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Gender-Differentiated Impacts of Climate Variability in Ethiopia

A Micro-Simulation Approach

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Gender-Differentiated Impacts of Climate Variability in Ethiopia: A Micro-Simulation Approach

Tesfamichael Wossen

Abstract

In this paper, we examine the gender-specific effects of climate variability using household level data from rural Ethiopia. In particular, this paper investigates whether female-headed households are more vulnerable to the impacts of climate variability and to what extent policy interventions are effective in improving adaptive capacity of female-headed households. The analysis undertaken in this paper underscores that female-headed households are more vulnerable to the impacts of climate variability compared to male-headed households and the result is mainly explained by the endowment effect. Moreover, adaptation strategies through the adoption of new crop varieties that are resilient and adapted to local conditions are effective in reducing the adverse effect of climate variability for both female and male-headed households.

Key Words: climate variability, gender, adaptation, heterogeneity, Ethiopia

JEL Codes: C61, Q54, Q12

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Gender-Differentiated Impacts of Climate Variability in Ethiopia: A Micro-Simulation Approach

Tesfamichael Wossen*

1. Introduction

Climate variability, manifested by changes in rainfall amount, intensity and timing, as well as through changes in temperature, often causes serious agricultural production losses and exacerbates food insecurity in Sub-Saharan Africa (SSA). Given that the direct impacts of climate variability are transmitted through the agricultural sector, improving farm households' capacity to adapt to the adverse effects of climate-related shocks through effective adaptation and policy interventions is imperative (Milman and Arsano 2013; Arndt et al. 2011; Deressa 2009). Previous studies by Deressa et al. (2009), Block et al. (2008), Arndt et al. (2011), Robinson et al. (2012) and Di Falco et al. (2011) documented that farm households in Ethiopia are vulnerable to the impacts of climate variability. Although a great deal of progress has been made in disentangling the effects of climate variability, uncertainties still remain. For example, it is acknowledged that climate variability matters; however, the exact magnitude of the effect is not yet clear (Milman and Arsano 2013; Di Falco et al. 2011; Di Falco et al. 2011; Di Falco et al. 2014; Deressa et al. 2009; De Pinto et al. 2013; Kandulu et al. 2012; Alauddin and Sarker 2013; Wossen et al. 2015). Studies show that the estimated climate change effects range in the order of 7-10% decline in GDP compared to a scenario of no climate change (Arndt et al. 2011; Robinson et al. 2012). Cognizant of this fact, the Ethiopian government has developed a National Adaptation Program of Action (NAPA) in 2007 (National Meteorological Agency 2007). The NAPA sets out potential adaptation options suited for small-scale and subsistence farm households.

Because successful implementation of policy interventions in response to climate variability depends on the magnitude and direction of expected effects of variability at a disaggregated level, examining the distributional effects of climate variability as well as the current roles of adaptation strategies will be crucial (Juana et al. 2013). Ideally, such analysis should also include gender dimensions. However, the evidence on the gender-specific effects of climate variability is rather scant. Capturing the gender-specific effects

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of climate variability is crucial because climate variability may have differential impacts on male-headed households (MHHs) and female-headed households (FHHs) because of differences in the perception of climate variability, adaptive capacity (Bryan et al. 2009), physical assets and social capital and hence adaptive and coping capacity, risk perception and choice of crop portfolios.[1]

In addition, women and men may have different levels of access to extension and climate information. For example, Asfaw and Admassie (2004) found that MHHs are more likely than FHHs to get information about new technologies and to undertake risky businesses. The Ethiopian Rural Household Survey (ERHS) 2009 also shows that only 15% of MHHs are eligible for safety nets, such as work-for-food programs, compared to 26% of FHHs. This result further underscores that FHHs are poorer than MHHs, as access to safety nets is granted based on the initial poverty status of households. Similarly, Tenge and Hella (2004) found that FHHs have limited access to information, land, and other resources due to traditional social barriers. Empirical evidence in many developing countries further shows that FHHs own less land and assets and also use less improved seed varieties (World Bank 2013**)**. In line with this, Kilic et al. (2014) documented that female-managed plots are on average 25% less productive and 91% of this difference is explained by the endowment effect. In particular for Ethiopia, Dercon et al. (2005) found that drought shocks have disproportionately higher impacts on FHHs compared to MHHs.

[1] The focus of previous research has been rather on how gender-related differences (mainly differences in empowerment between men and women in a male-headed household) affect welfare outcomes, instead of examining how vulnerable FHHs are compared to MHHs. In line with this, Alkire et al. (2013) and Sraboni et al. (2014) reported a positive relationship between women's empowerment and productivity and food security outcomes. Moreover, Fafchamps et al. (2009) documented that the relative nutrition of spouses is associated with bargaining power. Wiig (2013) also reported that joint property rights have a strong effect on the decision to make large investments in agriculture. In addition, previous studies captured the gender-specific effects of climate variability, using regression-based approaches where gender effects were captured through a gender dummy. This approach, however, does not take into account the existence of interaction effects between gender and other socio-economic variables (i,e., each individual socio-economic variable has the same effect and only the intercept differs between MHHs and FFHs).

This paper examines to what extent FHHs are vulnerable to the impacts of current climate variability compared to MHHs.[2] In particular, the study aims at examining how current climate variability may disproportionately affect FHHs compared to MHHs and to what extent adaptation options such as adoption of new crop varieties may reduce the vulnerability of FHHs. The paper also assesses the responsiveness of FHHs to policy interventions compared to MHHs when exposed to the same policy treatment after climate shocks.[3] The paper employs a micro-simulation approach that captures farm-level impacts of climate variability while taking into account a wide range of adaptation options. This is quite novel compared to the existing climate variability research which focuses on macro-level impacts. In particular, the micro-simulation approach employs a scenario-based analysis to examine the possible impacts of climate variability on income and food security levels of FHHs and MHHs. The model captures uncertainty in production and consumption decision-making processes, captures causes and outcomes of adaptation processes due to its recursive nature, and assesses trade-offs and synergies among food production, consumption (and hence food security) and environmental impacts resulting from the use of adaptation options. Furthermore, the model captures heterogeneity among households in terms of resource and wealth dynamics, adaptive capacity, production and consumption preference, knowledge and learning ability. Because farm-level costs and returns are explicitly captured, adaptation to climate variability occurs endogenously.

The remainder of the paper is organized as follows. Section 2 introduces the conceptual framework developed for evaluating gender-specific roles in adaptation; Section 3 presents the data sources and the micro-simulation model; Section 4 discusses our findings; and Section 5 concludes with a list of open questions and an outlook on next research steps.

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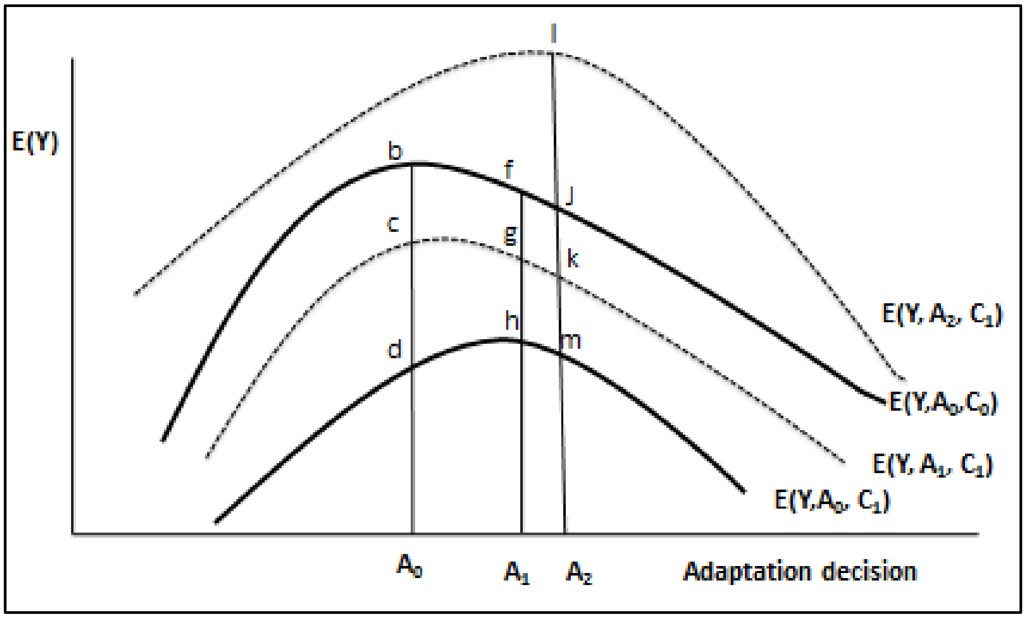
[2] Examining the gender-specific effects of climate variability is not a trivial matter due to the problem of over-controlling and endogeneity bias (Dell et al. 2014). In particular, some of the socio-economic variables that affect intra-household decision-making and bargaining power are also directly affected by climate variability. In this case, controlling for household-specific characteristics can have the effect of partially eliminating the explanatory power of climate even if climate is the underlying fundamental cause (Dell et al. 2014). A second key methodological issue is the endogeneity of female headship status for some types of FHHs.

[3] Our approach does not differentiate between the *de facto* FHHs and *de jure* FHHs due to lack of data.

2. Conceptual Framework

In principle, exposure to climate variability should, *ceteris paribus*, have the same effect irrespective of the gender dimension. However, due to differences in initial endowments, climate variability will have differential effects on MHHs and FHHs. In this section, we first show how climate variability may affect productivity, using a conceptual framework developed by Antle and Capalbo (2010). We then show how adaptation strategies in response to climate variability may become gender-biased. Figure 1 is a generic representation of how the effectiveness of adaptation options may differ under different weather realizations without taking into account gender dimensions. Y represents expected outcome variables measured to evaluate the impacts of climate variability (in our case, mainly that of expected household income and food security).

Figure 1. Evaluation of the Effectiveness of Adaptation Options



$A_i, [1 \cdots n]$ represents the different set of adaptation options available to a given household and (C_0 &C_1) are the different weather realizations. (Y, A_0C_0) represents the production function without climate variability. Point ***b*** represents the corresponding income or food security level of farm households at the level of adaptation (A_0) under no climate variability.[4] With the same level of adaptation (A_0), point ***d*** then represents the

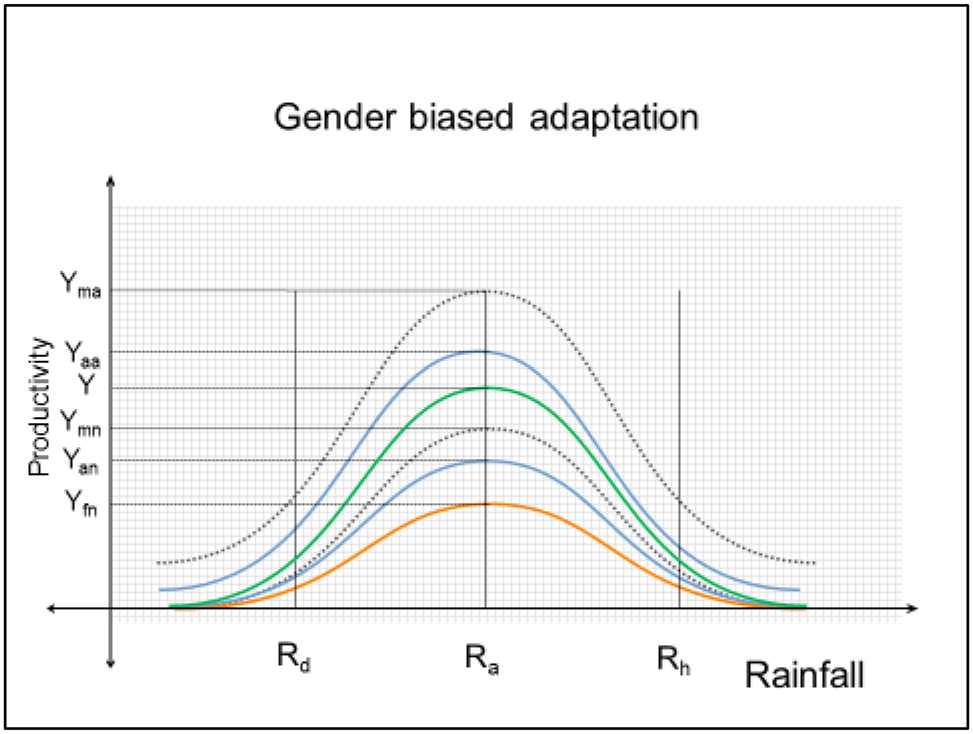
[4] We assume that climate variability (C1) will have a higher adverse effect than the situtation of no variability (C0).

level of income or food security that a household achieves under climate variability $(Y, A_0 C_1)$. The impact of climate variability is represented by the vertical distance ($\boldsymbol{b - d}$). In order to reduce the impacts of variability, households may respond by increasing the scale of their adaptation through the use of more credit, off-farm income or adoption of new and improved seed varieties, which is represented by (A_1). Under the new level of adaptation, the level of income or food security achieved by a household is given by point $\boldsymbol{g}$ and the corresponding effect of climate variability is given by ($\boldsymbol{f - g}$). The vertical difference ($\boldsymbol{g - h}$) captures the role of adaptation strategies. In the extreme scenario, when the scale of adaptation reaches (A_2), adaptation not only successfully reduces the impacts of variability but also improve food security and income beyond the initial condition.

However, Figure 1 does not take into account gender differences in vulnerability. As mentioned in the introduction, FHHs may be more vulnerable than MHHs due to the endowment effect. Figure 2 below further shows how adaptation options may have differential impacts between MHHs and FHHs. As shown in Figure 1 above, adaptation practices through policy interventions can reduce vulnerability. This leads to the question of what constitutes a successful adaptation strategy. We argue that successful policy interventions aimed at increasing adaptive capacity should improve the livelihoods of the most disadvantaged and poor groups (irrespective of households being MHHs or FHHs).[5] Adaptation can be successful but still gender-biased. Gender-biased adaptation may produce unintended consequences by exacerbating the existing inequality between FHHs and MHHs. We show how successful adaptation might lead, on average, to gender-biased outcomes in the following conceptual framework. In the figure below, Y represents the income level of a given household in the situation of no climate variability, while Y_{mn} and Y_{an} show income levels of MHHs and FHHs, respectively, under climate variability. Y_{ma} and Y_{fn} represent the respective income levels of MHHs and FHHs after adaptation to climate variability has been undertaken. Finally, Y_{aa} represents the average outcome for the whole community (average outcome irrespective of gender). R_d, R_h and R_a refer to the different possible weather realizations (from bad to good).

[5] In this regard, while considering adaptation options, both economic efficiency and equity objectives should be taken into account.

Figure 2. Example of a Gender-Biased Policy Intervention



Because FHHs own fewer assets, they apply less fertilizer, improved seed and other inputs of production.[6] Given that both MHHs and FHHs are exposed to the same type of climate/weather shocks, we expect MHHs to be less vulnerable than FHHs due to higher use of agricultural inputs. Here, it is clear that FHHs operate at the lower production frontier due to the endowment effects. The difference $(Y_{mn} - Y_{fn})$ is therefore regarded as the endowment effect without climate variability. $(Y - Y_{mn})$ is the average effect of climate variability on MHHs while $(Y - Y_{fn})$ is the average effect of climate variability on FHHs. The magnitude of the difference between the two then provides the gender-specific effects of climate variability ($(Y - Y_{mn})$ - $(Y - Y_{fn})$).

Now, let us consider a new adaptation intervention through the promotion of new crop varieties. Such an intervention definitely improves productivity under the same weather exposure level but also requires more investment. As a result, we observe two

[6] Note that this assumption also can be made for male-headed households depending on the context and hence our assumption does not change the implications of our conceptual framework.

effects on households' productivity: the initial endowment effect that affects adaptive capacity and the climate variability effect. The endowment effect is always positive, that is, better endowment leads to higher use of inputs and hence higher adaptive capacity. The climate variability effect is, however, negative because it erodes households' ability to adapt. The net effect on household productivity is then the sum of the two effects plus the (positive) new technology effect.[7] The figure above shows that the new intervention yields a higher outcome level for the community on average ($Y_{aa} - Y_{an}$). However, it has no effect on the income level of FHHs. The average effect is influenced by the higher gains of MHHs ($Y_{ma} - Y_{mn}$). Such an intervention is clearly successful on average but is also gender-biased[8] and leads to higher inequality between MHHs and FHHs. It is unlikely that the objective of a policy intervention is to produce gender-biased outcomes. However, due to the initial levels of inequality, an intervention may yield a higher average outcome but at the expense of higher inequality.

The other important aspect of vulnerability, which is perhaps not well documented, is vulnerability to extreme events. MHHs and FHHs may be equally sensitive to adverse events on average but differ in their vulnerability when extreme events occur. In such a case, adaptation is successful on average but becomes gender-biased when an extreme event occurs.

3. Data Sources and Methodology

3.1. Data Sources

The analysis of this paper uses the last round of Ethiopian Rural Household Survey (ERHS). This data set contains information about farm household characteristics, crop and livestock production, and food consumption, among other factors, in rural Ethiopia for both MHHs and FHHs. Further, data provided by the National Meteorology Agency (NMA) of Ethiopia is used to specify the meteorological conditions for climate variability. In particular, we used historical records over the last 60 years (1951-2010) and grouped the years into normal, dry, wet, extremely dry and extremely wet categories,

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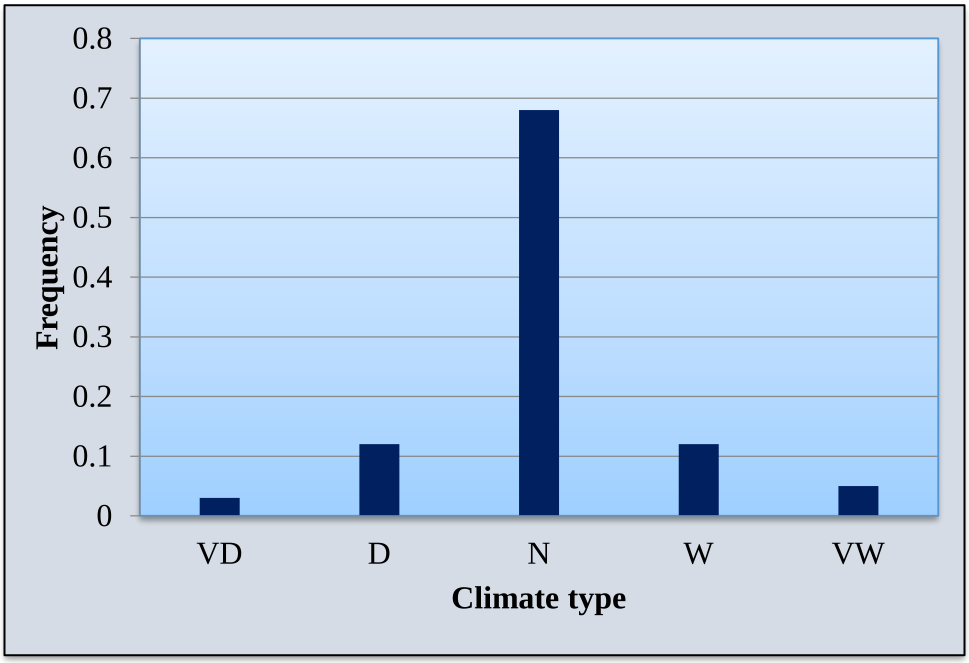
7 The technology effect is positive because the adoption decision is based on profitability.

8 Gender-biased refers to an outcome that exacerbates inequality between men and women. Note that a gender-biased intervention could improve the welfare of FHHs but at the same time result in deterioration of the welfare of MHHs.

using the standardized annual rainfall anomaly index against the 1971-2000 period.[9] The years were grouped into five categories using the Standardized Anomaly Index (SAI) and the distribution of each category is presented in the figure below.

Figure 3. Observations and Frequencies of Current Climate Variability



Selling and buying prices on output and input markets were also extracted for each Peasant Association (PA)[10] from the ERHS and FAO. In the price data set, we found considerable variation of prices across PAs and hence decided to use PA-level prices instead of regional or country average prices. As a result, farm households receive different prices for the same product depending on their geographical location. In general, data quality is sufficient for use in bio-economic modeling but crop-specific labor and fertilizer production functions cannot be estimated from this data source. We therefore used IFPRI's Nile Basin survey (Deressa et al. 2009) as a complementary data source for the estimation of these parameters. Crop data from the Ethiopian Central Statistical Agency (CSA), including yield damage assessments, were used to compute crop yields for very dry, dry, normal, wet and very wet years for each site of the ERHS.

[9] Normal (N): -0.5 < SAI < 0.5; Very Dry (VD): SAI <= -1.0; Dry (D): -1.0 < SAI < -0.5; Wet (W): 1.0< SAI < 0.5; Very Wet (VW): SAI >= 1.0.

[10] A PA is the lowest administrative unit in Ethiopia.

3.2. Methodology

We employ the agent-based modeling framework MPMAS, which allows us to simulate farm level decision-making in agricultural systems based on whole-farm mathematical programming (Schreinemachers and Berger 2011; Schreinemachers et al. 2007; Wossen et al. 2014; Wossen and Berger 2015). In our MPMAS model, each model agent represents a farm household from the survey (i.e., there is a one-to-one correspondence of agents to their real-world analogues). MPMAS captures the characteristics of each agent household, its demographic composition, land rights, ownership of durable assets and locations within agro-ecological zones and administrative units based on ERHS data set. Further, MPMAS captures differences across different households (e.g., MHHs versus FHHs) in terms of resource and wealth dynamics, adaptive capacity, production and consumption preference, knowledge and learning ability (Wossen and Berger 2015; Troost and Berger 2014; Berger and Troost 2013; Wossen et al. 2014; Schreinemachers and Berger 2011). Because MPMAS includes every farm household interviewed in the ERHS, the agent population is representative of rural Ethiopia to the extent that the ERHS sample is representative. In the model, households maximize the expected utility (U), which has to be maximized subject to a set of constraints. The general optimization problem can be presented in a generic form as follows:[11]

$$
\left\{
\begin{array}{c}
\max U(Z) = \sum_{j=1}^{n} c_j x_j \\
St. \\
\sum_{i=1}^{n} a_i x_i \ \leq b_i \\
\sum_{i=1}^{n} w_i x_i \ = 0 \\
x_j \ \leq u_j \\
x_k \ \in Z \\
x_j \ \geq 0 \\
a, b, c, w, x \ \in R
\end{array}
\right.
$$

[11] Note that our agent-based model has 8175 activities, 769 constraints and 133 integers.

where $U(Z)$ represents the utility that a given agent derives by choosing the optimal combination of crop, livestock and non-farm activities subject to production and consumption preferences, as well as resource endowment constraints. In the above equation, x_i represents the decision variables (such as crop, livestock and non-farm activities), which can take only non-negative values; c_i is a vector of coefficients of the objective function; a & w are specific constraint coefficients; and b_i captures the resources required to produce one unit of activity x_j. These include resources such as labor, credit, financial capital, land, water etc. The input requirement a_{ij} of a particular activity x_j can be presented at specific time interval (monthly, yearly, quarterly, or seasonally). For instance, labor requirements are disaggregated on a monthly basis to capture the different growing stages (land preparation, planting, weeding, and harvesting). Some activities in the model are subject to upper bounds ($x_j \leq u_j$). For example, households are only allowed to take the maximum allowable credit. As mentioned above, the solution to the above maximization problem contains values for x_i, for which $U(Z)$ takes the highest value that can be achieved without violation of specified constraints.

The above maximization problem in MPMAS is implemented in three stages. These include investment, production, and consumption decision stages; see Table 1. Such segmentation of decision-making is required to reflect the resource allocation and timing of activities (e.g., liquid assets that a farmer uses for a long-term investment at the start of a cropping season cannot be used in production activities throughout the season). The steps are implemented by recursive solutions of agent mixed integer linear programming (MILP) problems: each decision step involves optimizing a particular MILP and transferring certain parts of the solution vector to the MILP of the next step. Each agent MILP is specified such that, when taking an investment decision, an agent already plans for production and consumption, and, when taking a production decision, an agent plans for consumption. All investment and production decisions are made based on actual resource supply and expected yields and prices. Because production and investments decisions are made based on expected yields and prices, climate and price variability can reduce income due to yield and price prediction errors.

Table 1. Flow Chart of Household Decision Making in MPMAS

Stage	Investment decision	Production decision	Consumption decision
Timing	Start of the period	Start of the period	End of the period
Yields	Expected	Expected	Actual
Prices	Expected	Expected	Actual
Resource supply	Expected	Expected	Actual

We used the Decision Support System for Agrotechnology Transfer (DSSAT) to estimate the impact of climate variability on crop yields based on weather realizations, as shown in Figure 3 (see Jones et al. 2003). These yields are then translated into consumption vulnerability in MPMAS using a parameterized demand system in a three-stage budgeting process (Wossen and Berger 2015; Wossen et al. 2014; Schreinemachers and Berger 2011). The budgeting process allocates income into savings and expenditures in the first stage, expenditure into food and non-food expenditures in the second stage, and finally food expenditure into specific food items, using a parameterized demands system called Almost Ideal Demand System (AIDS). The first stage in the budgeting process allocates income into savings and expenditures using the following simple relationship between total income (*Y)*, savings (*S)* and total expenditure (*TE).*

$$Y = S + TE \quad (1).$$

For an individual household, savings are specified as a function of income and other household specific characteristics using the following quadratic specification:

$$S = \alpha_0 + \beta_1 Y + \beta_2 Y^2 + \beta_3 x^{hc} + \sum_{n=1}^{n} \beta_n D + \mu_i \quad (2).$$

where x^{hc} includes a vector of household characteristics such as household size and D is a vector of regional dummies. The next stage uses the following budget share equation to allocate income (after saving) into food and non-food expenditure:

$$\omega_i = \alpha_0 + \beta_1 \ln(PCE) + \beta_2 x^{hc} + \sum_{n=1}^{n} \beta_n D + \mu_i \quad (3).$$

where ω_i is the share of food expenditure[12] from the total expenditure and PCE is per capita expenditure. In the final stage of the budgeting process, households allocate their food expenditures to specific food items. At this stage, the food preference of farm households is estimated using the Linear Approximation of the Almost Ideal Demand System (LA-AIDS), which is specified as a function of own price, the price of other goods in the demand system and the real total expenditure on the group of food items, as follows:

$$F_i = \alpha_i + \sum_{j=1}^{j} \gamma_{ij}\, lnp_j + \delta_i \left(\frac{x}{\sum_{n=1}^{n} w_n lnp_n} \right) + \varphi_i x^{hc} + \sum_{n=1}^{n} \beta_n D + \mu_i \qquad (4).$$

where F_i refers to the budget share of food category i, p is a vector of prices, and x refers to the total per capita food expenditure. In MPMAS, the complete household demand system was implemented through piece-wise linear segmentation of the underlying functions according to the size of the expenditure budget. The final income allocation is agent-specific and is defined by the amount of current income and household size and composition of a particular agent. In most cases, households satisfy food requirements through own production and income generating activities. When food production is not enough to satisfy the minimum requirements, households will use other sources of income, such as savings and livestock assets.

Given the above parameterization of production and consumption processes in our model, the relevant question will then be the estimation of welfare outcomes under climate and price variability. Given our objective of examining the vulnerability of households differentiated by headship (i.e., what is the effect of climate variability on household welfare and what would have happened to their welfare without climate variability), a counterfactual analysis would be the obvious choice. A similar counterfactual analysis can also be applied for adaptation to climate variability (what would have happened to the welfare of adopters without adaptation and what actually happened with adaptation). However, constructing a counterfactual for no climate variability is not a trivial matter because the scale of variability differs over time and

[12] Household food consumption is comprised of monetary expenditures on food, quantity of consumption from own harvest, and gifts. The quantity of own consumption was converted into imputed values using PA-level price information for food items.

hence induces behavioral change.[13] The problem in the experimental design is therefore to find a control group which was not exposed to climate variability. In reality, this is impossible as there is no possibility of living in a world without climate variability. We address this problem through the use of a novel simulation approach. In particular, we construct a hypothetical baseline situation without any climate variability based on long-term expected average climate variables. For capturing the effect of climate variability, we then exposed households to random variability based on observed year to year variation of weather as obtained from NMA (i.e., for each simulation run, a sequence of specific years was randomly drawn from the climate database, and effects were simulated using the agent-based decision model). As such, this experiment answers the question of what happens in a world of *increased* climate variability without policy intervention. Running the simulation with climate variability but without any form of policy intervention enables us to examine the effect of climate variability on MHHs and FHHs.

Note that the focus of this paper is to examine the impact of current climate variability differentiated by gender. As such, the no-variability scenario is not a forecast, but instead provides a counterfactual – a reasonable trajectory of income in the absence of climate variability. We choose the baseline as a situation without any climate variability because a lack of an appropriate comparison unit may pose challenges for impact estimation. As a baseline, one can, for example, use current levels of variability as a benchmark. However, without establishing how household income would have evolved without any climate variability, it is impossible to estimate the impact of climate variability on household income. As such, it will not be possible to measure the impact of climate variability by simply assuming an increased percentage relative to current variability; this is because, due to behavioral responses, effects are not additive.

As mentioned in the introduction, one possible intervention in response to climate variability is the introduction of new technologies, which increase agricultural productivity under climate variability. The innovation considered in this study is the promotion of new and improved maize and wheat varieties. In our approach, agents consider adoption of novel adaptation practices only after gaining knowledge and being persuaded by their peer groups (Maertens 2012; Wossen et al. 2013). In order to capture the effect of peer-to-peer communication on an individual's decision to adopt adaptation

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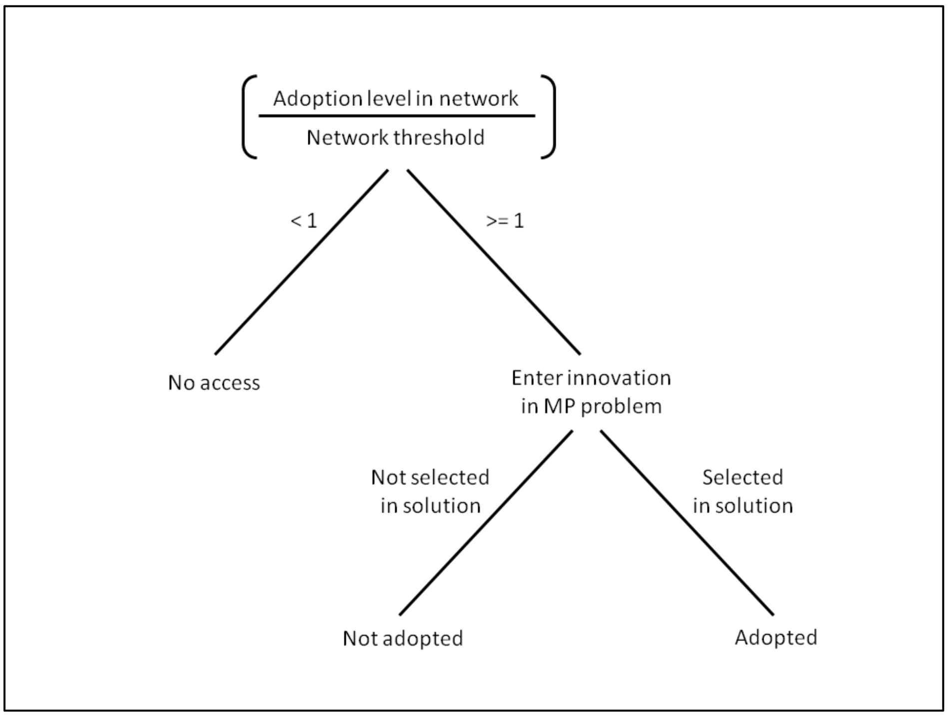
[13] Constructing a counterfactual for climate variability through experimental methods is unfortunately impossible.

practices, we implemented a network-threshold model of innovation communication in MPMAS (Berger 2001; Rogers 1995). The actual adoption process of adaptation strategies is presented in Figure 4. First, the household assesses whether the adoption level (i.e., exposure) has reached its network threshold. If reached, the second step allows the agent to include the innovation in the decision-making process (through the MILP tableau), allowing an agent to select the innovation if she expects it to be profitable on her specific farm (Berger 2001). Adoption is subject to various constraints, such as availability of labor, land, cash, and other farm assets. Also, the profitability of the innovation is evaluated against that of the cropping options already existing before the farmer had access to the new innovation.

Figure 4. Adoption Process as Implemented in MPMAS



In order to assign network thresholds to households in MPMAS, we use an econometric procedure that reflects the adoption decision-making process. The procedure corresponds to the knowledge and persuasion parts of the adoption process, in which farm households need to reach their social network thresholds before actually considering possible adoption of an innovation. The first key indicator of innovativeness is the time lag between the moment of introduction (technology adopted for the first time) and the individual adoption decision. The shorter the time lag, the higher the innovativeness.[14] However, this ranking based on time lag is incomplete, as many households are associated with identical time lags or unknown time lags. These households were consequently assigned the same rank. We therefore complement the time lag information by the predicted adoption probabilities from a binary adoption model. In particular, we use predicted probabilities of a probit model to assign innovativeness groups conditional on the characteristics of households (e.g., for a household to be in an innovativeness group, it should have a certain amount of land, education level, liquidity, etc., as obtained from the probit model). This procedure leads to an endogenous threshold model of technology diffusion, because innovativeness levels can change over time. Moreover, this approach captures observed differences in socio-economic characteristics and innovativeness levels of FHHs and MHHs. Finally, we constructed an ideal technical change scenario where all households were given full access to new adaptation practices (new and improved maize and wheat varieties) without incurring any information costs. The result was then compared to the scenario of the network threshold approach to examine the role of an efficient information delivery system.

3.3. Observed Gender-Specific Difference in Initial Endowments

In order to assess the endowment effect from our data set, we compare MHHs and FHHs in terms of socio-economic and demographic variables, using ERHS data. According to ERHS data, only 30% of the sample households are FHHs. We hypothesize that differences in endowments in terms of economic and social characteristics can lead to different levels of vulnerability. The descriptive statistics in Table 2 show that FHHs have significantly less assets compared to MHHs. For instance, MHHs own an average of 1.28 livestock, as measured by tropical livestock units (TLU), higher than FHHs. The difference is statistically significant at the 1% significance level. Similarly, MHHs are more educated than FHHs. This difference is particularly interesting since education is an important factor for decision making and for the adoption of adaptation mechanisms under climate variability.

[14] However, a shorter time lag may not necessarily imply higher innovativeness levels, because differences in economic conditions, farm size and asset endowment may be the major reasons for differences in time lag. Identifying the determinants of time lag is therefore a key step in order to use it as indicator of innovativeness levels. To this end, we analyzed the determinants of time lag using a regression model.

In addition, we also found significant differences between MHHs and FHHs in terms of access to safety nets and extension services. According to our data, about 15% of MHHs have access to a production safety net, compared to 26% of FHHs. The difference in safety net access is also significant at the 1% level. As noted above, this is additional evidence that FHHs are poorer than MHHs, in that safety net eligibility is based on poverty.

Table 2. Comparison of Household Characteristics, by Gender of Household Head

Variable	MHHs	FHHs	Difference
Demographic characteristics			
Household size (Family size in numbers)	6.5	4.5	1.95***
Age (Age of the household head in years)	54.7	55.6	-0.96
Education (1= household head is literate)	0.65	0.25	0.39***
Assets and resource constraints			
TLU (Livestock herd size in tropical livestock units)	3.35	2.07	1.28***
Soil fertility (the level of soil fertility[15] 1=Lem, 2=Lem-Tef, 3=Tef)	1.55	1.68	-0.118***
Land tenure[16] (1= has tenure security)	0.85	0.84	0.018
Access variables			
Access to credit (1= has access to credit)	0.527	0.523	0.037
Access to safety nets	0.15	0.26	-0.105***
Access to extension	0.53	0.38	0.147***
Other variables			
Fertilizer use	0.698	0.565	0.133***
Farm land area	0.41	0.263	0.141***
N	1069	459	

MHHs have better access to extension services compared to FHHs, which is particularly important because extension is an important source of information for the provision of climate information and for acquiring new practices and technologies. We also found that MHHs apply more fertilizer and have larger farm size than FHHs. In terms of credit access, however, we do not find any significant differences between MHHs and FHHs.

[15] Lem, Lem-Tef, and Tef refers to fertile, moderate and infertile soil quality, respectively

[16] Land tenure security is attained when the land is officially registered and the household has the right to transfer the land.

4. Simulation Results

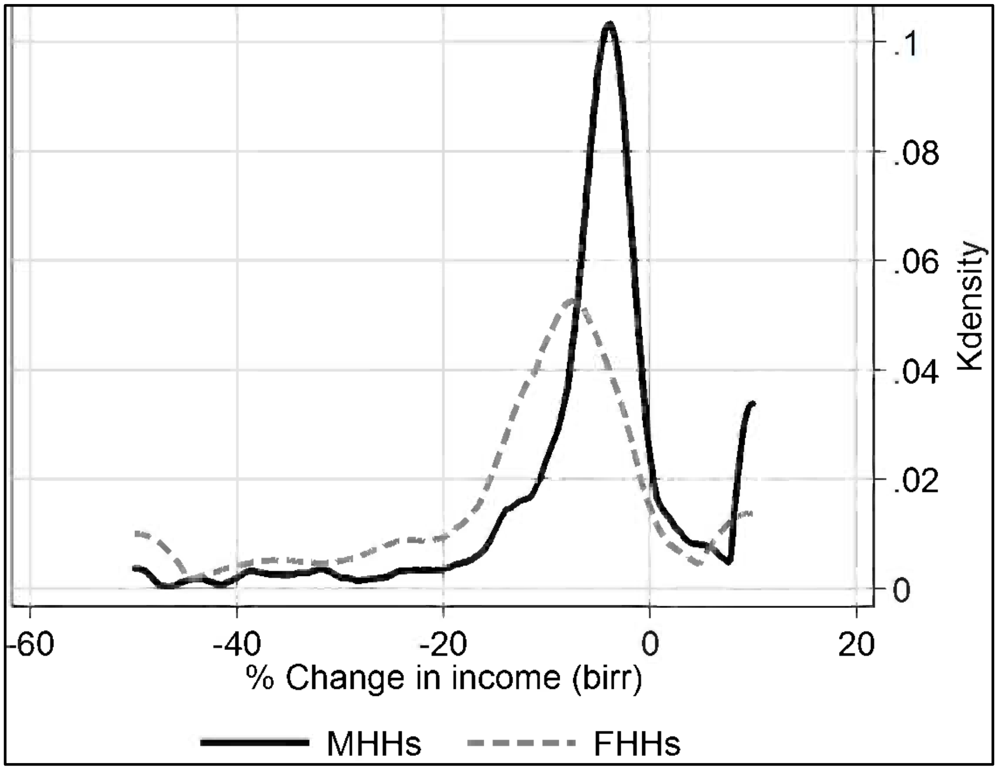
In this section, we present the results of our simulation experiment in which we exposed both MHHs and FHHs to similar levels of climate variability. As a reference, we constructed a baseline using constant climate, along with current levels of household characteristics and assets. For measuring vulnerability, we again used the current levels of household characteristics and assets but with variable climate. Because we only altered the level of climate variability, the difference between the two designs will be a result of climate variability. In the previous section, we showed that FHHs own fewer assets and have less access to other services, including social capital. In this section, through the use of our simulation experiment, we intend to show whether such differences are translated into vulnerabilities to climate variability. For simplicity, we divided this section into three main sub-sections. The first sub-section presents the gender-specific effects of climate variability. The second sub-section then presents the heterogeneous effects of climate variability. Finally, sub-section three addresses the role of adaptation strategies.

4.1. Gender-Specific Effects of Climate Variability

In this section, we present gender-specfic impacts of climate variability, focusing on MHHs and FHHs.[17] Our result shows that both MHHs and FHHs are vulnerable to the impacts of climate variability. However, the magnitude of the effect differs. In particular, our result clearly underscores that FHHs are more vulnerable to the impacts of climate variability compared to MHHs, mostly due to the endowment effect. On average, household income in FHHs declined by 12.4% due to climate variability, while income declined by 5.7% in MHHs. Given that we exposed both MHHs and FHHs to the same level of climate shock, the effect is attributed to differences in endowments and adaptive capacity.

[17] Note that this paper does not consider female members of MHHs.

Figure 5. Gender-Specific Effects of Climate Variability

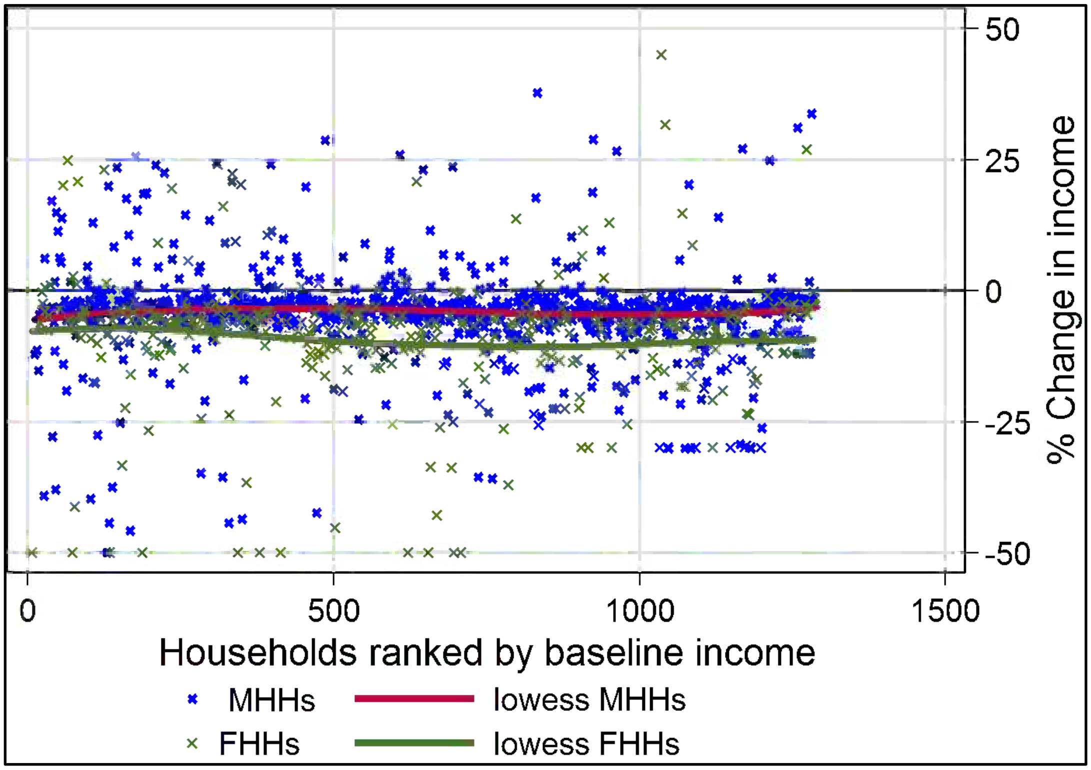


Next, we examined whether climate variability has an effect on the income distribution of households. As shown in Table 4, climate variability increases overall income inequality, as the Gini coefficient has increased from 0.47 to 0.5 due to climate variability. Because the impact of climate variability is larger among FHHs, the change in income inequality is triggered by FHHs becoming poorer than MHHs as a result of climate variability.

4.2. Heterogeneity Effects

To further underline the magnitude of the effects, we analyzed the heterogeneous effect of climate variability by considering individual MHHs and FHHs. The result is presented in Figure 6. A dot in the scatter plot represents the change of a MHH's or FHH's income under climate variability compared to the income level of the same household under the baseline scenario (without any variability).

Figure 6. Heterogeneity Effects of Climate Variability



The result shows that all households are vulnerable to the impacts of climate variability. However, as shown in the lowess smoother, the magnitude of the effect is stronger on FHHs compared to MHHs. In addition, the effect of variability is not distributed uniformly across the agent population. To underscore this observed heterogeneity in vulnerability, we examined the different impact pathways of climate variability. We found that FHHs, more so than MHHs, substantially reduce the use of fertilizer and improved seed as a result of climate variability. This should not, however, be interpreted as a behavioral response only attributed to FHHs, as it merely shows vulnerability as a result of lack of adaptive capacity (endowment effects). In particular, we found that FHHs reduce the use of fertilizer by 14.89% while MHHs reduce fertilizer use by 9.2%.

4.3. Role of Adaptation Strategies

In the previous section, we showed that the impact of climate variability is largely negative but also heterogeneous. Here, we discuss to what extent adaptation strategies designed at improving the livelihood of farmers are effective. We also investigate the issue of gender-biased adaptation (if there is any) by examining the gender-specific impacts of adaptation options. Table 5 presents the impact of adaptation strategies on household income compared to the situation of no adaptation under climate variability. On average, all the adaptation strategies considered in the simulation are effective in reducing the impacts of climate variability. Policy intervention through the promotion of short-term production credit increases income of MHHs and FHHs by 1.44% and 2% respectively. Note that in our model we implemented a strict repayment rule. As such, the above-reported impacts were realized after full repayment of credit. However, the impact of credit intervention was not enough to lift farmers to their initial condition (the condition before climate variability) because the negative impact of climate variability is much larger than the positive impact of credit. Similarly, a 25% fertilizer subsidy has a higher impact than credit but still falls short in compensating the adverse impact of climate variability. The third adaptation strategy considered in the simulation experiment is relaxing information constraints for adoption of improved wheat and maize varieties. In simulating this effect, we relaxed the information constraints that farmers face in accessing information about new technologies (here, we assume ideal technical change in which both FHHs and MHHs access adaptation practices equally and without delays because of imperfect information). As shown in Table 5, relaxing information constraints improves income compared to the situation of no adaptation. Moreover, the benefits are slightly higher for FHHs.

Table 3. Effect of Adaptation Strategies

	FHHs		MHHs	
	Median	Mean	Median	Mean
Climate variability effects (%)	-9.1	-12.4	-4.4	-5.7
Effect of adaptation strategies				
Access to credit (%)	0.51	2	0.31	1.44
Fertilizer subsidy (%)	1.7	3.1	1.5	2.9
Access to information (%)	0.58	3.6	0.29	3.5
All policy packages (%)	3.5	7.4	2.8	7.1

The final adaptation strategy, referred as "*All policy packages,*" is a combination of credit access, a 25% fertilizer subsidy and access to improved wheat and maize varieties. Because adoption of new maize and crop varieties is rather expensive, FHHs may not adopt because of the endowment effect. As a result, the difference in the effectiveness of the policy intervention captures both the endowment and the technology-specific effect. Because our objective is mainly to examine the gender dimensions of adaptation (the technology effect), we designed a strategy to offset the gender-specific endowment effect by granting all households credit access irrespective of gender.[18] As such, the values reported in the row "*All policy packages*" show the maximum possible effect of policy intervention including adoption of improved wheat and maize varieties. The results show that adaptation through a combination of these policy actions offsets the adverse effect of climate variability for MHHs. Impacts on FHHs are also high compared to other adaptation options; the income level of FHHs increased by 7.4%. However, the median effects of all the adaptation strategies considered in this paper are much lower than the mean effects, suggesting heterogeneity in the effects of adaptation options.

5. Conclusion

In this paper, we addressed the question of whether climate variability affects MHHs and FHHs differently and whether adaptation to climate variability exacerbates income inequality and results in gender-biased outcomes. To address the gender-specific effects, we developed a conceptual framework for evaluating climate variability effects and the effectiveness of adaptation strategies. In particular, we stressed that successful policy interventions aimed at increasing adaptive capacity should improve the livelihood of the most disadvantaged and poor groups (irrespective of households being MHHs or FHHs). The results of our descriptive analysis reveal that FHHs own significantly fewer assets, particularly land and livestock. In addition, FHHs were less educated and have less access to extension services than do MHHs. These existing differences in endowments make FHHs more vulnerable to the impacts of climate variability.

The main findings of this paper can be summarized as follows. First, both MHHs and FHHs are vulnerable to climate variability. However, the magnitude of the effect differs. In particular, FHHs are more vulnerable to the impacts of climate variability compared to MHHs, mostly due to differences in initial endowments. Second, climate variability not only affects income adversely but also increases income inequality. Third, the effect of climate variability is not distributed uniformly among MHHs and FHHs and between MHHs and FHHs. Fourth, policy interventions through the promotion of new

[18] Note that, in principle, credit access will not remove the full effects of the endowment effect. However, because we considered a technology in which the endowment effects operate through the liquidity constraints, controlling for credit will provide a robust comparison unit.

crop varieties, which are adapted to the local climate conditions, yield gender-unbiased outcomes and were largely successful in offsetting the impacts of climate variability. Overall, our analysis suggests that climate variability is a major threat but its impact can be reduced significantly if carefully designed adaptation options are implemented.

Finally, this paper examined gender-specific impacts of climate variability focusing on MHHs and FHHs. However, the impact of climate variability on women can be much larger since the majority of adult women live in male-headed households, and intra-household allocation decisions may mean that women in male-headed households are also hurt more than men by increased climate variability. As such, considering intra-household decision making while examining the impact of climate variability would be an important future research area. In addition, due to a lack of future climate projections at the level of disaggregation required in this paper, we did not consider future climate variability in our simulation experiment. Given the importance of future climate variability, it will be interesting to examine the gender-specific effects of future climate variability.

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