Impacts of Adaptation to Climate Change on farmers' income in the Savana Region of Togo

Pilo Mikémina , Deputy Director of the higher institute of agricultural business, University of Kara
University of Kara, Togo
Email: pilomikemina15@gmail.com
Nicolas Gerber
Center for Development Research, University of Bonn
Tobias Wünscher
Center for Development Research, University of Bonn

Abstract

Do farm households taking steps to adapt to climate change experience a higher income than those who do not? This paper aims to answer this question in the context of crop and livestock income in the Savana region of Togo. To that end, we build a bio-economic model based on farm household model theory. Using survey data collected from a representative sample of 450 farm households in the agricultural year 2013/2014, we identify farm-household types through cluster analysis and apply them in the simulation model. From the simulation results, we conclude that at their current costs, soil and water conservation techniques and irrigation can on average provide higher income even under climate change, since they are able to mitigate the impacts of climate change on crop and livestock income. By contrast, reducing the quantity of applied fertilizer, mentioned as an adaptation option by farmers, increases the farm households' vulnerability to climate change. The policy message we draw from this study is to encourage Soil and Water Conservation techniques and sustainable irrigation as sound strategies for higher income under climate change in the region. These are "no regret options" with a positive impact on livelihoods while preserving the resource base.

Keywords: adaptation, bio-economic model, climate change, Savana region of Togo

Résumé

Les ménages agricoles qui s'adaptent au changement climatique ont-ils un revenu plus élevé que ceux qui ne le font pas ? Cet article vise à répondre à cette question dans le contexte du revenu agricole issu de l'agriculture et de l'élevage dans la région des Savanes au Togo. À cette fin, nous construisons un modèle bioéconomique basé sur la théorie du modèle de ménage agricole. En utilisant des données d'enquête recueillies auprès d'un échantillon représentatif de 450 ménages agricoles au cours de l'année agricole 2013/2014, nous identifions les types de ménages agricoles par l'analyse typologique et les appliquons dans un modèle de simulation. À partir des résultats de la simulation, nous concluons qu'à leurs coûts actuels, les techniques de conservation des sols et de l'eau et d'irrigation peuvent en moyenne fournir des revenus plus élevés même sous des conditions du changement climatique, car ils sont capables d'atténuer les impacts du changement climatique sur les revenus des cultures et du bétail. En revanche, la réduction de la quantité d'engrais appliquée, mentionnée comme option d'adaptation par les agriculteurs, augmente la vulnérabilité des ménages agricoles au changement climatique. Le message de politique que nous tirons de cette étude est d'encourager les techniques de conservation des sols et de l'eau et l'irrigation durable en tant que stratégies judicieuses pour des revenus plus élevés dans le contexte du changement climatique dans la région. Ce sont des

« options sans regret » qui ont un impact positif sur les moyens de subsistance tout en préservant la base des ressources.

Mots-clés : adaptation, changement climatique, modèle bioéconomique, région de Savanes au Togo

Introduction

The agricultural sector still plays a central role in Sub-Saharan African (SSA) countries' economic development. It supports the welfare of most of the residents directly or indirectly. However, recent agricultural performance trends of the region are discouraging. Indeed, the agricultural productivity growth in SSA region has been lower compared to the rest of the world (Willy and Holm-Müller, 2013) and some authors have suggested that the region is falling further away from the agricultural productivity frontier, thus contradicting the convergence hypothesis (Wurlod and Eaton, 2015). This situation may, among other things, be a signal of low land productivity in agriculture. The latter can be partly attributed to the low investment in agricultural sector, high rates of land fragmentation, intensive tillage of land, nutrient mining and extraction of crop residues to feed livestock, and climate variability and change (e.g., high average temperature, scarce and erratic rainfall) which characterized agricultural activities of the region (Di Falco et al, 2011; Willy and Holm-Müller, 2013, OCDE, 2015). Climate change and variability are major challenges to SSA agriculture today because they not only increase production costs and the risk of crop failure, but also put at risk the stability of the whole agricultural production chain (Wheeler and von Braun, 2013). Scientific evidence on climate change suggests that even with a strong mitigation policy the observed lower and stagnant agricultural performance of the SSA region will persist or even get worse if the sector does not find ways to adapt to climate change (IPCC, 2007) under a business-as-usual scenario for agricultural sector.

Farmers have always and will continue to adapt to the changing climate. However, it is unclear whether they are able to identify practices and options that are appropriate to respond to climate change as the required adjustments may fall beyond their range of experience (Seo et al., 2010). The implication of this is the possibility of maladaptation resulting in transitional losses of unknown duration (Di Falco et al, 2011). By maladaptation we mean any practice which is more harmful than helpful, by contrast to an adaptation, which is more helpful than harmful. That is, adaptation practices, if not appropriately implemented, can increase vulnerability to climate change.

Determining the productive implications of adaptation to climate change is therefore crucial. It helps understand how the set of strategies implemented by the farmers (e.g., irrigation, low fertilizer use, soil conservation techniques, etc.) in response to changes in environmental conditions affect farm income from cropping and livestock. More specifically, it is necessary to assess whether the farm households that actually did implement adaptation strategies are getting benefits in terms of an increase in farm income. Thus, the aim of this paper is to assess the impact of private adaptation to climate change on households' income from farming and livestock. This is central if adaptation strategies need to be put in place. Although there is an overwhelming number of studies dealing with adaptation, quantitative estimates of adaptation and its impacts are only starting to emerge (e.g. Zhang and Zhao, 2015; Shah and Dulal, 2015).

The impacts of adaptation to climate change are traditionally estimated using agronomic models or Ricardian analysis (Di Falco et al., 2011). Agronomic models first estimate climate change impact and then feed the results into behavioural models that assess the impact of different agricultural system on farm income. The Ricardian approach isolates the impact of climate change by implicitly incorporating the potential of adaptation since it assumes that farm households have been adapting optimally, an assumption that is not necessarily verified for the reasons mentioned above. In our study we use a bio-economic model for empirical estimates. This type of model has been used because of its capability to handle economic and agricultural interactions that prevail within a given farm system.

The remainder of the paper is structured as follows: Section 2 presents data and materials while section 3 develops the bio-economic model. In section 4 we walk the reader through the simulations of the identified adaptation strategies and discuss the empirical results in section 5. The paper concludes with section 6.

1. Data and materials

1..1 Data

The data used in this study come mainly from a cross-sectional, representative farm household survey in the Savana region of Togo during the agricultural year 2013/2014on 450 households (Pilo, 2015). The survey is representative of the four zones of the Savana region which were identified as most vulnerable to food insecurity and income shocks by the PADAT project. The survey collected information on farmers' perception of current and future states of rainfall, adaptation strategies developed by farmers, household assets and livestock. Additional data were gathered from literature and interviews with extension service managers that operate in the region.

1..2 Materials and Methods

We employ a bio-economic model based on risk-averse, constrained profit maximizing behaviour and apply it to the Savana region of Togo. Characterized by high climate variability and frequent climatic shocks, the Savana region of Togo has soils of average productivity (relative to other regions in Togo) and a landscape which ranges from flat to gently rolling hills. The region activities are dominated by rain-fed agriculture associated with livestock raising (crop-livestock farming). Its climate varies from tropical to Savana with the main climatic risks, according to the National Adaptation Programme of Action (NAPA, 2011), being poor distribution of rainfall, flood and drought.

Crop-livestock farming is the main farming system of the region. In this system many adaptation strategies are adopted by farmers in their attempts to withstand climatic shocks that the region is experiencing. To simulate the impact of these strategies in this farming system we link a model of constrained profit maximization for risk averse farmers (allowing for alternative adaptation options) to a biophysical model.

1..2.1 Biophysical inputs of the bio-economic model

A typical bio-economic model includes a biophysical model which simulates plant growth, development and yield, along with nutrient cycling and nonpoint source water pollution, hydrology, and greenhouse gas emissions, for example. A commonly used biophysical model in bio-economic simulations is the Environmental Policy Integrated Climate model (EPIC) (Egbendewe-Mondzozo et al, 2015; Belhouchette et al. 2011; Barbier and Bergeron, 2001). We could not run the EPIC model because of considerable missing data constraints. Instead, the biophysical components of our model comprise data characterizing the biophysical context of the study site (type of soil, states of rainfall). In particular, we retained five types of rainfall states for the survey.

1..2.2 Specification of the crops yield

For the sake of analysis, we distinguish two type of crops: i) the traditional crops and ii) the cash crops. The traditional crops include millet, groundnut, and beans while the cash crops include rice, maize and cotton. The traditional crops are assumed to depend on rudimentary technologies as is the case for most of the SSA countries where it can be assumed that inputs are used in fixed proportion (Dutilly-Diane et al, 2003). Consequently, the two most important factors determining the yield level of traditional crops are the prevailing rainfall condition and the adaptation practice used. Thus, the yield level which accounts for adaptation strategy implemented and the state of rainfall is therefore specified as:

$$y_j \quad = m \quad \{\alpha_j \quad X_i\}$$
(1)

y_j represents yield level of crop j cultivated under the adaptation strategy q and the rainfall condition s. X_i is the level of *i*th input and α_j are constant production coefficients representing the necessary input per unit of output. The yield level of cash crops was specified as follow:

$$y_k \quad = \beta_C * L_k^{\beta_1} * F_{1k}^{\beta 2} * F_{2k}^{(1-\beta_1-\beta_2)} \qquad (2)$$

y_k stands for the yield level of the cash crop k practiced under the adaptation strategy q and the rainfall condition s. β_C , β_1 a β_2 are parameters while L_k, F_{1k} and F_{2k} are production factors representing labour, urea and NPK respectively.

1..2.3 Specification of the livestock yield

Grazing is the dominant livestock farming system in the Savana region of Togo. To capture how a given adaptation strategy influences the size of livestock heads on the one hand, and on the other, how rainfall patterns could affect it in the other, we specify the yield of livestock as follow:

$$y_m \quad = m \quad \{a \quad _m \quad \} \qquad (3)$$

y_m stands for the yield level of livestock m (beef, sheep, etc.), depending on forage X devoted to livestock m, practiced under the adaptation strategy q and the rainfall condition s.

2. The regional Mathematical Programming Model to simulating adaptation impacts

Most agricultural producers in Africa are risk averse, particularly smallholders (Antle, 1987; Binswanger, 1981). They face a variety of yield, price and resource risks that make incomes unstable. All these risks can be classified into production and price risks (Hardaker et al, 1997). To account for risk in the programming model, our analysis is based on Telser's safety first (SF) approach, a downside risk approach. The general structure of Telser's SF model is the following:

$$\text{Max: } E(Z) = E_Y' X$$

$$\text{S.t : } \begin{cases} AX < b \\ \text{Prob } (Z < g) < \alpha \end{cases}$$

In the above specification, $E(Z)$ represents the total expected gross margin, AX a set of resource constraints, b resource endowments, (Z) is income level, (*g*) is exogenously determined minimum level of income a household must earn to meet obligations of high priority, and (α) is the acceptable limit on the probability of failing to meet that minimum level of income. Telser's SF approach accounting for the rainfall risk, adaptation to climate change and the subsistence level of farming in the Savana region of Togo is empirically specified as follows.

2..1 Specification of the objective function

Maximize: $E(Z) = \left(\sum_j \overline{C_j} X_j^P - iX^J\right) + \left(\sum_k \overline{C_k} X_k^P - iX^K\right) - \sum_{t=1}^{1} P_W' X_t^F - \sum_{t=1}^{1} (1 + i) P_W X_t^l + \sum_{t=1}^{1} P_W X_t^U + \sum_{li=1}^{4} \sum_{t=1}^{1} P_{li} X^L$ - $\sum_{li=1}^{4} \sum_{t=1}^{1} P_W X_t^{li}$
(4)

Where $\overline{C_j}$ = expected gross margin of traditional crop production activity j,

$\overline{C_k}$ = expected gross margin of cash crop production activity k,

X_j^P = j^{th} traditional crop production activity measured in hectare,

X_k^P = k^{th} cash crop production activity measured in hectare,
X^{li} = liv^{th} livestock production activity. liv= {chicken, goats, sheep and caws}
P_w = Wage rate in franc CFA per Man-Day (MD),
P_w' = reservation wage rate which accounts for household leisure demand. It has been set in the range of 50% of P_w for wealthier farmers and 0% of P_w for poor farmers in the study of Dessalegn (2005) in the Upper East Region of Ghana. This means that poor farmers' leisure time is negligible. Given the similarities between our study area and that region, we used the same reservation wage rate.
X_t^U= t^{th} month off-farm activity in Man-Days (MD),
i = interest rate, a rate which accounts for the cost of capital and the transaction costs in the credit market. It usually differs between farmers depending on the farmer's wealth. For instance, in the case of Dessalegn (2005) study in Ghana, it was set in the range of 50% for poor farmers and 25% for wealthier farmers,
X_t^l = t^{th} month hired labour hiring activity (in MD),
X_t^F = t^{th} month family labour used for crop farming (in MD),
X_t^L = t^{th} month labour used for livestock farming (in MD),
X^J = borrowing activity related to traditional crop production in Franc CFA,
X^K = borrowing activity related to cash crop production in Franc CFA,

$$\overline{C_j} = E(g_j), \ \overline{C_k} = E(g_k)$$

$$g_j = Y_j * P_j - X^J, \ g_k = Y_k * P_k - X^K$$

$$E(g_j) = \sum_{s=G,N,B,F,D} P_s Y_{j.} * P_j - X^J, \qquad E(g_k) = \sum_{s=G,N,B,F,D} P_s Y_{j.} * P_j - X^K$$

Where g_j, g_k are gross margin per hectare of traditional crop j and cash crop k respectively, which are gross return in rainfall states, less capital cost per hectare. The capital cost includes cash cost on fertilizer, seed, tractor/bullock. And Y_j and Y_k is the yield level of traditional crop j and cash crop k respectively in state of rainfall s. The rainfall conditions are grouped into five states namely: G=good, B=bad, N= normal, F= disastrous due to floods and D=disastrous due to droughts.

2..2 Specification of the set of constraints

In the following sections, the various constraints of the programming model are discussed.

2..2.1 Land Constraint

The sum of crop allocated surface under each type of land (compound land, irrigated land, bush land, water and soil conservation area) cannot exceed total available surface for the given type. For the sake of analysis, this study identifies four land types that are compound land, non-irrigated bush land, irrigated land, water and soil conservation area. For each of these land type we implement a corresponding constraint. For compound land it is specified as:

$$\sum_{j=1} X_j^P \leq L_c$$

Where X_j^P is production activity of crop j (measured in hectares) on compound plots and Lc is total compound land available. The superscript p indicates that the activity is a production activity on the other hand the suffix c indicates that the production activity is on compound land. The remaining constraints relative to land are presented below.

$\sum_{j=1} X_j^P \leq L_B$ Bush land constraint,

$\sum_{j=1} X_j^P \leq L_I$ Irrigated land constraint

$\sum_{j=1} X_{js}^P \leq L_s$ Water and soil conservation constraint

2..2.2 Labour Constraint

Labour is the most important factor of production constraining agricultural and livestock production in the study area. There is a relatively working labour market so the model assumes that farm households can both hire-in and hire-out labour. Households make labour allocation decision both during the rainy and dry seasons mainly between crop and livestock farming. Traditionally, during the rainy season labour is allocated between rainfed agriculture production and livestock rearing, while during the dry season the allocation is made across livestock rearing, temporary irrigation, leisure, and off-farm activities. Thus, the labour constraint can be represented as:

$L_R^F + L_D^F + L^o - L_R^H - L_D^H - L_R^L - L_D^L \leq \overline{L}$ Household annual labour constraint,

$L_R^F - L_R^H - L_R^L \leq L_1$ Rainy season labour constraint,

$L_D^F + L_D^o + l - L_D^H + L_D^L \leq L_2$ Dry season labour constraint,

Where the super- and subscripts R stands for rainy season and D for dry season, F for farm labour, H for hired labour, O for off farm labour and L for livestock labour, while l is leisure and $\overline{L}$ total household labour endowments over the year respectively. L_1, L_2 represent rainy season and dry season specific labour endowments. Because of the seasonality of most farming activities, supply of labour may be more critical at some time of the year than others (Hazell and Norton, 1986). Thus, we disaggregated annual labour into monthly labour.

2..2.3 Fertilizer and Credit Constraints

The fertilizer type commonly used in the study area is a combination of Nitrogen, Phosphorus and Potassium nutrients (NPK) and Urea. Due to the risk associated with rainfall variability farmers apply fertilizer mainly on cash crops. All fertilizer used is purchased from the market. The fertilizer constraints on these fields can be specified as:

$$\sum_{j=1} a_f \; X_j^P - X_f \le 0 \qquad \text{Fertilizer balance,}$$

Where a_f = Kg of fertilizer f required to produce a hectare of jth crop activity and X_f= Amount of fertilizer purchased in Kgs.

$$\sum_{j=1} a_j \; X_j^P + \sum_{t=1} P_W X_t^J - X^k - \sum_{t=1} P_W X^O \le K \quad \text{Credit constraint,}$$

$$X^k \le \overline{K} \qquad \text{Credit market constraint,}$$

Where:

a_j = the amount of direct cash cost required to produce a hectare of the jth crop activity, X^k = the amount of borrowed fund, K = total available own fund in CFA and $\overline{K}$= amount of cash available from credit market (rationing in the credit market). The rationing constraint accounts for the fact that under the existing market condition, households can access to only limited amount of cash. The rationing system in the credit market can be clearly observed in agricultural input markets where farmers get fixed amount of in kind input credit.

2.3 Consumption Constraint (captured through Engel curves)

Households in the study area consume a whole set of food and non-food items. The major consumables are cereals such as Millet, Groundnut, beans and Rice. On the other hand households solely depend on the market for the purchase of some consumable items such as sugar, salt, root and tuber crops and non-food items such as kerosene.

Consumption estimates usually use Calories to measure the quantity of food consumed, this approach has advantage in aggregating different food types and also when there is policy interest to know the nutritional implication of the consumption decisions. In our case the main modelling interest is to incorporate the impact of consumption decision on overall household resource allocation decision, for which units like Kg are more useful than Calorie units, since farmers think in terms of Kg, not in Mega joules. Therefore, in order to keep consistency and ease of integration into the matrix the quantitative terms (in Kg) of consumption are retained. The empirical specification of the Engel curves is specified by the below equation.

$$KG_p = b_0 + b_1 \, TOTINC + b_2 \, HHSIZE + e_p$$

KG_P = is Kg of crop P consumed, which includes Maize, Soya, Beans and Rice, TOTINC = is total household expenditure in CFA, HHSIZE= is household size measured in the number of household members (not weighted by age or gender, for lack of data), and b's are parameters to be estimated while e is the error term.

2..4 Imposing Probabilistic Constraints

The probabilistic constraint in a Telser's SF model is specified as: $pr(Z<g)<\alpha$ Where (Z) is income level, (*g*) is exogenously determined minimum level of income a household must earn to meet obligations of high priority, pr (.) is the probability of event and (α) is an acceptable limit on the probability of goal failure.

In order to incorporate the probabilistic constraint into a linear programming model one needs to either make assumption on the distribution of income or use distribution free methods. Here, we implemented Atwood (1985) where a Lower Partial Moment (LPM) based constraint allows optimization algorithms to endogenously select the appropriate and least constraining level of (t) given statistical data set. Indeed, Atwood (1985) demonstrated that the sufficiency constraint necessary to impose the probabilistic constraint, ($\Pr(Z < g) \leq \alpha$) is: $t - L^{*}Q(t) \geq g$. Where t is a reference level below which deviations are measured, Q (t) is the LPM.

3.. Simulation of the impact of adaptation

3..1 Farm Household Classification

One approach is to aggregate all households into a mega household (e.g. Okumu, 2000). This approach ignores the heterogeneity among farm households which prevails even within a very small area. To avoid this paramount drawback, a second approach assumes that farm households' land use and technology choice decisions are governed by their objectives and constraints. The major limitation of this second approach is that it ignores the interactions among farm household groups. Because interactions among farmers are most likely not truly significant, we follow this approach in this study.

To classify farm households we first select clustering variables using factor analysis. Seventeen variables representing the households' technology use, resource endowments and adaptation strategies were used for factor analysis. We hypothesize that these choices implicitly incorporate the objectives of the farmers. The Kaiser-Meyer-Olkin (KMO) and Bartlett's test of sphericity indicated that all the variables included were relevant. Six factors which cumulatively explain about 65.21 percent of the total variance of the seventeen variables were identified. These factors have been retained according to Kaiser's criterion.

From the factor analysis results, the following variables had the largest factor loading on the first factor: operated land, quantity of fertilizer bought (NPK and Urea), farm equipment value, available own funds, credit obtained, number of household members. Since these variables measure household resources status the factor is referred to as *Resources Endowment*. The second factor has more factor loadings from the variables assets value and livestock value, thus it is referred to here as *Wealth*. The third factor has more factors loading from household irrigation practice and from the access to water for irrigation; therefore, it is referred to here as *Irrigation development capacity.* The fourth has the largest loadings from crop diversification and plant different varieties (of the same crop); we refer to it as *on farm diversification*. The fifth factor has the largest loadings from farm size reduction and change from crop to livestock so we refer to it as *livestock development*. The last factor has the largest loadings from the variables measuring off farm activities and stone bunds development; this last factor is named *Soil and Water Conservation techniques development capacity*. It is worth justifying the name given to this last factor. Off-farm activities are not soil and water conservation (SWC) technique but we posit that because off-farm activities development provides resources necessary for SWC practices, it can be consider as contributing to SWC capacity building. The results of Factor Analysis (FA) are presented in table 1 below.

Table 1: Results of Factor Analysis

Variables	Components						Total
	1	2	3	4	5	6	
Operated land	**0.823**	-0.163	0.062	-0.071	-0.016	-0.089	
Urea bought in 50 kg-bag	**0.801**	0.322	0.092	0.008	0.108	0.008	
NPK bought in 50 kg-bags	**0.798**	0.372	0.138	0.001	0.046	-0.009	
Farm equipment value	**0.756**	0.378	-0.079	-0.053	-0.113	0.102	
Available own fund	**0.629**	0.374	-0.037	-0.165	-0.036	-0.133	
Credit obtained	**0.489**	-0.168	-0.280	0.180	-0.121	0.022	
HH members	**0.339**	-0.10	-0.154	-0.163	-0.127	0.028	
Assets value	0.286	**0.854**	0.034	-0.020	-0.080	0.040	
Livestock value	0.142	**0.851**	0.015	-0.041	-0.006	0.056	
Access to water for irrigation	-0.077	0.053	**0.815**	0.015	0.034	0.038	
Irrigation dummy	0.051	-0.033	**0.809**	0.166	-0.104	0.056	
Has developed crop diversification	-0.225	0.082	0.011	**0.707**	0.074	0.132	
Has developed plant different varieties	0.047	-0.146	0.154	**0.575**	0.019	-0.113	
Has developed reduce farm size	-0.104	-0.329	-0.090	-0.011	**0.808**	0.233	
Has developed change from crop to livestock	0.018	0.119	0.041	0.136	**0.701**	-0.255	
Off activities	0.05	-0.169	-0.045	-0.102	-0.157	**0.753**	
Has developed Stone bunds	-0.131	0.084	0.68	0.131	0.238	**0.696**	
	Summary						
Sum of squares (Eigenvalues)	4.18	1.77	1.56	1.35	1.16	1.06	11.08
Percentage of trace	24.64	10.41	9.17	7.96	6.83	6.21	65.21

Source: Authors 2017 from survey data

Based on the identified factors, we select representative farm households using cluster analysis (see Hair et al., 1998 for more details on cluster analysis). There are several clustering techniques; here we used a Ward hierarchical method in combination with a non-hierarchical method. By doing this the advantage of the hierarchical method is complemented by the ability of the non-hierarchical approach to "fine-tune" the results by allowing the switching of cluster membership. Thus, the 444 farm households in the dataset were grouped into 6 clusters, one of them a single cluster (consisting of one farm only) and another one a pair cluster (consisting of two farms only). The single cluster and the pair-cluster are discarded since we conclude that they are too different from the rest of the sample. Finally, four clusters with the size of 90, 8, 40 and 303 are retained. The analysis of the characteristics of the clusters reveals that the cluster 2 (with 8 observations) has the highest level of asset value, farm equipment, own fund and operated land; so, we refer to it as *wealthier farmers group*. By contrast, the cluster 4 (with 303 observations) has the lowest level of asset value, farm equipment, own fund and operated land; we refer to it as *poorer farmers group*. These two clusters represent the "extreme cases" in our dataset. We undertake simulation analysis first for these two clusters and complement our analysis with simulations for the remaining two "middle" clusters, in order not to lose any information these two groups can provide.

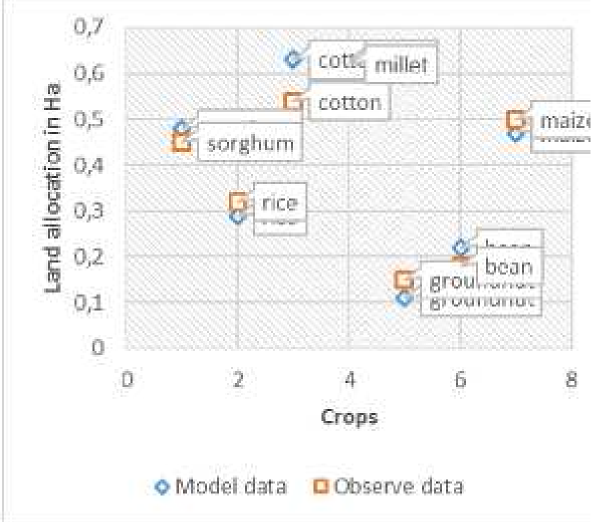
4.. Results and discussions

Farmers' perceptions of rainfall risks, reflected in their evaluation of rainfall conditions in the area, were used as a reference to elicit their subjective probabilities. The most important consideration in eliciting subjective probabilities is to organize the questions so as to help the respondents to make judgments that are consistent with their real feelings of uncertainty and as well as with the rules of probability (Dessalegn, 2005). In our survey farmers were asked to evaluate the rainfall conditions of their community for the period from 2003 to 2012 as good, normal, bad, disastrous due to floods or disastrous due to droughts. Some of the questions employed in the elicitation exercise were: "Following your characterization of the rainfall conditions in this locality, how many of the years between 2003 and 2012 had good, normal, bad, disastrous due to floods or disastrous due to droughts?". In addition, farmers were asked to name a representative year for each rainfall condition between 2003 and 2012 so as to help them have a good focus on the past rainfall events. The results of the elicitation process, indicate that on average good, normal, bad, disastrous due to floods, disastrous due to droughts conditions have a probability of 0.29, 0.34 and 0.24, 0.04 and 0.09 respectively.

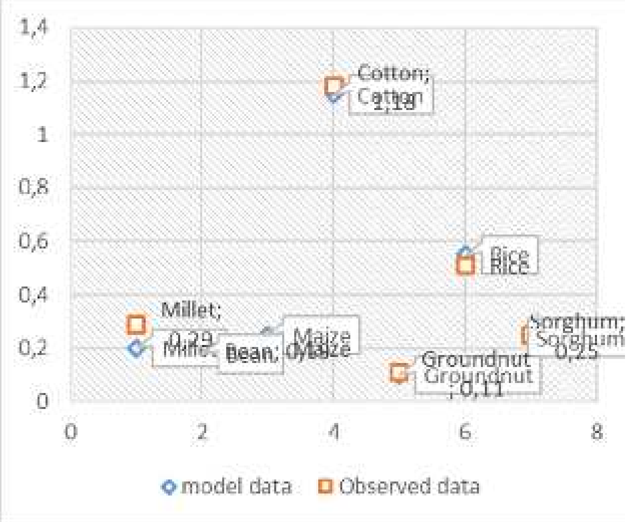
4..1 Base Run Scenario

This section tests how well the previous constructed model serves its intended purpose. Naturally, the model cannot replicate each and every empirical observation. However, this is rarely realised because of information gap between the modeller and the decision maker. Thus, the realisable approach consists to value the extent to which certain model outputs, which are of policy and research interests, are depicted. For example, Dessalegn (2005) used land use as an indicator variable to validate their model. Land allocation across different land use types is of much importance in this study, therefore we retain it as our indicator variable. Figure 2 shows how correctly the model predicts the observed data.

Figure 2: The calibration of the bio-economic model



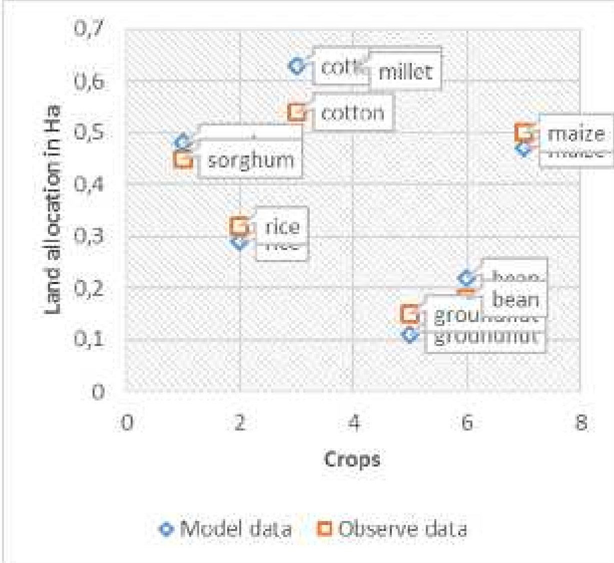
Calibration of the bio-economic model for cluster 1



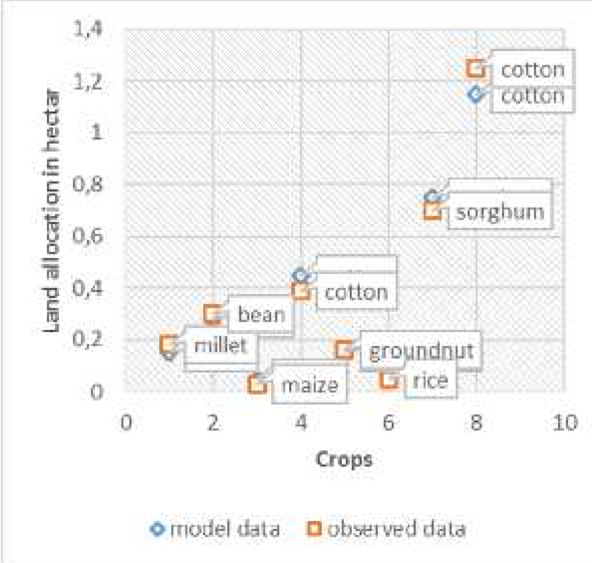
Calibration of the bio-economic model for cluster 2

Source: Authors, 2017 from simulations in GAMS

Title?



Calibration of the bio-economic model for cluster 3



Calibration of the bio-economic model for cluster 4

Source: Authors, 2017 from simulations in GAMS

We used in addition to the plotted figures above, the regression technique to assess the association of the model values with observed values. This is captured as bellow:

$$X^M = \beta_0 + \beta_1 X^o$$

X^o is observed land use type, X^M is modelled land use while $\beta_i's$ are parameters. For a valid model there is a high association between the model results and observed values and the intercept tends to be zero while the slope is one. The table 1 below gives the results of the regression.

	β_0	β_1
Values	-0.009827	1.047698
P-Values	0.545	0.000

R-squared = 0.9770

The value of the slope is 1.048 and significant at 1% level while the constant was not significantly different from zero. In addition, the R-square of 0.9770 implies that there is a very good association between modelled and observed land use. Thus, the constructed model can be used for simulation purpose.

4..2 Simulation experiment

A climate change scenario is implemented in the model through the creation of an additional climate file representing possible future climate. This scenario is based on farmers' subjective perception of future climate given the absence of scientific forecast of future climate for the study area. The new climate is an average weather condition of the five states of nature prevailing in Togo, namely: good rainfall condition, normal rainfall condition, bad rainfall condition, disastrous due to floods and disastrous due to droughts. This new climate is obtained by asking farmers to state their subjective perception of future rainfall conditions based on their past experience. The exact question was: "Based on your experience, in the ten coming years (2013 to 2023), how many years are you expecting to be Good, Normal and Bad in terms of rainfall, disastrous due flood and disastrous due to drought? The new climate file is substituted to the baseline[1] climate file (S0) to simulate the climate change scenarios (S1). The outcomes of the scenario S1 are then compared to the outcomes from the scenario S0 for the four farmers' groups retained. To assess the impact of adaptation strategies, we introduce successively the retained strategies in the scenario S1. Thus, we first introduce irrigation by converting 25% of the operating area into irrigated area, this scenario is referred to as S2. For soil and Water conservation (SWC) techniques, we supposed these techniques are implemented on 25% of the operated land, this scenario is named scenario S3. For fertilizer reduction, we reduce applied fertilizer quantity by 25%, this is the scenario S4. These figures are guided by the ongoing country policy debates regarding adaptation. The results are presented in the table 2 below.

[1] The baseline scenario in this study represents simulation outcomes from the calibration procedure

Table 2: Annual average operating profit per hectare

Scenarios (Sn)	Profits/Benefits (US$)		Percentage of variation		Residual Impacts	
	Wealthier farmers (cluster 2), n=8	*Poor farmers (cluster 4), n=303*	*Wealthier farmers (cluster 2)*	*Poor farmers (cluster 4)*	*Wealthier farmers (cluster 2)*	*Poor farmers (cluster 4)*
S0	710.54	582.34	-	-	-	-
S1	451.45	335.23	-36.46%	-42.47%	-36.46%	-42.47%
S2	693.82	487.45	+32.89%	+27.43%	-3.57%	-16.76%
S3	549.08	397.00	+ 12.94%	+ 18.34%	-24.19%	-24.54%
S4	379.86	268.16	-10.78%	12.09%	-46.99%	-54.78
	Cluster 1 (n=90)	Cluster 3 (n=40)	Cluster 1	Cluster 3	Cluster 1	Cluster 3
S0	630.32	588.90	-	-	-	-
S1	355.00	340.23	-43.67%	- 42.22%	-43.67%-	-42.22%
S2	582.17	517.67	+36.04%	+30.13%	-07.64%	-12.09%
S3	486.95	375.76	+20.93%	+06.03%	-22.75%	-36.19%
S4	289.43	269.00	-10.40%	-12.09%	-54.08%	-54.32%

Source: Authors, 2017 from simulations in GAMS

The overall research question of this study is: to which extent do private adaptation strategies mitigate climate change impacts on farm income from crops and livestock? To answer this question, the bio-economic model is solved introducing sequentially the retained strategies. From the results one can note that adaptation strategies in terms of irrigation and SWC techniques do mitigate climate change impact for all the four identified groups although the impacts vary from one group to another. Specifically, if a representative wealthier farm group household converts 25% of its operated land into irrigated area, this will mitigate on average 96.43% of the climate change impacts. However, this will reduce climate change impact by only 83.24%, 92.36% and 87.10% on average if the representative household was from cluster 4 (the poor group), or from clusters 1 or 3 (the middle groups), respectively. These performances fall to 75.81%, 75.46%, 77.25% and 63.81% for cluster 2 (wealthier), cluster 4 (poor), cluster 1 and cluster 3 (middle groups), respectively, if the converted area was devoted to SWC techniques. As one could have predicted, the reduction of applied fertilizer quantity by 25% increases the four groups' vulnerability to climate change (by 10.53% for the wealthier farm group and 12.31% for the poor farm group, for instance). The variation of impacts observed between groups is more likely the result of differences in households' managerial skills and farms' specific characteristics, though specific categories of technologies might be of various quality and efficiency across income groups (e.g. both apply water conservation, for instance rain water tanks, but not of the same quality). Clearly, irrigation practice appears to be the superior strategy for the four groups. It should be the first target for any policy aiming to reduce climate change adverse impacts on farm households' income. SWC techniques should not be ignored in the pursuit of this aim since irrigation practices could merely be impossible for some farms.

Conclusion

Achieving food security under the climate change context is a crucial challenge especially for countries relying heavily on rain-fed agriculture like in Togo. For these countries, it is crucial for agriculture to adapt to the changing climate. However, quantitative analysis of the impacts of adaptation strategies is only starting to emerge since most studies have been focusing on the impacts of climate change and adaptation adoption rather than its implications on welfare. We contribute to filling this research gap by simulating climate change adaptation options and assessing their impact on farm income from crops and livestock in the Savana region of Togo. Contrary to the existing studies on the topic, a farm modelling approach is used. The approach represents the integration of the economic decision-making environment with the spatial and temporally biophysical conditions. The findings reveal that irrigation and soil and water conservation techniques can be used to deal with the adverse impacts of climate change on farm households' income. These are of course win-win strategies with adaptation and conservation pay-offs coupled with productivity impacts. However, fertilizer reduction, an adaptation strategy used by farmers in the study area, decreases income for all farm types covered in our model: wealthier farm group, poorer farm group and the middle farm groups. Given the social benefits and private costs nature of water and soil conservation techniques, policy makers should consider their promotion to stimulate farmers' adaptation to climate change. Irrigation is also shown to have strong adaptation benefits in our model. Yet, given its high costs, there are definite financial barriers to its adoption at individual level. Support to institutional arrangements, such as community-based irrigation schemes based on local water user associations, could pay high dividends by allowing farm households to benefit from economies of scale in irrigation infrastructure. The community-based irrigation developed in the Sidiki village of the Savana region could serve as an example in the move towards such a system. The Sidiki village-based irrigation system is co-managed by the village development committee (CVD), one of the village coordination mechanisms, and the ministry of agriculture.

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