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Intra-household risk perceptions and climate change adaptation in sub-Saharan Africa

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Abstract

We examine the effects of spouses' climate risk perceptions (CRPs), defined by their beliefs about unfavourable climatic events and associated damages, on climate change adaptation (CCA) and the observed gender gap in adaptation. Our analysis uses the intra-household data collected by independent interviews with 1,274 female and male spouses in Kenya, Uganda and Senegal. By addressing the CRP endogeneity issue using the exogenous weather shocks during data collection months as instruments, we find that a higher CRP of both female and male spouses increases their probability of adopting CCA strategies. We also find that a higher CRP of female spouses reduces the adaptation gap by increasing their relative adoption of soil and water conservation practices. Our results highlight the importance of understanding gender-differentiated behavioural and economic factors to design effective climate policy interventions.

Keywords: risk perceptions, climate change adaptation, gender gap, climate-smart agriculture

1. Introduction

Policies for mitigating climatic risks, alleviating poverty and ensuring gender equality remain imperative to sustainable development in sub-Saharan Africa. Risks posed by climate change affect livelihoods, health outcomes and gender roles among others (see e.g. IPCC, 2014c, 2022; Sorensen *et al.*, 2018). In this regard, designing effective climate policies, including promoting households' actions for climate change adaptation (CCA, hereafter), can help

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achieve multiple goals of sustainable development in Africa. In this regard, understanding the behaviours driving adaptation responses of decision makers within a household, including spouses' perceptions of climatic risks and their choices of coping strategies, is crucial to enhance the effectiveness of climate policies.

Existing studies on CCA commonly consider a farm household as a unitary entity and investigate the drivers of households' adaptation to climate change (see e.g. Adzawla *et al.*, 2019; Alpizar, Carlsson and Naranjo, 2011; Bryan *et al.*, 2013; Di Falco, Doku and Mahajan, 2020; Di Falco, Veronesi and Yesuf, 2011; Fisher and Kandiwa, 2014; Jianjun *et al.*, 2015; Wossen, Berger and Di Falco, 2015). Unitary household studies usually consider the effects of the behaviours of household heads on households' technology adoption decisions. For example, Alpizar, Carlsson and Naranjo (2011), Fisher and Kandiwa (2014), Jianjun *et al.* (2015) and Adzawla *et al.* (2019) indicate that male-headed households are more likely to adopt CCA compared to female-headed households. However, analyses that consider the characteristics of household heads only may not provide a complete picture of the roles of household members other than a household head in adaptation decisions. Particularly, it is not clear what roles the behaviours of female spouses in male-headed households and male spouses in female-headed households play in CCA decisions.[1] This is due to several reasons. First, there are observed differences between females and males in climate risk perceptions (CRPs) (see e.g. Ngigi, Mueller and Birner, 2017; Sullivan-Wiley and Short Gianotti, 2017). In particular, because individuals' actual past experiences influence their subjective judgement of future climatic events and associated damages (see e.g. Demuth *et al.*, 2016), the observed differences in CRP between spouses may reflect the true difference in climate risk exposure. Second, there are considerable differences between men and women in general in terms of the impacts of climate change in developing countries (see e.g. Eastin, 2018; IPCC, 2014d, 2014e; Quisumbing, Kumar and Behrman, 2018) and between spouses within a household regarding the uptake of new practices to adapt and mitigate climatic changes (see e.g. Ngigi, Mueller and Birner, 2017; Teklewold, Adam and Marenya, 2020). The differences in perceptions, vulnerability and adaptive capacity between females and males are commonly due to the higher reliance of females on climate-sensitive roles and less access to assets that support resilience than men within households (FAO, 2021; Wright and Chandani, 2014). Despite these gender-related differences in roles and vulnerability, gender-based intra-household studies on CRPs and choices of adaptation strategies are limited. A few exceptions are Ngigi, Mueller and Birner (2017), Magnan *et al.* (2020) and Teklewold, Adam and Marenya (2020) which examined intra-household gender differences in CCA and relationships between CCA and risk preferences

1 As highlighted by Twyman, Useche and Deere (2015), the role of each spouse in CCA decisions cannot be clearly understood by only considering the gender of the household head in the unitary household model. Moreover, male household heads tend to underreport the role of their female spouses in agricultural decisions (Acosta *et al.*, 2020; Twyman, Useche and Deere, 2015).

and climatic shock experiences in developing countries.[2] Moreover, it is not clear what effects spouses' perceptions of climatic risks have on the observed gender gap in adaptation to climate change within a household.

In this paper, we contribute to the existing literature on climate resilience by identifying the plausible causal impacts of each spouse's perceptions of climatic risks on their CCA decisions. We also explicitly investigate whether the observed differences in their perceptions of climate risks can explain the gap in CCA between female and male spouses within a household. For these purposes, we use cross-sectional data from a unique intra-household survey that independently interviews female and male spouses in a household about their perceptions of climatic risks and choices of adaptation strategies. Since risk perception is a strong predictor of intended adaptive behaviour (van Valkengoed and Steg, 2019), understanding individuals' perception is important to design policy interventions that stimulate climate-resilient agriculture and build gender-based resilience in Africa, south of the Sahara, and in other regions with similar contexts. In particular, the empirical case study presented in the paper comes from Kenya, Uganda and Senegal in sub-Saharan Africa, where the issues of climate resilience and gender empowerment are the centre of the current economic and social development policy initiatives.

In our empirical analysis, we use the instrumental variables (IVs) approach to address the endogeneity issue in perceptions of climatic risks. For this purpose, we exploit the exogenous shocks in rainfall and temperature during the data collection months relative to the historical averages of both variables. We construct the shocks as the mean deviation of the observed rainfall and temperature at a village from their respective historical averages to net out the effect of past trends and extreme weather occurrences (Dell, Jones and Olken, 2014; see Hidalgo *et al.*, 2010; Liang and Sim, 2019). In addition, we control for the subjective (respondents self-reported) occurrence of weather and climatic shocks during the 5 years before the data collection period. By doing so, we argue that we are able to mitigate the potential concern that contemporary rainfall shocks may not be independent of the past shocks, which may influence the current adaptation decisions through influencing past perceptions about climatic risk. Furthermore, we control for the differential land ownership and bargaining power between spouses, measured by the total number of agricultural decisions made by each spouse.

Our empirical results highlight that both female and male spouses' perceptions of higher climatic risks increase their probability of CCA adoption. As implied by theoretical frameworks for protective adaptation decision-making processes (Grothmann and Patt, 2005; Lindell and Perry, 2012), the possible channels through which CRP affects adaptation are through enhancing

2 While Magnan *et al.* (2020) defined CCA as male spouses reported adoption of improved maize variety, data in Teklewold, Adam and Marenya (2020) came from joint (but not independent) interviews of household heads and their spouses and included female-headed households where there were no male spouses.

spouses' adaptive farm management decisions and awareness about climate-resilient practices. We also find that a higher CRP of female spouses reduces the CCA gap within a household by increasing females' adoption of soil and water conservation (SWC) mechanisms. Our results are relevant inputs for the formulation of policies to reduce climate change vulnerability by focusing on the resilience of livelihoods of smallholder households to climatic shocks through strengthening climate information systems and enhancing awareness about climate change risks to promote climate-smart agriculture. The remainder of this paper is organized as follows. Section 2 describes the methods employed in our analysis. We then present the discussion of our main results in Section 3, while Section 4 highlights the main policy implications.

2. Materials and methods

2.1. Conceptual framework

Our analysis is conceptually framed within the gender-climate adaptation decision pathway (see Behrman, Bryan and Goh, 2014; Bryan and Behrman, 2013; Ngigi, Mueller and Birner, 2017). In line with the protection motivation theory (Grothmann and Patt, 2005) and protective action decision model (Lindell and Perry, 2012) frameworks guiding individuals' adaptation behaviours, the impacts of climatic changes (observed in various signals such as drought or increased temperature) on individuals' well-being depend on their vulnerability and adaptation responses. Vulnerability represents not only exposure and sensitivity to climatic shocks but also adaptive capacity of individuals and communities (Kristjanson *et al.*, 2017). Particularly, it depends on biophysical factors, technology and information, institutional setup and decision makers' characteristics. Moreover, cognitive characteristics of decision makers, including their perceptions about risk, can also determine how decision makers respond to climate change and adopt new practices to build their resilience. This implies that differences in the way individuals perceive about and act to climatic risks influence their vulnerability and resilience to climate change. Moreover, gender can also play a role in climate adaptation process by influencing the interactions among actors that determine resources and decision-making power (Roy *et al.*, 2022). For instance, the differences among gender in risk perceptions and resources ownership can create differences in the vulnerability to climatic changes and the capacity to adapt to it (IPCC, 2014b, 2014d).

2.2. Theoretical framework

We adopt a collective household model framework, in line with Basu (2006) and Mohapatra and Simon (2017), to study how female and male spouses' perceptions of climatic risks affect the adoption of CCA and the gender gap in adaptation. We assume a cooperative household's decision-making, where a male spouse and a female spouse are the two main decision makers in a household. In our case, this framework implies that decisions in favour of adopting CCA depend on both spouses' utility, in case of joint decisions, or the individual spouse's utility, in case of independent decisions, from the expected gains associated with the adopted strategies.

Consequently, each spouse maximises their household's total utility, $U_i(A_i(x_i, z_i), c_i)$, as a weighted sum of the utility of the female (F) and male (M) spouses, $U_i^F(A_i(x_i, z_i), c_i)$ and $U_i^M(A_i(x_i, z_i), c_i)$, respectively, obtained from CCA, where i represents the household, A_i represents adaptation decision and c_i is a numeraire that stands for the consumption of $i's$ household. This is provided in Equation (1) where $\rho_i(x_i, z_i)$ represents female spouses' relative influence in adaptation decisions jointly made by both spouses in a household and/or for jointly owned/managed land plots, and it takes a value between 0 and 1 for cases where decisions are made solely by individual spouse. For jointly owned/managed plots where both spouses jointly decide to adopt CCA, the higher value of $\rho_i(x_i, z_i)$ reflects the stronger power of a female spouse relative to male spouse in a household's decision-making process. In this case, in addition to the socio-economic and cultural factors that Basu (2006) highlighted, we consider spouses' relative participation in households' adaptation decisions, $\rho_i(x_i, z_i)$, as dependent on behavioural factors, including spouses' risk perceptions, (z_i), that influence their role in households' decision-making processes.

$$\max_{A_i} U_i(A_i, c_i) = \max_{A_i} \{\rho_i(x_i, z_i) U_i^F(A_i(x_i, z_i), c_i) + [1 - \rho_i(x_i, z_i)] U_i^M(A_i(x_i, z_i), c_i)\} \quad (1)$$

In Equation (1), whether to adapt or not to adapt, A_i, is the decision that both spouses choose to maximize their utility given their resource endowment (E_i), which is the sum of each spouse's income and shared overall earnings that they allocate between consumption, c_i, and expenses of farm technology adoption, T_i, i.e. $c_i + T_i \leq E_i$.

We assume that both spouses compare their benefits from the adaptation against non-adaptation that gives no benefit. Under this assumption, a spouse decides to adopt a CCA strategy if the expected benefit from the adoption is greater than the expected benefit from non-adoption. In this regard, spouses' probabilities of adopting CCA, $P(A_i(x_i, z_i))$, become positive if the condition in Equation (2) is satisfied.

$$\rho_i(x_i, z_i) U_i^F(A_i^*(x_i, z_i), E_i - T_i) + [1 - \rho_i(x_i, z_i)] U_i^M(A_i^*(x_i, z_i), E_i - T_i) > 0 \quad (2)$$

As we illustrated, the decision in favour of adopting a given CCA strategy is the function of how female and male spouses in the household perceive climatic risk (CR_{iF}, CR_{iM}), the expected benefits or protection that the CCA strategies provide them against the risks and the household's characteristics

(x_i), as indicated in Equation (3). Spouses' perceptions of climatic risks, CRP_{iF} and CRP_{iM}, are the indices constructed, first by multiplying the likelihood of occurrence and expected impacts of climate events, such as drought, flooding, rainfall variability, rain shortage and heatwaves (see Hasibuan, Gregg and Stringer, 2020; Sullivan-Wiley and Short Gianotti, 2017), and then by computing a composite index under the formative latent constructs framework.

$$P[\{\rho_i(x_i,z_i)U_i^F(A_i^*(x_i,z_i)) + [1-\rho_i(x_i,z_i)]U_i^M(A_i^*(x_i,z_i))\} > 0] = f(CRP_{iF}, CRP_{iM}, x_i) \quad (3)$$

Furthermore, we consider that male and female spouses' relative CRP and intra-household bargaining power, which is determined by $\rho_i(x_i,z_i)$ in Equations (1–3), influence CCA gap between spouses. The vector Z_i in $\rho_i(x_i,z_i)$ includes factors, such as spouses' differential access to resources, that affect intra-household bargaining powers (Basu, 2006). In addition, we hypothesize that spouses' relative CRP influences the existing gender gap in climate adaptation. Hence, the gender gap in CCA between female and male spouses in a household is endogenously determined by differences in spouses' CRP, cultural and socio-economic factors (x_i). In this regard, we model the probability of the CCA gap between male and female spouses, as given in Equation (4):

$$P[A_i^{M*}(CRP_{iM}, x_i, z_{Mi}) - A_i^{F*}(CRP_{iF}, x_i, z_{Fi}) \geq 0] = f(dCRP_i, dx_i, dz_i) \quad (4)$$

In Equation (4), $A_i^{M*}(.) - A_i^{F*}(.)$ represents the CCA gap between male and female spouses. Similarly, $dCRP_i$ stands for the differences in CRP, while dx_i and dz_i represent gaps in socio-economic and cultural factors, including differences in land and other asset ownership, and other behavioural factors that influence the CCA gap between male and female spouses.

2.3. Data and description of the variables

We use the unique intra-household survey data collected from both female and male spouses of households in Kenya, Uganda and Senegal in 2013. Administered by the Research Program on Climate Change, Agriculture and Food Security of the Consortium of International Agricultural Research Centers, the survey covers 200 households each from the Nyando and Wote regions in Kenya, the Rakai region in Uganda and the Kaffrine region in Senegal.[3] The samples of households were randomly selected from each of the villages selected through stratified sampling based on their agro-ecological and

3 The survey documentation and data are publicly available at the Harvard Dataverse: https://dataverse.harvard.edu/dataverse/IFPRI?q=%22IFPRI-CCAFS+Gender+and+Climate+Change+Survey+Data%22

other factors in the regions (see Bryan, Bernier and Ringler, 2018). The surveys gathered the gender-disaggregated data about intra-household decision-making processes, personal values, access to agricultural services, CRPs and adoption of CCA strategies by independently interviewing both female and male spouses within a household. For the sake of comparison between spouses to capture intra-household decision-making dynamics, our analysis considers only 637 households where there exist both male and female spouses, i.e. we exclude the single-headed households in which spouses are divorced or widowed. As the households were selected randomly (regardless of the headship of spouses) for the survey, dropping households where spouses divorced or widowed from the targeted sample is non-systematic and will not introduce any systematic bias.

We construct the variables of interest for our empirical analysis based on each spouse responses to the survey questions. The dependent variables in our analysis are spouses' adoption of CCA and adoption gaps. Spouses' adoption of CCA strategies is generated as a binary variable that takes the value 1 if a spouse answers 'yes' to a question in the survey that asks whether she/he made any changes to protect themselves and their family against climatic changes, or 0 otherwise. We define the adoption of CCA based on spouses' self-reported adaptation decisions she/he made independently for any land plots they individually own or manage or made jointly with their spouses for jointly owned or managed land plots.[4] Spouses also report the five most important CCA strategies they adopted. We group these strategies into three main categories, namely crop-based, SWC and livestock-based strategies to take into account interrelatedness and complementarity among the strategies (see Acevedo *et al.*, 2020; Di Falco, Doku and Mahajan, 2020; Ngigi, Mueller and Birner, 2017). In addition, we construct the CCA gap (adoption gap) between spouses as a multinomial variable that takes the value 0 if there is no gap in adaptation (both spouses adapt), 1 if male spouses adapt but females do not or 2 if female spouses adapt but males do not. Adaptation gaps mainly refer to the differences in CCA adoption decisions between spouses where each spouse independently owns or manages plots of land and makes adaptation decisions at their discretion.[5] The cases of no adaptation gap also comprise

4 Spouses' responses to adaptation question are general and do not distinguish among cases where a spouses manage/own one or several plots of land, joint ownership or joint management of land plots, or if they manage land plots they do not own. In these cases, we cannot observe which spouse is the ultimate decision maker when the response is joint or when there are contested decisions for the land plots jointly owned or managed by both spouses. Moreover, the caveat here is that there can be measurement errors in CCA variables as we rely on spouses' self-reported adoptions of CCA. Consequently, there can be some misclassification in adoption status, which is a common issue in farmers' self-reported survey data in developing countries (see e.g. Abay, 2020; Wossen *et al.*, 2019).

5 In addition to the dual ownership of land and other assets, each spouse individually owns some plots of agricultural land and the data show differences in land ownership status between spouses (see Table 2). This difference in the land ownership status between spouses within a household allows us to define gaps in adaptation decisions they made for the land plots they individually own or manage.

the cases of spouses both joint adoption and joint non-adoption cases. We also define the adoption gap for overall CCA adoption (considering the adoption of any of the strategies) and separately for each crop-based, livestock-based and SWC strategies.[6] The main independent variables of interest, namely female and male spouses' CRP, are constructed as indices using their belief about the likelihood and expected impacts of unfavourable climatic events, namely, drought, heatwaves, rain shortage, rain variability and flooding. Specifically, CRP indices are constructed based on spouses' responses to the questions about what they think is the likelihood that they will be affected by and how much impacts the unfavourable climatic events will have on the livelihood of their household.[7]We combine this data with the IMPACT Lite Survey of the same households to extract information about spouses' land and other assets ownership.[8] Table 1 presents the definitions of the main variables in our analysis.

Table 2 presents the proportion of spouses' adoption of CCA strategies in a household. Overall, about 63 per cent of female spouses and 71 per cent of male spouses adopted CCA strategies (see Table 2). Specifically, crop-based and SWC strategies are the most frequently adopted CCA strategies, compared to livestock-based actions (see Table 2). There is also a gap in the adaptation to climate change between female and male spouses within a household. In our sample, about 32 per cent and 44 per cent of females do not adopt crop-based and SWC strategies, while their male counterparts adopt, respectively. The adoption rate, females' participation and the adaptation gap vary across countries (see Table A1 in the Supplementary Material). We include the country dummy variable in empirical model estimation to account for the heterogeneities among the three countries.

Our main explanatory variables of interest in our empirical models are female and male spouses' perceptions of climatic risks. The surveys ask how each spouse perceived the likelihood of the occurrence and expected impacts of specific climatic events, namely, drought, heatwaves, flood, rainfall variability, as well as rainfall shortage. Based on these questions, we compute the expected risk associated with each of the climatic events by multiplying the likelihood of occurrence and magnitude of expected impacts as perceived by the spouses. We then construct composite indices for spouses' CRP by using the principal

6 For the adaptation gap analysis, we excluded households where both female and male spouses report no adaptation to climate change. As a result, the gap is defined only for the cases where either female or male spouses adopt CCA.

7 Responses to the perceived likelihood and impact questions have scales. Scales for the likelihood of being affected by unfavourable climatic events are 1 = not likely at all, 2 = somewhat likely, 3 = likely and 4 = very likely. Scales for impacts of the climatic events are 1 = no impact, 2 = minimal impact, 3 = moderate impact, 4 = high impact and 5 = severe impact.

8 Documentation and data of the IMPACT Lite surveys are available at the Harvard Dataverse: https://dataverse.harvard.edu/dataset.xhtml?persistentId=doi:10.7910/DVN/24751.

Table 1. Definitions of main variables

Variables	Definitions
CRP	Composite index (continuous variable) constructed from the products of the perceived likelihood and the magnitude of associated damages to spouses and their families from unfavourable climatic events, namely, drought, heatwaves, rain shortage, rain variability and flooding
CCA adoption	Dummy variable that takes the value 1 if a spouse reports any changes she or he made for CCA or 0 otherwise
Crop-based strategies	Dummy variable that takes the value 1 if a spouse report changes in crop planting dates, type, variety, field location, amount of input use and others for CCA or 0 otherwise
SWC	Dummy variable that takes the value 1 if a spouse participates in SWC activities, planting trees on farm or in community places others related activities for CCA or 0 otherwise
Livestock-based strategies	Dummy variable that takes the value 1 if a spouse report changes in livestock species, breeds, feeds, number, location and other related actions for CCA or 0 otherwise
Adaptation gap	Multinomial variable that takes the value 0 if both spouses report CCA adoption, 1 if male spouses adopt but females do not and 2 if female spouses adopt but males do not. It is defined for CCA adoption in general and separately for crop-based, livestock-based and SWC strategies
Past 5 years' climate shocks	The total number of climatic shocks each spouse's experience during the past 5 years before the data collection year
Land ownership	Dummy for whether a female or male spouses own a plot of a farmland in a household
Number of total household decisions	The total number of decisions about crop farming, livestock rearing, farm investment and others made by each of female and male spouses in a household
Access to weather information	Dummy variable that takes the value 1 if a spouse has access to future weather forecasts or 0 otherwise
Access to extension services	Dummy variable that takes the value 1 if a spouse has access to agricultural extension services or 0 otherwise
Access to credit services	Dummy variable that takes the value 1 if a spouse has access to credit services or 0 otherwise
Asset owned	Index constructed (using the principal component analysis) for the total number of productive assets owned by each spouse

component analysis (see Table A2 in the Supplementary Material).[9] From the information in the survey, we create control variables namely climatic shocks in the past 5 years, households' access to weather information, credit and extension services and each spouse's age, education and openness to new farm

9 The unit of analysis for this study is spouses within household since the adaptation variable is defined at spouse level and we do not have plot-level information regarding CCA adoption decisions in the survey.

Table 2. Summary of spouses' CCA and adoption gaps

	Adoption rates		Adoption gap		
Variables	(1) Females	(2) Males	(3) No gap	(4) Gap 1	(5) Gap 2
Overall CCA adoption	63.6	71.6	60.3	24.6	15.1
Crop-based strategies adoption	45.7	47.4	39.2	31.7	29.1
SWC strategies adoption	35.0	72.9	39.3	44.5	16.2
Livestock-based strategies adoption	13.0	11.1	12.4	39.4	48.2

Notes: In columns (3)–(5), 'No gap' is the case where both female and male spouses report the adoption of CCA, 'Gap 1' is when females do not adopt CCA whereas males do and 'Gap 2' is when males do not adopt CCA whereas females do.

practices (see Table A3 in the Supplementary Material for the construction of openness variable). In addition, we extract the village-level rainfall and temperature data, from Worldclim[10] using the raster map of the Database of Global Administrative Areas (GADM).[11] Based on the extracted data, we calculate rainfall and temperature shocks to use as instruments to control for the endogeneity of the risk perception variable in our empirical models. Table 3 presents the differences in main variables between male and female spouses in our sample.

As shown in Table 3, there are statistically significant differences in the adoption of CCA strategies and CRPs between female and male spouses in a household. For example, compared to male spouses, female spouses perceive that climatic risks are more likely to occur in the future and will have a higher impact on their family (see Table 3). Females' higher perception of climatic risks can be due to their higher reliance of activities most vulnerable to climatic shocks and stress, as described by Wright and Chandani (2014) and FAO (2021). On the other hand, more males than females adopt CCA and implement SWC strategies. This is in line with the previous studies that report positive association between male headship of household and the adoption of CCA strategies (Adzawla *et al.*, 2019; Fisher and Kandiwa, 2014). Furthermore, the data indicate statistically significant differences in decision-making power, behavioural and socio-economic factors between spouses. For instance, male spouses made larger number of agricultural and non-agricultural decisions than female spouses in a household. Moreover, male spouses have more access to land ownership, extension services and weather information compared to female spouses (see Table 3). By controlling for these differences, our empirical analysis provides an insight whether the observed difference in risk perception explains the differences in the adoption of CCA strategies between male and female spouses.

10 These data are available at https://www.worldclim.org/data/monthlywth.html.

11 We use GADM's (https://gadm.org/data.html) administrative maps to project Global Positioning System coordinates of area 5 km × 5 km polygons in the villages.

Table 3. Mean differences in main variables between female and male spouses

Variables	(1) Females	(2) Males	(3) Mean difference
CRP	7.340	6.635	0.705***
Adoption of CCA strategies	0.636	0.716	–0.080***
Crop-based strategies	0.457	0.474	–0.017
SWC strategies	0.350	0.529	–0.179***
Livestock-based strategies	0.130	0.111	0.019
Final decision maker for CCA	0.308	0.630	–0.322***
Number of total household decisions	60.08	129.3	–69.201***
Number of crop farming decisions	47.34	85.36	–38.011***
Number of livestock rearing decisions	10.65	36.08	–25.432***
Number of farm investment decisions	0.096	2.896	–2.801***
Number of other decisions	2.024	4.976	–2.953***
Openness to new practices	–0.066	0.034	–0.100**
Education (years of schooling)	5.148	5.184	–0.036
Age	49.14	49.08	0.063
Access to extension services	0.542	0.592	–0.050*
Access to credit services	0.592	0.568	0.024
Asset owned	–0.143	0.020	–0.163
Land ownership	0.256	0.765	–0.509***
Past 5 years' climate shocks	0.805	0.783	0.022
Access to weather information	0.436	0.673	–0.237***

Notes: The number of observations for all variables is 637 each for male and female spouses. The mean difference represents the *t*-test results for females' mean responses – males' mean responses. *$p < 0.10$, **$p < 0.05$, ***$p < 0.010$.

2.4. Empirical model and identification strategy

Based on Equations (3) and (4) in the theoretical framework, we specify our main regression models. First, we use the model in Equation (5) to estimate the effects of spouses' risk perceptions on household decisions to adopt CCA strategies.

$$Y_{ji} = a_1 + \beta_1 \times CRP_{ji} + \delta_1 \times X_{ji} + \varepsilon_{1ji} \quad (5)$$

The dependent variable Y_{ji} in model 1 given by Equation (5) is the dummy variable that takes value 1 if a $j \in (Female, Male)$ spouse in a household i has adopted any CCA strategies or 0 otherwise in a household i. In Equation (5), the variable of our main interest is β_1 that represents the effect of spouses' CRP on their adoption of CCA strategies. In addition, as illustrated earlier, we group CCA strategies into crop-based, SWC and livestock-based strategies. In this case, Y_{ji} in Equation (5) also represents the indicator variable that assumes value 1 if a spouse adopts crop-based, livestock-based or SWC strategy or 0 otherwise in respective models for each category of CCA. While the vector X_{ji} includes a spouse- and household-level covariates (control variables), δ_1 represent coefficients of corresponding control variables. The terms a_1 and ε_{1ji} represent the constant term and the robust standard error in model 1, respectively.

Moreover, we specify model 2 in Equation (6) to examine whether the observed difference in CRP explains the adaptation gap between the female and male spouses in a household. We construct the adaptation gap (dY_{ji} variable) as a multinomial variable that takes the value 0 if there is no gap in adaptation between spouses (both spouses adapt), 1 if male spouses adapt but females do not or 2 if female spouses adapt but males do not adapt. The d operator in Equation (6) represents the difference between male and female responses, whereas the variables Y_{ji} and X_{ji} and terms a_2 and ε_{2ji} have similar definitions as in Equation (5).

$$dY_{ji} = a_2 + \beta_2 \times dCRP_{ji} + \delta_2 \times dX_{ji} + \varepsilon_{2ji} \tag{6}$$

In the model presented in Equation (6), our emphasis is estimate parameter β_2 which represents the effect of differences in perception of CRP, i.e. $dCRP_{ji}$, on the adaptation gap (the difference in CCA adoption) between male and female spouses, i.e. dY_{ji}. The control variables represented by the vectors X_{ji} in Equations (5) and (6) include socio-economic characteristics of the household, including household size, land size, asset ownership, past exposure to climatic shocks as well as male and female spouses' education, age, openness to new practices and their access to credit, extension and climate information.

As highlighted earlier, we emphasize the estimation of β_1 and β_2 in models given in Equations (5) and (6). However, estimating β_1 and β_2 from the models 1 and 2 using the standard linear probability or probit/logit regression models may result in biased parameter estimates. This is because spouses' perceptions of climatic risk are endogenous as there may exist measurement errors and omitted variable problems. For example, people may underestimate or overestimate the probabilities of climate changes and the magnitude of its potential impacts.

Therefore, we use the IVs approach to address the endogeneity problem and estimate the causal effect of spouses' CRP on their decision for CCA. For this purpose, we use exogenous shocks in temperature and rainfall during the data collection months as instruments. We calculate the rainfall and temperature shocks, given by $\bar{W}_v^{MD}$ in Equation (7), as a deviation of observed rainfall and temperature at a village during the data collection months from the respective historical averages (see Dell, Jones and Olken, 2014; Hidalgo *et al.*, 2010; Liang and Sim, 2019). In Equation (7), $\bar{W}_v^{MD}$ represents both rainfall and temperature, whereas v represent village.

$$\bar{W}_v^{MD} = \frac{W_v - \bar{W}_v}{sd} \tag{7}$$

The main identifying assumption in our estimation strategy is that climatic shock contemporaneous to the period of data collection does not directly affect the CCA decisions already made by a household during the last production season. Nevertheless, it affects spouses' current perceptions about future climatic

Table 4. First-stage regression results for instrument relevance and exclusion restrictions

	CRP in CCA adoption models		CRP in adoption gaps models	
	(1) Females adoption	(2) Males adoption	(3) CCA gap	(4) SWC gap
Rainfall shock	−0.083** (0.007)	−0.049** (0.011)	0.034** (0.007)	0.035** (0.006)
Rainfall × temperature shocks	−0.266** (0.024)	−0.287** (0.058)	0.093* (0.038)	0.072* (0.033)
Uganda (compared to Kenya)	−8.877** (0.835)	−4.889** (1.069)	3.068** (0.855)	2.974** (0.748)
Senegal (compared to Kenya)	−12.274** (1.109)	−7.786** (1.193)	4.724** (0.818)	4.660** (0.708)
Kleibergen–Paap Lagrange-multiplier statistic	63.046	11.480	13.367	21.237
Observations	637	637	537	402

Notes: Regressions in columns (1)–(4) include explanatory variables, namely spouses' access to weather information, extension, credit, land ownership and household size, as well as spouses' education, age and their openness to new farm practices. Standard errors are clustered at village level and presented in parentheses. The first instrument is constructed as one standard deviation of rainfall during the data collection months from its historical 10 years' average. The second instrument is constructed as interaction between rainfall and temperature shocks during the data collection months from their respective averages for the past 10 years. *$p<0.10$, **$p<0.05$, ***$p<0.010$.

changes.[12] We argue that our assumption is sensible, given that the shocks construction approach we employ enables us to net out the effect of past trends and extreme weather occurrences (see Hidalgo *et al.*, 2010). We also control for the subjective measure of weather and climatic shocks during the 5 years prior to data collection period reported by the respondents. This helps us to mitigate the potential concern that contemporary rainfall shocks may depend on the past shocks, and it may influence the current adaptation decisions through influencing past CRPs. Under these conditions, the contemporaneous shock is exogenous to CCA adoption decisions during the cropping season preceding the survey period captured in the data. That means contemporaneous shocks in temperature and rainfall satisfy exclusion restrictions and hence can be plausible instruments to address the endogeneity of spouses' perceptions about climate risks.[13] The first-stage regression results are presented in Table 3; both rainfall shock and its interaction with temperature shock have a positive and statistically significant correlation with spouses' CRPs in Kenya. The Kleibergen–Paap F-statistic in the columns (1)–(6) of Table 4 is higher than the

12 Hence, it will influence a potential decision of the household to adopt CCA in the future.

13 Furthermore, we assume that the potential measurement error in CRP is classical in the sense that it is not systematically correlated with spouses' unobserved characteristics. In this regard, our linear IV-based estimators are valid and provides consistent estimate about the impacts of spouses' climate risk perception on their CCA decisions.

threshold of 10, which shows that rainfall and temperature shocks are strong enough to alleviate bias from weak instruments (see Staiger and Stock, 1997). Finally, we employ two empirical approaches for model estimation. First, we use IV probit to estimate the model in Equation (5) to examine the impact of spouses' CRP on their CCA adoption. Second, we estimate a multinomial model in Equation (6) to investigate the factors influencing the gap in CCA between spouses using the control function procedure. Finally, we discuss some falsification tests and cautions for interpreting our regression coefficients as causal estimates, as well as assumptions and conditions under which the causal claim can be plausible.

3. Empirical results

3.1. Effects of spouses' CRP on their CCA

We estimate the relationship between spouses' risk perceptions and their decisions to adapt to climate change by controlling for a country-fixed effects in our regression model. While Table 5 presents the main results from the IV estimation of the model in Equation (5) for each spouses' overall adoption of CCA, Table 6 provides the estimates for crop-based, SWC and livestock-based strategies. As we use a linear probability model, our estimates of CRP coefficients in Tables 5 and 6 can be interpreted as marginal effects. We present the corresponding IV probit estimates of the coefficients of our main variable and all covariates in Appendix B.

Our results indicate that spouses' perception of climatic risks has positive impacts on their adoption of CCA strategies. The results show that female spouses who perceive higher climatic risks have 13 per cent higher probabilities to adopt CCA strategies (see Table 5). Similarly, we find statistically significant effects of male spouses' perception of climatic risks on their decisions about CCA, where males who perceive climatic risk as a likely danger have 13.2 per cent higher probabilities to adopt climate-resilient practices. Moreover, our results are found to be specific to the type of CCA strategies when we consider each of the adaptation categories. For example, female and male spouses who perceive higher climatic risks have 16 per cent and 17.5 per cent higher probabilities to adopt SWC strategies, respectively, but

Table 5. Impacts of spouses' CRP on overall CCA adoption

	(1) Females	(2) Males
CRP	0.130*** (0.015)	0.132** (0.060)
Uganda (compared to Kenya)	−0.060 (0.050)	0.118* (0.061)
Senegal (compared to Kenya)	−0.556*** (0.065)	−0.314*** (0.070)
Observations	637	637

Notes: The coefficients are the IV estimates of linear probability model using Equation (5). See Table B1 of Appendix B in the Supplementary Material for the extended (IV probit) results, including all control variables. Standard errors are clustered at village level and presented in parentheses. *$p<0.10$, **$p<0.05$, ***$p<0.010$.

Table 6. Impacts of spouses' CRP on specific CCA strategies adoption

	Crop-based strategies		SWC strategies		Livestock-based strategies	
	(1) Females	(2) Males	(3) Females	(4) Males	(5) Females	(6) Males
CRP	0.017 (0.014)	0.060 (0.054)	0.160*** (0.017)	0.175*** (0.051)	−0.003 (0.018)	−0.019 (0.013)
Uganda (compared to Kenya)	0.091* (0.048)	−0.034 (0.051)	−0.167*** (0.054)	0.020 (0.070)	−0.126*** (0.037)	−0.144*** (0.021)
Senegal (compared to Kenya)	−0.526*** (0.092)	−0.351*** (0.082)	−0.305*** (0.059)	−0.372*** (0.088)	−0.239*** (0.060)	−0.043 (0.064)
Observations	637	634	637	637	637	634

Notes: Dependent variables in models in columns (1)–(6) are the adoption of crop-based, SWC and livestock-based strategies by female and male spouses. The coefficients are the IV estimates (marginal effects) from linear probability model estimation of Equation (5), whereas the corresponding marginal effects from IV probit estimates are given in Table B2 of Appendix B in the Supplementary Material. We control for socio-economic and farm characteristics in all regression models, the results of which are presented in extended Table A3 in the Supplementary Material. Standard errors are clustered at the village level and presented in parentheses.
*$p < 0.10$, **$p < 0.05$, ***$p < 0.010$.

the results are statistically insignificant for the case crop–based and livestock-based strategies (see Table 6). There is also heterogeneity in the effects of risk perception on CCA decisions across the countries. For instance, compared to Kenya, female and male spouses in Senegal have lower probabilities of adopting CCA strategies (see Table 5), whereas females spouses' likelihood of adopting crop-based strategies is higher in Uganda compared to Kenya (see Table 6).

Our results corroborate the finding of existing literature in CCA. The positive effect of (both female and male) spouses' perception of climate risk on the household decision is consistent with the results of Holden and Quiggin (2016) and Teklewold, Adam and Marenya (2020), who found that households exposed to drought in the past are more likely to adopt drought-tolerant varieties of maize in Malawi, Tanzania and Uganda. Other studies in developing countries also report a positive association between spouses' experience of climatic shocks, such as severe drought, and their adoption of CCA strategies (see e.g. Al-Amin *et al.*, 2019; Holden and Quiggin, 2016; Teklewold, Adam and Marenya, 2020).

Specifically, the positive effects of female spouses' perception of climatic risks on households' adoption of CCA strategies are consistent with the findings of Ngigi, Mueller and Birner (2017) that female spouses who perceive temperature rising and rainfall declining adopt several climate-smart practices. This implies the sizeable role of female spouses in technology adoption, regardless of the household headship or asset management emphasized by Fisher and Kandiwa (2014) and Teklewold, Adam and Marenya (2020). Our results are also in line with the previous literature's summary by Sellers (2018) that women in developed countries are more likely than men to perceive climate change as a danger and are more disposed to promote policies targeting CCA or mitigation. Furthermore, female spouses' sensitivity to climatic risks and preferences for adaptation options could be due to their dependence on livelihoods and activities vulnerable to climate change (IPCC, 2014a, 2014d). The implication of our findings is that climate policies need to target strategies to strengthen the spouses' awareness of climatic risks. This in turn helps to promote adaptation to climate change since a reduced gender inequality is associated with an increased climate action in several countries (Andrijevic *et al.*, 2020).[14]

Given the potential measurement error in our regression model's dependent variable, i.e. CCA adoption, caution is needed in the interpretation of its coefficients as a causal estimate. This is because misclassifications in adoption status are a common issue in farmers' self-reported data on technology uptake (see e.g. Abay, 2020; Wossen *et al.*, 2019). To that end, we discuss the assumptions and conditions under which our claim of causal estimates

14 Overall results are consistent when we consider two alternative specifications, namely, (I) the adaptation decision defined at a household level and (II) separate analysis for each of the countries, as the robustness checks (see Tables D1 and D2 in Appendix D of the Supplementary Material).

can be plausible by considering some falsification tests. First, as a falsification test, we test the uniqueness of CRP effects on climate change–related decisions by estimating its effect on spouses' self-reported civic group participation, which is unrelated to their climate change response. Second, we estimate the effects of male CRP on female CCA adoption and vice versa, to check the influence of each spouse on their respective partner's CCA decisions, i.e. to evaluate the interdependence of spousal decisions. The effects of CRP on spouse participation in civic groups are not statistically significant, as shown in Table C1 of Appendix C in the Supplementary Material. This implies that the effects of CRP on CCA are specific to decisions related to coping with the negative impacts of climate change, but not spurious, because they are unrelated to other self-reported decisions unrelated to climatic conditions. On the other hand, we find that male CRP has a positive and statistically significant impact on female CCA adoption and female CRP on male CCA adoption. This points to the interdependence of spouses' CRP, which influences their respective spouse's adaptation decisions. The interdependence of risk perceptions between spouses within a household is consistent with Di Falco and Vieider (2018), who found a positive relationship between risk preferences of spouses and the number of marriage years, confirming the evidence for social transmission of preferences. These two cases can provide a plausible argument to support our claims of interpreting CRP coefficient estimates as causal, even though a due caution is needed given the potential adoption misclassification and interdependence of spousal preferences.

3.2. Effects of CRP on adaptation gap between spouses

In this subsection, we examine what factors explain the observed differences in climate adaptation between spouses, demonstrated in Table 2 of Section 2.2, within a household. By doing so, we attempt to shade a light on key implications for polices aiming at reducing gender gap in adoption of climate-resilient practices. Table 7 presents the results of the control function estimation of the multinomial model for the factors affecting the gap in CCA between spouses.

Our empirical results indicate that a higher CRP of female spouses relative to males reduces the adaptation gap by increasing females' probability of adopting SWC compared to males. Specifically, column (4) of Table 7 shows that a one-unit increase in females' CRP compared to males leads to a 3 per cent increase in the likelihood of females adopting SWC, while males do not adopt. An interesting implication of this finding is that enhancing female spouses' awareness of climatic risks can close the adaptation gap between males and females in developing countries and help build the climate resilience of women's livelihoods. Closing a gender CCA gap has a paramount importance because, as highlighted in previous subsection, women are more likely than men to perceive climate change as a danger and are more disposed to promote policies to adapt to and mitigate it (see e.g. Sellers, 2018). Specially, if females, especially those with stronger perceptions of climate risk,

Table 7. Impacts of differences in spouses' CRP on adoption gap

	CCA adoption gap		SWC adoption gap	
	(1) Males adopted, females did not	(2) Females adopted, males did not	(3) Males adopted, females did not	(4) Females adopted, males did not
CRP gap	−0.0035	0.0146	−0.0096	0.0305**
	(0.0180)	(0.0162)	(0.0289)	(0.0138)
Agricultural decision gap	0.0003	0.0000	0.0003**	0.0002
	(0.0002)	(0.0002)	(0.0001)	(0.0003)
Land ownership gap	0.2212***	0.0759	0.0116	0.1409***
	(0.0746)	(0.0606)	(0.1222)	(0.0505)
Extension access gap	0.0297	0.1206**	0.1496**	0.0974**
	(0.0530)	(0.0502)	(0.0731)	(0.0459)
Weather information gap	0.1680***	−0.0270	0.0730	0.0212
	(0.0480)	(0.0425)	(0.0620)	(0.0314)
Uganda (compared with Kenya)	−0.0679	−0.1003**	0.0981	−0.0388
	(0.0679)	(0.0408)	(0.0723)	(0.0371)
Senegal (compared with Kenya)	0.3252***	0.0008	0.1978*	0.0995
	(0.0926)	(0.0505)	(0.1105)	(0.0643)
Observations	537	537	402	402

Notes: A reference group in regressions presented in columns (1)–(4) is adaptation gap 0 (cases where both female and male spouses adopt a given strategy under consideration). The total number of observations in all columns excludes the households where both spouses do not adapt to climate change. In all regressions, we control for the gaps in assets, credit, age and education between spouses. Standard errors are clustered at the village level and presented in parentheses. *$p<0.10$, **$p<0.05$, ***$p<0.010$.

could participate more in uptake decisions, they could initiate more adoption of CCA.

However, as shown in columns (1) and (2) of Table 7, we do not find statistically significant effects of differences in CRP on the adoption gap of overall CCA. On the other hand, gaps in spouses' land ownership and access to weather information increase the gap in CCA by increasing the probability of males adopting CCA, while females do not adopt (see column (1) of Table 7). This is in line with Mersha and Van Laerhoven (2016) who highlight that differences in access to resources and information are drivers of differences in CCA between males and females. In this regard, addressing gender gaps in resources' ownership and strengthening women's rights-based approaches to development (IPCC, 2014a) also help to reduce climate vulnerability and foster sustainability.

4. Discussion

We find that female and male spouses' higher CRPs increase their adoption of CCA and females' higher CRP reduces the adaptation gap by increasing their adoption of SWC relative to males. In this section, we discuss the possible mechanisms (channels) of the effects of spouses' CRP on their CCA. While identifying the comprehensive mechanisms requires more detailed data, we highlight some direct channels through which a higher perception of climatic risks is likely to influence the adoption of climate-resilient practices. Our discussion of the potential channels is based on the theoretical frameworks guiding individuals' adaptation behaviours, namely protection motivation theory (Grothmann and Patt, 2005) and protective action decision model (Lindell and Perry, 2012). Under these theories, environmental cues stimulate perceptions and awareness about both threat and protective actions which initiate decision-making for chosen protective actions. In this regard, one of the channels through which risk perception could affect the adoption of CCA is by increasing spouses' awareness of adaptation options.

Tables 8 and 9 show that the perception of higher climatic risks increases spouses' awareness of stress-tolerant crop varieties, drought-tolerant livestock breeds and water harvesting. This is in line with the findings of previous studies on climate-resilient agriculture practices. For example, Acevedo *et al.* (2020) summarized that about 50 per cent of studies they reviewed identified awareness outreach as an effective mechanism to promote the adoption of climate-resilient crops. Awareness of not only climatic change risks but also available technologies to reduce its unfavourable impacts is the first crucial step in the adaptation process. Quiroga, Suárez and Solís (2015) also indicated a positive association between being aware of future soil erosion and water shortage risks and farmers' perceived adaptive capacity. In this regard, access to information and extension services can play important roles in increasing

Table 8. Mechanisms through which females' CRP affects their CCA

	(1) Stress-tolerant crop varieties awareness	(2) Drought-tolerant livestock breeds awareness	(3) Water harvesting awareness	(4) Agricultural decisions
CRP	0.2942***	0.1265***	0.1917***	26.7700***
	(0.0210)	(0.0254)	(0.0223)	(4.4828)
Uganda (compared to Kenya)	0.2087***	0.2981***	−0.1056	−1.6876
	(0.0658)	(0.0516)	(0.0665)	(9.1499)
Senegal (compared to Kenya)	−0.5809***	−0.1951***	−0.6058***	−75.4397***
	(0.0934)	(0.0539)	(0.0911)	(9.7890)

Notes: Dependent variable in models in columns (1)–(4) are the number of agricultural decisions by female, females' awareness of water harvesting, awareness of the use of stress-tolerant crops and switching to drought-tolerant livestock breeds by female and male spouses. The coefficients are the estimates (marginal effects) from the linear probability model estimation of Equation (5). We control for socio-economic and farm characteristics in all regression models, similar with regressions reported in Tables 5–6. The number of observations in all models is 637. Standard errors are clustered at the village level and presented in parentheses.
*$p<0.10$, **$p<0.05$, ***$p<0.010$.

Table 9. Mechanisms through which males' CRP affects their CCA

	(1) Stress-tolerant crop varieties awareness	(2) Drought-tolerant livestock breeds awareness	(3) Water harvesting awareness	(4) Agricultural decisions
CRP	0.5894***	0.0742***	0.0930***	20.2297*
	(0.1738)	(0.0198)	(0.0222)	(11.6821)
Uganda (compared to Kenya)	0.3505*	0.5852***	0.1522***	9.0583
	(0.1880)	(0.0274)	(0.0404)	(8.0018)
Senegal (compared to Kenya)	−0.4698**	−0.0337	−0.4609***	39.6707**
	(0.2247)	(0.0445)	(0.0949)	(16.3238)

Notes: Dependent variable in models in columns (1)–(4) are the number of agricultural decisions by male, males' awareness of water harvesting, awareness of the use of stress-tolerant crops and switching to drought-tolerant livestock breeds by female and male spouses. The coefficients are the estimates (marginal effects) from the linear probability model estimation of Equation (5). We control for socio-economic and farm characteristics in all regression models, similar with regressions reported in Tables 5–6. The number of observations in all models is 637. Standard errors are clustered at the village level and presented in parentheses.
$^{*}p<0.10$, $^{**}p<0.05$, $^{***}p<0.010$.

farmers' awareness of CCA and risk mitigation options. Several studies in sub-Saharan Africa conform this and reported positive associations of information and extension services with farmers' adaptation to climate change (Bryan *et al.*, 2013; Di Falco, Veronesi and Yesuf, 2011; Teklewold, Adam and Marenya, 2020).

Furthermore, spouses' perception of higher climatic risk could increase their responsiveness in making agricultural decisions to protect their agricultural production and livelihoods. As shown in column (1) of Tables 8 and 9, female and male spouses' CRP increase the number of agricultural decisions they make in their households. Farmers' pro-activeness in agricultural decisions influences their CCA decisions. This is because many CCA actions are often mechanisms for risk reductions or production enhancements of existing or new farming activities (Howden *et al.*, 2007). In this regard, higher CRP could enhance alertness to their farming practice and increase decision-making. To sum up, we provide suggestive evidence that the positive effects of spouses' CRP on their adoption of CCA and reduction of adaption gap are likely driven by the enhanced awareness of climate-resilient technologies and proactive agricultural decisions to make adaptation changes.

5. Conclusion and policy implications

We illustrate the effects of gender-differentiated perceptions of climatic risks on spouses' decisions about CCA in sub-Saharan Africa using the data from Kenya, Uganda and Senegal. Our analysis controls for the endogeneity of spouses' perception of climatic risks by using the exogenous shocks in temperature and rainfall during the data collection months as instruments. In doing so, we introduce a novel approach to study the role of gender in climate-smart agriculture by considering the impacts of both female and male spouses' perceptions of climatic risk on the adoption of CCA strategies and the observed adaptation gaps. Consequently, we could detail the impact of spouse behaviours on CCA adoption decisions. Our results indicate that male and female spouses' higher CRP increase their likelihood of adopting CCA strategies. This implies that it is not only household heads, who are usually males in the African context, whose behaviour matters, but also behaviours and perceptions of female spouses' matter in household's decision for CCA. Furthermore, we find that female spouses' higher CRP reduces the observed adaptation gaps between male and female spouses by increasing females' adoption of SWC relative to males. Our findings are generally robust to various alternative approaches.

The findings of this paper suggest the three main implications for climate policies and future research in sub-Saharan Africa. First, policies enhancing spouses' awareness about climatic risks can enhance households' adoption of CCA and help build climate resilience. In this regard, policy interventions aimed at strengthening weather and climate information systems and improving spouses' access to information can enhance household members' knowledge about climatic risks and their adaptation responses. If females with stronger perceptions of climate risk had more to say, they could initiate more adoption of SWC and reduce the gender gap in CCA. This would also support policies targeting gender equality and women empowerment in agricultural decision-making. In this regard, it is important to address gender gaps in access to resources and strengthen women's rights-based approaches to development, as highlighted by IPCC (2014a), to reduce climate vulnerability. Second, climate policy should consider intra-household and inter-country heterogeneities in CRPs, climate change vulnerability and preferences for CCA strategies to promote climate-resilient agricultural development. In this regard, it is crucial to target different groups differently when designing effective climate policy initiatives. Third, studies of climate-smart technology adoption should consider intra-household behaviours and roles of both female and male spouses within a household. There is a need for future research to study the impacts of CCA adoption on the welfare of female spouses (and grown-up children). In this regard, the proper identification of the adoption status using approaches, for example, varietal identification by deoxyribonucleic acid (DNA) fingerprinting, can help mitigate the issues of adoption misclassification associated with spouses' self-reported information.[15] Finally, investigating the policy actions to address the underlying mechanisms driving the high sensitivity of females to climatic risks can provide better guidance to climate-resilient development policies.

15 DNA fingerprinting is the process of using funda- mental genome coding to identify a crop variety by comparing the DNA extracted from a field sample with a reference set of genetic profiles from known improved and unimproved varieties (Poets et al., 2020).

Supplementary data

Supplementary data are available at *ERAE* online.

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