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Climate Change Adaptation Mechanisms for Smallholder Farmers in Côte d'Ivoire

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Authors' contributions

This work was carried out in collaboration between both authors. Author WBD designed and managed the study. Author FN performed the statistical analysis and wrote the first draft of the manuscript. Both authors read and approved the final manuscript.

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ABSTRACT

This paper analyzes the adaptation mechanisms employed by smallholder farmers in Côte d'Ivoire in response to climate change. Using data from the World Bank's CGAP survey (2016) and applying the Heckman's probit model with sample selection, the study accounts for farmers' perception of climate change and its impact on adaptation strategies. The findings show that perception is a key factor in adopting climate-smart strategies, with access to agricultural information, cooperative membership, insurance, gender, education, and income levels being decisive variables. The study recommends policies that enhance advisory support, promote cooperatives, and ensure gender equality in accessing productive resources. These measures are essential for strengthening the adaptive capacity of smallholder farmers in Côte d'Ivoire.

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Keywords: Côte d'Ivoire; climate change; adaptation; perception; smallholder farmers; Heckman's probit model with sample selection.

1. INTRODUCTION

Adaptation remains the preferred option for countering the adverse effects of climate change, Barnabàs et al. [1], Mustapha et al. [2], Traoré [3], Sissoko et al. [4], Traoré et al. [5], El Bilali H. [6] and Niang and Ruppel [7]. According to IPCC [8], adaptation is defined as an adjustment in natural or human systems in response to present or future climatic stimuli or their effects in order to mitigate adverse effects or exploit beneficial opportunities. In agriculture, these adaptation strategies take several forms, including new crop varieties and animal species better suited to drier conditions, irrigation, crop and livestock diversification and changes to the cropping calendar, Deressa et al. [9] and Di Falco et al. [10].

In countries with agricultural economies, such as those in Africa, the implementation of these strategies is of the utmost importance, as the social and economic well-being of the population depends on them. The agricultural sector, dominated by rain-fed agriculture, plays a key socio-economic role, contributing between 30% and 60% of GDP and employing 2/3 of working population, FAO [11] and World Bank [12]. Studies show that the impact of climate change will be severe in Sub-saharan Africa in general and in the sahel and West Africa in particular, Baarsch et al. [13], Bakshi et al. [14], Bornemann et al. [15], Hassan [16], Lokonon et al. [17], Sultan and Gaetani [18] and Egbebiyi et al. [19], given that these countries are already experiencing low agricultural yields that are worsening their food situation, World Bank [12] and Sawadogo et al. [20]. Despite their importance in the sector in terms of food production (80%) and workforce (75%), Poole [21], World Bank [22], smallholders do not always have the necessary means to cope with climatic hazards.

Although adaptation strategies are important and are being adopted by farmers to varying degrees, their effectiveness has yet to be demonstrated, Below et al. [23], Steward et al. [24], Dimon [25], Bello et al. [26], Traoré et al. [5] and Adou et al. [27]. This situation translates into either, a low level of adoption, or inappropriate strategies. Hence, we need to identify the factors behind the adoption of appropriate and effective strategies.

The literature highlights several factors linked to adoption. Some authors point out financial and technological constraints, Garcia de Jalon et al. [28] and Kalame et al. [29], that limit the choice of adaptation strategy. Others mention factors linked to human and social capital (Jones et al. [30] and Garcia de Jalon et al. [31]. Furthermore, selected authors point out governance problems, in general, and in particular, the failure to take local knowledge into account in the design of adaptation strategies, Dimon [25], Bello et al. [26], Kanté [32], Traoré et al. [5] and Bambara et al. [33]. Thus, several studies neglect the farmers' perception dimension in the identification of factors favourable to the adoption of adaptation strategies, Mustapha et al. [2] and Traoré et al. [5]. However, it is the driving force behind the adoption process, Agossou et al. [34], Ruault [35] and Ban van den et al. [36]. Indeed, the nature of adaptation and its effectiveness depend on how danger or risk is perceived. Farmers' behaviour is shaped more by their perceptions of climate change than by actual climate trends, De Longueville et al. [37], Adger et al. [38], Mertz et al. [39], Deressa et al. [40], Maddison [41] and Gbetibouo [42]. Further to the above, authors indicate that the incidence of climate change is not a determining factor in the adoption of adaptation strategies, Schlenker and Lobell [43] and Garcia de Jalon et al. [28]. For example, Garcia de Jalon et al. [28] show that countries most exposed to the effects of climate change have a low probability of adopting adaptation strategies. Similarly, climate change adaptation measures differ according to the realities of each area, Chemura et al. [44] and Rippke et al. [45]. It is therefore necessary to have clear understanding of smallholder farmers' perceptions of climate change and the factors driving their decision to adapt, Esham and Garforth [46].

In Côte d'Ivoire, where changes in climatic conditions, characterised in particular by variations in the dates of the seasons and rainfall amounts, Ochou [47], Goroza [48], Brou and Chaléard [49] and Goula et al. [50], have already been observed, MEDD [51], smallholder rural farmers, the main producers, have only partial knowledge, Isbell et al. [52] and little capacity to adapt, CDN [53]. Although, studies have been carried out on perception and adaptation in Côte d'Ivoire, not only they have done little to explore the link between the two phenomena, Kouassi et al. [54] and Attoumane et al. [55] but those studies also have been partial as they are specific to a given study area, Brou et al. [56], Timité et al. [57], Boko et al. [58] and Bodji et al. [59].

This paper aims to fill this gap with the main objective of analysing the adaptation mechanisms of smallholder farmers in Côte d'Ivoire to climate change. The contribution of this paper is twofold. The first relates to the modelling of the adaptation process, which takes account of farmers' perceptions in the form of a two-stage econometric estimation technique. Indeed, most studies do not link the two phenomena. Those that do, study the two phenomena separately as in the case of Kaboré et al. [60]. The second concerns the inclusion of all smallholder farmers throughout the country, in contrast to the partial studies that have been carried out to date. In this way, a better understanding of adaptation factors would help guide decision-making with a view of promoting rapid and effective adaptation by smallholder farmers.

The rest of the paper is structured as follows. Section 2 describes the methodology and data. Section 3 presents the results and section 4 discusses them. The final section concludes the study and draws out the economic policy implications.

2. METHODOLOGY AND DATA

This section presents the modelling and data sources in turn.

2.1 Presentation of the Theoretical and Empirical Model

The strategy for identifying the determinants of climate change adaptation by smallholder farmers is based on random utility models. A representative farmer *i* decides to implement an adaptation strategy if his expected utility, in case of adaptation, U_1 is higher than that without adaptation U_0. In other words, if $A^* = U_1 - U_0 > 0$ corresponding to a net gain from adoption, then the farmer adopts the adaptation strategy. Also, as A^* it is not observable, it is specified as follows:

$$A_i^* = X_i\alpha + \varepsilon_i \qquad (1)$$

with $A_i = \begin{cases} 1 \; if \; A_i^* > 0 \\ 0 \; if \; A_i^* \leq 0 \end{cases}$

where $\varepsilon_i \sim N(0, \sigma^2)$

A_i being the observed behaviour of farmer *i* and X_i the vector of characteristics of farmer *i* with α and ε_i respectively the vector of parameters and the error term. Thus equation (1) states that farmer *i* will choose to implement the adaptation strategy ($A_i = 1$) if his net utility is positive ($A_i^* > 0$).

Estimation of equation (1) by a standard binary probit model would give unbiased estimators. However, adaptation follows from the perception of climate change. According to Maddison [41] and Gbetibouo [42], perception is a prerequisite for adaptation. In other words, perception precedes adaptation. Consequently, omitting this step undoubtedly leads to selection bias and biased estimators. In fact, estimating equation (1) using a probit poses a problem of sample selection insofar as farmers who adopt an adaptation strategy are only those who have a good perception of climate change. A sample selection bias is a type of bias in statistical analysis deriving from a non-random sampling. Adaptation to climate change is therefore a two-stage process. In the first stage, the farmer perceives climate change, and in the second stage he decides whether to adapt by adopting a particular measure or not. This reality is taken into account using a probit or logit model with sample selection, and the two dependant variables are binary. Based on the Heckman [61] sampling selection procedure, the final model is as follows:

$$A_i^* = X_i\lambda + \varepsilon_i \qquad (1')$$

$$P_i^* = Z_i\beta + \mu_i \qquad (2)$$

with $P_i = \begin{cases} 1 \; if \; P_i^* > 0 \\ 0 \; if \; P_i^* \leq 0 \end{cases}$

and $A_i = \begin{cases} 1 \; if \; A_i^* > 0 \; and \; P_i = 1 \\ 0 \; if \; A_i \leq 0 \; and \; P_i = 1 \\ 0 \; if \qquad P_i = 0 \end{cases}$

where $\begin{pmatrix} \varepsilon_i \\ \mu_i \end{pmatrix} \sim N_2 \left(\begin{bmatrix} 0 \\ 0 \end{bmatrix}, \begin{bmatrix} \sigma^2 & \rho\sigma \\ \rho\sigma & 1 \end{bmatrix} \right)$

Equation 2 is the perception equation (being the latent variable) explaining the level of perception of climate change from characteristics Z relating to farmer *i*. μ_i is the error term. If $P_i = 1$, the farmer has a good perception of climate variability and 0 otherwise. The parameters λ and β are estimated by maximizing the following likelihood function:

$$L = \prod_i \Phi_2(Z_i\beta, X_i\lambda; \rho)^{1(y_i=1)} x\ \Phi_2(Z_i\beta, -X_i\lambda; -\rho)^{1(y_i=0\&P_i=1)} x\Phi(-Z_i\beta)^{1(p_i=0)})$$

Φ is the normal distribution function; 1(A) is the indicator function taking the value 1 if event A is true and 0 otherwise; and ρ measures the degree of correlation between the error terms ε_i and μ_i. When $\rho \neq 0$, standard probit techniques applied to the first equation give biased results. Empirically, the model is as follows:

Equation 1 : $A_i = \lambda_0 + \lambda_1 Sex_i + \lambda_2 Coop_i + \lambda_3 Exp_i + \lambda_4 Educ_i + \lambda_5 Agri_{ad_i} + \lambda_6 Age_i + \lambda_7 Rev_i + \lambda_8 HHsize_i + \lambda_9 Info_i + \lambda_{10} Loan_i + \lambda_{11} Land_i + \lambda_{12} Insur_i + \varepsilon_i$ (3)

Equation 2 : $P_i = \beta_0 + \beta_1 Sex_i + \beta_2 Coop_i + \beta_3 Exp_i + \beta_4 Educ_i + \beta_5 Age_i + \beta_6 Info_i + \beta_7 Loan_i + \beta_8 Land_i + \beta_9 Insur_i + \beta_{10} Area_i + \mu_i$ (4)

A_i is the adaptation decision of head of household i; Sex_i gender of head of household *i;* $Coop_i$ agricultural cooperative membership status of head of household *i;* Exp_i agricultural experience of head of household *i;* $Educ_i$ education level of head of household *i;* $Agri\_ad_i$ access to agricultural advices of head of household *i;* Age_i age of head of household *i;* Rev_i income of head of household *i;* $HHsize_i$ size of household *i;* $Info_i$ access to agricultural information of head of household *i;* $Loan_i$ access to credit of head of household *i;* $Land_i$ type of ownership of plot farmed by head of household *i;* $Insur_i$ agricultural insurance status of head of household *i;* $Area_i$ place of residence of head of household *i* and P_i the level of perception of climate change by household *i.*

Details of the description of the study variables are given in Table A0 in Appendix. The Stata Heckprobit command provides consistent and asymptotically efficient estimates for all the parameters of this model. However, for the model to be properly identified, the selection equation (the perception equation) must include at least one variable that does not appear in the outcome equation (the adaptation equation). Otherwise, the model is identified only by its functional form, and the coefficients have no structural interpretation. To interpret the coefficients, marginal effects are calculated.

2.2 The Data

This paper uses data from the Consultative Group to Assist the Poor (CGAP) survey of small farm households in Côte d'Ivoire conducted by the World Bank in 2016. This survey was based on three questionnaires. The first questionnaire focuses on the household as a whole, with the head of household or a knowledgeable adult as the respondent. It deals with basic information about the household (assets and characteristics of the dwelling). The second questionnaire was sent to multiple respondents, i.e. all household members over the age of 15 who participate in the household's agricultural activities. This questionnaire covers demographic data, agricultural activities and household economic data. The third questionnaire was sent to a randomly selected adult in the household and covers farming activities and formal and informal financial instruments. For this study, we reconciled these 3 databases using the household identifier. This enabled us to obtain a database with all the questions/answers from respondents unique to each household, in this case the heads of household.

3. RESULTS AND DISCUSSION

3.1 Descriptive Statistics

The characteristics of the sample are presented in Table A1 in appendix. The sample comprised 11674 smallholder farmers, 43% of whom were men and 57% women, with an average household size of around 6 members. They were almost equally distributed between the three zones studied, i.e. 38.76% in the western forest zone, 31.72% in the savannah zone and 29.52% in the eastern forest zone. Around 43% of households surveyed were between 30 and 50 years old. Over 70% of farmers have no more than primary education. On the other hand, over 90% of farmers have more than 10 years' farming experience. Unfortunately, few farmers belong to agricultural cooperatives (3.14%) and receive advice on farming techniques (6.30%). Only 0.44% of respondents have access to agricultural information (prices of inputs, agricultural products on the market, etc.).

In terms of perception of climate change, Table 1 shows that over 80% of farmers do not have a good perception of climate change. Only 1,875 respondents, or 16% of those surveyed, said that they had observed and noticed changes in climatic phenomena over the past 3 years.

Table 1. Producers' perception and adaptation to climate change

	Adaptation			
	No use of strategies	**Use of strategies**	***Percentage (%)***	***Total***
Perception				
No perception	9799	0	83.94	9799
Perception	1033	842	16.06	1875
Percentage (%)	55.09	44.91	100	-
Total	10832	842	-	11674

Source: authors based on World Bank survey data (CGAP, 2016)

For the latter, weather is the most important risk for agricultural activities with a percentage of 77.2% as shown in Table 2. The parameters or variables measured are weather-related factors i.e. changes in climatic variables (drought, floods and late rains). Despite the concerns raised by the respondents on the effects of climate change on their livelihoods, only 45% of farmers adopted strategies to cope with the adverse effects of climate variability on their crops. In fact, in addition to adaptation strategies, resilience measures have been adopted, including the development of secondary activities, the sale of livestock, and the use of savings or even loans where appropriate.

According to Table 3, most producers drew on their savings to overcome the difficulties associated with poor harvests.

3.2 Econometric Results

We present the results for the whole sample and those taking account of the heterogeneities in the sample. Farm size and crop type are the forms of heterogeneity considered in this study.

3.2.1 Factors favouring adaptation to climate change by smallholder farmers

Table 4 presents the results of the estimation of the probit model with Heckman sample selection, which includes the selection equation and the outcome equation. The model is globally significant at the 1% level. The Heckman approach is appropriate because rho is significantly different from zero. In other words, the adoption of adaptation strategies by small-scale farmers is conditioned by their level of perception of climate change. Several variables in the model are also significant. These include membership of an agricultural cooperative, gender, household size, access to agricultural information, possession of agricultural insurance, age, level of education, agricultural experience and type of land ownership.

Among the above variables, those favouring the adoption of coping strategies were membership of an agricultural cooperative, male gender, large household size, access to agricultural information, and possession of agricultural insurance. Farmers benefiting from cooperative services, agricultural information and insurance were 7.9%, 5.5% and 5.6% respectively more likely to adapt to climate variability. On the other hand, farmers who are older, more experienced, illiterate and do not own land are less likely to adopt adaptation strategies. Thus, age, experience, illiteracy and common ownership of land are factors that reduce the incentive for farmers to adapt to climate change. Furthermore, the adoption of adaptation strategies depends on small-scale farmers having a good perception of climate change. In this respect, the results show that factors such as membership of a cooperative, access to agricultural information and subscription to insurance improve farmers' perceptions.

All these results show that being male, young, a member of a cooperative, having access to agricultural information, taking out insurance and having a private title to land encourage the adoption of adaptation strategies.

Table 2. The most important risks for farming according to producers

The most important risks	*Nber of producers*	*Total nber of producers*	*Percentage (%)*
Weather-related risks	9013	11674	77.2
Health and market imperfections	1705	11674	14.61
Input prices and risks	907	11674	07.77
Others	49	11674	00.42

Source: authors based on World Bank survey data (CGAP, 2016)

Table 3. The various resilience factors used by farmers following their perception

Strategies	**Secondary activities**	**Loans**	**Sale of livestock**	**Savings**	***Total***
Nber of producers	135	251	47	409	842
Percentage (%)	16.03	29.81	5.58	48.57	100

Source: authors based on World Bank survey data (CGAP, 2016)

Table 4. Results of the estimation of the probit model with Heckman sample selection

	Outcome model		**Selection model**	
Explanatory variables	**Regression Coefficient**	**Marginal effects dy/dx**	**Regression coefficient**	**Marginal effects dy/dx**
Age (base: <31years old)				
From 51 and over	**-0.091*****	-0.013	**-0.116*****	**-0.021*****
31 to 50 years old	**-0.192*****	-0.028	**-0.455****	**-0.071*****
Coop				
Yes	**0.546*****	0.079	**1.078*****	**0.247*****
Educ (base :primary)				
Secondary	0.010	0.001	0.023	0.006
Superior	-0.066	-0.009	0.063	0.019
No level	**-0.576*****	**-0.079***	**-0.987*****	**-0.223*****
Sex				
Male	**0.201*****	0.031	0.286	**0.045*****
Exp(base: <6 years)				
From 6 to 10 years	0.100	0.015	0.045	0.014
Over 10 years	**-0.706*****	**-0.097***	**-1.094*****	**-0.256*****
Hhsize(base: <6pers)				
From 6 to 10 pers	-0.26	-0.024		
Over 10 pers	**3.291*****	**0.847*****		
Agri_ad				
yes	0.047	0.007		
Info				
yes	**0.373***	0.055	**0.635*****	**0.125****
Rev(base :<52M)				
52 000M to 110 000M	0.041	0.005		
110 000M to <600 000M	-0.0006	-0.001		
600 000M to< 1 200 000M	-0.135	-0.019		
> 1 200 000M	-0.126	-0.018		
Land(base :private)				
community or State	**-0.227****	-0.032	-0.001	-0.001
others	**-0.371*****	-0.054	**-0.609*****	**-0.104*****
Loan				
yes	0.249	0.037	0.118	0.191
Insur				
yes	**0.383*****	0.056	0.483	**0.090*****
Area(base :Eastern forest)				
West forest zone			**0.151*****	**0.022*****
Savannah zone			**0.222*****	**0.033*****
_cons	-0.247		**0.891*****	
Number of obs	11 674			
Selected	1875			
Not selected	9799			
Prob > chi2	0.0000			

Source: authors based on World Bank survey data (CGAP, 2016)
*Notes: ***, **, * = significant at 1%, 5%, and 10% probability level, respectively.*

3.2.2 Sensitivity analysis (robustness tests)

The above results (in Table 4) assume that the entire sample is homogeneous. However, not all growers are confronted with the realities with the same intensity. These differences in exposure to climatic realities may result in different reactions from producers. We tested heterogeneities relating to farm size and crop type. For farm size, we consider farms of less than five hectares (small farms) and farms of more than five hectares (large farms). In terms of crop type, we distinguish between food crops and perennial crops.

Table 5 presents the results for farm size. Overall, the models are significant at the 1% level. However, there are differences in the results for the two farm categories. The first difference is the independence of the outcome and selection equations. Unlike small farms, the adoption of adaptation strategies by producers on large farms is not linked to their perception, as rho is not statistically different from zero (prob > chi2=0.377). The second difference is linked to the variables that were found to be decisive in explaining the adoption of adaptation strategies. Unlike large farms, where age and household size were found to be relevant, the adoption of coping strategies by smallholders was linked to membership of a cooperative, access to agricultural information, subscription to insurance and, above all, income level. The results also showed that, in addition to the factors identified above, household income proved to be a relevant factor to consider when designing adaptation policies for smallholder farmers.

Regarding crop type, the results in Table 6 reveal different determinants. Although the significant variables are virtually the same for the two types of crops, their signs are opposite. Thus, while belonging to a cooperative and being a man significantly and positively affected the probability of adopting strategies among food crop producers, these same variables negatively affect that of perennial crop producers. The same was true for the education and work experience variables.

In addition, other variables are decisive on both sides of the two crop groups considered. These are access to information and income in the case of perennial crop farmers, on the one hand, and age, form of land ownership and household size in the case of food crop promoters, on the other.

3.3 Discussion

Analysis of the determinants of smallholder farmers' adaptation to climate change in Côte d'Ivoire revealed several factors, including membership of an agricultural cooperative, gender (male), large household size, access to agricultural information, possession of agricultural insurance, level of education and experience.

3.3.1 Farmers' organizations, information and adaptation strategies

As expected, membership of a cooperative has a positive influence not only on farmers' perception of climate change but also on their willingness to adopt adaptation strategies. This result is corroborated by several authors including Parcell and Gedikoglu [62], who show that considering cooperation between farmers helps to better explain adoption behaviour. Farmers' organisations are places where information about the agricultural sector is shared, Donahue and Miller [63], Jones et al. [30] and Polyzou et al. [64]. According to Jones et al. [30], there is a link between the density of the social network, representing the amount of information held by members, and awareness of environmental problems. In addition, these cooperatives also receive technical training from government and non-governmental organisations (NGOs) as part of agricultural development projects and programmes that include components on climate change in relation to agricultural activities, Yegbemey et al. [65] and Kaboré et al. [60]. The significance and sign of the "access to agricultural information" variable confirms this result. Certainly, one of the objectives of agricultural cooperatives is to facilitate the sharing of information and experience between members for good practices. By reducing uncertainty, information enables farmers to better perceive new practices and the associated risks. In addition to information sharing, the association plays a supervisory role and acts as a guarantor for access to finance, Below et al. [23], Hammill et al. [66] and McLeman et al. [67]. The result obtained confirms those contained in Table 2 (small versus large) insofar as this variable is a determining factor for smallholders, whereas it is not for large farms. In fact, thanks to their organisation and financial resources, large farms have access to high-quality strategic information that enables them to make better decisions, unlike small farms. So, for smallholders, associations are sources of information

Table 5. Results of the estimation of the probit model with Heckman sample selection according to farm size

Explanatory variables	Farmers with less than 5 hectares		Farmers with more than 5 hectares	
	Outcome model (adaptation)	Selection model(perception)	Outcome model (adaptation)	Selection model (perception)
	Coefficient	coefficient	Coefficient	Coefficient
Age(base :<31years old)				
From 51 and over	0.058	0.009	-0.009	**-0.234*****
31 to 50 years old	0.075	-0.054	**0.424****	**-0.628*****
Coop				
Yes	**0.476*****	**0.884*****	-0.656	**1.205*****
Educ(base :primary)				
secondary	-0.064	0.019	0.026	0.031
supérior	-0.394	-0.017	0.276	0.067
No level	-0.459***	**-0.714*****	**0.610**	**-1.205*****
Sex				
male	**0.121****	**0.187*****	-0.117	**0.330*****
Exp(base : <6 years)				
From 6 to 10 years	0.253	-0.042	-0.253	0.317
>10 years	**-0.423***	**-0.993*****	0.150	**-0.958*****
Hhsize(base : <6pers)				
6 to 10 pers	-0.128		-0.496	
>10pers			**5.620*****	
Agri_ad				
yes	0.029		0.071	
Info				
yes	**0.775*****	**0.932*****	-0.444	0.516
Rev(réf :<52M)				
52M to 110M	0.019		0.054	
110M to 600M	-0.078		0.079	
600M to <1200M	-0.052		-0.032	
>1200M	**2.402*****		-0.068	
Land(base :private)				
Community or State	-0.133	-0.011	**-0.407***	0.048
Others	0.065	-0.029	0.257	**-0.608*****

Explanatory variables	Farmers with less than 5 hectares		Farmers with more than 5 hectares	
	Outcome model (adaptation)	Selection model(perception)	Outcome model (adaptation)	Selection model (perception)
	Coefficient	coefficient	Coefficient	Coefficient
Loan				
Yes	0.195	-0.028	-0.006	0.210
Insur				
Yees	**0.514*****	**0.794*****	0.178	0.010
Area(base :Eastern forest)				
West forest zone		**0.216*****		-0.127
Savannah zone		**0.346*****		-0.135
_cons	**-0.607****	**0.533***	0.208	**1.124*****
Number of obs	2 973		8 701	
Selected	1 004		871	
Not selected	1 969		7 830	
Prob > chi2	0.0000		0.0000	

Source: authors based on World Bank survey data (CGAP, 2016)
*Notes: ***, **, * = significant at 1%, 5%, and 10% probability level, respectively*

Table 6. Results of estimating the probit model with Heckman sample selection according to crop type

Explanatory variables	Food crop farming		Perennial crop farming	
	Outcome model(adaptation)	Selection model(perception)	Outcome model(adaptation)	Selection model(perception)
	Coefficient	coefficient	Coefficient	Coefficient
Age(base :<31yearsold)				
From 51 to over	0.044	**0.004*** **	-0.026	-0.041
31 to 50 years old	**0.383*** **	**0.032*** **	0.131	-0.045
Coop				
yes	**-0.811*** **	**1.259*** **	**0.428*** **	**0.819*** **
Educ (base :primary)				
Secondary	-0.111	0.168	-0.049	-0.146
Superior	-0.242	0.119	0.059	-0.222
No level	0.636***	**-0.988*** **	-0.445***	**-0.858*** **
Sex				
Male	**-0.201*** **	**0.282*** **	**0.174**	**0.144** **
Exp(base: <6years)				
From 6 to 10 years	0.250	-0.017	0.098	0.376
>10 years	**0.847*** **	**-1.224*** **	**-0.539***	**-0.559***
Hhsize(base : <6pers)				
From 6 to 10	-0.334		-0.109	
>10pers	**6.332*** **			
Agri_ad				
yes	0.032		0.126	
Info				
oui	-0.337	0.250	**0.828*** **	**1.238**
Rev(base :<52M)				
52M to 110M	-0.003		0.080	
110M to 600M	-0.027		0.038	
600M to <1200M	**-0.719** **		0.076	
>1200M	-0.353		**2.077*** **	
Land(base :private)				
community or State	**-0.445*** **	0.084	-0.024	-0.040
others	**0.443*** **	**-0.708*** **	0.116	0.026

Explanatory variables	**Food crop farming**		**Perennial crop farming**	
	Outcome model(adaptation)	**Selection model(perception)**	**Outcome model(adaptation)**	**Selection model(perception)**
	Coefficient	**coefficient**	**Coefficient**	**Coefficient**
Loan				
yes	0.030	**0.414****	-0.264	**-0.507**
Insur				
yes	-0.148	**0.436****	0.292	**0.429**
Area(base :Eastern forest)				
West forest zone		**-0.191*****		**0.213**
Savannah zone		**-0.176*****		**0.361**
_cons	-0.167	**1.277*****	**-0.603***	0.249
Number of obs	9 654		2 020	
Selected	1 188		687	
Not sélected	8 466		1 333	
Prob > chi2	0.0000		0.0000	

Source: author based on World Bank survey data (CGAP, 2016)
*Notes: ***, **, * = significant at 1%, 5%, and 10% probability level, respectively*

with low transaction costs. Furthermore, the mutual supervision of members facilitates the adoption of innovative strategies, Thiombiano and Ouoba [68]. The effects of information are similar to those of education insofar as our results show that a low level of education (no level of education) reduces the probability of adopting adaptation strategies. Thus, the higher the level of education of the head of household (large stock of knowledge), the more willing he or she is to adopt new agricultural strategies, as highlighted by several authors including Garcia de Jalon et al. [31], Deressa et al. [40], Salhi et al. [69], Goulden et al. [70], Roussy et al. [71] and Iglesias et al. [72].

On the contrary, experience in agriculture considered as an accumulation of knowledge and know-how reduces the producer's incentive to adopt adaptation strategies. Although surprising, this result can be explained by the fact that a good control of the production system acquired through experience leads the producer to minimise the associated risks by not adopting adaptation strategies. Similar results have been highlighted by Kebede et al. [73] and Belay et al. [74]. Age has the same effect as the above but can be explained differently. Indeed, with a shorter planning horizon, older farmers do not adopt agricultural innovations that offer only long-term benefits. Several studies confirm this result, D'Souza et al. [75], Foltz and Chang [76], Anderson et al. [77], Abdulai and Huffman [78], Featherstone and Goodwin [79] and Soule et al., [80].

3.3.2 Gender and adaptation strategies

Contrary to several authors such as Denton F. [81], Hassan and Nhemachena [82], Bello et al. [26], Traoré et al. [5] and Chimi et al. [83], adaptation to climate change has a gender effect. Men are more willing to adopt adaptation strategies than women. The result above, corroborated by Below et al. [23] and Kaboré et al. [60] can be linked to land access rules. Indeed, in most African communities in general and in Côte d'Ivoire in particular, women have limited access to land resources; this reduces their incentive to invest in farms. Similarly, the socio-cultural status [1] that society attributes to women does not allow them to be always available for associative activities in which information on new practices circulates. This reality is confirmed by the results relating to the sub-sample of food crop growers dominated by women. At this level, the type of land ownership, particularly communal ownership, has a negative impact on the adoption of adaptation strategies by producers, unlike private ownership, Schuck et al. [84], Thiombiano and Ouoba [69]. In reality, women generally do not have ownership rights to land, even though they are the main producers of food crops. Under these conditions, they cannot adopt an adaptation strategy, either because they lack the financial resources or because they have no assets (land) to use as collateral to obtain loans from financial institutions.

3.3.3 Financial constraints and adaptation strategies

The importance of income or financial capital in adaptation strategies has been confirmed in several studies, Mertz et al. [85], Adou et al. [27], Belay et al. [73], Negash [86], Beyé [87], Campbell [88], Osbahr et al. [89] and Thomas et al. [90]. Financial constraints are a major obstacle to the adoption of new practices, which often require a significant amount of capital. For example, agricultural equipment (irrigation systems) and improved seeds. The level of income or availability of financial resources has two effects. The first is to reduce the degree of risk aversion and the second is about the capacity to finance the investment. In line with the relevance of financial resources in the adaptation process, the "access to credit" variable shows a positive sign, even though it is not significant for the sample in hand. At this level, some authors found significant results, Boansi et al. [91], Jahel et al. [92], Zampaligré & Fuchs [93] and Kaboré et al. [60].

3.3.4 Farm size and adaptation Strategies

Household size seems to have an indirect effect on adaptation through the size of the farm. In fact, the number of people in the household (the workforce) contributes to large farms, which are favourable to the adoption of adaptation strategies. Table 6 confirms these facts insofar as household size is only relevant to adaptation on large farms. The relevance of this determinant is also highlighted by Traoré et al. [5] who obtained similar results.

3.3.5 Limitations of the study

The paper has some limitations, related mainly to the lack of access to specific data. Analysis of

[1] Socio-cultural practices mean that women do not have access to productive assets (land, bank loans, etc.) and their main activity is housework.

the adoption of an innovation (in this case an adaptation strategy) requires some important variables that are not available in the dataset. These include the cost associated with the innovation, the characteristics of the innovation and psychological (cognitive) factors. The availability of those data would have enhanced the robustness and originality of the analysis (behavioural economics).

In addition, our database is relatively old, dating from 2016, i.e. approximately 8 years old, whereas perceptions of climate change evolve with time and meteorological events, Thornton and Herrero [94].

As regards the methodology, we were more concerned with understanding the choice of adopting an adaptation strategy without specifying the strategy itself. The study could go further by specifying the type of adaptation strategy, which would help in formulating more operational recommendations.

4. CONCLUSION AND POLICY IMPLICATIONS

Although Africa makes a marginal contribution to greenhouse gas emissions, which are responsible for climate change, it is strongly affected by it. In Côte d'Ivoire, climate change is manifesting itself in droughts, floods and late rains. Climate change is disrupting farmers' cropping calendars and threatening Côte d'Ivoire's economy, which is fundamentally based on agriculture. The main objective of this paper is to analyse the mechanisms by which smallholder farmers are adapting to climate change in Côte d'Ivoire. To achieve this, we adopted Heckman's probit model with sample selection to consider farmers' level of perception of climate change. The data used come from the survey of small agricultural households in Côte d'Ivoire conducted, in 2016, by the World Bank (CGAP, 2016). The results of our econometric estimations confirm the relevance of perception in the process of identifying adaptation factors for smallholder farmers with meteorological information as a determining factor in improving the degree to which farmers perceive climate change. Furthermore, access to agricultural information, membership of a cooperative, subscription to agricultural insurance and the level of income have a positive influence on the probability of adapting to climate change. In addition, the level of education and gender were also found to be relevant in the adaptation process.

Consequently, the means of strengthening small farmers' ability to adapt involve advisory support through farmers' sensibilization on climate change, agricultural advice, training and meteorological information dissemination. In addition, farmers' cooperatives, guarantee funds and agriculture risk coverage facilities should be promoted. These measures should be gender sensitive by facilitating women's access to productive resources (land, financial loans) enabling them to effectively meet their food production needs. The important contribution of women to food production requires a particular attention on gender consideration to ensure efficiency in implementing smart climate adaptation policy.

In overall, strengthening adaptation capacity of smallholder farmers requires a coordinated action with all stakeholders (researcher, policy makers, investors, civil society) from global to local levels as mentioned by Lipper et al. [95].

DISCLAIMER (ARTIFICIAL INTELLIGENCE)

Authors hereby declare that NO generative AI technologies such as Large Language Models (ChatGPT, COPILOT, etc) and text-to-image generators have been used during writing or editing of this manuscript.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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APPENDIX

Table A0. Description of variables

Variables	Description	Coding	Min	Max
Age	Age of head of household	1= if the head of household is under 31 years of age 2= if the age of the head of household is between 31 and 50 3= if aged over 50	1	3
Exp	Agricultural experience of the head of household	1= if the head of household has less than 6 years' experience 2= if he has between 6 and 10 years' experience 3= if he has more than 10 years' experience	1	3
HHsize	The size of household	1= if the household has more than 6 members 2= if the size of the household is between 6 and 10 members 3= if the household has more than 10 members	1	3
Rev	Average household income	1= if the household income is less than 52,000f 2= if income is between 52,000f and 110,000f 3= if income is between 110,000f and 600,000f 4= if income is between 600,000f and 1,200,000f 5= if income exceeds 1,200,000f	1	5
Coop	Head of household's membership of an agricultural cooperative	1= if he belongs to 0= otherwise	0	1
Educ	Level of education of the head of household	1= no level 2= primary 3= secondary 4= superior	1	4
Sex	gender of head of household	1= male 0= female	0	1
Agri_ad	The farm manager's access to agricultural advice	1= if he has access to farm advisory services 0= otherwise	0	1
Area	Where the household lives	1= if the household belongs to the East Forest zone 2= if the household belongs to the West Forest zone 3= if the household belongs to the Savannah zone	1	3

Variables	Description	Coding	Min	Max
Info	access to agricultural information	1= whether the head of household has access to agricultural information 0= otherwise	0	1
Land	the form of plot ownership	1= if the plot is individually owned 2= if the plot belongs to the community or the State 3= other forms of ownership	1	3
Loan	Household heads' access to agricultural credit	1= whether the head of the household has access to agricultural credit 0= otherwise	0	1
Insur	Possession of agricultural insurance by the head of household	1= if he has agricultural insurance 0= otherwise	0	1

Table A1. Descriptive statistics for explanatory variables

Variables	*Observation*	*Proportion*	*Std.Dev*	*Min*	*Max*
Quantitative variables					
Age	11674	2.221	0.77	1	3
Exp	11674	2.867	0.447	1	3
Hhsize	11674	1.988	0.995	1	3
Rev	11674	4.153	1.49	1	5
Qualitative variables					
Coop	11674	0.031	0.174	0	1
Educ	11674	2.547	0.776	1	3
Sex	11674	0.429	0.495	0	1
Agri_ad	11674	0.063	0.243	0	1
Area	11674	2.022	0.782	1	3
Info	11674	0.004	0.066	0	1
Land	11674	2.311	0.936	1	3
Loan	11674	0.011	0.099	0	1
Insur	11674	0.008	0.092	0	1

Source: authors based on World Bank survey data (CGAP, 2016)

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