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To cite this article: Essossinam Ali, Nadège Essossolim Awade & Tahirou Abdoulaye | (2020) Gender and impact of climate change adaptation on soybean farmers' revenue in rural Togo, West Africa, Cogent Food & Agriculture, 6:1, 1743625

To link to this article: <https://doi.org/10.1080/23311932.2020.1743625>



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Published online: 01 Apr 2020.



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Received: 16 February 2020
Accepted: 06 March 2020

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Reviewing editor:
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FOOD SCIENCE & TECHNOLOGY | RESEARCH ARTICLE

Gender and impact of climate change adaptation on soybean farmers' revenue in rural Togo, West Africa

Essossinam Ali^{1*}, Nadège Essossolim Awade^{1,2} and Tahirou Abdoulaye³

Abstract: This study assesses the impact of climate change (CC) adaptation on farm-level revenue among 500 soybean farmers randomly selected in three districts in Togo using endogenous switching regression method. The survey results indicate that only 40.37% of the women have adapted to CC against 59.62% of the men. Moreover, being member of farmer-based organization (FBO), access to credit and extension services, agricultural training of women are the main factors that increase the likelihood of adaptation. The gender-differentiated impact shows that women would earn more than men from adaptation, while losing compared to men if they do not take any adaptation actions. The loss from non-adapting to CC will increase by 0.268% of the soybean revenue. However, the heterogeneity effects suggest further assessment on the adopted technology in soybean farming in the study areas. Adaptation policy that seeks to ensure food security and enhance farmers' welfare in subsistence agriculture should consider the gender dimension, while reviewing the financial policy in terms of affordability, access of extension



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PUBLIC INTEREST STATEMENT

Climate change (CC) is a phenomenon that mostly generates negative externalities in food production systems in developing countries including Togo. Soybean as part of staple food crops and source of revenue of many households, especially women, is not exempted. This is evident in Togo where temperature levels had annually increased about 1.1°C since 1960, while precipitation has been decreasing at the rate of 2.3 mm per month. The implementation of CC adaptation policy could be difficult if all stakeholders are not involved equitably in the process. The gender bias in CC adaptation process could affect household food production, consumption. Identifying the drivers of the decision of adaptation to CC and assessing the impact of adaptation on soybean farmers' revenue by focusing on the gender aspect would guide policymakers for better implementation of policy that seeks to mainstream gender in CC adaptation policy in subsistence agriculture.

services and supporting FBO will increase technologies adoption and farming revenue.

Subjects: Agricultural Economics; Climate Change; Rural Development; Adaptation Policy

Keywords: adaptation; climate change; gender; soybean; endogenous switching regression

1. Introduction

Climate change (CC) is a phenomenon that generate not only the positive externalities in food production systems (Deschênes & Greenstone, 2007; Mendelsohn et al., 1994) but also a negative effects that could weight heavily on population that rely on activities directly related to weather conditions (Adger et al., 2005). According to the Intergovernmental Panel on Climate Change (IPCC, 2014), global warming has led to the change in rainfall patterns, the increase of extreme weather events, such as floods and drought. All these events contribute to the deterioration of human health as well as increasing food insecurity status. Developing countries seem to be the most vulnerable to CC since agriculture is the primary source of food supply (Pham et al., 2016; Sakamoto et al., 2020; Schlosberg et al., 2017). Food and Agriculture Organization [FAO] (2015) has indicated that one billion of people continue to suffer from food insecurity and these nutritional deficiencies are correlated to the new climate trends. In sub-Saharan Africa, the status of food insecurity is projected to increase by 15% to 40% as a result of CC (Di Falco, 2014). The effect of CC is fast spreading and its impacts on agricultural development and poverty are well recognized (Arora-Jonsson, 2011; Parry et al., 2007; Tambo & Abdoulaye, 2012). For instance, Parry et al. (2007) have indicated that within other regions in the world, the Sub-Saharan region could be the most affected area as a result of CC. Also, 46.8% of the population in Sub-Saharan Africa is still living in extreme poverty with 70% of the women living under the poverty line (Parry et al., 2007). Togo, as part of sub-Saharan Africa, is not exempted from the phenomenon. For instance, Ali (2018) found that cereals production in Togo is negatively affected by CC.

Indeed, agriculture is the major component of the Togolese economy. It involves at least 70% of the active population with 80% of them living in rural areas (AfDB, 2016). Togolese agricultural sector contributes about 42% of the gross domestic product (GDP) and 20% of the exports (FAO, 2015). However, the temperature levels in Togo have annually increased about 1.1°C, while precipitation has been decreasing at the rate of 2.3 mm per month (McSweeney et al., 2010). The wet seasons are perceived to become shorter and shorter, while food insecurity trend is still upward (Grote, 2018). Soybean as part of staple food crops and source of revenue of many households, especially women, is not exempted to the CC phenomenon (Carbone et al., 2003; Peri, 2017; Southworth et al., 2002).

Soybean has great potentiality in the improvement of soil fertility and contributes in the control of parasitic weed (Pagano & Miransari, 2016; Sinclair et al., 2014; Van Vugt et al., 2018). To overcome food security in the context of CC, soybean is highly recommended when compared to other grain legumes (Franke et al., 2018; Singh & Singh, 1992). Mixed conclusions about CC impacts on soybean production are found in the literature (Carbone et al., 2003; Peri, 2017; Ramteke et al., 2015; Rose et al., 2016; Southworth et al., 2002). For instance, Peri (2017) found that climatic shocks would increase soybean global prices volatility. It is also reported that high temperature is one of the most abiotic constraints leading to the reduction of soybean production and seeds' quality (Hartman et al., 2011; Ramteke et al., 2015). However, positive impact of CC on soybean production was found in the Midwestern of the US. For example, Southworth et al. (2002), using simulated data found that CC would increase soybean production by 40% in Midwestern region of the United States, but decrease by 69% in Southeastern in the study by Carbone et al. (2003).

Khojely et al. (2018) have reported that the soybean yield in Sub-Saharan Africa has been stagnant during the last decade (1.1 tons per hectare) and lower than the worldwide average in

2016 (2.8 tons per hectare) according to FAOSTAT (2018). This might be imputed to many factors such as climate change that is expected to be more accentuated in Sub-Saharan Africa (IPCC, 2014; Parry et al., 2007; Rosenzweig & Parry, 1994). Therefore, there is a need to adapt to new climate realities and scaling up soybean productivity (Abdoulaye et al., 2018). Climate risk management theories seek to help population to influence significantly the current environment and reduce future harmful effect of CC through organization which can increase their adaptive capacities. Adaptation is one of the policy options for reducing the negative effect of CC (Di Falco, 2014; Kurukulasuriya & Mendelsohn, 2008; Nordhaus & Yang, 1996; Sakamoto et al., 2020). According to Bassett and Fogelman (2013), adaptation policy can provide the political space for engagement, sharing information, knowledge and guidance and strengthening the technical and institutional capacities. Short and long-term actions are needed in vulnerable regions, with the inclusion of all stakeholders without any gender discrimination. The implementation of CC adaptation policy could be difficult if all stakeholders are not involved equitably in the process.

Finding the ways to promote soybean cultivation and reduce farmers' vulnerability needs to pay attention to women in the agriculture sector (Galiè et al., 2017). In general, women's contribution to the labour force should not be neglected particularly, it represents at least 40% of the agricultural workforce in African countries (Doss et al., 2018; Nabalamba et al., 2011; Palacios-Lopez et al., 2017). In Togo, for example, the proportion of women in the agriculture sector is about 48% of the total agricultural working force (Nabalamba et al., 2011). The gender bias in CC adaptation process could affect household food production, consumption, and redistribution since household-oriented crops and market-oriented crops are both affected by CC. Women are often seen as victims of CC and their positive roles as agents in CC adaptation are overlooked (Mersha & Van Laerhoven, 2016). Therefore, there is a need to mainstream gender in CC adaptation project, whether to be implemented at local, national or international level (Acosta et al., 2019; Alstron et al., 2014; Chandra et al., 2017; Pearse, 2017). The inclination on gender is justified by its implication in grain legume production, processing and commercialization in Sub-Saharan Africa (Dolan, 2001; De Jager et al., 2017; Snapp et al., 2019; Waldman et al., 2016) and the gender vulnerability to climate change (Arora-Jonsson, 2011; Denton, 2002). Moreover, within the grain legumes, soybean has become a major crop that fulfils food security and provides revenue for the most farmers in the tropical areas (Dolan, 2001; Njuki et al., 2011; Sinclair et al., 2014; Waldman et al., 2016), especially women along the soybean value chain in Togo as reported by FARA, ITRA, & ZEF (2015) and Institutional Monetary Fund [IMF] (2014).

This study aims to identify the drivers of the decision of adaptation to CC. Using a sound impact evaluation method, the study also assesses the impact of adaptation on soybean farmers' revenue by focusing on the gender aspect. This would guide policymakers for better implementation of policy that seeks to mainstream gender in CC adaptation policy in subsistence agriculture.

2. Materials and methods

2.1. Study area and data collection

The study was conducted in the Central Region of Togo since it remains the most producing area of soybean in Togo according to FARA, ITRA, & ZEF (2015). Its geographical area represents 23.5% of the national territory and it is one of the poorest regions in the country where the incidence of poverty is estimated at 77.7%, relatively high compared to other regions (59% of the poverty line a). The centrale region is characterized by one rainy season from April and October and one dry season lasting from November to March. The Data were randomly collected at the farm level in three districts (Tchamba, Sotouboua, and Blitta) under the supervision of the International Institute of Tropical Agriculture (IITA-Ibadan Hubs and headquarter) as part of capacity building project for graduate students. These districts were randomly chosen within the four districts of the Central Region. Structured questionnaire was used to collect data from 500 farmers using the soybean farmers' database provided by the district-level administrators and the NGO that often buy soybean grain in the region.

2.2. The determinants of the decision to adapt to climate change

Assume that the farmers have a rational behavior in their activities. If so, they allocate the available resources rationally and use the available technology efficiently depending on their expected utility. For instance, a farmer may decide to adapt to CC by using some technology or farming strategy, if and only if, his or her expected utility is greater than what he or she gains by not adopting for such technology or not applying for such farming strategy. Then, on the one hand, the expected utility of adapting and non-adapting to CCs could be stated as follows:

$$U_{1i} = \beta_1 X_i + \delta_{1i} \tag{1}$$

$$U_{0i} = \beta_0 X_i + \delta_{0i} \tag{2}$$

Equation (1) is the expected utility from adapting to CC for farmer i . Equation (2) is the expected utility with non-adapting to CC for farmer i . X is a set of socioeconomic and demographic characteristics of the respondent i . δ is a disturbance term, which is identically independently disturbed with mean zero. As previously stated, the decision-maker or respondent to adopt for adaptation strategy for CC or his or her application decision is based on the fact that the utility for adapting to CC (U_{1i}) is greater than the utility for non-adapting to CC (U_{0i}). It follows:

$$U_{1i} > U_{0i} \Leftrightarrow \beta_1 X_i + \delta_{1i} > \beta_0 X_i + \delta_{0i} \tag{3}$$

$$U_{1i} - U_{0i} > 0 \Leftrightarrow (\beta_1 - \beta_0) X_i + (\delta_{1i} - \delta_{0i}) > 0 \tag{4}$$

Indeed, the difference in the expected utility from adapting to CC is not directly observable. This is called latent variable. Let us denote Z_i^* this latent variable. If Z_i denotes the binary variable of adaptation or non-adaptation, then it follows:

$$Z_i = \begin{cases} 1 & \text{if } Z_i^* > 0 \text{ (decision of adaptation to climate change)} \\ 0 & \text{if } Z_i^* \leq 0 \text{ (decision of non - adaptation to climate change)} \end{cases} \tag{5}$$

Then, a farmer's utility function takes the form as:

$$Z_i^* = X_i \beta + \varepsilon_i \tag{6}$$

2.3. The impact evaluation of climate change adaptation on soybean farmers' revenue: endogenous switching regression methods

Endogenous switching regression method was used to assess the impact of adaptation to CC on soybean farmers' revenue in the study area. This method helps correct the selection bias that can occur during field survey (Asfaw et al., 2012; Lokshin & Sajaia, 2004). The farmers' decision of adaptation to CC is derived from the maximization of expected utility subject given the typical farmer socioeconomic characteristics. The decision of adaptation to CC could be influenced not only by the observable characteristics but also by some unobservable factors. The unobservable characteristics that could influence the adaptation decision would lead to underestimate or overestimate the impact of CC adaptation. Using the endogenous switching regression method can help to correct this selection bias.

The farmer may face two regimes (Equations (7) and (8)) due to selection bias.

$$Y_{1i} = \theta_1 X_i + \mu_{1i} \quad \text{if } Z_i = 1 \tag{7}$$

$$Y_{0i} = \theta_0 X_i + \mu_{0i} \quad \text{if } Z_i = 0 \tag{8}$$

where Y_{1i} and Y_{0i} are soybean revenues of farmer i , adopting for adaptation to CC and non-adaptation to CC, respectively. X_i is a vector of potential exogenous variable that could probably affect farmers' revenue. θ_j is a vector of parameters to be estimated. μ_{1i} and μ_{0i} are the error terms and assumed to have a normal distribution with zero mean and non-singular covariate matrix expressed as follows:

$$\text{Cov}(\mu_{1i}, \mu_{0i}, \epsilon_i) = \begin{bmatrix} \sigma_{\mu_0}^2 & \cdot & \sigma_{\mu_0\epsilon} \\ \cdot & \sigma_{\mu_1}^2 & \sigma_{\mu_1\epsilon} \\ \cdot & \cdot & \sigma_{\epsilon}^2 \end{bmatrix} \tag{9}$$

In Equation (9), σ_{ϵ}^2 represents the variance of the error term in the farmer’s decision Equation (6) and assumed to be equal to 1. $\sigma_{\mu_0}^2$ and $\sigma_{\mu_1}^2$ are the variances of the error terms in the soybean production functions (7) and (8); $\sigma_{\mu_1\epsilon}$ and $\sigma_{\mu_0\epsilon}$ represent the covariance of μ_{1i} , μ_{0i} and ϵ_i . ϵ_i is correlated with μ_{1i} and μ_{0i} meaning that the expected values of μ_{1i} and μ_{0i} conditional on the sample selection are different from zero. It follows that:

$$E[\mu_{1i}/Z_i = 1] = \sigma_{\mu_1\epsilon} \frac{\phi(\beta X_i)}{\Phi(\beta X_i)} = \sigma_{\mu_1\epsilon} \lambda_{1i} \tag{10}$$

$$E[\mu_{0i}/Z_i = 0] = -\sigma_{\mu_0\epsilon} \frac{\phi(\beta X_i)}{1 - \Phi(\beta X_i)} = \sigma_{\mu_0\epsilon} \lambda_{0i} \tag{11}$$

In Equations (10) and (11), $\phi(\cdot)$ and $\Phi(\cdot)$ are the standard normal probability density function and the standard normal cumulative density function, respectively, with:

$$\lambda_{1i} = \frac{\phi(\beta X_i)}{\Phi(\beta X_i)} \quad \text{and} \quad \lambda_{0i} = \frac{\phi(\beta X_i)}{1 - \Phi(\beta X_i)}$$

The assumption to be tested is to check whether there is any correlation between the decision to adapt to CC and the soybean revenue. The null hypothesis is that there is no sample selection bias. If $\sigma_{\mu_0\epsilon}$ and $\sigma_{\mu_1\epsilon}$ are statistically different from zero, then the null hypothesis is rejected and we use the endogenous switching regression method. Following Lokshin and Sajaia (2004), this study used a single-stage approach and not a two-stage method to estimate the endogenous switching model as some previous studies have shown. The Full Information Maximum Likelihood (FIML) estimation technique is used to estimate the model parameters (Lokshin & Sajaia, 2004). The logarithmic likelihood function using decision equations of adaptation to CC can be derived as:

$$\ln L_i = \sum_{i=1}^N Z_i \left[\ln \phi \left(\frac{\mu_{1i}}{\sigma_{\mu_1}} \right) - \ln \sigma_{\mu_1} + \ln \Phi(\gamma_{1i}) \right] + (1 - Z_i) \left[\ln \phi \left(\frac{\mu_{0i}}{\sigma_{\mu_0}} \right) - \ln \sigma_{\mu_0} + \ln(1 - \Phi(\gamma_{0i})) \right] \tag{12}$$

In Equation (12), $\gamma_{1i} = \frac{(\beta X_i + \eta_{1\epsilon} \mu_{1i})}{\sqrt{1 - \eta_{1\epsilon}^2}}$ and $\gamma_{0i} = \frac{(\beta X_i + \eta_{0\epsilon} \mu_{0i})}{\sqrt{1 - \eta_{0\epsilon}^2}}$ with the terms $\eta_{1\epsilon}$ and $\eta_{0\epsilon}$, denoting the correlation coefficient between the error terms μ_{1i} and μ_{0i} and ϵ_i

If $\eta_{1\epsilon}$ have alternate signs, it implies that the farmers’ decision of adaptation to CC based on their comparative advantage. It means that the farmers that adopt for adaptation to CC have above-average returns from adapting to CC. As for the farmers that do not adapt to CC, they have above-average for non-adapting to CC. If $\eta_{1\epsilon}$ and $\eta_{0\epsilon}$ have the same signs, this implies that whether the soybean farmers have decided to adapt to CC or not, have above-average returns and better-off if they adopt for CC adaptation. Alternatively, those who do not adopt for CC adaptation have below-average returns whether they adopt for CC adaptation or not, but they are still better-off by non-adapting to CC. The endogenous switching regression method can be used to compare the expected revenue of farmers that adapted with respect to farmers that did not adapt. Following Di Falco et al. (2011) and Asfaw et al. (2012), we can express the conditional expectation of revenue in the four cases present in this table and define as follows:

$$E[Y_{0i}/Z_i = 1] = \theta_0 X_i + \sigma_{\mu_0\epsilon} \lambda_{0i} \tag{13}$$

$$E[Y_{1i}/Z_i = 0] = \theta_1 X_i + \sigma_{\mu_1\epsilon} \lambda_{1i} \tag{14}$$

$$E[Y_{1i}/Z_i = 1] = \theta_1 X_i + \sigma_{\mu_1 \varepsilon} \lambda_{0i} \quad (15)$$

$$E[Y_{0i}/Z_i = 0] = \theta_0 X_i + \sigma_{\mu_0 \varepsilon} \lambda_{1i} \quad (16)$$

The average treatment effect (ATTE) of farmers without adaptation to CC is derived as the difference between the expected revenue for farmers that have adapted to CC conditional on having adapted to CC and the expected revenue for farmers that have not adapted to CC conditional on they have chosen not to adapt to CC. It follows:

$$ATTE = E((Y_{1i} - Y_{0i})Z_i = 1) = X_i(\theta_1 - \theta_0) + (\sigma_{\mu_1} - \sigma_{\mu_0})\psi_1 \quad (17)$$

where ψ_1 is the estimate of the covariance term between adaptation to CC and revenue and defined as the Inverse Mills Ratio that capture the selection bias. This Inverse Mills Ratio (IMR) indicates the correlation between adaptation to CC and revenue. The effect of treatment of untreated captures the expected revenue from non-adapting to CC and could be calculated as the difference between Equations (16) and (14). Moreover, the heterogeneity effect of farmers that have chosen for adaptation to CC could be calculated as the difference between Equations (13) and (16) while the base heterogeneity effect from non-adapting to CC is derived as the difference between Equations (15) and (14).

2.4. Descriptive statistics

Data were collected at farm level and covered the socioeconomic characteristics, such as age, gender, education level, off-farm activities. Also, the data cover the farmers' perception and adaptation to CC, the constraints that farmers face in CC adaptation, access to credit, soybean productivity, and market accessibility (Table 1). The average age of respondents was 37 years indicating the involvement of youth in the sector. In terms of access to credit and uptaking of off-farm activities as well as livestock farming, there is not a gender difference in the data (Table 1).

However, one would note a significant difference between men and women in terms of adaptation to CC, education, access to land and extension services, amount of credit obtained and liquid access. Most of the coefficients of the difference of variables means between men and women are positive and significant at 1% level. This indicates the gender bias in agriculture found in the literature (Doss et al., 2018; Palacios-Lopez et al., 2017; Pearse, 2017; Pham et al., 2016).

3. Results and discussion

3.1. Adaptation strategies to climate change

Diverse strategies have been adopted by soybean farmers to increase the expected yield as a result of an observed change of climate pattern (Table 2).

The results show that the use of selected soybean seeds and adjustment of sowing time are the most used adaptation measures. On average 53.60% of the respondents have decided to use the selected seeds that are high yield and drought tolerant to adapt to climate conditions, while, 58% often use to adjust plating dates. On average, 37% of the respondents have adopted for the mono-cropping system and 23.20% only have used the inter-cropping system. Soil and water conservation systems are employed by 16.80% and low level of adoption of soil fertilization system (Table 2). Due to the frequent dry spell that often occurs after planting, 40.20% of the respondents were involved in agroforestry systems, while 34.20% were interested in off-farm activities.

3.2. Gender role and decision of CC adaptation in Togo

The gender inclusion in decision-making about CC adaptation would speed the process of implementation of CC adaptation policy in the study areas. Overall, 64.40% of the respondents have taken at least an adaptation measure to respond to CC (Table 3). Moreover, the marginal rate of women that decided to adapt to CC was on average about 40.37% compared to 59.62% of the men. This indicates that men are likely to choose for adaptation to CC compared to women.

Table 1. Soybean farmers' socioeconomic characteristics

Variables	Men		Women		Diff (1) -(2)	Std. Err.
	Mean (1)	SD	Mean (2)	SD		
Age (number of years)	36.988	12.87	37.752	12.32	-0.763	1.13
Adaptation (Dummy)	0.711	0.45	0.565	0.49	0.145***	0.04
Formal education (Dummy)	0.90	0.30	0.573	0.49	0.326***	0.03
Experience (Number of years)	9.222	8.51	6.647	6.37	2.574***	0.68
Land (Number of hectares)	43.181	42.34	21.36	19.02	21.82***	3.02
Quantity of seeds used (number of kg)	1.720	1.37	0.806	6.64	0.91***	0.09
Access to Extension Services (Dummy)	0.666	0.47	0.543	0.49	0.123***	0.04
Access to credit (Dummy)	0.592	0.49	0.608	0.48	-0.01	0.04
Amount of credit (FCFA)	87,983	322,746	39,404	62,526	48,578**	21,621
Member of soybean farmer-based organization (Dummy)	0.396	0.49	0.239	0.42	0.157***	0.04
Crop rotation (Dummy)	0.481	0.50	0.308	0.46	0.172***	0.04
Off-farm activity (Dummy)	0.540	0.49	0.591	0.49	-0.050	0.04
Total livestock unit (Continuous variable)	6.514	8.82	5.952	8.34	0.562	0.77
Liquid asset (FCFA)	383,992	548,281	220,438	339,381	163,553***	41,639
Soybean farm revenue (FCFA)	168,361	243,260	71,405	152,159	96,956***	18,522

***P < 0.01; **p < 0.05; *p < 0.1.

Table 2. Adopted adaptation technologies in the study areas

Adaptation measures	Mean	SD
Use of selected seeds	0.536	0.49
Crops rotation	0.402	0.49
Mono-cropping	0.370	0.48
Inter-cropping	0.232	0.42
Soil and water conservation technics	0.168	0.37
Soil fertilization system	0.382	0.48
Adjustment of planting days	0.580	0.49
Planting trees	0.402	0.49
Off farm activities	0.342	0.47

The difference in farmers' socioeconomic characteristics would probably explain this result. The women empowerment in decision-making about CC adaptation could be determinants. Woman's voice in the decision of adaptation to CC is very important.

Table 3. Gender and climate change adaptation

Gender	Climate change adaptation		Total
	Did not adapt	Adapted	
Males	43.37%	59.63%	100%
Females	59.63%	40.37%	100%
Total	35.6%	64.40%	100%

3.3. Determinants of the decision of adaptation to CC and impact on soybean farmers' revenue in Togo

The results indicate that farm households' socioeconomic characteristics, as well as institutional factors, are determinants of CC adaptation in the study areas. The coefficient of gender is negative and significant at 10% level (Table 4). This indicates that women are less likely to adopt for adaptation to CC compared to men. This result is consistent with previous studies (Arora-Jonsson, 2011; Partey et al., 2018). For instance, Partey et al. (2018) find that men are more responsive to CC in terms of adoption and use of climate information systems in the case

Table 4. Full information maximum likelihood estimator of CC adaptation on soybean revenue

Variables	Selection equation: Adaptation (1/0)	Net revenue	
		Not adapt to CC	Adapted to CC
Asset (Log)	0.046*(0.02)		
Ownership of TV	-0.125(0.17)		
Total livestock unit	0.012(0.01)		
Age square	0.0004**(0.0002)		
Gender	-0.225*(0.13)	-0.679*** (0.23)	0.482** (0.22)
Age	-0.044** (0.01)	0.0009 (0.008)	0.010* (0.006)
Access to extension services	0.759*** (0.12)	-0.258 (0.28)	0.337* (0.18)
Access to credit	0.230* (0.12)	0.639** (0.25)	0.341** (0.17)
Cultivated soybean land (Log)	-0.095 (0.08)	0.940*** (0.18)	0.600*** (0.14)
Experience	0.031*** (0.01)	-0.011 (0.02)	-0.010 (0.01)
Formal education		0.183 (0.19)	0.237 (0.14)
Gender*LogLand		0.140 (0.22)	0.838*** (0.17)
Gender*log(amount of credit)		0.093*** (0.03)	-0.012 (0.02)
Use of pesticide		-0.163 (0.23)	-0.494*** (0.17)
Off farm activities		0.314** (0.16)	0.013 (0.11)
Quantity of seeds (Log)		0.376** (0.14)	0.360*** (0.10)
Crop rotation		0.529 (0.73)	0.368*** (0.12)
Member of farmer based organisation		0.552*** (0.20)	0.111 (0.13)
Constant	0.047 (0.48)	8.939*** (0.88)	9.454*** (0.45)
$\ln\sigma_{\mu 0} / \ln\sigma_{\mu 1}$		0.010 (0.08)	0.296*** (0.05)
Rho0/Rho1		-0.231 (0.43)	-0.916*** (0.03)
Number of obs	500	Wald chi2(14)	206.77***
Log likelihood	990.600		
Likelihood ratio test of indep. Eqns		chi2(2)	13.73***

***P < 0.01; **p < 0.05; *p < 0.1; Standard errors in parenthesis.

study of Ghana with similar economic conditions. Also, Arora-Jonsson (2011) points out that the inequality between men and women in terms of decision-making would significantly increase as a result of women's vulnerability to CC in the Southern Countries. However, the finding of gender bias in climate change adaptation is inconsistent with the study by McCright (2010) who finds that women have greater scientific knowledge on climate change compared to men in the case study of the US general public. This difference may be due to the difference in socioeconomic characteristics and gender mainstreaming in decision-making in developing countries in the one hand and developed countries in the other hand (Alene & Manyong, 2007; Mutenje et al., 2016).

The age of the farmer is negatively correlated to the decision of adaptation to CC, while age square has a positive sign. This indicates that young farmers do not use to take measures to tackle CC effects up to 37 years, beyond which they believe that adapting to CC would increase their expected utility.

Probably, the young soybean farmers are not experienced as much as the elder's soybean farmers. The evidence is that the coefficient of experience in the selection equation is positive and significant at 1% level. This implies that the increase of farming experience would motivate farmers in adopting for adaptation to CC. An experienced farmer would have an advantage of the best practices in mitigation of CC-induced effects. The farmers' asset is important in the decision-making of CC mitigation and adaptation. Moreover, the coefficient of credit is positive and statistically significant at 1% level. This implies that having access to credit would increase the chance of adoption of at least an adaptation strategy to CC in the study areas. This result is in line with those from Ali and Awade (2019) and Deressa et al. (2009), who highlight the role of credit in soybean farmers' welfare and its importance in the promotion of CC adaptation in subsistence agriculture, respectively. The extension service is positive and statistically significant at 1%. This implies that the regular contact with extension service would enhance farmers' adaptive capacities through the dissemination of knowledge on the available technologies.

The Likelihood Ratio (LR) test for joint independence of the three equations from the Full Information Maximum Likelihood estimation technique of the endogenous switching regression model is statistically significant (Table 4). This implies that these three models are jointly dependent and should not be estimated separately. As indicated previously, crossing sex with other explanatory variable would help capture the gender-differentiated impact. Once again, the farmers' socioeconomic characteristics and institutional and CC adaptation decision factors have played an important role in farmers' revenue in the study areas.

The gender is negative and statistically significant at 1% level for the farmers that did not take any adaptation measures, while it is positive and statistically significant at 5% for the farmers that have chosen for adaptation. This implies that women that have adapted to CC have higher return from soybean farming, while the net revenue of those who did not adapt to CC has is worse compared to other farmers. This might be explained by women's access to resources such as education that would enhance their adaptive capacities, the level of asset land and financial resources (Awotide et al., 2015; Doss et al., 2018; Rodriguez et al., 2007). As has been emphasized by Doss et al. (2018), women are constrained to land distribution. In most communities, women do not have the right on land ownership. This status coupled with non-adaptation would probably affect negatively farm-level revenue. One would recommend the gender mainstreaming in CC adaptation policy and women's empowerment through technologies adoption as found by Galiè et al. (2017). The results show that the women's access to land would increase soybean revenue of farmers that adapt to CC. This result is consistent with those found by Doss et al. (2018). Also, Awotide et al. (2015) found that farmers with larger assets tend to use inputs such as drought tolerant and high-yielding seeds and increase productivity. Whether a farmer has responded to CC by implementing an adaption measure or not, increasing the cultivated land or having access to credit wherever it comes from would increase significantly soybean farmers' revenue. Similarly, Rodriguez et al. (2007) highlight the role of credit in agricultural development and significant

impact on the farm income. Having access to financial resources would strengthen farmers in adopting new technologies and use of adaptation strategies, such as soil and water conservation, irrigation system, soil fertilization system, changes in crop varieties, which help to improve productivity and farmers' welfare.

The results show that the adopted adaptation practice might also affect soybean farmers' revenue in the study areas. For instance, using crop rotation techniques would increase the net soybean revenue of farmers that adapt to CC, while the use of pesticide would reduce it. Crop rotation adoption as farm level technology to deal with climatic change would ensure food security and improve household welfare as found by Asfaw et al. (2012). However, the finding that use of pesticides in soybean farming would negatively affect soybean yield and revenue is consistent with the results from Lee and Choe (2019) who find that organic farming would be more environmentally friendly and productive. Even though farmers' would be willing to adopt for the pesticides use, they are not aware about the induced hazards leading to the negative impact on soybean production induced by overdose (Bondori et al., 2018). Nevertheless, soybean yield could be increased under certain threshold of the amount of pesticide use (Henry et al., 2011). Access to extension services would increase adoption of farming technology and increase farmers' revenue. This is consistent with Deressa et al. (2009) and Asfaw et al. (2012). Extension services would enhance farmers' abilities in the use of pesticides and ensure food security.

However, off-farm activity and being a member of a farmer-based organization would increase soybean revenue of farmers that did not adapt to CC. Probably, the technique of farmer by farmer learning through the organization would be an advantage. Also, being a member of the soybean farmers' organization would increase the accessibility of financial resources, such as credit. In rural areas like that in Togo, the access to formal financial resources is sometimes constrained by the fact that the financial institutions require a legal document when applying for. The lack of collateral is also another constraint that limits farmers' access to loans in rural areas. In that case, the farmer-based organization would be a form of collateral and having access to financial services would increase the chance for adaptation. Being a member of the farmer-based organization would increase the access of inputs such as improved and high yield soybean seed, as well as the access to extension services. This result is similar to those from (Bandiera & Rasul, 2006), who find that belonging to a farmer-based organization tends to increase the probability of adopting the technologies. Social networks facilitate the flow of information and then increase the adoption of new technologies in agriculture (Bandiera & Rasul, 2006).

The correlation coefficient for farmers that have decided to adapt and those who did not, have alternative signs. The coefficient of correlation for the first regime (ρ_1) has a negative sign, but not statistically significant. However, the coefficient of correlation the second regime (ρ_2) has a negative sign and statistically significant at 1% level (Table 4). This suggests the self-selection in the decision of climate change adaptation. Therefore, it should be inappropriate to estimate the three models separately. This negative sign indicates a positive selection bias implying that the individuals that have soybean net revenue above the average have a higher probability of adapting to climate change than a random individual in the sample. Those who adapt to CC have above-average returns from adaptation compared to what a random individual would have earned from non-adaptation. This finding is consistent with previous studies (Abdulai & Huffman, 2014; Cachorro et al., 2018; Di Falco et al., 2011), but in contrast with Boonwichai et al. (2019) and Lobell (2014) who point that the impact of adaptation on crops productivity would be dependent on the adopted adaptation technology; hence, best innovation would not necessarily affect positively farming profit. Since the correlation coefficient for the farmers that have decided to not take any adaptation measures is not statistically significant, one would conclude that the farmers who have not taken any adaptation do not better performed or worse return from adaptation compared to an individual taken randomly in the sample. The expected increase of soybean revenue from adaptation to CC compared to non-adaptation is summarized in Table 5.

Table 5. Average percentage of increase of soybean revenue and heterogeneity between groups

Sub-sample	Mean outcome ^a		Treatment effects
	Adapted to CC	Not adapted to CC	
Adapted to CC	10.835(0.06)	12.484(0.07)	-1.649(0.10)
Not Adapted to CC	10.874(0.07)	10.605(0.08)	0.268***(0.11)
Heterogeneity effects	-0.038(0.10)	1.879***(0.11)	-1.917***(0.14)

^aLog of net revenue, ***P < 0.01, standard errors in parenthesis.

The average treatment effect and the heterogeneity effects of farmers that have adapted and those who did not adapt conditional on adaptation are negative and not significant at level (-1.649 and -0.038, respectively). However, the results show that the effect of the treatment on the untreated of the farmers that did not take any adaptation measures is positive and statistically significant and 1% level. This result is consistent with previous studies (Abdoulaye et al., 2018; Di Falco et al., 2011). However, the effect of based heterogeneity from non-adapting to CC is positive and statistically significant at 1%. This result indicates that even though farmers do not take any adaptation measure, they still earn more than the farmers that have adapted to CC. The difference of soybean revenue between farmers that have chosen for adaptation if they do not adapt and the soybean revenue of farmers that do not adapt to CC if they still not adapt is about 1.87% (Table 5). This finding is similar to Lobell (2014) but in contrast with Di Falco et al. (2011). These results could be because farmers who decided to adapt do not efficiently use the available technologies. Probably, soybean farmers in the study areas did not choose the convenient technology. They may have a low adaptive capacity or need more information on the available technologies. In that case, the intervention of extension services would be useful to strengthening farmers' adaptive capacities and retraining on the use of available technologies. Moreover, the transitional heterogeneity effect between adapted and non-adapted farmers is negative and statistically significant at 1%. This result is consistent with Di Falco et al. (2011) who found that the farm households that have adapted to CC did not are food secure with respect to those who did not adapt. Further assessment on the adopted technology to adapt to CC in soybean farming would shed light on the effectiveness of the adopted technology on soybean farmers' revenue in the study areas.

4. Conclusion and policy implications

Climate change (CC) in sub-Saharan Africa is a phenomenon that affects agricultural productivity and constitutes a major cause of food insecurity. Mitigation and adaptation to CC are common recommendations to increase farm-level production and reduce farm households' vulnerability in developing countries, where agriculture is an important sector of the economy. The formulation and implementation of CC adaptation policy in developing world could speed up if all stakeholders are involved in decision-making. Thus, the gender aspect that is often neglected in the development of climate technologies would be one of the key components. This paper has analyzed the determinants of CC adaptation and assessed the impact of CC adaptation on soybean farmers' revenue, using cross-sectional data that were collected from 500 farmers in the Central Region of Togo. To control a potential sample selection bias, the endogenous switching regression method was used to examine the impact of CC adaptation on soybean farmers' revenue.

The results from the Full Information Maximum Likelihood Estimator of the endogenous switching regression model showed that women are likely to not adapt to CC compared to men. However, the regular contact with extension agents, the access to credit and the experience in soybean farming, including are the main factors that motivate farmers in CC adaptation. The gender-differentiated impact shows that women who adapt to climate change would earn more than men while losing from soybean farming compared to men if they do not take any adaptation actions. The results conclude that women in the study areas would earn more if they could get more land for soybean cultivation. Having access to credit and extension services, using the

required quantity of seed per hectare as well as the crop rotation techniques would increase soybean revenue of farmers who adapt to CC, while pesticide/herbicides use would affect soybean farming revenue negatively. However, being a member of soybean farmers based organization or undertaking off-farm activity would enhance soybean farming revenue of farmers that did not adapt to CC. The results of the average treatment effect on untreated have shown that farmers would lose by 0.268% of their revenue from non-adapting to climate change. However, the base heterogeneity effects suggest further assessment on the adopted technology to adapt to CC in soybean farming in the study areas. Climate policy that seeks to ensure food security and enhance farmers' welfare in soybean farming in subsistence agriculture would target women and rethink about the technologies used to adapt to CC.

Acknowledgements

The authors acknowledge the financial support of the Alliance for Green Revolution in Africa (AGRA), International Development Research Centre (IDRC), the West and Central Africa Council for Agricultural Research and Development (CORAF/WECARD) and the International Institute of Tropical Agriculture (IITA) through the grant for thesis writing. However, any opinions, findings, and conclusions or recommendations expressed in this material are those of the authors and do not necessarily reflect the views of the AGRA, IDRC, the CORAF/WECARD and the IITA. The authors would like to thank Prof PAM ZAHONOGO from the University of Ouaga 2, Mr. Bamba Zoumana and the capacity building office of IITA for their supports and Mrs Sawsan Musa Adam Abdul-Jalil from University of Khartoum (Sudan) for her comments.

Funding

This work was supported by the Alliance for a Green Revolution in Africa (AGRA), International Development Research Centre (IDRC), the West and Central Africa Council for Agricultural Research and Development (CORAF/WECARD) and the International Institute of Tropical Agriculture (IITA) [107855-001].

Competing Interests

The authors declare no competing interests.

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Disclosure statement

The authors declared that they have no conflict of interest.

Citation information

Cite this article as: Gender and impact of climate change adaptation on soybean farmers' revenue in rural Togo, West Africa, Essossinam Ali, Nadège Essossolim Awade & Tahirou Abdoulaye, *Cogent Food & Agriculture* (2020), 6: 1743625.

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