. The first is the 'positive' notation that focuses on the percentage of empowered women and adequacies among the disempowered ones. The second notation focuses on the percentage of women who are disempowered and the percentage of domains in which they face inadequate achievements. In this study, we use the second notation which is consistent and applicable with the M_0 measurement of multidimensional poverty (Alkire and Foster, 2011a, 2011b).

To make the identification process of disempowerment simple, we first need to code all the adequacy indicators. All adequacy indicators need to be coded so that they assume the value 1 if the individual is inadequate in that indicator and 0 otherwise.

Let us consider a sample of N individuals and let $D \geq 2$ be the number of domains and $x = [x_{ij}]$ be the N×D matrix of inadequacy achievements, where x_{ij} is the achievement of individual i (i = 1, ..., N) in domain j (j = 1, ..., D). Then x has the following form:

$$x = \begin{bmatrix} x_{11} & . & x_{1j} & . & x_{1D} \\ . & . & . & . & . \\ x_{i1} & . & x_{ij} & . & x_{iD} \\ . & . & . & . & . \\ x_{N1} & . & x_{Nj} & . & x_{ND} \end{bmatrix}$$

Let $|z_j| > 0$ be the 1xD vector, $z = (z_1, \ldots, z_D)$, containing the inadequacy cut-offs of the D dimensions; this is used for determining if a person is inadequate in each of the D dimensions. In this case it should be noted that each row vector x_i is the individual i's achievements in each dimension, and x_j is a column vector of dimension j achievements across the set of individuals. For the purpose of our analysis under this part, we assume that for an indicator j and individual i the inadequacy occurs when x_{ij} falls strictly below the respective cut-off, that is, $x_{ij} < z_j$.

Given the weights for each domain, a matrix of inadequacy achievement $\tilde{x}^0 = [\tilde{x}_{ij}^0]$ is derived from x as: $\forall\ i\ and\ j$:

(9) $$\tilde{x}_{ij}^0 = \begin{cases} 1 & if\ x_{ij} < z_j \\ 0 & otherwise \end{cases}$$

This implies that if $\tilde{x}_{ij}^0$= 1 it means that individual i is inadequate in dimension j and $\tilde{x}_{ij}^0$= 0 otherwise. A horizontal summation of each row of $\tilde{x}^0$ gives us a column vector c of the inadequacy count containing c_i, the number of inadequacies suffered by individual i.

An inadequacy score c_i is computed for each person according to his or her inadequacies across all indicators. The inadequacy score of each person is calculated by summing the weighted inadequacies experienced so that the inadequacy score for each person lies between 0 and 1. The score reaches its maximum of 1 when the person experiences inadequacy in all the 6 indicators. A person who has no inadequacy in any indicator receives a c_i score equal to 0. This can be given more formally in the following sections.

The weighted inadequacy score c_i, is ($w_j \tilde{x}_{ij}^0$) for each indicator, finding the aggregate inadequacy score for each individual (c_i) is constructed as the horizontal sum of the weighted inadequacy score for each individual given as:

$$(10) \qquad c_i = \sum_{j=1}^{D} w_j \, \tilde{x}_{ij}^0$$

$$= w_1 \tilde{x}_{1i}^0 + w_2 \tilde{x}_{2i}^0 + \cdots w_D \tilde{x}_{Di}^0$$

where $\tilde{x}_{Di}^0 = 1$ if person i has an inadequate achievement in indicator D and $\tilde{x}_{Di}^0 = 0$ otherwise and w_D is the weight attached to indicator i with $\sum_{d=1}^{D} w_D = 1$.

As Alkire et al. (2013) state, a second cut-off or threshold is used for identifying the disempowered portion of the population. This threshold, the disempowerment cut-off, is the share of (weighted) inadequacies that a woman must have to be considered disempowered, and it is denoted by k. Unlike the Alkire and Foster (2011a, 2011b) approach we do not censor the inadequacies of the empowered for those whose inadequacy score is less than or equal to the disempowerment cut-off.[4]

iii) Computing 5DE

First, we compute the five domains of the disempowerment index (M_0) following Alkire and Foster's (2011a, 2011b) method and structure of the adjusted headcount measure, M_0 that combines two key pieces of information: first the proportion or incidence of individuals (within a given population) whose share of weighted inadequacies is more than the disempowerment cut-off, k and second, the intensity of their inadequacies, the average proportion of (weighted) inadequacies that they experience.

More formally, the first component is called the disempowered headcount ratio (H_p) and is given by:

$$H_p = \frac{q}{N}$$

Here q is the number of individuals who are disempowered, and N is the total population.

[4] As discussed in Alkire et al. (2013, p.34), "For those whose inadequacy score is less than or equal to the disempowerment cut-off, even if it is not 0, their score is replaced by 0, and any existing inadequacies are not considered in the censored headcounts." This important step is referred to as censoring the inadequacies of the empowered (Alkire and Foster, 2011a, 2011b; Alkire et al., 2011). To differentiate the original inadequacy score from the censored one, the notation $c_i(k)$ is used for the censored inadequacy score. Note that when $c_i > k$, then $c_i(k) = c_i$, but if $c_i \leq k$, then $c_i(k) = 0$ in the censored inadequacy score.

The second element of 5DE is called the intensity (or breadth) of disempowerment (A_p). It is the average inadequacy score of disempowered individuals in the population and can be expressed as:

$$\boldsymbol{A_p = \frac{\sum_{i=1}^{N} c_i}{q}}$$

where $\boldsymbol{c_i}$ is the inadequacy score of individual i, N is the total population, and q is the number of disempowered individuals.

Once we have computed the disempowered headcount ratio and intensity of disempowerment, we need to find M_0. M_0 is the product of H_p and $\boldsymbol{A_p}$. Finally, the 5DE is easily computed from M_0:

$$M_0 = H_p \times A_p$$

(11) $$5DE = 1 - M_0$$

The sensitivity of the empowerment classification for different cut-offs and the selected disempowerment cut-off is 20 percent (Alkire et al., 2013). This definition of the disempowerment cut-off implies that an individual is disempowered if his/her inadequacy score is greater than 20 percent. This is like saying that an individual is identified as empowered in 5DE if he/she has adequate achievements in four of the five domains and enjoys adequacy in some combination of the weighted indicators that sum up to 80 percent or more.

iv) Breaking down M_0 by domains and indicators

Once we have computed 5DE and M_0 following the Alkire et al. (2013) method, M_0 can be decomposed into its different domains and indicators following the approach developed by Alkire and Foster, (2011a, 2011b) and Alkire and Santos (2013, 2014). One of the most important features of M_0 is that once the disempowered have been identified (M_0 has been computed), it can easily be decomposed into its component or indicators to reveal how people are disempowered across those components, the composition by indicator of the inadequacies that they experience, and so on.

To decompose M_0 by indicators, we need to compute the disempowered headcount ratio in each indicator. The headcount ratio for a particular indicator is the number of disempowered people who are inadequate in that indicator divided by the total population. After all the headcount ratios have been computed, it can be verified that the weighted sum of the headcount ratios also generates the population's M_0. That is, if M_0 is constructed from all 6 indicators, then the decomposition becomes:

(12) $$M_{0_{Population}} = \sum_{d=1}^{D} w_i H_i$$
$$= w_1 H_1 + w_2 H_2 + \cdots + w_6 H_6$$

where w_i is the weight of indicator i and H_i is the headcount ratio of indicator i.

The percentage contribution of each domain to overall disempowerment is computed as: Percentage contribution of domain D to $M_0 = \frac{w_D H_D}{M_{0_{Populatiom}}} \times 100$

The contributions of all domains will add up to 100 percent. Alkire et al. (2013, p.78) state, "whenever the contribution to disempowerment of a certain indicator greatly exceeds its weight, this suggests that the disempowered are more inadequate in this indicator than in others. Such indicators with high inadequacy point to areas for intervention to increase empowerment."

v) Decomposing M_0 by population sub-groups

The main decomposing factors in this study are region and gender of the sample households. The second key feature of M_0 (and of 5DE) is that it can be decomposed by population sub-groups such as regions, sex, ethnic groups, or other categories, depending on the sample design. For instance, in our study we have included all the nine rural regions in the country in which the data from the survey is representative; the formula for their decomposition is given as:

$$M_{0_{country}} = \frac{N_1}{N} \times M_{0_1} + \frac{N_2}{N} \times M_{0_2} + \cdots + \frac{N_9}{N} \times M_{0_9} \quad (13)$$

where N_1 denotes region one, N_2 denotes region two and so on, $\frac{N_1}{N}$ is the population share of region one to the total population, and similar to others implying that $N_1 + N_2 + \cdots + N_9 = N$. This relationship can be extended for any number of groups (such as for sex and ethnic groups) if their respective populations add up to the total population.

The contribution of each group to overall disempowerment can also be computed using the formula:

Contribution of region one to $M_{0_{country}} = \frac{\frac{N_1}{N} \times M_{0_1}}{M_{0_{country}}} \times 100$

The same method can be followed to compute the contribution of the remaining regions. When a region or some group's contribution to disempowerment widely exceeds its population share, this a good indicator that some regions or groups may bear an unequal share of poverty in the country. This also calls for relevant and appropriate policy interventions in these regions.

vi) The Gender Parity Index (GPI)

WEAI's GPI sub-index is a measure of intra-household inequalities. In one way, it measures the relative parity (equality) in 5DE scores of the women and men indices in the same household and in another way it accounts for the gap in empowerment between men and women for households in which there is no gender parity (Gupta et al., 2017). Like 5DE, GPI is computed on the basis of how people experience gender parity in a positive sense; however, its construction also facilitates an analysis of households that lack gender parity directly (Alkire et al., 2013).

We calculate the male inadequacy scores in the same way as the female inadequacy scores. For the purpose of establishing gender parity, the score for women whose inadequacy score is less than or equal to the disempowerment threshold of k is replaced by 0 even if the value is not zero, and we use the notation $c_i(k)$for the new censored inadequacy score. Note that when $c_i > k$, then $c_i(k) = c_i$, but if $c_i \leq k$, then $c_i(k) = 0$. This censoring of the inadequacy score enables us to easily identify a change in the empowerment gap (EG) among women who lack parity with primary men in their households.

Each dual-adult household is classified as having or lacking gender parity. Households lack parity if the female is disempowered and her censored inadequacy score is higher than the censored inadequacy score of her male counterpart (Alkire et al., 2013).

GPI provides two streams of important information about women's empowerment: (1) the percentage of women who lack gender parity relative to their male household counterparts, and (2) the extent of the inequality in empowerment between those women who lack parity and the men with whom they live.

The first component corresponds to the proportion of gender parity–inadequate households (H_{GPI}):

$$H_{GPI} = \frac{h}{m}$$

where h is the number of households classified as lacking gender parity and m is the total number of dual-adult households in the population.

The second component is called average empowerment and it provides information about the average percentage gap between the censored inadequacy scores for women and men living in households that lack gender parity (I_{GPI}), and is given as:

$$I_{GPI} = \frac{1}{h}\sum_{j=1}^{h}\frac{c_j(k)^M - c_j(k)^W}{1 - c_j(k)^M}$$

where $c_j(k)^W$and $c_j(k)^M$ are the censored inadequacy scores of the primary women and men respectively living in household j, and h is the number of households that are gender parity inadequate.

GPI is computed as:

$$GPI = 1 - (H_{GPI} \times I_{GPI}) \quad (14)$$

As is evident, GPI is equivalent to one minus a 'poverty gap' or P_1 measure of the Foster–Greer–Thorbecke family of poverty measures (1984), and GPI is likewise decomposable by sub-groups. It is also parallel in structure to 5DE, both being one minus a poverty-gap type of measure. The GPI score can be improved by increasing the percentage of women who enjoy gender parity (reducing H_{GPI}) or, for those women who are less empowered than men, by reducing the empowerment gap between the males and females in the same household (reducing I_{GPI}).

3.5 Data and a description of the Variables

This analysis is based on panel data obtained from the World Bank's Living Standard Measurement Survey-Integrated Surveys on Agriculture (LSMS-ISA): Ethiopia Socioeconomic Survey (ESS)-Waves 1-3. The data targeted the rural parts and small and medium towns in Ethiopia, but households from both small and medium towns were excluded because of non-applicability of agricultural technology adoption. The survey data has good qualities like it covers different household members including males and females in the same household. We restrict the sample to rural households to ensure that women's A-WEAI indicators among urban households that are not engaged in agricultural production are not misinterpreted as low empowerment achievements.

The original WEAI includes 5 domains and the indicator, but this study uses A-WEAI which still retains the 5 domains of empowerment, but WEAI's 10 indicators are reduced to 6. To measure disempowerment scores, we first identified the inadequacy achievements of each person on the five domains (production, resources, income, leadership, and time). Next, we calculated inadequacy scores for each person by taking a weighted sum of the inadequacies experienced.

We included households that had dual-adult households (primary adult male and female pairs in the same household). To ensure this pairing, households without a primary adult male and female pair were excluded from the sample. In several cases, the primary and secondary male and female were husband and wife; however, men and women can be classified as the primary male and female decision makers regardless of their relationship to each other. Finally, we obtained 3,382 (1,691 females and males) for each wave giving us a sample of 10,146 individuals. In this study, agricultural technology refers to joint application of recommended amounts of chemical fertilizers with extension services.

4. Empirical Results

4.1 Results of the Descriptive Analyses

Agricultural technology in this study refers to joint application of a recommended amount of chemical fertilizers per plot with extension services. So, adopters are farm households who use the recommended amount of fertilizers per plot with extension services, while non-adopters are those who do not use both in combination.

Even if the objective of the current study is identifying the impact of improved agricultural technology adoption on women's empowerment in rural parts of Ethiopia, the 5DE was constructed in such a way that disempowerment can be analyzed at different levels which enables us to identify which dimensions of women's empowerment drive the process of empowerment/disempowerment. The advantage of this construction is that it allows us to identify the critical indicators of the most disempowered which must be a focus area for improving women's empowerment. So, here the computation of a disempowerment index across the five domains (M_0) is done as the first step and then 5DE is computed as (1- M_0).

For comparison purposes, we present M_0 and its decomposition also for the sample of men. Decomposition was also done for both males and females based on their adoption status. To identify the areas that contribute most to women's disempowerment, we decomposed the women's disempowerment index (M_0) by domain and indicator. Table 1 gives the summary of empowerment levels and adoption status for the whole sample categorized by sex. The results show that women's empowerment is almost similar to that of men's in general, but non-adopter men have relatively more empowerment scores than women. A simple description of the inadequacy scores also shows that about 8.73 percent of the women and 9.68 percent of the men in the sample were empowered.

Concerning empowerment by adoption status, farmers who adopted the specified technology were more empowered as compared to the non-adopters. The result shows that about 14 percent of the adopters were empowered as compared to 8.43 percent empowerment level for the non-adopters. In Table 2 we can see that the adopters achieved higher adequacy scores (47.72 percent in the six indicators), as compared to non-adopters (44.66 percent). This result shows that there are significant differences in 5DE scores between the two technology adoption groups.

[Insert Table 1 about here]
[Insert Table 2 about here]

Another comparison is given in Table 3 on women's empowerment and gender parity by women's status of technology adoption. Gender parity is enjoyed by 58.80 percent of the women, which implies that about 41.20 percent of the women lack gender parity with the primary males in their households. In each category, about 67.42 percent of the adopters and 57.31 percent of the non-adopters enjoyed parity in their households. Women in the adopter group were significantly more empowered in 5DE and enjoyed more gender parity as compared to women in the non-adopter group. This implies that about 14.51 percent and 7 percent women in the adopter and non-adopter group respectively, enjoyed empowerment in both 5DE and gender parity. More women were found under the category in which parity is enjoyed, but with no empowerment in 5DE. About 52.95 percent of the women the who adopted technology and 50.31 percent who did not enjoyed gender parity, but they were disempowered. The results also show that about 32.12 percent adopters and 42.02 percent non-adopters lacked empowerment and parity with the males in their households.

[Insert Table 3 about here]

The results of the sample A-WEAI score and its components are reported in Table 4, and it shows a sample achievement score of 0.46. in 5DE and 0.91in GPI score. The average empowerment gap of the 41.20 percent women who were less empowered than the primary males in their households is 22.3 percent that leads to the overall GPI of 0.91 (1 – [41.20 percent x 22.3 percent]).

Table 5 gives descriptions of inadequacy scores and the contribution of each domain/ indicator. The results show that the domains that contributed the most to women's disempowerment are control overuse of income (27.90 percent) and lack of control over resources (23.80 percent). Three-fourth of the women in the study were not empowered and lacked access to credit and the ability to take sole or joint decisions about it and control over use of income. In Table 5 we can also see that more than 60 percent of the women are not yet empowered and lack control over assets and about 52 percent women are not yet empowered and lack decision making in agricultural production. Similarly, about 43 percent of the women are not empowered and are not group members or do not belong to any group in their community, and about 37 percent are overburdened with work and have inadequate time allocated for doing this work. When we further decompose the results into adopter females and non-adopter females, the former achieves better in more indicators.

When it comes to the contribution of each indicator to women's disempowerment, women were the most disempowered in control over use of income indicator (27.90 percent) followed by decision making in productive inputs (19.10 percent). On the other hand, women were less disempowered in access to and decisions on credit (9.40 percent).

A comparison of men's inadequacies in empowerment with those of women shows that it is the same for both. Lack of control over use of income and group membership in the community contributed more to men's disempowerment than to women's disempowerment. On the other hand, men's results show relatively little disempowerment in workload overburden and in decision making on agricultural production as compared to women. These results are also supported by different figures drawn for different disaggregated portions of the population (by sex, adoption groups, and regions, see Figures 1-6 in the Appendix).

[Insert Table 4 about here]
[Insert Table 5 about here]

4.2 Econometric Results

One more step before the estimation of causal effects was the balancing test and passing different quality checking tests. After estimating the propensity scores for the adopter and non-adopter groups, the common support conditions were checked. The covariate balancing tests before and after matching are reported in Table B3 in the Appendix. The standardized mean difference in the overall covariates used in the propensity score for the three technologies (around 15 percent before matching) reduced to around 2 percent after matching. The pseudo R^2 also dropped significantly from around 9-12 percent before matching to about 0.3-1.17 percent after matching. The likelihood ratio test was also statistically significant before matching under all the outcomes but became insignificant after matching. The low pseudo R^2, high bias reduction, and the insignificant p-values of the likelihood ratio test after matching suggest that the proposed specification of the propensity score was successful in terms of balancing the distribution of covariates between the two groups.

After computing the propensity scores, we estimated the ATT of the outcome variables, namely 5DE and GPI using PSM and DID with fixed effects for different samples (for pooled, females, and males) separately. Following the PSM approach we used four matching algorithms -- nearest neighborhood matching (NNM), kernel matching (KM), radius matching (RM), and stratified matching (SM). A separate model was estimated for 5DE, its components, and GPI under each approach.

The estimated results based on PSM using the whole sample are reported in Table 6. The results show that the adoption of a recommended amount of chemical fertilizers with extension services had a positive and significant effect on 5DE across all matching algorithms. The estimated impact ranged from 4.3 to 6.1 percent and it was statistically significant. This result implies that estimated average differences in the five domains of empowerment for similar pairs of household members (females and males in each household) who have different technological status is significantly different. The results also show that the adopters were better-off due to the technology as compared to the non-adopters such that adopters got more empowered in 5DE and their empowerment score increased on average by about 5 percent.

[Insert Table 6 about here]

Table 7 gives the estimated impact of technology adoption on each sex separately; the results show that adoption affected empowerment positively and significantly for both the sexes. In the case of females, the empowerment score in 5DE increased from 5.6 to 8.3 percentage points while the increase in 5DE for males was in the range of 2.9- 4.9 percent. On average, the proportion of adopter women and men empowered in each of the five domains of A-WEAI is closer to each other. Adopter females and males had almost similar empowerment scores in 5DE which is about 48 percent as the outcome mean shows.

Unlike women in the adopter households, women in the non-adopter households had a lower empowerment score in 5DE than non-adopter men. This suggests that even if they do not adopt the technology non-adopter men are more empowered as compared to non-adopter women. On average, disempowerment in the five domains of agriculture is more severe in the non-adopter female group. In other words, women would have benefited more from adopting the technology as compared to men. This result supports the real condition of most developing countries, especially in the agriculture sector, where men usually enjoy more empowerment than women. Thus, interventions will affect more women and girls who face more burdens in the sector than men.

[Insert Table 7 about here]

Next the impact of technology adoption on each domain and the contribution of each domain to women's empowerment in 5DE was computed, and the results are reported in Table 8. The findings support the results in Table 5 in general. The domain that contributed the most to women's empowerment is time use. Its estimated impact ranged from 3.2 to 4.2 percent increase in the empowerment score measured by 5DE. The second domain that contributed the most to women's empowerment is resource control and use. On average, adoption led to a 1.5 percent increase in the total empowerment score through ownership of assets and access to and decisions on credit use.

When it comes to the domain-wise impact, we observe that adoption was not associated with a statistically significant change in decisions on production, except for radius and stratification matching. Unlike 5DE's other domains, the coefficient estimate for leadership was negative and statistically significant. This means that the empowerment of women who adopted the technology went down through the leadership component. A possible reason for this could be that as women participate in their community and take positions, they will spend less time on their fields and take lesser time to deal with the technology.

[Insert Table 8 about here]

The last estimation of PSM gives the impact of the technology adopted on the empowerment gap (EG)[5] or gender disparities (Table 9. The ATT term is negative in all the matching methods and statistically significant. The result suggests that EG declined for adopter

[5] Reflects the relative empowerment gap between female and male scores in the 5DE.

women compared to non-adopter households. EG for adopter women declined between 2.0-2.98 percent. These results remain consistent with different matching algorithms and suggest that there is a negative effect of being an adopter of the specified technology on EG, which means technology adoption leads to a reduction in gender disparities between men and women in the same household. Looking more closely at the issue we also considered the impact of the specific technology on women who lacked parity with the primary males in their households and the results are reported in Table 10. Unlike the estimation of the model for all the females, this time the results show that adoption was not associated with a statistically significant change in EG, but it still supports the earlier results in sign that all are negatively related to adoption, except for NNM with five neighbors.

[Insert Table 9 about here]
[Insert Table 10 about here]

Next, we estimated the impact using DID following the fixed effects approach. Table 11 gives the DID results for three different models -- pooled sample, females, and males --- separately. The findings show that adoption of chemical fertilizers with extension services increased 5DE for adopters under all the three models (see Columns 2 to 4 in Table 11). In the entire sample, technology increased empowerment scores in the five domains by about 4.30 percent. This result tells us that adoption led to a 4.30 percent increase in 5DE scores if an individual adopted a technology, irrespective of sex. Concerning the second model, the results show that adoption led to a 4.80 percent increase in empowerment for women who used the specified technology as measured by the 5DE score. Similarly, adopter males also benefitted from the technology as their empowerment score increased by about 3.90 percent, but the impact was less than that for female adopters which is contrary to our expectations.

After including other controls our results are almost similar under all the models. However, while computing the impact of the technology on each component of 5DE using DID, our results were different from what we obtained under PSM (see Table 12), except for the time dimension. We found that adoption was not statistically significant for any of the first four components. The exception was time allocation where adoption led to a 3.50 percent increase in empowerment. This finding shows that time use domain still drives the change in 5DE, as we see in the PSM results in Table 8. The other exception for the time use dimension of 5DE was that none of the control variables included in the model affected it, while they did affect the first four components.

[Insert Table 11 about here]
[Insert Table 12 about here]

Contrary to PSM's results concerning the impact of technology on EG, the results are mixed following the DID approach. Technology adoption leads to a reduction in EG under the first three models in Table 13 when all women are included. For example, in Model 1 when we only include the treatment status of households and observation periods, the results show that adoption is associated with a 1.20 percent decline in EG for all the women. In Model 2 we estimated the impact by adding personal and household characteristics, but the result is still negative though it is not statistically significant implying that adoption led to narrowing the empowerment gap even if the impact was not powerful enough. In Model 3 we added other controls and the findings support the results of the first two models in sign.

However, when only women who lack gender parity are considered, the result has the opposite sign, where adoption leads to an increase in the empowerment gap, but it is not statistically insignificant (see Model 4 in Table 13). These mixed results make the impact of technology adoption on EG inconclusive following the DID approach. However, since our interest is seeing the impact on women who lack parity, it is possible to argue that adoption does not help women reduce the empowerment gap with the primary males in their households. This implies that improved agricultural technologies do not necessarily affect the empowerment gap.

[Insert Table 13 about here]

A further disaggregation was done based on major regions in the country and the results are presented in Table 14. Disaggregating A-WEAI by components can help identify key areas of empowerment/disempowerment (for men as well as women), which can be used for prioritizing interventions. Our disaggregation of the index helped us identify regional variations to see the achievements and consider the status of empowerment conditions between primary males and females in these regions. We estimated the technology impact on 5DE and its components for both pool sample and women only.

Based on the results of the regional disaggregation we can see that adoption did not improve women's empowerment in all the regions. The impact was more in regions like Amhara and Oromia. In Amhara region adoption increased the 5DE by 14.30 percent and 15.50 percent for the whole sample and women respectively. Similarly, in Oromia the technology impact was significant which led to an increase in 5DE by 12.90 percent and 15 percent for the whole sample and women respectively. These results support the real situation in the country that the two regions are dominant in all economic indicators; the most arable land and productive resources are found in these regions. New and improved agricultural technologies are also used widely in these two regions.

We also found that the impact of technology adoption was negative and significant in regions like Benishangul and SNNP. Even if available literature has come to the conclusion that modern agricultural technologies improve welfare, it should also be noted that they may also worsen social welfare. In our case adoption led to a decline in 5DE in some regions. However, the aggregate impact was positive and significant indicating that technology has the power to improve empowerment in 5DE. The results are almost similar to the components of 5DE across regions, with a few exceptions.

Finally, we compared the impact of the technology on 5DE and EG computed using DID and PSM (Table 15). The results show that there were almost similar impacts under both approaches in magnitude as well as in signs, except in a few cases.

[Insert Table 14 about here]
[Insert Table 15 about here]

To conclude, the process of change in A-WEAI is derived by 5DE so that technology adoption affects 5DE more than GPI as both the PSM and DID results show. These results also show that the driving force behind changes in A-WEAI is women's empowerment in the five domains rather than the issue of gender parity.

5. Conclusion

So far, very few studies have measured women's empowerment in agriculture and incorporated this in program evaluation settings. Its complex and multidimensional nature has made these attempts difficult in the areas of empowerment and gender parity/disparity. However, evidence shows that the important role that women play in the agriculture sector is growing both in terms of their participation and contribution to the sector which implies that women's empowerment plays a big role in welfare improvements such as increase in food security, reduction in poverty, and increase in agriculture production and consumption.

To fill this gap and contribute to existing literature, the current study evaluated the impact of adopting recommended amounts of chemical fertilizers with extension services on women's empowerment. For estimation purposes, we used DID with fixed-effects and PSM methods.

Prior to the formal estimation of the technology's impact on empowerment, we looked at each domain and the components of A-WEAI briefly. Here we were interested in seeing women's disempowerment and gender disparities which are relevant for policy interventions. The results showed that women's disempowerment was almost similar to that of men. About 91.27 percent of women and 90.32 percent of men were disempowered in A-WEAI's five domains. The sample achievement score in 5DE was 0.46 while GPI was 0.91 which implies that the sample A-WEAI is 0.50. Gender parity was enjoyed by 58.80 percent of the women, which implies that about 41.20 percent of the women did not enjoy gender parity with the primary males in their households and the average empowerment gap (EG) of women who lacked parity was 22.30 percent.

About 67.42 percent of the adopters and 57.31 percent of the non-adopters enjoyed parity in their households. Women in the adopter group were significantly more empowered in 5DE and enjoyed more gender parity as compared to women in the non-adopter group. When we look at the contribution of each domain to disempowerment, the results show that women were the most disempowered in the income domain (27.90 percent) followed by lack of control over resources (23.80 percent) and providing inputs for production decisions (19.10 percent).

In the empirical section, the estimation results from our study under both the methods showed that adoption of the specified agricultural technology had a robust, significant, and positive impact on the 5DE components of A-WEAI while the results are mixed for GPI. Our results are also consistent across estimation methods, except in a few cases and the magnitude of the estimated effects is closer to each other under both the estimation methods.

Using the PSM method, we found that adoption led to a 4.3 to 6.1 percent increase in 5DE. Sex-wise, 5DE for females increased from 5.6 to 8.3 percent while for men it increased from 2.9 to 4.9 percent. Looking at the impact of technology adoption on each domain, we found that the domain that contributed the most to women's empowerment was time use, which increased in the range 3.2 to 4.2 percent. The second domain that contributed the most to women's empowerment was resource control and use where the increase was about 1.5 percent. Last, using PSM, we estimated the impact of the technology on the empowerment gap for all women, and we found that EG for adopter women declined between 2.0 and 2.98

percent. But, when we considered only women who lacked parity with the primary males in their households, the result showed that adoption did not affect EG, but it still had a negative sign.

Almost similar results were obtained using DID with a fixed effects approach. We estimated three different models, for the whole sample, for females, and for males separately, and the findings for the whole sample showed that technology increased the empowerment score by about 4.30 percent, while for the females group adoption led to a 4.80 percent increase in their empowerment and for the male group it led to 3.90 percent increase in empowerment. In computing the impact of the technology on each component of 5DE, adoption did not affect any of the first four components, except time allocation where adoption led to a 3.50 percent increase in empowerment. The results for the impact of technology on EG were mixed following the DID approach. Technology adoption led to a reduction in EG when all women were included, but when only women who lacked gender parity were considered adoption led to an increase in the empowerment gap, but it was statistically insignificant. This implies that the improved agricultural technology did not necessarily affect the empowerment gap. Thus, program interventions in relation to agriculture technologies and gender parity need to be context or country specific when extrapolating results from a specific location to other areas for policy guidelines.

Finally, a regional disaggregation of the impact showed that adoption did not improve women's empowerment in all the regions. The impact was more powerful in regions like Amhara and Oromia while it was negative and significant in regions like Benishangul and SNNP. However, the aggregate impact was positive and significant indicating that technology had the power of improving empowerment in 5DE. Last, we observed that the change in A-WEAI was derived by 5DE rather than by GPI.

6. Policy implications

Since women's empowerment is a relatively new concept in the agriculture sector and this study is the first attempt to study this in a program evaluation setting(context), it highlights some potential areas that need important policy interventions to enable farm households to exploit the full benefits of improved agricultural technologies.

On the basis of our results there is a positive and significant impact of improved agricultural technologies on 5DE, while at the same time we observed that there is a weak association between the impact of adoption and GPI.

Even though we found a strong impact of adoption on 5DE, the value of this component of A-WEAI (5DE) is by far lower than other developing countries, for example, Uganda's 5DE is 0.83 (Malapit et al., 2015, p. 24) while in our case 5DE for Ethiopia is only about 0.46. Similarly, A-WEAI is also lower, with a value of 0.500, compared again to Uganda's score of 0.84. This needs policy interventions that increase A-WEAI and its sub-indices, especially 5DE.

The strong relationship between the impact of adoption and 5DE levels in our study suggests that empowerment of women could be a pathway for reducing poverty and vulnerability to food insecurity. It was, however, observed that more that 75 percent of the women did not have access to credit or did not take sole or joint decisions. A significant number of women did not have control over the use of income generated or owned by their household members. Policy support is needed for improving access to and methods of using credit in households and for ensuring that women have the ability to take decisions related to incomes. It is also important to note that provision and access to improved inputs like fertilizers and support extension services also need to be improved.

Another finding of our study is that there was no difference in the empowerment gap between adopter and non-adopter females. Adoption did not help adopter females to narrow down the existing empowerment gap with the primary males in their households. One possible reason for this is that men and women are able to take decisions to differing degrees in the same households. Hence, awareness generation about joint decisions and cooperation on issues in their households will increase the impact of the technology on the existing gender gap.

In Ethiopia, social norms are important determinants of participation in economic and social activities. Accounting for social norms or practices that possibly up-grade/limit women's participation need to be an important component of policies and strategies in shaping access to opportunities such as healthcare, education, and employment. This will also help women take decisions within the established gender roles if they are provided with skills and knowledge improvements through awareness creation about gender equity and its importance for social welfare across contexts.

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Appendix-A: Estimation output Tables

Table 1: Empowerment and Adoption status by sex

Sex	Adoption status		Enjoy Empowerment		
	Adopter	Non-Adopter	Adopter	Non-Adopter	Total
Male	701	4372	13 %	9.19 %	9.68%
Female	744	4329	14.92 %	7.67 %	8.73 %
Total	1445	8701	13.96 %	8.43 %	

Source: Author's calculations using WB LSMS data (2011, 2013, and 2015) (2019).

Table 2: Adequacy achievements in the 5DE by Adoption status and sex

Sex	Adoption status		
	Adopter	Non-Adopter	Total
Male	46.97 %	45.04 %	45.31 %
Female	48.42 %	44.27 %	44.87 %
Total	47.72 %	44.66 %	

Source: Author's calculations using WB LSMS data (2011, 2013, and 2015) (2019).

Table 3: Women's empowerment and Gender Parity by Adoption status

Adoption Status	Enjoy parity	Enjoy Both	Parity, but not empowered	No parity, but empowered	Lack both
Adopter	67.42%	14.51 %	52.95 %	0.43 %	32.12 %
Non-adopter	57.31 %	7.00 %	50.31 %	0.67 %	42.02 %
Total	58.80%				

Source: Author's calculations using WB LSMS data (2011, 2013, and 2015) (2019).

Table 4. Results of Sample A-WEAI Scores with its Components

Indexes	Total Sample	
	Women	Men
Disempowered headcount (H)	94.00 %	93.70 %
Average inadequacy score (A)	58.20 %	57.84 %
Disempowerment Index (M_0)	0.547	0.542
5DE Index (1- M_0)	0.453	0.458
Number of observations	5073	5073
Percentage of women with no gender parity (H_{GPI})	41.2 %	
Average Empowerment Gap (I_{GPI})	22.3 %	
Gender Parity Index (GPI)	0.908	
A-WEAI score (0.9 x 5DE + 0.1 x GPI)	0.500	

Source: Author's calculations using WB LSMS data (2011, 2013, and 2015) (2019).

Table 5: Summary of Inadequacy scores and contribution of each indicator

Statistics	Production	Resources		Income	Leadership	Time
	Input in productive decisions	Ownership of assets	Access to and decisions on credit	Control over use of income	Group membership	Workload
Indicator weight	0.20	0.13	0.07	0.20	0.20	0.20
Women (All)						
% Headcount	52.20%	63.00%	78.06%	76.35%	42.64%	37.35%
% Contribution	19.10%	14.40%	9.40%	27.90%	15.6%	13.60%
% Contribution by dimension	19.10%	23.80%		27.90%	15.60%	13.60%
Women (Adopter)						
% Headcount	47.85%	58.33%	74.46%	72.85%	50.94%	23.39%
% Contribution	18.70%	14.40%	9.20%	28.50%	19.90%	9.20%
% Contribution by dimension	18.70%	23.60%		28.50%	19.90%	9.20%
Women (Non-Adopter)						
% Headcount	52.59%	63.78%	78.68%	76.95%	41.21%	39.76%
% Contribution	19.10%	14.40%	9.40%	27.90%	15.6%	13.60%
% Contribution by dimension	19.10%	23.80%		27.90%	15.60%	13.60%
Men						
% Headcount	51.03%	62.53%	77.92%	77.92%	43.00%	36.49%
% Contribution	18.80%	14.40%	9.40%	28.30%	15.70%	13.50%
% Contribution by dimension	18.80%	23.80%		28.30%	15.70%	13.50%

Source: Author’s calculations using WB LSMS data (2011, 2013, and 2015) (2019).

Table 6: Impact of technology adoption on 5DE (Pooled sample)

Matching Type	Outcome mean		ATT
	Adopters	Non-adopters	
NNMa[6]	0.480	0.428	0.052(5.97) ***
NNMb[7]	0.480	0.431	0.048(4.60) ***
RM	0.480	0.418	0.061(5.83) ***
KMa[8]	0.480	0.432	0.047(5.79) ***
KMb[9]	0.480	0.436	0.043(5.34) ***
SM[10]	0.480	0.424	0.056(11.47) ***

Note: Statistically significant at the 1 % (***) probability level.
Absolute values of t-statistics in parenthesis.
Source: Author’s calculations using WB LSMS data (2011, 2013, and 2015) (2019).

[6] NNM based on five neighbors and common support.
[7] NNM based on a single neighbor and common support.
[8] Kernel-based matching with a band width of 0.06 and common support.
[9] Kernel-based matching with a band width of 0.03 and common support.
[10] Stratification matching based on the survey year.

Table 7: Impact of technology adoption on 5DE by Sex

Matching Type	Outcome mean and ATT					
	Female			Male		
	Adopters	Non-adopters	ATT	Adopters	Non-adopters	ATT
NNMa	0.487	0.425	0.062(5.05) ***	0.472	0.431	0.041(3.34) ***
NNMb	0.487	0.405	0.082(5.55) ***	0.472	0.433	0.039(2.59) **
RM	0.488	0.405	0.083(5.67) ***	0.478	0.440	0.038(2.48) **
KMa	0.487	0.431	0.056(4.90) ***	0.472	0.443	0.029(2.55) **
KMb	0.487	0.427	0.060(5.51) ***	0.472	0.438	0.034(2.95) ***
SM	0.487	0.425	0.062(7.36) ***	0.472	0.422	0.049(6.53) ***

Note: Statistically significant at the 1 % (***) and 5 % (**) probability levels respectively.
Absolute values of t-statistics in parenthesis.
Source: Author’s calculations using WB LSMS data (2011, 2013, and 2015) (2019).

Table 8: PSM Results of the Impact of technology adoption on each Domain of 5DE

ATT by Domain					
Matching Type	Production	Resources	Income	Leadership	Time
NNMa	0.004(0.85)	0.016(4.51) ***	0.014(3.17) ***	-0.007(1.38)	0.035(7.94) ***
RM	0.012(1.90) *	0.021(5.00) ***	0.013(2.49) **	-0.006(0.95)	0.042(7.22) ***
KMa	0.002(0.50)	0.013(4.27) ***	0.012(3.19) ***	-0.008(1.90) *	0.036(8.99) ***
KMb	0.002(0.47)	0.014(4.32) ***	0.014(3.42) ***	-0.007(1.53) *	0.037(8.96) ***
SM	0.013(3.16) ***	0.013(4.62) ***	0.005(2.22) **	-0.000(0.18)	0.032(9.69) ***

Note: Statistically significant at the 1 % (***), 5 % (**), and 10 % (*) probability levels respectively.
Absolute values of t-statistics in parenthesis.
Source: Author’s calculations using WB LSMS data (2011, 2013, and 2015) (2019).

Table 9: Impact of technology adoption on the Empowerment Gap (EG), All Female, n=5,073

Matching Type	Outcome mean		ATT
	Adopters	Non-adopters	
NNMa	0.063	0.084	-0.020(3.30) ***
NNMb	0.063	0.091	-0.028(3.41) ***
RM	0.062	0.092	-0.030(3.58) ***
KMa	0.063	0.088	-0.025(4.36) ***
KMb	0.063	0.087	-0.023(4.12) ***
SM	0.063	0.088	-0.025(4.46) ***

Note: Statistically significant at the 1 % (***) probability level.
Absolute values of t-statistics in parenthesis.
Source: Author’s calculations using WB LSMS data (2011, 2013, and 2015) (2019).

Table 10: Impact of technology adoption on the Empowerment Gap (EG), for Females without parity, n=2,090

Matching Type	Outcome mean		ATT
	Adopters	Non-adopters	
NNMa	0.208	0.206	0.004(0.13)
NNMb	0.208	0.221	-0.013(0.92)
RM	0.209	0.222	-0.013(0.98)
KMa	0.208	0.209	-0.001(0.11)
KMb	0.209	0.211	-0.002(0.17)
SM	0.208	0.213	-0.005(0.53)

Note: Absolute values of t-statistics in parenthesis.
Source: Author's calculations using WB LSMS data (2011, 2013, and 2015) (2019).

Table 11: DID results Adoption: Outcome variable is 5DE

Variable	Model 1: Total Sample	Model 2: Female	Model 3: Male
Treatment	0.043(6.35) ***	0.048(5.06) ***	0.039(3.94) ***
Year dummy			
2013_Dummy	0.295(67.82) ***	0.296(48.28) ***	0.294(47.50) ***
2015_Dummy		0.358(45.64) ***	0.364(45.90) ***
Religion dummy	0.361(64.86) ***		
Protestant_dummy	-0.060(3.17) ***	-0.053(2.00) ***	-0.066(2.47) **
Tradition_dummy	-0.079(2.81) **	-0.084(2.07) **	-0.076(1.91) *
Pagan_dummy		0.055(1.29)	0.039(0.95)
Marital_stat_dummy			
Married_dummy	0.019(1.37)	0.007(0.36)	0.029(1.57)
Single_dummy	0.014(0.47)	0.002(0.04)	0.026(0.62)
Separeted_dummy	0.139(2.33) **	0.117(1.49)	0.167(1.82) *
Crop_rotation	0.034(5.97) ***	0.037(4.57) ***	0.031(3.86) ***
House_rooms	0.005(1.53)	0.007(1.51)	0.003(0.69)
Kitchen_type	-0.010(1.51)	-0.008(0.99)	-0.010(1.16)
Family_size_AE	0.001(2.41) **	0.006(1.61) *	0.007(1.80) *
Mother's Educ	0.030(2.19) **	0.026(1.40)	0.034(1.68) *
Light_source	0.008(1.23)	0.007(0.81)	0.009(0.95)
Age	0.004(3.03) ***	0.005(2.24) ***	0.004(2.05) **
Age^2	-0.000(2.88) **	-0.000(2.22) **	-0.000(1.86) *
Constant	0.175 (7.69) ***	0.171(5.35) ***	0.181 (5.57) ***
Observation	8,914	4,455	4,459
No. of Groups	3,382	1,691	1,691

Note: Statistically significant at the 1 % (***), 5 % (**), and 10 % (*) probability levels respectively.
Absolute values of t-statistics in parenthesis.
Source: Author's calculations using WB LSMS data (2011, 2013, and 2015) (2019).

Table 12: DID Results of the Impact of technology adoption on each Domain of 5DE

Variable	Production	Resources	Income	Leadership	Time
Treatment	0.005(1.01)	0.003(0.99)	0.002(0.60)	0.004(1.01)	0.035(6.63) ***
Year dummy					
2013_Dummy	0.089(22.80) ***	0.025(11.37) ***	0.049(8.21) ***	0.169(74.29) ***	-0.002(0.70)
2015_Dummy	0.002(0.53)	0.054(19.56) ***	0.163(71.72) ***	0.134(47.18) ***	0.003(0.74)
Religion dummy					
Tradition_dummy	-0.034(1.63)	-0.013(0.91)	-0.013(1.10)	0.007(0.44)	-0.012(0.57)
Crop_rotation	0.012(2.89) ***	-0.000(0.02)	0.010(3.86) ***	0.017(5.53) ***	0.002(0.42)
Family_size_AE	0.005(2.45) **	0.003(2.32) **	0.000(0.81)	-0.002(1.39)	0.000(0.02)
Mother's Educ	-0.008(0.85)	0.002(0.26)	-0.001(1.49)	0.020(3.13) ***	0.013(1.31)
Age	0.002(1.82) *	0.001(0.75)	0.000(0.49)	0.000(0.39)	0.001(1.21)
Age^2	-0.000(1.87) *	-0.000(0.41)	-0.000(0.29)	-0.000(0.19)	-0.000(1.60)
Constant	0.285(30.15) ***	0.804(44.94) ***	0.786(53.44) ***	0.794(43.32) ***	0.899(33.07) ***
Observation	4,458	4,458	4,458	4,458	4,458
No. of Groups	1,691	1,691	1,691	1,691	1,691

Note: Statistically significant at the 1 % (***), 5 % (**), and 10 % (*) probability levels respectively.
Absolute values of t-statistics in parenthesis.
Source: Author's calculations using WB LSMS data (2011, 2013, and 2015) (2019).

Table 13: DID results Adoption: Outcome variable is EG

Variable	Model 1	Model 2	Model 3	Model 4(Female without parity)
Treatment	-0.012(1.67) *	-0.010(1.37)	-0.017(2.27) **	0.029(1.54)
Year dummy				
2013_Dummy	0.005(1.02)	0.005(1.11)	0.007(1.45)	0.018(1.65)
2015_Dummy	0.033(6.98) ***	0.036(7.08) ***	0.021(3.23) ***	0.042(3.02) ***
Religion dummy				
Protestant_dummy		0.019(0.93)	-0.054(1.61)	-0.007(0.15)
Pagan_dummy		-0.030(0.89)	0.025(1.21)	-0.001(0.02)
Family_size_AE		-0.003(0.99)	-0.002(0.49)	0.004(0.60)
Mother's Educ		-0.001(0.45)	-0.008(0.62)	-0.010(0.33)
Age		-0.003(1.80) *	-0.004(2.35) **	-0.001(0.16)
Age^2		0.0001.57)	0.000(2.00) **	0.000(0.01)
Crop_rotation			0.010(1.45)	0.026(1.98) *
Cooking_fuel			-0.064(2.16) **	-0.120(1.72) *
Light_source			-0.013(1.88) *	-0.019(1.23)
Water_source			0.010(1.25)	0.005(0.37)
Toilet_type			0.009(1.84) *	0.003(0.30)
Constant	0.081)22.22) ***	0.156(4.30) ***	0.159(4.11) ***	0.153(1.88) *
Observation	5,073	5,029	4,458	1,763
No. of Groups	1,691	1,691	1,691	1,213

Note: Statistically significant at the 1 % (***), 5 % (**), and 10 % (*) probability levels respectively.
Absolute values of t-statistics in parenthesis.
Source: Author's calculations using WB LSMS data (2011, 2013, and 2015) (2019).

Table 14: Decomposition of the technology impact on 5DE and each component by Regions

Region	ATT					
	5DE	Production	Resources	Income	Leadership	Time
Tigray_A[11]	0.021(1.27)	0.021(2.71) **	0.006(1.14)	-0.018(3.17) ***	-0.018(2.37) **	0.030(4.21) ***
Tigray_B[12]	0.029(1.18)	0.024(2.12) **	0.007(0.94)	-0.018(2.16) **	-0.012(1.11)	0.027(2.69) **
Amhara_A	0.143(12.05) ***	0.012(2.24) **	0.021(5.58) ***	0.038(7.38) ***	0.042(8.89) ***	0.030(6.57) ***
Amhara-B_	0.155(9.66) ***	0.012(1.58)	0.024(4.65) ***	0.043(6.03) ***	0.046(7.12) ***	0.031(5.02) ***
Oromiya_A	0.129(6.51) ***	0.040(5.40) ***	0.021(3.56) ***	0.012(1.73) *	0.010(1.26)	0.046(7.71) ***
Oromiya_B	0.150(5.34) ***	0.038(3.59) ***	0.027(3.27) ***	0.024(2.29) **	0.007(0.64)	0.053(6.97) ***
Benishan_A	-0.155(4.35) ***	-0.066(6.19) ***	0.005(0.39)	-0.044(4.16) ***	-0.086(6.48) ***	0.036(2.85) **
Benishan_B	-0.155(3.09) ***	-0.075(6.14) ***	0.008(0.50)	-0.033(1.95) *	-0.086(4.50) ***	0.031(1.63)
SNNP_A	-0.102(7.88) ***	-0.009(1.70)	-0.009(2.37) **	-0.023(5.76) ***	-0.075(15.48) ***	0.014(2.86) **
SNNP_B	-0.098(5.37) ***	-0.012(1.55)	-0.007(1.24)	-0.021(3.60) ***	-0.075(10.94) ***	0.016(2.27) **
Harari_A	-0.001(0.037)	-0.007(0.58)	0.004(0.52)	-0.004(0.38)	0.029(2.47) **	0.035(3.25) ***
Harari_B	0.005(0.11)	-0.011(0.68)	0.011(0.99)	0.001(0.08)	-0.036(2.19) **	0.039(2.67) **

Note: Statistically significant at the 1 % (***), 5 % (**), and 10 % (*) probability levels respectively.
Absolute values of t-statistics in parenthesis.
Source: Author's calculations using WB LSMS data (2011, 2013, and 2015) (2019).

Table 15: Comparisons of the Impact Using DID and PSM Results on 5DE and EG

Estimation method		Outcome variables			
		5DE: Total Sample	5DE: Female	EG (All Female)	EG (Female without parity)
DID		0.043(6.35) ***	0.048(5.05) ***	-0.017(2.27) **	0.028(1.48)
PSM	NNMa	0.052(5.97) ***	0.062(5.05) ***	-0.020(3.30) ***	0.004(0.13)
	RM	0.061(5.83) ***	0.083(5.67) ***	-0.030(3.58) ***	-0.013(0.98)
	KMa	0.047(5.79) ***	0.056(4.90) ***	-0.025(4.36) ***	-0.001(0.11)
	KMb	0.043(5.34) ***	0.060(5.51) ***	-0.023(4.12) ***	-0.002(0.17)
	SM	0.056(11.47) ***	0.062(5.05) ***	-0.025(4.46) ***	-0.005(0.53)

Note: Statistically significant at the 1 % (***), 5 % (**), and 10 % (*) probability levels respectively.
Absolute values of t-statistics in parenthesis.
Source: Author's calculations using WB LSMS data (2011, 2013, and 2015) (2019).

[11] Region name followed by "A" is the result for the whole sample.
[12] Region name followed by "B" is the result for the women only.

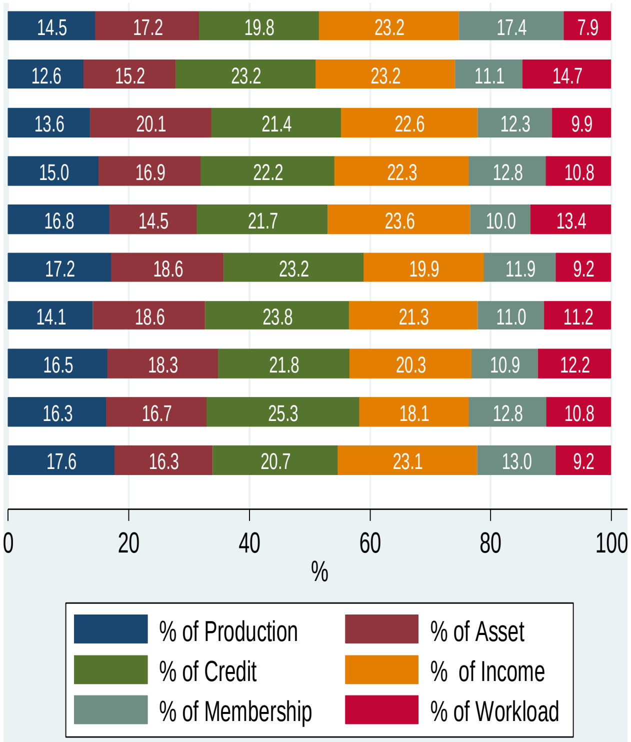

Figure 1: Contribution of each indicator to inadequacy by region

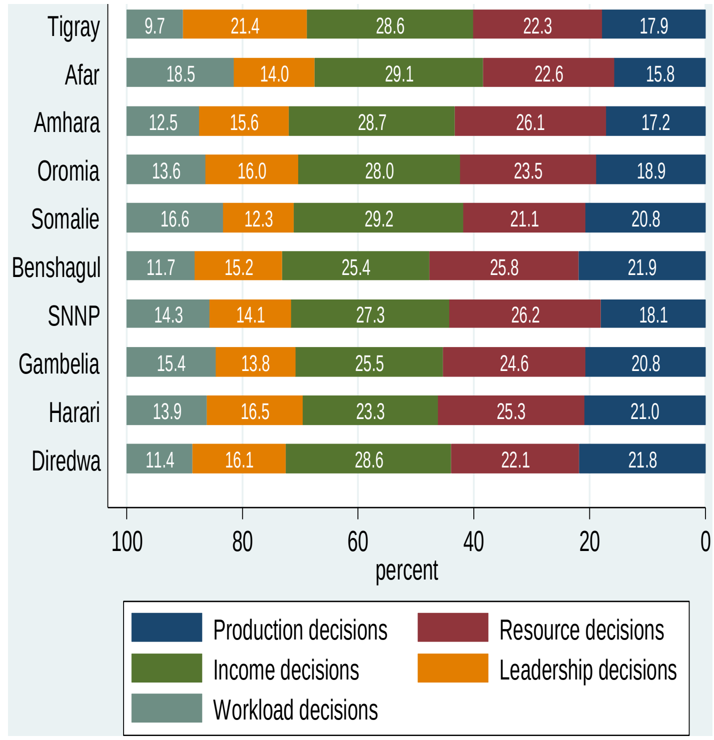

Figure 2: Contribution of each of the five domains to disempowerment by region

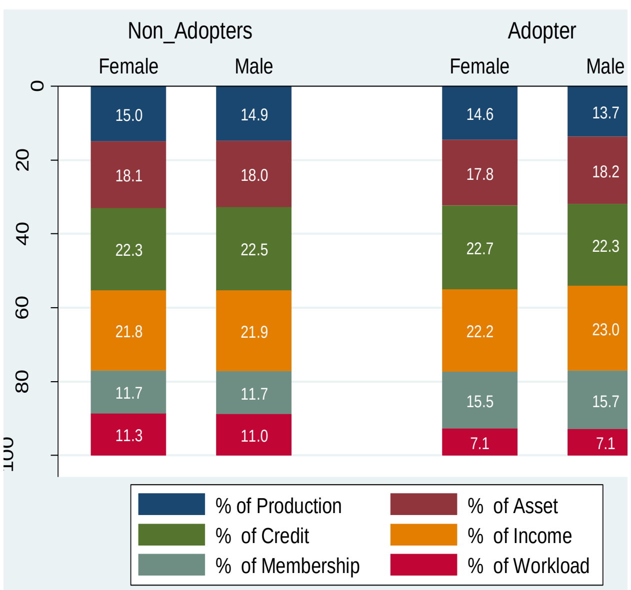

Figure 3: Contribution of each indicators to inadequacy by sex and adoption status

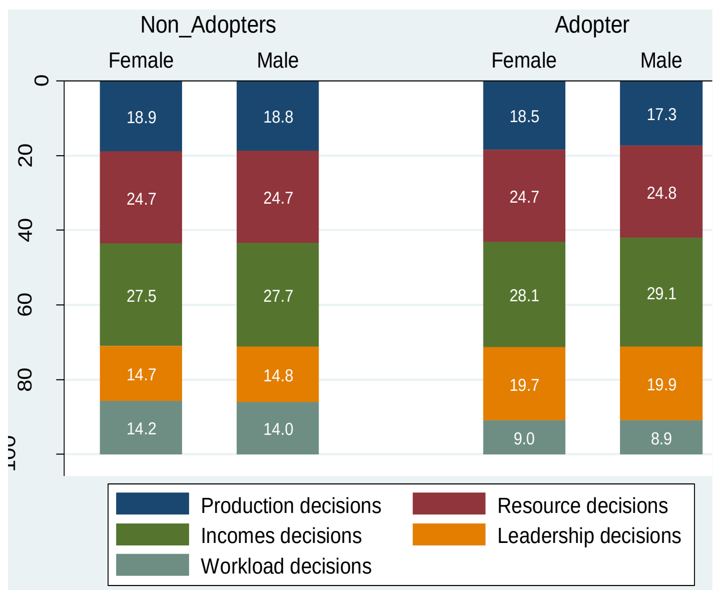

Figure 4: Contribution of each of the five domains to disempowerment by sex and adoption status

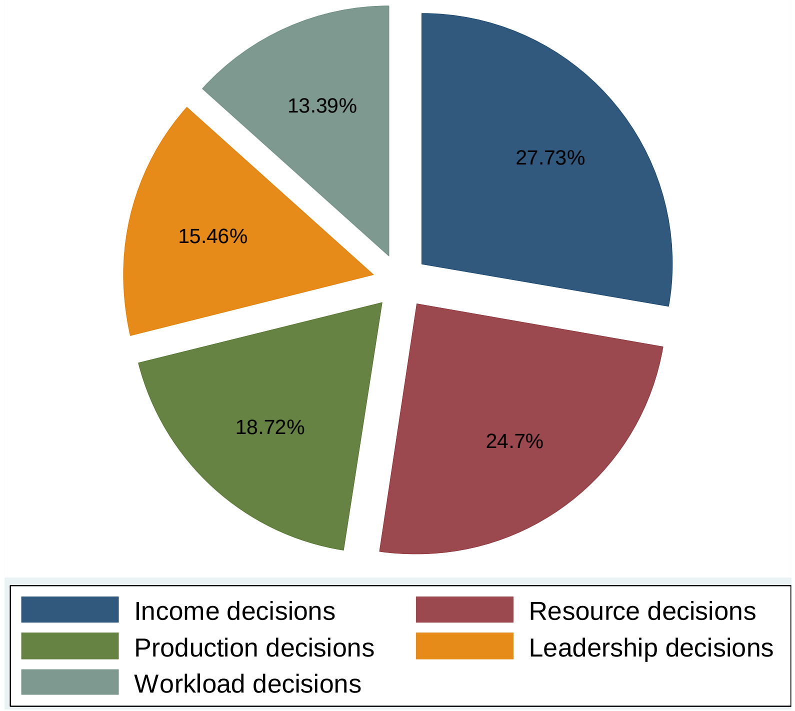

Figure 5: Contribution of each of the five domains to disempowerment

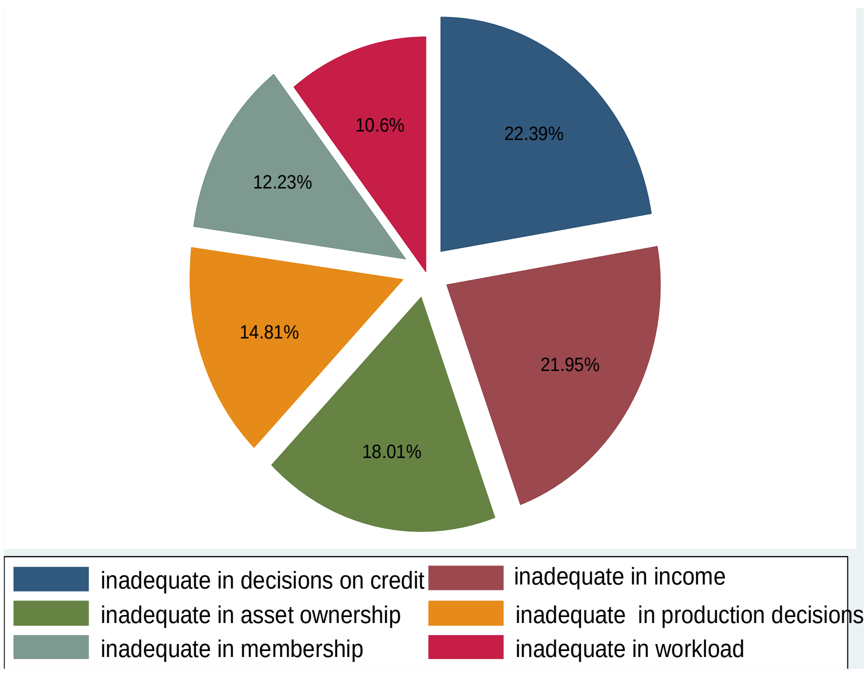

Figure 6: Contribution of each indicator to inadequacy by sex and adoption status

Appendix-B: Supporting Tables

Table B1: The domains, indicators, survey questions, aggregation method, inadequacy cut-offs, and weights in the A-WEAI

Dimension	Indicator name	Survey questions	Aggregation method	Inadequacy cut-off	Weight
Production	Input in productive decisions	Individual has some input, or feels he/she could have, in production decisions	Achievement in two	Individual participates BUT does not have input in decisions; or she does not make the decisions nor feels she could.	1/5
Resource	Ownership of assets	Individual has sole/joint ownership of at least one major asset	Achievement in any if not only one small asset	Household does not own any asset or owns the asset BUT does not own most of it alone	2/15
	Access to and decisions on credit	Individual takes at least one sole/joint decision about use of credit	Achievement in any	Household has no credit OR used credit BUT did not participate in ANY decisions about it	1/15
Income	Control over use of income	Individual has sole/joint input in decisions about income, conditional on participation in activity	Achievement in any if not only minor household expenditures	Individual participates in the activity BUT has no say in decisions about income or does not feels she can take decisions on use of income	1/5
Leadership	Group membership	Individual is a member of at least one group	Achievement in any	individual is not part of at least one group	1/5
Time	Workload	Individual worked < 10.5 hours in the previous 24 hours	NA	Inadequate if works more than 10.5 hours a day	1/5

Source: Adapted from Alkire et al. (2013) and Malapit et al. (2015).

Table B3: Comparison of the WEAI and the A-WEAI: Domains, indicators, and weights

Original WEAI			**A-WEAI**		
Domains	Indicators	Weight	Domains	Indicators	Weight
Production	Input in productive decisions	1/10	Production	Input in productive decisions	1/5
	Autonomy in production	1/10			
Resources	Ownership of assets	1/15	Resources	Ownership of assets	2/15
	Purchase, sale, or transfer of assets	1/15			
	Access to and decisions on credit	1/15		Access to and decisions on credit	1/15
Income	Control over use of income	1/5	Income	Control over use of income	1/5
Leadership	Group membership	1/10	Leadership	Group membership	1/5
	Speaking in public	1/10			
Time	Workload	1/10	Time	Workload	1/5
	Leisure	1/10			

Source: Alkire et al. 2013 and Malapit et al. (2017).

Table B3: Covariate Balance Indicators before and after Matching: Quality Test.

Outcome Variable	Matching type	Pseudo R^2 Before matching	Pseudo R^2 After matching	LR χ 2 (p − value) Before matching	LR χ 2 (p − value) After matching	Mean standardized bias before matching	Mean standardized bias After matching
5DE[13]	NNM	0.093	0.004	672.66***	15.46	15.1	2.3
	KM	0.093	0.003	672.66***	10.66	15.1	1.8
	RM	0.093	0.004	672.66***	14.56	15.1	2.3
5DE [14]	NNM	0.091	0.005	334.37***	8.87	15.6	2.7
	KM	0.091	0.005	334.37***	9.09	15.6	2.3
	RM	0.091	0.013	334.37***	25.26	15.6	4.5
EG[15]	NNM	0.110	0.004	394.06***	6.62	17.2	2.9
	KM	0.110	0.004	394.06***	6.68	17.2	2.2
	RM	0.110	0.017	394.06***	31.61	17.2	5.6
EG[16]	NNM	0.119	0.005	145.98***	2.99	13.0	3.0
	KM	0.119	0.002	145.98***	0.93	13.0	1.8
	RM	0.119	0.016	145.98***	8.98	13.0	4.9

Note: Statistically significant at the 1 % (***) probability level.
Source: Author's calculations using WB LSMS data (2011, 2013, and 2015) (2019).

[13] Empowerment in the five domains for the pooled sample.
[14] Empowerment in the five domains for women only.
[15] Empowerment gap for all women.
[16] Empowerment gap for women without parity.

Table B4: A Description of outcome, treatment and explanatory variables

Variables	Description	Full Sample		Adopters		Non-adopters	
		Mean	SD	Mean	SD	Mean	SD
Outcome variables:							
5DE***	Empowerment score in the five domains	0.45	0.23	0.48	0.25	0.45	0.23
EG***	Relative empowerment gap between female and male scores in 5DE	0.55	0.23	0.52	0.26	0.55	0.23
M_o components							
Production***	=1 if inadequate in input in production decisions	0.51		0.47		0.52	
Assets***	=1 if inadequate in asset ownership	0.63		0.60		0.63	
Credit***	=1 if inadequate in access to and decisions on credit	0.78		0.75		0.79	
Income*	=1 if inadequate in control over use of income	0.76		0.75		0.77	
Leadership***	=1 if inadequate in group membership	0.43		0.52		0.41	
Time***	=1 if inadequate in workload	0.37		0.24		0.39	
Treatment							
Adoption Dummy	Household adopted chemical fertilizers jointly with extension services (1 = adopter)	0.14		0.14		0	0
Year	Survey year (three round panel data, 2011, 2013, and 2015)						
Explanatory Variables:							
Religion dummy							
Protestant_dummy***	HHs major religion is Protestant (1=yes)	0.22		0.12		0.24	
Tradition_dummy***	HHs major religion is Traditional (1=yes)	0.01		0.00		0.01	

Pagan_dummy***	HHs major religion is Pagan(1=yes)	0.01		0.02		0.01	
Marital_stat_dummy							
Married_dummy*	Marital status of the individual: is married (1=yes)	0.95		0.96		0.95	
Single_dummy	Marital status of individual: is single (1=yes)	0.01		0.01		0.01	
Separeted_dummy***	Marital status of individual: is separated (1=yes)	0.00		0.01		0.00	
Crop_rotation***	The individual uses the crop rotation method(1=yes)	0.67		0.79		0.65	
House_rooms***	Numbers of rooms in the house (rooms)	1.79	0.96	1.95	0.94	1.77	0.96
Family_size_AE	HH size in adult equivalent (AE)	4.65	1.72	4.70	1.67	4.65	1.73
Mother's Educ	Mother's education status (1 = literate)	0.06		0.05		0.06	
Age	Age of the individual (years)	40.80	13.76	40.73	13.08	40.82	13.87
Age^2	Squared value of age of the individual (years)	1854	1299	1830	1217	1858	1312
Kitchen_type***	Type of kitchen in the house (1=traditional kitchen)	0.34		0.28		0.35	
Light_source***	Source of light in the house (1=electricity)	0.53		0.50		0.54	
Cooking_fuel	Type of cooking fuel (1=electricity or solar energy)	0.01		0.01		0.01	
Water_source***	Type of drinking water source (1=piped or protected water source)	0.57		0.61		0.56	
Toilet_type***	Toilet type in the HHs (1=modern toilet)	0.45		0.51		0.45	

Note: Adopters and non-adopters' characteristics mean differences are significant at the 1 percent (***), 5 percent (**), and 10 percent (*) probability levels respectively.

Source: Author's calculations using WB LSMS data (2011, 2013, and 2015) (2019).