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Gender equality and sustainable development: A cross-country study on women's contribution to the adoption of the climate-smart agriculture in Sub-Saharan Africa☆

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ABSTRACT

Women face severe gender-specific constraints and have minimal part in the farm decision-making systems in sub-Saharan Africa. This leads to additional barriers in the adoption of climate-smart agriculture (CSA) technologies. This paper contributes to the gender debate by focusing on intra-household gender dynamics that influence the adaptive capacities of small-holder farmers. Using a multi-country approach, and considering Ethiopia, Malawi, South Africa, and Tanzania as case studies, an endogenous-switching poisson regression model was conducted to (i) assess factors influencing the probability of women's engagement in agricultural technology decision-making; (ii) ascertain the effect of women's participation in farm decision-making on climate-smart agriculture adoption. The findings indicate a degree of complexity in women's roles within their communities and family contexts. While in Malawi women participating in the farm decision-making process positively affects CSA adoption, in the other countries their role remains marginal or negatively related with farm sustainability. Such women's empowerment is indeed influenced by the existence of social, regulatory, and cultural elements that uniquely define the considered countries. Context-specific policies that prioritize rural-women, youths, and other marginalized groups can enhance CSA adoption and thereby contribute to the Sustainable Development Goals such as gender equality, climate action and zero hunger in developing contexts.

1. Introduction

Although with some geographic disparities, women can be considered the backbone of agri-food systems, representing about 36% of the global agricultural workforce (FAO, 2023). Such prominent role is particularly evident in Sub-Saharan Africa, where women are mainly responsible for the most time-consuming and labour-intensive tasks, and make up 50% of the agricultural labour force (FAO, 2020). In this context, women are farmers, workers, and entrepreneurs; however, they still face severe gender-specific constraints that reduce their productivity and limit their contributions to agricultural production, economic growth, and the wellbeing of their families, communities, and countries (FAO, 2020). Although profound differences exist in terms of history, ecology and sociocultural norms, it may be argued that some Sub-Saharan African societies remain characterised by patriarchal family structures, being mainly based on men's predominance and visibility and women's subordination and/or marginalisation. Men particularly dominate in terms of family and political leadership, moral authority, social privilege, and control of property (Babugura, 2021), whereas women largely move behind the scenes, combining their work in the field (or kitchen garden) with essential but disregarded and unremunerated activities at home.

If it is true that women's participation in rural labour markets varies considerably across regions, there is also solid evidence that they have been overrepresented in unpaid, seasonal, part-time, low-skilled, and labour-intensive tasks (FAO, 2023). The activities typically carried on by

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women include producing crops, tending animals, collecting fuel and water, processing food, caring for family members, and home maintenance. Usually, the women's work in kitchen gardens or homestead plots is not counted as agriculture, despite their important role in contributing to households' food security and dietary diversity. Furthermore, they have either no or minimal part in farm decision-making, and are held back in determining farm-management strategies (Ogunlela and Mukhtar, 2009). Even when they hold the status of head of household, women continue to face severe gender-specific constraints due to limited access to productive and economic resources, advisory services, and lack of capacity to invest in agricultural technologies (Haug et al., 2021). In certain socio-cultural contexts, women are not even recognized as farmers; and accordingly, services and technologies are not designed and implemented to meet their needs (FAO, 2020). This gender gap greatly contributes to increase their already existing vulnerability, making them even more exposed to stresses associated with environmental and social changes (Azong et al., 2018). Relatedly, climate change might be considered an additional stressor in exacerbating women's vulnerability to natural shocks. It is crucial to recognize that climate change affects men and women differently, and that social differences, particularly gender inequality, must be taken into account in order to strengthen the effectiveness and sustainability of CSA interventions (Huyer and Chanana, 2021). However, the view of women as just vulnerable and unresponsive individuals — one that portrays them as victims of sexual and domestic violence, as mothers who sacrifice for their children, as unable to escape poverty, as being vulnerable and powerless, as passive beneficiaries — ignores or underestimates the potential they have in terms of resilience and adaptive capacity. In fact, such view has proliferated both in literature and development work, and has played a big role in erasing people's (and in particular, women's and girls') abilities and power to find solutions and improve their lives as active participants to development instead of passive beneficiaries who need to be educated about their rights, to improve their self-esteem, or be motivated to participate in public life. Furthermore, this short-sighted vision of women as victims conceals deep-rooted inequalities, patterns of marginalisation, and unequal power structures; particularly in the form of systematic material and educational deprivations that they experience on a daily basis in many places around the world (Tschakert and Machado, 2012). On the contrary, women should be understood as active agents who can greatly and intentionally contribute to the sustainable transition from vulnerable to resilient and climate-neutral agricultural systems. Based on this understanding of women's agency—and against the backdrop of an increasing feminisation of the agricultural sector—it is essential to design and promote more gender-inclusive and climate-smart strategies (Babugura, 2021).

In Sub-Saharan Africa, climate-smart agriculture (CSA) is considered an emerging paradigm for agriculture's adaptability to, and mitigation of, new climatic conditions; one that comprises a set of practices integrating the three dimensions of sustainable development—economic, social, and environmental—by jointly addressing food security and climate-change challenges (FAO, 2021). The main purpose of CSA is the promotion of a transition towards more sustainable agricultural systems based on a number of practices: an efficient use of inputs; developing strong resilience to risks, shocks, and long-term climate variability; and fostering an inclination towards natural-resource preservation (Rioux et al., 2016). This approach is additionally characterised by three specific goals: (i) sustainable increase in agricultural productivity and incomes; (ii) strengthening the resilience of agricultural systems to climate change; and (iii) reducing and/or eliminating greenhouse-gas emissions (FAO, 2021).

With specific relation to gender, some CSA practices may have an enormous potential in reducing rural women's labour burden, which often exceeds that of men due to cultural norms and gender-based roles (Autio et al., 2021). For example, practices like minimum/zero tillage and green manuring can significantly reduce the workload required of women in activities such as transplanting, nutrient management, and sowing crops (Khatri-Chhetri et al., 2020). However, such reductions in labour requirements are dependent on the existence of appropriate conditions as well as the availability of resources and agricultural inputs (e.g., herbicides), which in reality are not always available to women.

Women's limited access to economic, physical, and human resources, as well as their restricted involvement in intra-household decision-making systems, affect their capacity to adopt CSA practices. Despite the pervasive role gender dynamics play in the adoption and implementation of CSA strategies, the current literature fails to clearly focus on such root causes and underlying structures. Furthermore, studies on gender gaps in the context of climate-change adaptation have been limited to comparisons between households headed by men and those headed by women (Ngigi et al., 2017). This approach oversimplifies the complexity of the household management structure, as it gives little attention to family contexts where women live in dual-adult households (usually referred to as "male-headed") or farm-management systems in which wives participate in farm organizations and activities along with their husbands and other family members (Kristjanson et al., 2017).

This paper aims at contributing to the gender debate by focusing mainly on the intra-household decision-making dynamics that influence the adaptive capacities of small-holder farmers. Specifically, it analyses the role of women not only as household heads, but also as actors involved in the farm decision-making process. Furthermore, based on the assumption that decision-making power at the farm level is not always gender neutral, this study examines the factors influencing women's empowerment regarding household management. Households are here considered as complex units of production whose management is based on unitary (male-managed, female-managed and separately-managed) or collective decision models. Special attention will be paid to joint management models, which imply that decision-making occurs between two individuals, typically husband and wife, but can also involve other household members. 'Jointness' is here used as a potential indicator of gender equality, although situations may occur when jointness also implies the existence of conflicts, and power differentials and negotiations, within the family (Bjornlund et al., 2019).

The multi-country approach that informs the paper represents an innovative element whereas it prevents from falling into the trap of easy generalizations while facilitating the identification of differences across socio-cultural and economic contexts—each with unique traditions, cultural and gender norms, and social rules at large. A cross-sectional econometric analysis was conducted using primary data collected in Ethiopia, Malawi, South Africa, and Tanzania, which aimed to: i) identify socio-cultural factors affecting the level of women's involvement in household decision-making; and (ii) estimate the effect of women's involvement in farm management on the number of CSA practices that can be implemented at farm level.

2. Climate-smart agriculture between benefits, limits and gender inequality

The efficiency, resilience, adaptive capacity, and mitigation potential of the production systems characterising the CSA approach can be implemented through a wide range of agricultural practices at the farm level. For the purpose of the present study, a specific set of CSA practices was selected. Firstly, we considered *improved agronomic practices*, including: (i) the use of cover crops, (ii) improved crop varieties (more heat- and pest-tolerant varieties), (iii) crop rotation, and (iv) intercropping (especially with legume crops). The use of cover crops is reported to lead to higher yields due to decreased on-farm erosion and nutrient leaching, and reduced grain losses due to pest attacks (Branca et al., 2013). On the other hand, improved varieties can increase average yields due to greater pest and heat tolerance (Branca and Perelli, 2020). Crop rotation and intercropping ensure differential nutrient uptake. They enhance soil fertility, reduce pests and diseases, and enrich nutrient supplies to subsequent crops, overall leading to increased yields (Branca et al., 2013). The study also considered *integrated nutrient* *management practices,* which include soil-fertility practices that promote the use of fertilizers, organic inputs, and biological resources, which can be combined to maximise nutrients' efficiency and improve overall crop productivity (Vanlauwe et al., 2010). They enhance ecosystems' sustainability, especially with regard to nutrient mining and the degradation of soil and water resources. *Tillage systems* (no-tillage and minimum-tillage practices) and *residue management practices* (crop-residue mulching) were included for their contribution to the conservation of soil fertility, enhancement of water infiltration, protection of soil from sealing and crusting by rainfall, and increase of soil carbon sequestration (Rusu et al., 2009; Scopel et al., 2004). Finally, we considered the *enhanced water management practices*, such as tied ridging and planting pits, which can help capture more rain, therefore making more water available to crops in a more efficient fashion (McCarthy et al., 2011; Rockström and Barron, 2007; Vohland and Barry, 2009).

Despite the aforementioned environmental benefits related to the adoption of CSA practices, there is a debate regarding their economic advantages in Sub-Saharan Africa. Indeed, although labour is saved on tillage, the implementation of some CSA packages (i.e., conservation agriculture) requires labour-intensive digging of planting basins and more frequent weeding (particularly at the beginning of such transition). The increased amount of labour required for weeding may outweigh the labour-saving gained by not ploughing, unless herbicides are used to control weeds (Giller et al., 2009; McCarthy et al., 2011). However, such inputs are unavailable or too expensive in most areas. This means that the increased weed control (either by herbicide application or hand weeding) and related additional costs could reduce the economic advantage of CSA compared to conventional practices. The majority of farmers has no access to capital for purchasing of agricultural implements and cannot afford ever-rising costs for hired labour, agrochemicals, seeds and other inputs (Blanco and Lal, 2008). Furthermore, smallholder farmers have sometimes reservations about CSA because of yields reductions in the first four years or more, whereas costs tend to occur upfront (Blanco and Lal, 2008; Hobbs et al., 2008; McCarthy et al., 2011). This means that adopting conservation agriculture practices will be significantly harder for households with low finances and credit constraints, especially in cases where the initial investment required is quite significant (McCarthy et al., 2011).

With regard to the gender dimension, there is lack of evidence that CSA is necessarily relevant to, or beneficial for, women (Collins, 2018). Indeed, an increase in weeding requirements due to a decrease in tillage may shift the workload towards women, who are traditionally responsible for such field activities (Kaczan et al., 2013). In fact, the tendency to allocate additional labour-intensive activities to women may render them reluctant to adopt new climate-resilient practices in agriculture (Beuchelt and Badstue, 2013). Additionally, the cost of herbicides is high and particularly challenging for smallholder women. Another constraint underlying CSA adoption by women is connected with the maintenance of permanent soil covers. Specifically, the use of crop residues for mulching reduces the availability of residues for alternative (domestic) uses (i.e., as household fuel). As a result, mulching can increase the workload for women who are frequently those responsible for the collection of firewood for the household (Beuchelt and Badstue, 2013; Tsige et al., 2020).

Constraints from outside the agricultural field also influence women's willingness to adopt, and benefit from, CSA. In certain settings, barriers such as lack of access to finance, transport, or energy to support production activities need to be addressed in order for women to even start considering whether or not the adoption of CSA practices may be a viable and empowering option (Huyer and Partey, 2020).

Among other barriers to adopting CSA, the issue of gender-related time poverty should also be accounted for. For example, in Ethiopia as in several rural areas of sub-Saharan Africa, women experience a greater degree of time poverty due to their disproportionate responsibility for food production, processing, and household chores (Ogisi and Begho, 2023). Women are erroneously deemed to have universal responsibility for food preparation and consumption, and in many cultures for production and distribution as well. They are defined as 'natural' nurturers and caregivers, and even when employed outside of the home, women do the vast majority of household chores and take on more of the feeding role, frequently with a rare control of income generated through their paid labour. These extra tasks may be conflicting with the adoption of climate-smart farming techniques, which, in the absence of specific conditions (i.e., access to herbicides and other agricultural inputs), bear the risk to increase the amount of fieldwork required of women.

These highlighted contractions in relation to time poverty and the division of labour in food production, food acquisition, and meal preparation make it obvious that, although benefits of CSA can be registered at the plot level, this does not inherently mean that CSA will enhance the farming system and rural livelihood as a whole. In order to be effective from an environmental, economic and social point of view, CSA must be designed and adapted to biophysical elements, socio-economic characteristics, cultural resources and limitations, as well as to gender norms that are deeply engrained in individually and collectively held identities—all highly context-specific factors that are hardly captured by broad generalizations. Moreover, the adoption of CSA should foster a network and synergistic approach to engendering transformative change (that is, a combined action across scales and with the involvement of men and power-holders) to releasing 'women only' from the burden of working for climate adaptation and mitigation (the so-called feminisation of responsibility), and instead leveraging the positive complementarity between men and women, young and old, in achieving these interlocked goals through collective action, political engagement, and consciousness raising.

3. Methodology and data

3.1. Study area

The study we present here precisely focuses on the adoption of CSA practices and women's associated roles, and was conducted in Ethiopia, Malawi, South Africa and Tanzania —four Sub-Saharan countries characterised by socio-economic and environmental differences, but which also share similarities in terms of climate-change vulnerability and CSA adoption. Although we deem the data collected comparable to a certain degree, we also acknowledge that gender norms vary by context and intersect with other aspects of identity (such as wealth, ethnicity or religion), as well as other expectations and practices. In particular, the experiences of women vary widely between and within their female reference networks, as well as in relation to the experiences of men. The fact that gender norms are underlying drivers of gendered practices, but also dynamic and changeable, makes them critical leverage points for enhancing gender equality.

In Tanzania, the agricultural sector is dominated by rain-fed farming systems, whose fragility has been increasingly exacerbated by ongoing global warming. Adverse impacts include poor crop yields because of droughts and floods, reduced water availability, and increased occurrence of pests and diseases (Rwehumbiza, 2014). Despite continued efforts to scale up the implementation of climate-neutral strategies in Tanzania, the adoption of CSA practices such as maize-legume rotation and water-conservation techniques (ridges and soil bunds), remains slow and incomplete, and involves no more than 10% of farms (Kurgat et al., 2020). Furthermore, Tanzania's climate change policies largely neglect the interplay between climate change and the various socio-cultural and economic dimensions that influence vulnerability at the individual and community levels. Specifically, they are highlighted as showing insensitivity to gender issues, by treating women as one homogeneous group and ignoring that some of the adaptation strategies might be less available to specific categories of women, such as female household heads (Van Aelst and Holvoet, 2016).

The agricultural sector in Malawi is characterised by small-scale rainfall-dependent farming systems, which struggle with complex agroecosystems and an ever-increasing climate variability. Despite the efforts made by Malawi's government to promote conservation agriculture (Bell et al., 2018), drought-tolerant varieties (Katengeza et al., 2019), and physical infrastructure for soil and water preservation (Soroko et al., 2018)—the adoption rate of such CSA practices remains low due to high resource requirements centred around labour, capital, and land use (Amadu et al., 2020a, 2020b; Mutenje et al., 2019). This is particularly true for women farmers due to the persistence of gender norms that create a strong divide in relation to intra-household duties and responsibilities. In rural Malawi, women typically care for children and produce food crops, while men predominantly produce and sell cash crops, even when the processing is a shared task between all household members (Murray et al., 2016). Furthermore, women are usually excluded from household decision-making. Even if motivated to adopt CSA practices, women farmers usually lack access to basic agricultural tools, transportation, and rural energy (Ibid.).

In Ethiopia, agricultural productivity is prone to risks and uncertainties, such as land degradation, depletion of soil fertility, and climate change (Zerssa et al., 2021). In recent years, a greater frequency of extreme events, erratic rainfall, shorter rainy seasons, and increased drought periods have resulted in local crop-production shortfalls. In this context, CSA appears as a sustainable approach, yet scarcely used due to shrinking cropland and land-tenure issues, lack of adequate knowledge and information transfer, slow return of benefits, and lack of financial support (Ibid.). Furthermore, the adoption of these technologies is hindered by gender constraints. Customary laws in rural Ethiopia privilege men as the primary ‘owners,’ and land inheritance is guided by patrilineal principles. Women smallholders are affected by limited access to credit, information, and training, as well as restricted membership in cooperatives and associations, lack of access or user rights to land, and restricted mobility (Tsige et al., 2020; Covarrubias et al., 2021). Such gendered dynamics across institutional, information and knowledge-related levels contribute to women's limited uptake of CSA strategies.

South Africa main farming systems are characterised by the coexistence of large commercial and smallholder farming, whose activity is largely based on mixed cereal-livestock systems (Dixon et al., 2001). Their agricultural productivity faces exacerbated risks due to ongoing climate changes because of specific agro-climatic conditions (Myeni and Moeletsi, 2020), as well as water scarcity and quality. The effects of inconstant rainfall include livestock loss, low yields, and shortage of seeds for subsequent cultivation (Maponya and Mpandeli, 2012). Women are more vulnerable and exposed to such climatic shocks due to social stratification, which manifests itself in patriarchal dominance, race inequities, poor literacy levels, and limited access to critical resources (Nyahunda et al., 2021). This generalized inequality prevents women from weighing their options for climate-change adaptation, and hinders them from adopting CSA—an approach that has not yet been formalised in local policies but of growing interest within agricultural communities (Wilkinson and Pickett, 2009; Senyolo et al., 2018).

3.2. Sampling and data collection

The study used data collected through a field survey conducted from January to February 2018 within the EC-funded H2020 InnovAfrica Project.[1] Data were collected from seven sites: (i) Lindi District, located in the coastal lowlands of Tanzania; (ii) Mzimba and Dezda District, located in the northern and central regions of Malawi; (iii) Kombolcha and Meta Districts, both located in the Oromia region in Ethiopia; and (iv) the Free State Province of South Africa. The required sample size was determined using Cochran's sample formula:

$$n_0 = Z^2 pq / e^2$$

where Z represents the standard deviation of the 95% confidence interval, characterising a normal distribution; p is the estimated proportion of households adopting maize-legume/millet-legume cropping systems; q is equal to (1 − p); and e represents the desired level of precision.

A multistage sampling procedure was employed to obtain efficient and consistent estimates of the target population. During the first stage, clusters representing lower administrative units (e.g., regions, districts, villages, and wards) were selected. Once obtained a complete list of households in each administrative unit, farmers to be subsequently interviewed were selected randomly. The main purpose of this project was the dissemination of sustainable agricultural intensification systems. However, it is possible that a subset of the selected households had already adopted (or have prior experience with) some of the targeted CSA technologies. The original survey involved a total of 2218 households distributed in the different country-case studies. However, a subsample of rural farms was selected for the present research's purposes due to the variations in rural household size and composition throughout countries. Although there is no universal agreement in the literature on what size of landholding should be considered “small-scale,” we refer to the small-scale farming systems more common in African countries, which are typically traditional family-based farming operating on two hectares or less (Impiglia, 2017). As a result, the final sample used here consists of 1840 households. The questionnaire employed for data collection allowed the following information to be gathered: smallholders' sociodemographic and economic profiles; improved agriculture practices adopted and seed systems; climate-change perception, adaptation, and coping strategies; membership in agricultural associations and access to extension advisory services (EASs); access to agricultural input and credit; fieldwork division by gender; and participation in household's decision-making by gender.

3.3. Conceptual framework

The objective of the present research was to contribute to the gender debate by focusing mainly on intra-household dynamics that influence the adaptive capacities of small-holder farmers. Based on the random utility theory, this study hypothesizes that farmers will adopt CSA practises if they perceive more advantages or fewer risks in comparison to their non-adoptive state (Zakaria et al., 2020). In the description of intra-household dynamics, we referred to both the unitary and the collective decision-making models (Quisumbing and Maluccio, 2000). The first one, characterised by neoclassical roots, considers the household as a unit where single members make decisions, whereas the collective approach regards the household as a site of conflict, bargaining and cooperation, where decisions are made in such a way that the outcomes are pareto-optimal or pareto-efficient (Bolt and Bird, 2003). Such dynamics are complex and are also affected by multiple factors such as socially constructed roles and obligations, age and birth order, individual agency, power and knowledge asymmetry, access to and control over resources, and extra-household social interactions (ibid.). According to the collective model, decision-making and decision-makers are varying based on the household structure, type of decisions to be made, and cultural setting (Malapit et al., 2019).

In examining the gender-equality dynamics that underpin household decision-making, we especially focus on collective models since they reflect a setting where women's decision-making authority is granted through social and familial acknowledgment. The unitary model, on the other hand, is represented by situations in which the sole decision-maker is either a man or a woman. While the former case is typically determined by patriarchal family structures, the latter is usually associated with the phenomena of agricultural feminization, which is quite common in de-facto and *de-jure* female-headed households. In such contexts,

[1] ‘Innovations in Technology, Institutional, and Extensions Approaches towards Sustainable Agriculture and enhanced Food and Nutritional Security in Africa’ (Grant nr. 727201).

women are prime farmers while also struggling to balance their domestic duties with an increasing workload in the field (Johnston et al., 2018). Furthermore, they are usually characterised by low education level, limited access to production resources and agricultural services, and limited rights due to social constraints. All these elements can lead to more precarious economic and food security conditions, with rural households depending solely on women's work and income (Lastarria-Cornhiel, 2008). This demonstrates that feminization of agriculture is not always associated with social and economic women's empowerment, but rather with poverty and feminization of rural distress (Slavchevska et al., 2016; Pattnaik et al., 2018; Quisumbing et al., 2019; Haug et al., 2021).

A framework consisting of two-simultaneous equations system was developed to: (i) assess factors influencing the probability of women's engagement in agricultural technology decision-making; and (ii) ascertain the effect of women's participation in farm decision-making on CSA adoption. The participation of women in the farm management system might be influenced by some intrinsic farm characteristics, some of which could also affect the number of CSA practices adopted. This could cause endogeneity problems as well as selectivity bias in the adoption of CSA practices. Without accounting for sampling issues, estimating the impact of women's participation in the decision-making process may result in biased estimates. Following Terza (1998), Miranda (2004) and Zakaria et al. (2020), this study used an endogenous switching poisson model for analyses, since CSA adoption (the outcome variable) refers to a count of adaptation strategies that is characterised by a poisson probability distribution.

Based on the discussion in Miranda (2004), given an ith farm from a random sample $N = (1, \ldots, n)$, a vector of explanatory variables x_i representing the socio-economic and demographic characteristics of the household, an endogenous dummy d_i representing the participation of women to the farm management, and a stochastic term ε_i measuring the loss of information and omitted variables, the count variable y_i (which represents the number of CSA practices adopted) is supposed to follow a standard poisson distribution:

$$f\ (y_i|\ \varepsilon_i) = \frac{exp\{-exp(x_i^{'}\beta + \gamma\ d_i + \varepsilon_i)\}\{exp(x_i^{'}\beta + \gamma\ d_i + \varepsilon_i)\}^{yi}}{y_i!} \tag{1}$$

The endogenous variable d_i contained in the model is characterised by the following index process:

$$d_i = \begin{cases} 1, & \text{if } z^{'}\alpha + v_i > 0 \\ 0 & \text{otherwise} \end{cases} \tag{2}$$

where z_i is the vector of explanatory variables (which might encompass some or all elements of x_i), and α is a vector of coefficients to be estimated.

Assume that w_i represents all exogenous variables, and suppose that ε_i and v_i are normal distributed with mean equal to zero and covariance matrix structured as follow:

$$\sum = \begin{pmatrix} \sigma^2 & \sigma\rho \\ \sigma\rho & 1 \end{pmatrix}$$

conditional on ε_i, d_i and y_i are independent. As result, the joint conditional probability density of y_i, and d_i, given w_i, can be written as follow:

$$f(y_i, d_i|w_i) = \int_{-\infty}^{\infty} \Big\{ d_i f\ (y_i|d_i = 1, w_i, \varepsilon_i) Pr\ (d_i = 1|w_i, \varepsilon_i)$$

$$+ (1 - d_i) f(y_i|d_i = 0, w_i, \varepsilon_i)\ Pr\ (d_i = 0|\ w_i, \varepsilon_i)\Big\} f(\varepsilon_i)\ d\varepsilon_i \tag{3}$$

where $f(\varepsilon_i)$ represents the probability density function of the random term ε_i.

3.4. Empirical strategy

The Endogenous Switching poisson regression model here used consists of an equations system aimed to estimate the effect of women's participation to fam decision-making context on CSA adoption. It can be expressed as following:

$$E\ (CSAP_j / X_{ij}, W_j, \varepsilon_i) = Exp\ (X_{ij}\ \beta_i + \alpha W_j + \varepsilon_i) \tag{4}$$

$$W_j = \begin{cases} 1, & Z_{ij}\mu_i + u_i > 0 \\ 0, & \text{otherwise} \end{cases} \tag{5}$$

where $CSAP_i$ denotes the number of climate-smart practices adopted by sampled farmers,[2] and X_{ij} represents the independent variables included in the model, whose selection was realized following existing theories that link the adoption dynamics of climate-change-management strategies with various environmental, socioeconomic, demographic, and cultural factors (Deressa et al., 2009; Hassan and Nhemachena, 2008; Nhemachena and Hassan, 2007; Makate et al., 2019). Such group of explanatory variables include the demographic characteristics of the household head (gender, age and education level), the number of family members, the household's economic conditions (i.e. on-farm and off-farm budget, access to credit and subsidies), the human assets (number of hired workers per agricultural season/ha), the physical assets (agricultural tools and land), the use of chemical inputs, the participation to farmer's associations, the access to extension services, and the perception of climate changes. Furthermore, interaction terms combining household-head gender with important socioeconomic aspects, such as farmers' education level and households' access to agricultural credit, were introduced here as independent variables with the aim of conducting more in-depth analysis of women's role in CSA adoption.

The variable W_j denotes the participation of women in the decision-making process of the household. It takes the value 1 if women make decisions jointly with the husband and other family members, and 0 otherwise. Given the endogenous nature of such dummy variable, for each single country-case we selected a group of independent variables (Z_{ij}) which meets the conditions for instruments (Angrist and Krueger, 2001). Following Di Falco et al. (2011) a straightforward falsification test was used to confirm the acceptability of these instruments. As shown in Appendix A, the explanatory variables here used can be regarded as valid selection instruments for each country study. Specifically, they are statistically significant drivers of women's involvement in decision-making contexts (Model 1 is characterised by an X^2 statistically significant) but not of CSA adoption level (Model 2 illustrates an X^2 not statistically significant). The selection of such instrumental variables was realized based on the theoretical framework and past empirical literature, which identified a range of socioeconomic influences on household decision-making dynamics; namely, household head main characteristics (i.e. gender), age and education level of family members, number of adult male and female members, number of children, and access to critical resources (i.e., land) (Doss et al., 2014; Doss and Meinzen-Dick, 2015; Mutenje et al., 2016; Bjornlund et al., 2019).

Table 1 illustrates and describe all the variables used in the study.

[2] Due to lack of data at plot-level or hectare level, it was not possible to use the concept of "adoption intensity", which is usually expressed in terms of the number of practices adopted per unit area (Amadu et al., 2020). As a result, the present study refers to the number of practices adopted at household-base as a proxy of the CSA adoption level.

Table 1
Description and measurement of variables.

Variables	Variable description and measurement units
Climate Smart Agriculture practices (CSAP)	Number of climate-smart agricultural practices adopted
Household head, gender	1 if female, 0 if male
Household head, age	Age of the household head (years)
Household head, education	Education level of the household head (years of schooling)
Household members	Number of family members
On-farm income	Income generated by agricultural activities (USD)
Off-farm income	Income generated by non-agricultural activities (USD)
Land area	Size of the agricultural land (ha)
Hired labour/ha	Number of person/days per agricultural season/ha
Asset index[a]	Index ranges between 0 (low use of agricultural assets) and 1 (high use of agricultural assets)
Tropical Livestock Units (TLU)/ha	Livestock owned (expressed as tropical livestock units, TLU) per hectare
Chemicals	1 if household uses chemicals, 0 otherwise
Climate change	1 if household perceived climate changes, 0 otherwise
Group participation	1 if household is member of farmer's associations, 0 otherwise
Credit access	1 if household has access to credit, 0 otherwise
Subsidies	1 if household receives subsidies, 0 otherwise
Extension Advisory services (EASs)	1 if household has access to extension and advisory services, 0 otherwise
Joint decision-making	1 if women make decisions jointly with the husband/ other family members, 0 otherwise
Men-to-women ratio	Ratio of men to women (Number of men/Number of women)
Children-to-adults ratio	Ratio of children to adults (Number of children /Number of adults)
Age of men	Average age of men in the family
Age of women	Average age of women in the family
Education of men	Average years of schooling of men in the family
Education of women	Average years of schooling of women in the family
Joint land ownership	1 if the agricultural land is jointly owned by husband and wife, 0 otherwise

[a] The asset index includes the radio, telephone, bicycle, machete, sickle, spade, hoe, and water pump. Since they are dichotomous variables, we used Multiple Correspondence Analysis (MCA) to examine a pattern of relationships between numerous categorical variables (Abdi and Valentin, 2007).

4. Results and discussion

4.1. Descriptive analyses

4.1.1. Description of the sample

Descriptive statistics illustrated in Table 2 indicate that, in almost all countries, sampled farmers are mostly male, middle aged (39–59 years) with an education level ranging on average between 3 and 6 years of schooling. In Malawi, Ethiopia and Tanzania, the households headed by women are the minority, while in South Africa they represent about 50% of the sampled farms.

Female household heads are older in South Africa than in the other countries, and are also characterised by the higher education level (about 5 years of schooling on average), which is still less than those of their male counterparts. This element also characterizes the other selected countries. Indeed, although with some differences related to the average school years, women (household heads or adult family members) are on average the least educated.

Two indicators—one relating to the ratio of women to men and the other to the ratio of children to adults—have been defined in order to more properly represent the structure of the household. In this regard, Ethiopian families appear larger and have a structure that is characterised by a higher proportion of men to women. Furthermore, in Malawi and Ethiopia the number of children exceeds the number of adults on average.

The distribution of land ownership among family members is another element this study has taken in consideration to define the positionality of women within the household. The country cases here analysed are characterised by the culture of gender-disaggregated plots ownership. Ethiopia has the greatest percentage of households where women and men jointly own agricultural land, followed by Tanzania and Malawi. This condition is less common in South Africa, where just 19% of households are characterised by joint land ownership. However, there are significant differences in land tenure between countries that should be taken into account, given the great impact such factor plays on women's access to, and control over, land.

Malawi's land is designated as either under private freehold, public, or customary ownership. In this country smallholder agriculture occurs largely on customary land, which accounts for approximately 80% of the total land area (Fisher and Kandiwa, 2014). The state owns customary land, but chiefs of villages have the authority to allocate land within their jurisdiction (Kishindo, 2004; Place and Otsuka, 2001; Fisher and Kandiwa, 2014). In this context, women and men gain access to land primary through inheritance and marriage. Land transfer methods are due to either matrilineal or patrilineal descent practices. While in a patrilineal marriage land succession is through the male lineage and women can only access land through their husbands and sons, in matrilineal systems a man does not need to inherit land because he will receive it from his wife (Berge et al., 2014).

Land tenure systems in Ethiopia and Tanzania require that land ownership rights are kept within the State, granting their citizens only land use rights (Teklewold, 2023). In Ethiopia, a land certification programme launched in 1997 has taken steps to incorporate the gender dimension by issuing land certificates jointly to both spouses (ibid.). Also in Tanzania, co-ownership of land is granted to both spouses, and village councils are prohibited from discriminating against women (Jacobs, 2002). Although women's legal land status has improved in both countries, restrictions on land access, agricultural resources, and benefits from crop sales continue to affect women's economic autonomy (Grown et al., 2005; Jacobs, 2002; Teklewold, 2023).

The South Africa's land tenure system includes large-scale white commercial farming (based on the former colonial and apartheid system) and state land—areas inhabited by customary communities, with strong traditional authorities, and where subsistence-type agriculture is practiced (Weinberg, 2015). Typically, women are not eligible to own independent titles to land and still face difficulties in purchasing land in the market because of their limited access to capitals.

With regard to livestock activities, we calculated the tropical livestock unit (TLU) as a weighted index by assigning weights based on livestock type (0.50 for cattle, 0.10 for sheep and goats, 0.20 for pigs, and 0.01 for chickens). The number of animals in each livestock group per household was multiplied by their individual weights, yielding the unique TLU per household. Following Julien et al. (2019), the weighted indices (family labour and TLU) were then standardized by land size (in hectares). The highest value of Tropical Livestock Unit index confirms the importance of the livestock production for Ethiopian farmers (both male and female headed households). This value appears fairly low in the other countries, probably reflecting a low adoption of mixed crop-livestock systems.

Considering household's economic assets, Tanzania has the highest level of on-farm monthly income (about 71 USD), while South Africa has the highest value of income generated mainly by off-farm employment (private, public or NGO sector), which is equal to about 183 USD per month.

Furthermore, summary statistics show that in Tanzania and South Africa the access to credit is limited, while women are completely excluded from it.

On the other hand, in Tanzania approximately 47% of farmers can benefit from incentives to purchase agricultural inputs, while the access to such subsidies is limited in all the other countries. However, some gender differences can be detected. Specifically, in Tanzania the proportion of women eligible to receive input subsidies, although high, is

Table 2
Summary statistics of sampled farms, by country.

Variables	MALAWI			ETHIOPIA			TANZANIA			SOUTH AFRICA		
	Overall (*N* = 593)	Female (*N* = 166)	Male (*N* = 427)	Overall (*N* = 610)	Female (*N* = 47)	Male (*N* = 563)	Overall (*N* = 145)	Female (N37=)	Male (*N* = 108)	Overall (*N* = 492)	Female (*N* = 249)	Male (*N* = 243)
Household head, gender	0.28	n/a	n/a	0.08	n/a	n/a	0.26	n/a	n/a	0.51	n/a	n/a
Household head, age	44.34	51.72	41.47	39.27	40.96	39.13	46.85	48.49	46.29	56.80	58.84	54.72
Household head, education	6.29	4.89	6.83	3.23	1.00	3.42	3.74	2.65	4.12	5.94	5.52	6.38
Household members	3.59	3.14	3.77	4.53	3.77	4.59	2.88	2.81	2.90	2.14	2.14	2.14
Men-to-women ratio	0.89	0.36	1.14	1.20	0.63	1.25	0.84	0.31	1.04	0.71	0.46	1.11
Children-to-adults ratio	1.14	1.29	1.08	1.28	1.38	1.27	0.80	1.03	0.72	0.52	0.55	0.49
Age of men	36.71	25.07	38.35	34.58	23.78	35.10	44.12	36.91	44.85	44.18	35.54	48.44
Age of women	38.53	47.25	34.49	31.67	39.19	30.95	38.39	46.30	35.50	48.18	51.30	43.04
Education of men	7.29	8.43	7.13	4.32	6.15	4.23	4.23	4.00	4.25	8.22	9.74	7.47
Education of women	5.88	5.40	6.03	1.83	1.15	1.89	3.44	2.84	3.66	7.41	6.89	8.26
Joint decision-making	0.52	0.10	0.69	0.54	0.28	0.56	0.45	0.14	0.56	0.11	0.04	0.18
Joint land ownership	0.36	0.11	0.45	0.69	0.55	0.70	0.43	0.11	0.55	0.19	0.10	0.29
Hired labour/hectare	1.95	3.45	1.37	3.18	5.52	2.98	3.06	0.87	3.81	3.59	2.02	5.19
Group participation	0.25	0.25	0.26	0.12	0.13	0.12	0.10	0.11	0.09	0.01	0.01	0.00
EASs	0.32	0.30	0.32	0.39	0.32	0.39	0.04	0.00	0.06	0.02	0.03	0.01
Land area	0.82	0.75	0.84	0.40	0.38	0.40	1.13	1.08	1.14	0.74	0.70	0.78
Asset index	0.73	0.70	0.74	0.34	0.38	0.33	0.77	0.77	0.78	0.25	0.26	0.24
Chemicals	0.24	0.21	0.25	0.16	0.19	0.16	0.43	0.35	0.45	0.01	0.00	0.01
Livestock (TLU) / hectare	0.04	0.04	0.03	0.40	0.20	0.41	0.09	0.03	0.11	0.09	0.13	0.05
Off-farm income	17.54	13.56	19.08	11.67	18.96	11.06	29.96	19.57	33.52	182.56	158.50	207.22
On-farm income	16.71	9.86	19.38	49.49	35.34	50.67	71.44	52.46	77.94	18.18	16.64	19.75
Credit access	0.28	0.30	0.27	0.34	0.47	0.33	0.06	0.00	0.07	0.01	0.00	0.02
Subsidies	0.21	0.23	0.21	0.03	0.04	0.02	0.47	0.41	0.49	0.01	0.01	0.01
Climate change	0.86	0.87	0.86	0.97	0.96	0.98	0.77	0.76	0.78	0.77	0.77	0.78

8% lower than that of men.

With regard to the involvement in networks, associations and extension programs, Malawi has the largest percentage of farmers who participate to interest groups (25%), while Ethiopia has the highest percentage of farmers who use extension services (39%). Summary statistics also reveal that, in almost all countries (with the only exception of South Africa), the participation to extension programs is reduced for female household heads. Fletschner and Kenney (2014) indicate that women's capacity to attend training sessions and gain access to important information was hampered in those cultural contexts where social norms restrict women's mobility and communications with men. This means that, in the majority of cases, extension services to women are still underprovided.

Finally, in all the country cases, the majority of farmers (both women and men) reported to have perceived (in the last five years) changes in the intensity and frequency of extreme climate events such as floods, droughts and erratic rainfalls.

4.1.2. *Adoption levels of climate-smart practices*

Smallholder farmers considered in the present study are characterised by different adoption levels of CSA, depending on the specific practice studied and the country-case. However, it is important to consider that the climate-smart practices analysed here are usually adopted in a wide range of different combinations, which makes it difficult to isolate the effects of every single technology in terms of yields, input costs and socio-economic determinants; and overall, to generate comparisons across sites and combinations of technologies. This inclination towards "packaging" and combining practices is key to obtaining the desired results from the adoption of CSA. In fact, regardless of the type and composition of CSA packages, different studies reported that adopting numerous CSA practices helps mitigate the impact of climate change, enhances nutrient availability, reduces pests and diseases, and increases yields and income (Wekesa et al., 2018; Antwi-Agyei et al., 2021; Mthethwa et al., 2022). Each practice's importance is thus intimately related to the package into which it is incorporated, and to the synergies thereby produced. Based on such elements and given the heterogeneity of the geographical and agricultural contexts considered for this study, we therefore focus on the number of CSA practices adopted by smallholder farmers, which can be considered as a proxy of CSA adoption level (Aryal et al., 2018; Branca et al., 2022). The different levels of adoption in the study area are illustrated in Table 3.

4.1.3. *Intra-household dynamics*

Table 4 reports intra-household dynamics that see the involvement of men and women in decision-making with regard to agriculture and economic production. Although the joint participation of women (with the husband and other family members) in decision-making for different activities related to agricultural production represents a relevant indicator of women's empowerment (Malapit et al., 2019), it is necessary to highlight that the focus on agriculture at times does not capture other domains of empowerment that may be more relevant to specific desired outcomes (Alkire et al., 2013). For example, decision-making power

Table 3
Number CSA practices adopted at farm-level, by country.

	MALAWI		ETHIOPIA		TANZANIA		SOUTH AFRICA	
Number of CSAPs adopted	Number of farms	%	Number of farms	%	Number of farms	%	Number of farms	%
0	50	8.43	8	1.31	22	15.17	94	19.11
1	124	20.91	38	6.23	52	35.86	60	12.2
2	159	26.81	80	13.11	44	30.34	55	11.18
3	136	22.93	167	27.38	14	9.66	56	11.38
4	67	11.30	178	29.18	8	5.52	75	15.24
5	28	4.72	73	11.97	4	2.76	62	12.6
6	17	2.87	37	6.07	1	0.69	57	11.59
7	8	1.35	27	4.43	0	0.00	24	4.88
8	1	0.17	2	0.33	0	0.00	8	1.63
9	3	0.51	0	0.00	0	0.00	1	0.2
Mean	2		4		2		3	
Std. Dev.	1.60		1.49		1.24		2.30	

Table 4
Intra-household decision making systems for different decision settings, by country.

	Malawi	Ethiopia	Tanzania	South Africa	All
(a) Who makes decisions regarding technologies and practices to adopt for crop production (%)					
Male	15.96	30.57	29.79	30.94	24.98
Female	29.08	4.14	24.11	48.30	23.49
Joint	54.96	65.29	46.10	20.75	51.52
Total HH	100.00	100.00	100.00	100.00	100.00
(b) Who makes decisions over what crop variety to grow (%)					
Male	16.41	32.62	29.86	31.10	26.76
Female	27.92	5.96	25.00	50.61	26.54
Joint	55.67	61.42	45.14	18.29	46.70
Total HH	100.00	100.00	100.00	100.00	100.00
(a) Who makes decisions on workers to hire for agricultural activities (%)					
Male	15.08	42.71	31.11	31.54	25.78
Female	24.83	4.17	23.70	47.65	24.06
Joint	60.09	53,12	45.19	20.81	50.16
Total HH	100.00	100,00	100.00	100.00	100.00
(b) Who makes decisions on quantity and type of inputs to use (%)					
Male	15.79	29.69	29.86	30.51	25.10
Female	28.01	5.12	24.31	50.26	24.93
Joint	56.20	65.19	45.83	19.23	49.97
Total HH	100.00	100.00	100.00	100.00	100.00
(c) Who makes decisions on quantity of output to sell and consume (%)					
Male	13.99	17.86	30.77	28.85	19.71
Female	27.63	7.71	24.48	50.49	24.59
Joint	58.38	74.43	44.76	20.66	55.69
Total HH	100.00	100.00	100.01	100.00	99.99
(d) Who makes decisions on output price (%)					
Male	13.53	20.98	31.21	33.05	21.04
Female	28.30	8.70	24.82	46.44	23.88
Joint	58.17	70.32	43.97	20.50	55.07
Total HH	100.00	100.00	100.00	99.99	99.99
(e) Who makes decisions on joining farmers 'organizations and groups (%)					
Female	29.89	5.86	23.57	42.66	25.85
Joint	55.94	57.51	45.71	25.69	49.35
Total HH	100.01	100.00	99.99	100.00	100.00
(f) Who makes decisions on participating in extension and training activities (%)					
Male	13.93	44.60	30.07	31.90	27.79
Female	30.34	5.54	23.78	43.81	24.64
Joint	55.73	49.86	46.15	24.29	47.58
Total HH	100.00	100.00	100.00	100.00	100.01
(g) Who makes decisions regarding income allocation (%)					
Male	14.63	11.74	34.48	28.40	17.61
Female	26.68	5.70	24.83	41.63	21.03
Joint	58.69	82.55	40.69	29.96	61.37
Total HH	100.00	99.99	100.00	100.00	100.00
(h) Who makes decisions regarding financial planning and arrangement (%)					
Male	14.95	13.71	32.64	23.35	18.00
Female	27.84	6.50	24.31	46.19	24.63
Joint	57.22	79.79	43.06	30.46	57.37
Total HH	100.01	100.00	100.00	100.00	100.00

over the use of resources such as credit, finance and income, are indicators of empowerment (Haug et al., 2021). Furthermore, other interesting clues while observing intra-household dynamics are related to the household members decisions to join farmers' organizations and groups, or to participate in extension and training activities. Group membership may be empowering due to new access to information, resources, and connections with others (Malapit et al., 2019). Although Table 4 shows joint decision-making as an emerging general trend across the four countries, it is also worth noting that decision-making patterns differ somewhat across national contexts. In Malawi and Ethiopia, joint decision-making, with adoption of collective models that involve both men and women, prevails. However, if we consider the unitary decision-making model, it is also clear that in Ethiopia the role of the sole decision-maker remains a man's prerogative. In Tanzania, the adoption of a collective decision-making approach (in any of the decision areas studied) never exceeds 46%, indicating that a system based on a single decision-maker (typically a male) is dominant in this context. Furthermore, this decisional paradigm appears to be widespread also in South Africa, which has the highest number of women involved in sole decision-making systems.

A Cramer's V test was conducted to determine if there is any association between the decision-making models adopted (either unitary or collective) in each decision area (i.e., technology, input, output, finance, and income). The results illustrated in Table 5 show a high correlation existing between the different categories, and indicate that the decision-making settings used in each single decision area are strongly interconnected (results at country-case level are illustrated in Appendix B). The implication is that the same decision-making model is frequently used across several choice areas. Specifically, if women are involved in decisions about agricultural technologies to be adopted (the variable here considered for the econometric analysis), it is very likely that they will also have a say in relation to inputs to be used, quantity and price of the outputs to be sold, participation in groups and/or extension programs, financial planning, and income allocation. This strong correlation thus offers a first approximation of the existence of a significant presence of women in decision-making processes. However, such an assumption should be regarded with caution since it is based on data that do not allow a detailed analysis of the level of women's involvement in decision-making, nor of potential forms of women's marginality.

4.2. Econometric results

4.2.1. The role played by women in CSA adoption

This section reports estimates of the impact that women's engagement in farm decision-making has on CSA adoption (Table 6). It also assesses the role of other socio-demographic and economic factors in influencing the number of CSA practices implemented at the farm level.

Results obtained highlight similarities as well as important differences existing among countries in terms of factors affecting the adoption

Table 5
Correlation between decision-making models adopted in different decision areas.

Decision area	Technology	Crops	Financial	Labour	Input	Output	Price	Group	Extension	Income
Technology	1									
Crops	0.8162***	1								
Financial	0.7685***	0.7627***	1							
Labour	0.8454***	0.8949***	0.8210***	1						
Inputs	0.8135***	0.8707***	0.7752***	0.9206***	1					
Output	0.7927***	0.8108***	0.8138***	0.8741***	0.8597***	1				
Price	0.8037***	0.7949***	0.7719***	0.8544***	0.8033***	0.8146***	1			
Groups	0.8158***	0.767***	0.7962***	0.8421***	0.7803***	0.7641***	0.7857***	1		
Extension	0.8117***	0.7528***	0.7746***	0.8327***	0.7677***	0.7386***	0.7489***	0.8956***	1	
Income	0.7639***	0.7728***	0.8542***	0.8159***	0.7919***	0.8031***	0.7911***	0.7854***	0.7486***	1

of CSA practices. Such differences make up indeed for a degree of diversity that the econometric model employed in this study is unable to fully portray and translate. By acknowledging these limitations, the authors refrain from any simplistic assumptions that all women face the same inequalities and all men have the same privileges; and remain aware that other identities intersect with gender to form different patterns of disadvantage and exclusion. At the same time, they argue that CSA strategies are unlikely to be effective, let alone equitable or transformative, without active attention to gender.

Following Zakaria et al. (2020), for each country case considered in this study, we estimated two set of equations; one assumed endogeneity of the variable “women involvement in the decision-making process” (the endogenous switching poisson model) while the other not (the exogenous switching regression poisson model). We used the *rho* test to detect the correlation between the error terms of the women involvement in the farm decision-making and CSA adoption equation. Its significance implies that the two errors are correlated, meaning that selectivity bias is present in the model. As illustrated in Table 6, the *rho* test resulted statistically significant for Malawi and South Africa.

When we look at the households' demographic characteristics, a first result emerges that is linked to the age of the household head, which appears statistically significant only in Malawi. Specifically, in this context, an increase in the age of the household head positively influences the expected number of CSA adopted at farm level. This finding likely reflects the importance of more work experience and the greater availability of financial and agricultural assets for older farmers (Mignouna et al., 2011; Kariyasa and Dewi, 2013; Mwangi and Kariuki, 2015). Although not significant, in Ethiopia the variable indicating the age of the household head has a negative effect on the CSA adoption. One possible explanation for such negative relationship is that, in some contexts, the older farmers are risk-averse and suspicious of innovations. They might prefer to stick to farming practices that already exist and are trusted within the community (Negera et al., 2022).

In Malawi, the household head's education level is statistically significant and positively affects the expected number of CSA practices adopted at farm level. This demonstrates that a higher education level can raise household awareness of resource utilization, as well as their capacity to gather, evaluate, and process information about new advances in technology (Branca and Perelli, 2020).

If we turn to physical assets, the results show a significant and positive relationship between livestock (expressed in terms of TLU) and CSA adoption in Malawi, confirming that mixed crop-livestock systems might allow farmers to benefit from interactions and synergies between these two agricultural activities (Sumberg, 2002). Furthermore, in Ethiopia the use of chemicals resulted in an increase of the expected number of CSA practices adopted, confirming that the transition from conventional to climate-smart practices is gradual and often manifests itself as an initial coexistence of traditional and sustainable approaches. The availability of larger land plots appears statistically significant and positively related with CSA adoption level in Malawi. This result is unsurprising given Malawi's growing land scarcity (Fisher and Kandiwa, 2014), which may be associated with a lower propensity for farmers with small plots of land to utilize experimental agricultural practices that are perceived as riskier in terms of crop productivity.

With regard to economic assets, access to credit has a negative impact on CSA adoption level in the majority of countries, despite being statistically significant only in Ethiopia. Such finding may be explained by the fact that in Ethiopia access to external economic sources is limited, and only 5% of total credit is directed to the agricultural sector. In countries where credit is severely constrained, farmers are particularly risk-averse and prefer to invest in conventional practices (Branca and Perelli, 2020).

In relation to the gender dimension underlying credit access, it is important to notice that, in Malawi, female-headed households with access to agricultural credit adopt a higher number of CSA practices than those under male management. This means that an equal access to additional economic resources can lead to a greater propensity of women to adopt climate-smart practices. However, this result should be interpreted with caution, as the sampled female population may not have been in the position of actually exerting independent choices or authority. Indeed, the mere fact of being the head of a household does not imply substantial decision-making power (as in the case of *de jure* male-headed households) and does not guarantee a woman full autonomy in deciding how to manage the agricultural credit she has possibly received. However, the same variable is not significant in Ethiopia, where financial institutions do not recognize women as active economic agents and where credit is often provided only to male household heads (Tsige et al., 2020). The role of this variable was not detected in Tanzania and South Africa because of lack of specific data, confirming that access to funding and credit represents a critical barrier for female smallholder farmers in both countries. Access to input subsidies is positively related to CSA adoption in Tanzania and South Africa. This can be linked to the promotion of ad hoc policies aimed to stimulate the provision of fertilizers and seed subsidies to poor farmers who cultivate a maximum of one hectare of land (Kinuthia, 2020). Access to such economic instruments may have encouraged the use of agricultural inputs that are often considered complementary to the adoption of certain CSA packages (Branca and Perelli, 2020).

In terms of human and social characteristics, we notice that, in Malawi, the contribution of women towards the adoption of agricultural technologies at the household level can have a significant influence on CSA adoption level at large. Specifically, households in which women can jointly participate in such farm decisions together with their husbands and/or other family members are prone to adopt a higher number of CSA practices. This result is surprising and particularly interesting. It is clear that, in the Malawian sociocultural context, women are not always relegated to a merely subordinate role, and have the opportunity to exert their agency in alternative, although not always highly visible, ways. Heterogeneous elements, which is beyond the scope of this article to analyse, may determine the variable, and at times significant, involvement of rural women in the decision-making context. However, this positive contribution is not evident in the other case studies.

In Ethiopia, women's direct involvement in decision-making appears less effective and not statistically significant. In this country, the

Table 6
Endogenous switching Poisson regression model estimates.

	Malawi (N = 653)		*Ethiopia (N = 615)*		*Tanzania (N = 348)*		*South Africa (N = 602)*	
	Endogenous Switching Poisson	*Exogenous Switching Poisson*	*Endogenous Switching Poisson*	*Exogenous Switching Poisson*	*Endogenous Switching Poisson*	*Exogenous Switching Poisson*	*Endogenous Switching Poisson*	*Exogenous Switching Poisson*
Climate Smart Agriculture Practices (CSAP)	Coeff. (Std. Err.)	Coeff. (Std. Err.)	Coeff. (Std. Err.)	Coeff. (Std. Err.)	Coeff. (Std. Err.)	Coeff. (Std. Err.)	Coeff. (Std. Err.)	Coeff. (Std. Err.)
HH gender*education	0.007	0.005	0.012	0.012	−0.012	−0.012	–	–
	(0.017)	(0.016)	(0.032)	(0.032)	(0.071)	(0.071)	–	–
HH gender*credit	0.288 *	0.284 *	−0.245	−0.245	–	–	–	–
	(0.176)	(0.176)	(0.170)	(0.170)	–	–	–	–
Household head, age	0.007 ***	0.007 ***	−0.002	−0.002	0.003	0.003	0.004	0.003
	(0.002)	(0.002)	(0.002)	(0.002)	(0.005)	(0.005)	(0.003)	(0.003)
Household head, education	0.018 **	0.019 **	0.005	0.005	0.026	0.025	0.005	0.004
	(0.009)	(0.009)	(0.007)	(0.007)	(0.025)	(0.024)	(0.010)	(0.010)
Off-farm income	0.000	0.000	0.000	0.000	0.002	0.002	0.000	0.000
	(0.001)	(0.001)	(0.001)	(0.001)	(0.002)	(0.002)	(0.000)	(0.000)
On-farm income	0.000	0.000	0.000	0.000	−0.002 *	−0.002 *	−0.001	−0.001
	(0.001)	(0.001)	(0.000)	(0.000)	(0.001)	(0.001)	(0.001)	(0.001)
Land area	0.203 **	0.203 **	−0.021	−0.021	0.238	0.237	0.130	0.133
	(0.080)	(0.080)	(0.099)	(0.099)	(0.189)	(0.188)	(0.088)	(0.088)
Household members	−0.003	−0.003	0.015	0.015	0.024	0.024	0.058 **	0.054 **
	(0.019)	(0.019)	(0.013)	(0.013)	(0.048)	(0.048)	(0.024)	(0.023)
Hired labour/ha	−0.001	−0.001	0.001	0.001	−0.002	−0.001	0.003	0.003
	(0.003)	(0.003)	(0.001)	(0.001)	(0.012)	(0.012)	(0.005)	(0.005)
Asset index	0.058	0.060	0.024	0.024	−0.344	−0.341	−0.267	−0.278
	(0.258)	(0.258)	(0.176)	(0.176)	(0.603)	(0.602)	(0.326)	(0.324)
Tropical Livestock Unit (TLU)/ha	0.556 *	0.555 *	−0.018	−0.018	0.471	0.469	0.027	0.028
	(0.288)	(0.288)	(0.032)	(0.032)	(0.309)	(0.309)	(0.018)	(0.018)
Chemicals	0.088	0.089	0.141 **	0.141 **	−0.194	−0.193	−0.037	−0.172
	(0.075)	(0.075)	(0.061)	(0.061)	(0.223)	(0.223)	(0.430)	(0.423)
Climate change	0.348 ***	0.348 ***	0.321 *	0.321 *	−0.034	−0.035	1.282 ***	1.281 ***
	(0.117)	(0.117)	(0.169)	(0.169)	(0.209)	(0.208)	(0.126)	(0.126)
Group participation	0.013	0.013	0.029	0.029	−0.118	−0.115	0.271	0.259
	(0.093)	(0.093)	(0.069)	(0.069)	(0.281)	(0.280)	(0.394)	(0.392)
Credit access	0.095	0.096	−0.116 **	−0.116 **	−0.175	−0.176	−0.245	−0.218
	(0.075)	(0.075)	(0.052)	(0.052)	(0.328)	(0.327)	(0.536)	(0.534)
Subsidies	0.023	0.023	−0.114	−0.114	0.476 **	0.476 **	1.422 **	1.395 **
	(0.078)	(0.078)	(0.168)	(0.168)	(0.215)	(0.215)	(0.679)	(0.674)
Extension Advisory Services (EASs)	0.086	0.086	0.182 ***	0.182 ***	0.416	0.420	−1.280 ***	−1.269 ***
	(0.088)	(0.088)	(0.049)	(0.049)	(0.322)	(0.319)	(0.468)	(0.469)
Joint decision-making	0.225 **	0.204 ***	0.056	0.056	−0.392 **	−0.379 **	0.294	0.033
	(0.117)	(0.074)	(0.048)	(0.048)	(0.209)	(0.162)	(0.194)	(0.110)
_cons	−0.290	−0.282	0.929 ***	0.929 ***	0.332	0.323	−0.353	−0.263
	(0.261)	(0.259)	(0.214)	(0.214)	(0.648)	(0.642)	(0.275)	(0.288)
Switch (Women involvement in the farm decision making process)								
Household head, gender	−1.885 ***	−1.899 ***	–	–	−0.267	−0.269	−0.494 *	−0.428
	(0.270)	(0.269)	–	–	(0.545)	(0.544)	(0.272)	(0.270)
Men-to-women ratio	0.018	0.015	–	–	0.091	0.093	0.037	0.081
	(0.144)	(0.141)	–	–	(0.341)	(0.340)	(0.198)	(0.195)
Children-to-adults ratio	0.224 **	0.223 **	0.135 *	0.135 *	0.120	0.120	−0.230	−0.153
	(0.109)	(0.112)	(0.075)	(0.075)	(0.233)	(0.232)	(0.298)	(0.298)
Age of men	–	–	0.011	0.011	−0.010 **	−0.010 **	−0.008	−0.007
	–	–	(0.008)	(0.008)	(0.014)	(0.014)	(0.009)	(0.009)
Age of women	−0.001	−0.001	0.010	0.010	0.005	0.005	−0.003	−0.004
	(0.005)	(0.005)	(0.007)	(0.007)	(0.016)	(0.016)	(0.010)	(0.010)
Education of men	0.075 ***	0.075 ***	0.025	0.025	0.099	0.099	−0.056 *	−0.050
	(0.018)	(0.019)	(0.019)	(0.019)	(0.049)	(0.049)	(0.033)	(0.033)
Education of women	–	–	0.022	0.022	−0.029	−0.028	−0.010	−0.011
	–	–	(0.023)	(0.023)	(0.052)	(0.052)	(0.035)	(0.035)
Joint land ownership	0.506 ***	0.517 ***	0.118	0.118	1.418 ***	1.417 ***	0.663 ***	0.714 ***
	(0.151)	(0.144)	(0.126)	(0.126)	(0.293)	(0.293)	(0.220)	(0.219)
_cons	−0.383	−0.386	−0.860 ***	−0.860 ***	−0.765	−0.771	−0.137	−0.298
	(0.290)	(0.286)	(0.321)	(0.321)	(0.761)	(0.759)	(0.855)	(0.847)
sigma	0.017	0.000	0.000	0.000	0.015	0.000	0.194 **	0.165 *
	(0.074)	(0.046)	(0.006)	(0.000)	(0.139)	(0.043)	(0.093)	(0.096)
rho	−0.806 ***		−0.018		0.710		−0.775 ***	
	(0.257)		(38.715)		(1.621)		(0.262)	

* significant at 10%, ** significant at 5%, *** significant at 1%.

empowerment of women and their participation to household decision-making has traditionally and symbolically been perceived, also by institutions and agencies for agricultural development, as a threat to masculinity and male privilege, with farming being still largely considered a man's sphere. In most local languages the word 'farmer' is, by default, associated with 'he', the notion being that women are 'weak farmers' if they are farmers at all. In grain-growing areas there exists a taboo against women ploughing, regardless of their land ownership status. This gendered restriction on ploughing is usually justified by referring to 'honor' and women's physical ability (Peveri and Drucza, 2016). Although men emerge from the available literature as acting as the ultimate decision-makers regarding agricultural production, there is also evidence that they are used to consult their spouses before making decisions; a fact which demonstrates that women have more influence than might appear on the surface (Meinzen-Dick et al., 2019).

On the other hand, in Tanzania, the active participation of women in the decision about agricultural technologies even leads to a decrease in the expected number of CSA practices to adopt. The same happens in South Africa, although in this context the variable is not statistically significant This may be due to differences in the roles and responsibilities between men and women in such agricultural contexts. As previously mentioned, in most developing countries, women are usually responsible for all aspects of cultivating food crops, whose production is generally based on indigenous knowledge and traditional agricultural technologies, whereas men are largely responsible for cash-crop farming, from which they gain enough resources to experiment with new agricultural approaches, which in turn may increase productivity and profits. According to Leavens et al. (2019), in Tanzania men control the majority of production decisions, especially regarding methods and inputs, while women are more involved in decisions regarding the cultivation of food crops. Considering the adoption of CSA practices, women are likely to resist choices that stray away from food crops and traditional technology in favour of cash crops that would produce higher, more marketable yields, but would also result in household food security and other needs not being met. Furthermore, women may resist the adoption of new labour-intensive cropping systems (a risk often linked to the adoption of CSA practices carried out in the absence of specific agricultural inputs and assets) because of greater weeding and post-harvest processing (which are indeed considered women's work).

An increasing number of family members is statistically significant in South Africa, where it leads to an increase in CSA practices adopted. Given that household size is commonly seen as a proxy indicator of labour availability, our finding confirms that bigger families possess the ability to overcome obstacles associated with labour-intensive conservation agriculture methods, such as weeding during minimum tillage implementation (Rusu et al., 2009).

Access to Extension and Advisory Services (EAS) is statistically significant in Ethiopia and South Africa. In the former, the knowledge interaction regarding farm- and land-management practices between local farmers and extensionists seem to have encouraged the identification of appropriate climate-smart solutions. This is also supported in the literature, whereas a clear point is made of participatory systems approaches being pivotal in working in synergy with local scientific knowledge to identify appropriate climate-smart farming systems (Andrieu et al., 2019). However, it appears that access to extension services in South Africa is negatively connected to the adoption of CSA practices. This finding may be attributed to South African farmers' poor or non-existent access to extension and training services, as indicated by the descriptive statistics previously illustrated. Poor extension programs and irregular visits by extension staff might have a detrimental influence on training activities (Maka et al., 2019).

Finally, in exploring the environmental and climatic characteristics driving the adoption of CSA strategies, we found that the perception of extreme climate events—such as floods, drought, and erratic rainfall—increases the expected number of CSA practices in the majority of country-cases here considered.

4.2.2. Women's involvement in households' decision-making processes

Table 6 also makes apparent the factors affecting women's participation in decision-making processes with regard to the adoption of agricultural technologies. The underlying hypothesis is that women's bargaining power within the household is based on heterogeneous elements and specific socio-cultural characteristics of households themselves. However, in presenting this section of results, we must acknowledge and reassert that gender equality dynamics do not equate to simply featuring women and their accomplishments; and that even highly accurate econometric models are hardly capable to explore all the different socio-cultural aspects underlying gender inequality—which would rather require an in-depth capture and granular rendering of specific experiences of women and men farmers.

Results obtained show that the presence of a female household head negatively affects the joint participation of women in the decision-making process (although significant only in Malawi and South Africa). A possible explanation of this result can be linked to how the balance of power and responsibility within the household is constantly negotiated and recreated whenever women are left alone managing the farm, as a direct effect of out-migration of males and feminization of the agricultural sector (*de-jure* female-headed households) (Bjornlund et al., 2019). This also may happen in the case they are widowed, unmarried, divorced, or abandoned (de-facto female-headed households) (Moghadam, 2005). In all these cases, it is very likely to find either the unitary decision-making model linked to the total absence of other adults within the family (women left on the farm undertake more and more of the agricultural fieldwork and tasks, work longer hours, and make most of the decisions); or the non-cooperative collective model in which other male family members (fathers, brothers, etc.) make decisions, relegating women to a merely representative role with no active decision-making power. As a result, a collaborative decision-making setting may be hampered by the seclusion of women being forced to take decisions alone, or by the dominance of a patriarchal setting that grants priority and visibility to men within the family.

Mixed results were found with regard to the influence of education level of male family members. In fact, while in Malawi an increasing number of years of schooling of men was found statistically significant and positively related with the female participation in decision-making, in South Africa a higher education level of male members affects negatively the involvement of women in the decision-making setting. This result highlights a not univocal influence of men education, which should be probably contextualized within each specific socio-cultural environment. Although an increase in years of schooling (for both men and women) is typically associated with an improvement in women's inclusion in decision making (Mutenje et al., 2016), the current study suggests that, in some contexts, higher men's education levels may even worsen the gender gap by legitimising men in positions of leadership. On the other hand, in the other country-cases, the variables related to the education of the different family members (both women and men) was found to be not statistically significant, meaning that other socio-economic factors might have a higher influence in the definition of intra-household hierarchies and decision models. Such results indicate that the education of family members represent a complex aspect, one that is far from universal and rather closely linked to social and gender norms that greatly vary across local contexts.

Interestingly, in South Africa, the increasing age of men has a negative impact on women's participation in farm decision-making. This could be explained by the presence of intragenerational conflicts, which make older males reluctant to give women space and voice, particularly in the context of household decision-making and management (Dunham and Flores-Yeffal, 2019).

Despite their lack of statistical significance, the results related to the age of women are of particular interest. In Malawi and South Africa, an increase in the age of women has a detrimental impact on female empowerment in decision-making contexts. This finding may also be due to generational differences. Indeed, older women may be anchored in deeply rooted cultural heritages that hold them generally subordinate to men, mainly devoted to housework and time-consuming agricultural activities, and excluded from decision making. Gender identity, built over a lifetime and shaped by local norms and values, might affect how older people (and women in particular) conceive of their own identities and sense of self, and of what roles they believe they can and should play within the household, as well as at the community level and in the society at large (Schatz and Seeley, 2015).

Considering the variables connected to the family structure, in Malawi and Ethiopia the increase in the children-to-adults ratio has proved to be statistically significant and positively related to women's participation in decision-making. This may suggest that living in a nuclear family increases female empowerment, and somewhat attenuates the age effect (Arestoff and Djemai, 2016). Indeed, as discussed by Debnath (2015), women in joint families have less decision-making power and require the approval of other family members more frequently to carry out even regular household tasks. On the other hand, women in nuclear households have more decision-making authority, more flexibility to move outside the home, and higher participation in job opportunities.

As illustrated in the results, an important element common to all the country cases (with the only exception of Ethiopia) is the relevance of joint land ownership, which is statistically significant and positively related to the involvement of women in decision-making systems. This result is in line with studies that have shown how control of household assets, particularly land, is critical for women's empowerment within the household (Doss and Meinzen-Dick, 2015; Johnson et al., 2016; Quisumbing, 2010). However, we should also notice that, even when enough resources are available, a woman may not be able (or willing) to leverage these resources to fulfill her aspirations unless critical consciousness of the underlying causes of gender inequality and disempowerment is brought into the equation.

5. Conclusions

This study has focused on the role of women in the transition towards resilient and climate-smart agricultural systems in Sub-Saharan Africa. Using a multi-country approach, a cross-sectional econometric analysis was conducted in order to: (i) assess factors influencing the probability of women's engagement in agricultural technology decision-making; (ii) ascertain the effect of women's participation in farm decision-making on CSA adoption.

The results obtained show a certain degree of complexity in the role that women play within their communities and at the household level. The findings related to the role of women's participation in agricultural decisions are diverse, highlighting the existence of social, regulatory, and cultural elements that uniquely define the various contexts here examined. Specifically, while in Malawi women's involvement in farm decision-making processes positively influences CSA adoption, in the other selected countries such involvement remains marginal or negatively related to the implementation of climate-smart strategies. This means that women's decision-making authority in the transition to CSA systems can be critical in some circumstances, while it appears to have little or no influence in others. All this is closely related to the cultural backgrounds of the populations under consideration, which may have an impact not only on the roles that women and men play within societies and families (whether nuclear or extended), but also on the regulatory framework underlying land ownership and access to credit and financing.

The study has contributed to the existing literature by highlighting the complexity behind the development of sustainable agricultural systems on a large scale. Although linking multiple contexts, elements such as gender equality and access to physical and economic assets do not always have the same importance and impact on the adoption of agricultural innovations. This means that strategies to encourage the transition to climate-smart agricultural systems should take into account the heterogeneity of contexts and societies, tailoring broad templates and frameworks, to regional and even smaller scale contexts, based on the assumption that gender inequalities play out in different ways depending on the social, cultural or political context. Therefore, indicators and statistical models employed to investigate the multi-faceted nature of gender inequality at all levels of socio-economic development should be also accompanied with a qualitative analysis which, derived in consultation with local people to reflect the gender context of a particular region, country or community, might be capable of integrating and complexify what has been achieved through the adoption of an otherwise robust econometric model.

Although many studies on CSA adoption carry out sex-disaggregated analyses, more research is needed on developing options of climate smart agriculture tested by both women and men, *by context*, and based on perceptions and types of climate-related risks faced by women and men farmers. Future research should focus on supporting transformative and socially inclusive sustainable development through strategic research that informs key environment and development policy agendas. To address entrenched norms and attitudes, it might be necessary to use an intersectional lens able to detect systemic barriers to gender equality, social equity, and food security; and to employ people-centred and participatory methodologies at both the community and household levels. A clearer understanding of the different roles and the different vulnerabilities of men and women would generate more appropriate responses, viable economic opportunities, and context-sensitive solutions that prioritize rural women, youth, and other marginalized groups.

CRediT authorship contribution statement

Chiara Perelli: Writing – review & editing, Writing – original draft, Validation, Methodology, Formal analysis, Data curation, Conceptualization. **Luca Cacchiarelli:** Writing – review & editing, Writing – original draft, Validation, Methodology, Conceptualization. **Valentina Peveri:** Writing – review & editing, Writing – original draft, Conceptualization. **Giacomo Branca:** Writing – review & editing, Supervision, Funding acquisition, Conceptualization.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

Data will be made available on request.

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Appendix A. Appendix

A.1. Test on the validity of the selection instruments - Malawi

	Model 1	Model 2
	Participation to decision-making (1/0)	Number of CSA practices adopted at farm level
Instrumental variables		
Household head, gender	−1.899***(0.269)	0.012 (0.096)
Men-to-women ratio	0.015 (0.141)	0.018 (0.061)
Children-to-adults ratio	0.223**(0.112)	0.075 (0.048)
Age of men	–	–
Age of women	−0.001 (0.005)	0.003 (0.002)
Education of men	0.075***(0.019)	0.004 (0.005)
Education of women	–	–
Joint land ownership	0.517***(0.144)	0.071 (0.064)
Constant	−0.386 (0.286)	0.662 (0.119)
Wald test	X^2 = 117.93***	X^2 = 6.73

A.2. Test on the validity of the selection instruments Ethiopia

	Model 1	Model 2
	Participation to decision-making (1/0)	Number of CSA practices adopted at farm level
Instrumental variables		
Household head, gender	–	–
Men-to-women ratio	–	–
Children-to-adults ratio	0.135* (0.075)	0.027 (0.030)
Age of men	0.011 (0,008)	0.001 (0.003)
Age of women	0.010 (0,007)	−0.005* (0.003)
Education of men	0.025 (0,019)	0.007 (0.007)
Education of women	0.022 (0,023)	−0.003 (0.009)
Joint land ownership	0.118 (0,126)	0.122** (0.053)
Constant	−0.860 (0,321)	1.296 (0.131)
Wald test	X^2 = 12.76**	X^2 = 9.97

A.3. Test on the validity of the selection instruments Tanzania

	Model 1	Model 2
	Participation to decision-making (1/0)	Number of CSA practices adopted at farm level
Instrumental variables		
Household head, gender	−0.269 (0.544)	−0.246 (0.309)
Men-to-women ratio	0.093 (0.340)	−0.045 (0.177)
Children-to-adults ratio	0.120 (0.232)	0.066 (0.123)
Age of men	−0.010 (0.014)	0.009 (0.007)
Age of women	0.005 (0.016)	0.002 (0.008)
Education of men	0.099** (0.049)	0.012 (0.025)
Education of women	−0.028 (0.052)	0.041 (0.027)
Joint land ownership	1.417*** (1.417)	−0.269*(0.158)
Constant	−0,771	0.005 (0.400)
Wald test	X^2 = 40.84***	X^2 = 8.39

A.4. Test on the validity of the selection instruments – South Africa

	Model 1	Model 2
	Participation to decision-making (1/0)	Number of CSA practices adopted at farm level
Instrumental variables		
Household head, gender	−0.428 (0.270)	−0.239***(0.087)
Men-to-women ratio	0.081 (0.195)	−0.046 (0.061)
Children-to-adults ratio	−0.153 (0.298)	−0.065 (0.091)
Age of men	−0.007 (0.009)	0.001 (0.003)
Age of women	−0.004 (0.010)	0.003 (0.003)
Education of men	−0.050 (0.033)	0.002 (0.010)
Education of women	−0.011 (0.035)	−0.002 (0.011)
Joint land ownership	0.714***(0.219)	−0.100 (0.083)
Constant	−0.98 (0.847)	1.244 (0.257)
Wald test	X^2 = 23.23***	X^2 = 12.44

Appendix B. Appendix

B.1. Correlation matrix between decision areas - Malawi

Decision area	Technology	Crops	Financial	Labour	Input	Output	Price	Group	Extension	Income
Technology	1									
Crops	0.8401***	1								
Financial	0.8299***	0.8296***	1							
Labour	0.8672***	0.9100***	0.8633***	1						
Inputs	0.8382***	0.9004***	0.8242***	0.9244***	1					
Output	0.8521***	0.8588***	0.8529***	0.9038***	0.8973***	1				
Price	0.8557***	0.8699***	0.8270***	0.9025***	0.8725***	0.9050***	1			
Groups	0.8306***	0.7781***	0.8558***	0.8309***	0.7901***	0.8149***	0.8175***	1		
Extension	0.8398***	0.7790***	0.8280***	0.8267***	0.7847***	0.8026***	0.8106***	0.9551***	1	
Income	0.8378***	0.8428***	0.8410***	0.8402***	0.8558***	0.8572***	0.8753***	0.8417***	0.8309***	1

B.2. Correlation matrix between decision areas – Ethiopia

Decision area	Technology	Crops	Financial	Labour	Input	Output	Price	Group	Extension	Income
Technology	1									
Crops	0.6441***	1								
Financial	0.4699***	0.5546***	1							
Labour	0.6169***	0.7836***	0.4684***	1						
Inputs	0.5934***	0.7465***	0.5711***	0.8337***	1					
Output	0.4696***	0.5675***	0.6162***	0.5622***	0.6692***	1				
Price	0.4721***	0.4873***	0.4363***	0.4910***	0.4946***	0.4521***	1			
Groups	0.5310***	0.5569***	0.4436***	0.7031***	0.5971***	0.3947***	0.3438***	1		
Extension	0.5450***	0.4691***	0.4219***	0.5401***	0.4516***	0.3397***	0.3050***	0.6295***	1	
Income	0.5651***	0.6495***	0.6861***	0.6262***	0.6859***	0.5670***	0.4884***	0.5890***	0.4383***	1

B.3. Correlation matrix between decision areas – Tanzania

Decision area	Technology	Crops	Financial	Labour	Input	Output	Price	Group	Extension	Income
Technology	1									
Crops	0.9333***	1								
Financial	0.9398***	0.9050***	1							
Labour	0.9432***	0.9866***	0.9114***	1						
Inputs	0.9671***	0.9666***	0.9286***	0.9783***	1					
Output	0.9575***	0.9763***	0.9192***	0.9883***	0.9905***	1				
Price	0.9707***	0.9542***	0.9044***	0.9644***	0.9775***	0.9775***	1			
Groups	0.9524***	0.9366***	0.9500***	0.9359***	0.9483***	0.9389***	0.9337***	1		
Extension	0.9669***	0.9394***	0.9642***	0.9388***	0.9624***	0.9532***	0.9390***	0.9867***	1	
Income	0.9336***	0.8892***	0.9733***	0.9128***	0.9231***	0.9133***	0.8986***	0.9259***	0.9404***	1

B.4. Correlation matrix between decision areas – South Africa

Decision area	Technology	Crops	Financial	Labour	Input	Output	Price	Group	Extension	Income
Technology	1									
Crops	0.8287***	1								
Financial	0.7977***	0.7392***	1							
Labour	0.9086***	0.9350***	0.8752***	1						
Inputs	0.8600***	0.9005***	0.7803***	0.9568***	1					
Output	0.8907***	0.8735***	0.8084***	0.9733***	0.9268***	1				
Price	0.9000***	0.8615***	0.8379***	0.9539***	0.8885***	0.9237***	1			
Groups	0.9009***	0.8050***	0.8451***	0.9418***	0.8511***	0.8733***	0.9119***	1		
Extension	0.8711***	0.7888***	0.9011***	0.9092***	0.8434***	0.8747***	0.8925***	0.9195***	1	
Income	0.7150***	0.7425***	0.8907***	0.8934***	0.7480***	0.8159***	0.8317***	0.8075***	0.8198***	1

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