Assessing the impacts of climate shocks on farm performance and adaptation responses in the Niger basin of Benin

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Abstract

This farm-level study in the Niger basin of Benin aims to assess the impacts of climate shocks on farm activities and to simulate adaptation policy responses using a recursive dynamic mathematical programming model. Eight types of farmers were identified, and the results show that the average farm income declines under climate shocks, by 17.43 to 69.48%, compared to the baseline scenario. Farmers of agro-ecological zone II will be affected the most by climate shocks, followed by those in agro-ecological zones III, I and IV. Moreover, land and labour shadow price declines over the years due to climate shocks and extreme events. Adaptation policies, namely (i) improved irrigation, (ii) better access to credit, (iii) research and development, and (iv) better access to the labour market, contribute to coping with the adverse impacts of climate shocks on farm income. However, the success of adaptation policies depends on the ability of policymakers to implement them.

Key words: adaptation policies; climate shocks; farm income; mathematical programming; shadow prices

1. Introduction

Climate change constitutes a serious problem for the world. The planet is warming, rainfall patterns are shifting, and extreme events such as droughts, floods and forest fires are becoming more frequent (World Bank 2010). Everywhere around the world, evidence shows that the warming of the earth is unequivocal (the increases in global average air and ocean temperature, widespread melting of snow and ice and the rising global average sea level) (IPCC (Intergovernmental Panel on Climate Change) 2007). Thus, agricultural production becomes uncertain and unpredictable, especially rain-fed agriculture. However, the extent to which agriculture is subject to climate conditions differs across regions; agriculture, especially in developing countries, is expected to face serious difficulties due to climate change (Fofana 2011). For instance, Roudier *et al*. (2011) reviewed 16 studies that showed that yield impact is larger in northern West Africa (Sudano-Sahelian countries; -18% median response) than in the southern part of West Africa (Guinean countries; -13%).

Due to its high dependence on weather conditions, agriculture in Benin faces more risk and uncertainty due to climate shocks. There are two kinds of shocks, namely idiosyncratic and covariate shocks. Idiosyncratic shocks are specific to each household (e.g. death of the principal income earner, chronic illness, injury, etc.), while covariate shocks are common to every household, hence appear at the community level (e.g. floods, droughts, strong winds, etc.). Climate shocks could push some households that are already poor into the poverty trap. The issue is that, when caught in the poverty trap without any chance of aid (from government, non-governmental organisations (NGOs) or other institutions), they no longer can escape from poverty; they are on the other side of the Micawber frontier (Carter & Barrett 2006). They may develop highly risk-averse behaviour in the case where there are no policy interventions (micro-finance, insurance, irrigation, etc.), and therefore the production level will be low, leading to a vicious cycle of poverty.

The aim of this study was to assess the impacts of climate shocks on farm activities and to simulate adaptation policies using mathematical programming. Indeed, it is important to understand the extent to which climate shocks are affecting and will continue to affect the population, and which adaptation policies could be the best options to mitigate the adverse effects of these shocks. This will help to provide guidance to decision makers for improving the well-being of these mostly poor populations and for achieving the Millennium Development Goals (MDGs) and Sustainable Development Goals (SDGs).

Many authors have used mathematical programming models (bio-economic models) to simulate the impacts of risk on farming and farm planning decisions in the presence of risk due to their advantages over econometric regressions (Kingwell 1994; Barbier 1998; Visagie *et al*. 2004; John *et al*. 2005; Kehkha *et al*. 2005; Connor *et al*. 2009; Völker *et al*. 2009; Peck & Adams 2010; Fofana 2011). There also is a body of literature that assesses the impacts of climate change on agriculture using crop simulation models or agro-ecological zone (AEZ) models (Sultan *et al*. 2005; Felkner *et al*. 2009; Sultan *et al*. 2013), or econometric models, including Ricardian models (Deschênes & Greenstone 2007; Seo & Mendelsohn 2008; Koffi-Tessio 2009; Felkner *et al*. 2009; Janjua *et al*. 2010; Chebil *et al*. 2011; Kumar 2011). Yilma (2005), Fofana (2011), Sanfo and Gerard (2012) and Louhichi and Paloma (2014) have carried out policy simulation analyses in Ghana, Tunisia, Burkina Faso and Sierra Leone respectively, using mathematical programming models. This research applied mathematical programming to assess the impacts of climate shocks and to simulate adaptation policies. Moreover, extreme events (floods and droughts) are integrated in the analyses.

2. Methods

2.1 Study area

The study was undertaken among farmers of the Niger basin, which covers 37.74% of Benin, one of the poorest countries of the world. The agricultural sector employs 70% of the active population and contributes 35% to the gross domestic product (GDP) and 75% to export revenue (République du Bénin 2014). The agriculture is traditional and is characterised by its reliance on family labour, combined with limited use of improved inputs, production methods and farm equipment. Moreover, access to finance is limited outside of the cotton system. The performance of agricultural trade is weak, with a persistently negative trade balance.

The Niger basin of Benin, which belongs to the watershed of the Middle Niger,[1] is located in the extreme north of the country and covers 43 313 km^2. It is spread over five AEZs (wholly and partially) out of the eight in the country. In 2002, the Niger basin had a population of 1 012 886

[1] The Niger River is the largest in West Africa, at 4 200 km in length and with a watershed of 1 125 000 km^2.

inhabitants, with an annual rate of increase of 3.25%, which was predicted to give rise to a population of about 1 350 738 in 2012 (INSAE [Institut National de la Statistique et de l'Analyse Economique] 2003).

2.2 Data

The data for this study was collected in the Niger basin of Benin and is relative to the 2012/2013 agricultural year. Three-stage sampling was used: first, municipalities were randomly chosen within each AEZ based on their number of agricultural households; second, villages were randomly selected within selected municipalities; and last, random farm households within selected villages were selected. AEZ V was disregarded because only one of its municipalities is located in the basin. A total of 545 surveys were administered. Informal discussions were held with some leaders of farmers' organisations and also with randomly selected household heads. The informal discussions were on labour requirements for each crop, livestock feeding strategies, and fertiliser, herbicide and insecticide prices. In addition to the primary data, the study benefited from socio-economic data from INSAE, agronomic data from the Ministère de l'Agriculture de l'Elevage et de la Pêche (MAEP), and data from the general literature.

2.3 Model

This study used mathematical programming by relying on the Agricultural Household Model (Hazell & Norton 1986; Singh *et al*. 1986; Sadoulet & De Janvry 1995; Janssen & Van Ittersum 2007). The agricultural household model is about the household that is jointly engaged in production, consumption and labour supply (Singh *et al*. 1986). The advantage of mathematical programming models is their capacity to generally produce the results that best achieve the specified objective (e.g. profit maximisation or cost minimisation), given specified constraints. Another advantage is that they allow for the analysis of the technologies at both intensive and extensive margins. Moreover, they are less data intensive in comparison to other approaches (e.g. econometric or simulation) and can be dynamic or static. However, their two major limitations are that they do not explicitly capture the interaction between the agents in the model, and that they do not fully take into account the spatial dimension of agricultural activities (Berger 2001, in Van Wijk *et al.* 2012).

The empirical model uses static optimisation combined with a recursive dynamic component in which some parameters are updated every year based on the results of the previous growing period. Market imperfections are included in the model (labour and credit markets). The model is run for the planning horizon of ten years. Thus, the results of the first year of the planning horizon become the initial resources of a new model, which is solved for the following year and beyond. In this way, the model is solved for an additional 10 times, representing 10 future years. As a result if is possible to provide results on the long-term consequences of alternative assumptions about policies and market factors that are exogenous to the model.

Climate shocks are incorporated in the model through the probabilities of occurrence of the states of nature relative to the types of season.[2] Thus, climate shocks affect households' decisions through crop yields. Panel data that captures the yield level of different crops under different states of nature is not available. Therefore, the conditional yield levels are subjectively elicited by the respondents. The model incorporates the main crops and livestock production. Animal sell/buy transactions are made at the start of the planning period. For that reason, animals bought are considered in the animal feed intake planning and animals sold are excluded from the animal feed considerations. Milk activities are not considered in the model. The constraints of the model are:

[2] Five rainfall conditions are used: good, normal, bad, disastrous due to floods, and disastrous due to droughts.

- Land constraints: Land in the research area is split into four types: bush and valley bottom land, compound land (the land that surrounds the dwellings), supplementary irrigated land, and irrigated land. Correspondingly, there are four equations.

$$\sum_{c=1}^{n} X_{c,s,t} \leq A_{s,t}\ ,\ \ s = 1, 2, 3, 4 \quad (1)$$

where $c, s,$ and t are the indices of the crops, land types and years respectively, X is the land size in ha, and A is the total land size.

- Production constraints: Production should serve as self-consumption and as a means to get cash income.

$$\sum_{s=1}^{4} Y_{c,s,e,t}.X_{c,s,t} = CONSS_{c,e,t} + SOLD_{c,e,t},\ \ c = 1, 2, \dots, n\ and\ e = 1, 2, \dots, 5 \quad (2)$$

where e is the index of the probability of rainfall conditions, Y is the yield level, $CONSS$ is the quantity of crop kept for self-consumption and $SOLD$ is the quantity of crop sold.

- Labour constraints: Four periods are considered in order to take into account the peak and slack periods. Correspondingly, there are four labour constraints.

$$\sum_{c=1}^{n}\sum_{s=1}^{4} w_{c,p,t}.X_{c,s,t} \leq [(MEN_t + 0.75.WOMEN_t + 0.5.CHILDREN_t).actpop - \tau].availw_p + HIRIN_t - HIROUT_t - LEISURE_t,\ \ p = 1, 2, 3, 4 \quad (3)$$

where w is labour requirement, p is the index of the period, $MEN, WOMEN$ and $CHILDREN$ are the number of men, women and children in the household, $actpop$ and $availw$ are the proportion of active population and available working day, and $HIRIN, HIROUT$ and $LEISURE$ are hired and hired-out labour and leisure respectively. $\tau = 1$ for the farmers of agro-ecological zones I, II and III, and $\tau = 0$ for agro-ecological zone IV.

$$\sum_{c=1}^{n}\sum_{s=1}^{4} w_{c,p,t}.X_{c,s,t} = LABOUR_{p,t},\quad p = 1, 2, 3, 4 \quad (4)$$

where $LABOUR$ is total labour use for cropping.

- Labour market imperfection constraints under the assumption that hired and family labour are not perfect substitutes: Two constraints regarding the maximum labour that the households can hire and supply.

$$HIRIN_t \leq UPPERHIRIN_t \quad (5)$$
$$HIROUT_t \leq UPPERHIROUT_t \quad (6)$$

where $UPPERHIRIN\ and\ UPPERHIROUT$ are the upper bound of hired labour and off-farm labour supply respectively.

- Fertiliser balance: The sum of the fertiliser requirements times the area cultivated for each crop should be less than or equal to the available fertiliser, and this for NPK and urea.

$$\sum_{c=1}^{n}\sum_{s=1}^{4} npk_{c,t}.X_{c,s,t} \leq NPK_t \quad (7)$$
$$\sum_{c=1}^{n}\sum_{s=1}^{4} urea_{c,t}.X_{c,s,t} \leq UREA_t \quad (8)$$

where $npk, urea, NPK$ and $UREA$ are NPK requirement, urea requirement, available NPK and available urea respectively.

- Credit constraints: Fertiliser, herbicide, insecticide expenses, plus rented labour expenses should be less than or equal to the own initial available funds plus the amount of credit plus the yearly income from off-farm activities (agricultural and non-agricultural off-farm activities).

$$\sum_{c=1}^{n}\sum_{s=1}^{4} capn_{c,t}.X_{c,s,t} \leq CAP_t + CRED_t - wagein_t.HIRIN_t + wageout_t.HIROUT_t \quad (9)$$

where $capn,\ CAP, CRED, wagein$ and $wageout$ are the capital requirement, the available own funds, credit, the wage rate of hired labour and the wage rate of off-farm labour supply respectively.

- Credit market constraints: The amount of credit is less than or equal to 500 000 CFA F.

$$CRED_t \leq 500\,000 \quad (10)$$

- Consumption constraints: Through the Engel curve

$$\sum_{e=1}^{5} CONSS_{e,c1,t} - \beta_{1,c1,t}.Z_t - \beta_{2,c1,t}.SIZE_t - \beta_{0,c1,t} \geq 0,\ c1 = 1,\ 2, \dots, n_1 \quad (11)$$

where $CONSS,\ \beta_1,\ \beta_2,\ \beta_0, c1$ and $SIZE$ are self-consumption, the marginal propensity to consume crop out of income, the coefficient of variable size in the Engel curve, the lower bound of consumption requirement, the index of self-consumed crops and the household size respectively.

- Crop rotation strategies constraints

$$\alpha X_{j,t} = X_{k,t}, \qquad j \neq k \quad (12)$$

- Livestock buying and selling constraints: The actual number of animals, which is equal to the initial number of animals plus the number of animals bought, minus the number of animals sold, should be between the minimum and the maximum livestock carrying capacities of the farm. This holds for each livestock type.

$$\theta_{a,t} \leq WW_{a,t} + NN_{a,t} - ZZ_{a,t} \leq \varphi_{a,t}, \quad a = 1, 2, \dots, m \quad (13)$$

where $\theta,\ WW,\ NN,\ ZZ,\ \varphi$ and a are the minimum number of animals, the initial number of animals, the number of animals bought, the number of animals sold, the maximum number of animals and the index of livestock type respectively.

- Crop residues constraints: Sum of crop residue requirement for each livestock type times (the initial number of animal, plus the number of animal bought, minus the number of animal sold) should be less than or equal to the available crop residue quantity.

$$\sum_{a=1}^{m} feed_{a,t}.\left(WW_{a,t} + NN_{a,t} - ZZ_{a,t}\right) \leq \sum_{c=1}^{n}\sum_{s=1}^{4} yr_{c,t}.X_{c,s,t} \quad (14)$$

where $feed$ and yr are crop residue requirement and crop residues per ha respectively.

- Risk constraints: Telser's safety first (Telser 1955; Qiu *et al*. 2001) through lower partial moment (Atwood 1985).

$$\sum_{c=1}^{n}\left(SOLD_{c,e,t}.px_{c,t}\right) - t_t + d_{e,t} \geq 0, \qquad e = 1, 2, 3, 4 \quad (15)$$
$$\sum_{e=1}^{5}\left(prob_{e,t}.d_{e,t}\right) - LPM_t = 0 \quad (16)$$
$$t_t - 20.LPM_t \geq CAP_t + CRED_t \quad (17)$$

where $px, t, d, prob$ and LPM are the produce prices, the income reference level, the deviation of income from t in the rainfall conditions, the probability of rainfall conditions and the lower partial moment respectively.

- Non-negativity constraints:

$$X, CRED, CONSS, SOLD, HIRIN, HIROUT, NN, ZZ, LABOUR, d \geq 0 \quad (18)$$

The objective of the farmers is to maximise the discounted expected cash income from cropping, livestock and off-farm activities.

$$Max\ Z = [1/(1+i)^t].\left[\sum_{e=1}^{5}\sum_{c=1}^{n}\left(Prob_{e,t}.SOLD_{e,c,t}.px_{c,t}\right) - \sum_{c=1}^{n}\sum_{s=1}^{4} capn_{c,t}.X_{c,s,t} - 0.25.CRED_t - wagein_t.(HIRIN_t + FLABOR_t) + wageout_t.HIROUT_t + \sum_{a=1}^{m} priceliv_{a,t}.\left(ZZ_{a,t} - NN_{a,t}\right)\right], \quad t = 0, 1, \dots, 10 \quad (19)$$

where i is the discount rate.

The model is run with General Algebraic Modelling System (GAMS).

3. Results and discussion

The farmers produced mainly during the rainy season. Most (94.5%) produced maize, while 56.9%, 47.7%, 41.3%, 40.7%, 33%, 31.4%, 31.2% and 19.1% of them produced millet, yam, sorghum, cotton, bean, soya bean, rice and cassava respectively. Maize served mainly to earn cash income in order to afford school fees and cotton harvest costs. In terms of irrigated crops during the dry season, the major products were rice (2.8%), onions (1.8%), pepper (1.3%), tomatoes (0.6%) and okra (0.2%). Given that the subsistence and mixed crop-livestock production system is the dominant production system, livestock keeping was common among the surveyed farmers, with 43.3%, 55.6%, 42.8%, 65.1% and 4.2% of the households owning cattle, goat, sheep, poultry and other animals respectively.

Households were clustered into homogenous groups using hierarchical and non-hierarchical clustering (K-means clustering) methods (Larose 2005) in order to better describe the representative farmers. Indeed, how climatic shocks affect farmers depends on their specific circumstances. First, the dataset was split into the four AEZs, because farmers develop specific adaptive capacities in each AEZ with regard to the physical, biological and social constraints they face. To avoid using collinear variables, factor analysis was run to extract factors that are non-collinear to one another (Larose 2006). The hierarchical clustering was used first to get the number of clusters in each AEZ. This number then was used for the non-hierarchical clustering. Two clusters were built into each of the four AEZs (Tables 1 and 2). The clusters can be named as (i) less poor farm households with weak social capital, (ii) poor farm households with strong social capital, (iii) poor farm households with weak social capital, (iv) less poor farm households with strong social capital, (v) less poor farm households with weak social capital, (vi) poor farm households with weak social capital, (vii) less poor farm households with weak social capital, and (viii) poor farm households with weak social capital respectively.

Table 1: Descriptive statistics of the clusters in AEZs I and II

AEZ	AEZ I			AEZ II		
Cluster	**Less poor with weak social capital (31.25%)**	**Poor with strong social capital (68.75%)**	**Total**	**Less poor with strong social capital (8%)**	**Poor with weak social capital (92%)**	**Total**
Bush and valley bottom land in ha	6.23	2.10	3.24	9.02	7.98	8.06
Compound land in ha	1.41	0.70	0.90	6.25	0.59	1.04
Supplementary irrigated land in ha	0.88	1.35	1.22	0.11	0.03	0.04
Irrigated land in ha	0.32	0.59	0.52	0.00	0.05	0.04
Number of children	2.77	3.79	3.51	5.79	3.41	3.60
Number of men	4.32	1.93	2.59	3.57	2.27	2.37
Number of women	2.91	2.12	2.34	2.43	2.34	2.35
Yearly income from non-agricultural off-farm activities in CFA F	488 409.09	309 051.72	358 375.00	860 700.89	150 332.30	207 161.79
Yearly income from agricultural off-farm activities in CFA F	47 000.00	37 137.93	39 850.00	2 857.14	21 515.53	20 022.86
Financial assistance in CFA F	2 727.27	12 000.00	5 625.00	39 464.29	1 677.02	4 700.00
Value of assistance in nature in CFA F	159.38	1 712.17	1 285.15	1 535.71	2 182.23	2 130.51
Moral assistance	0.36	0.71	0.61	0.71	0.56	0.57
Rented labour use in man-days	186.91	19.24	65.35	138.00	57.43	63.87
Household head validated attained school years	1.53	1.72	1.59	2.29	1.23	1.31
Household head age	52.18	38.14	42.00	41.71	40.18	40.30
Credit in CFA F	70 454.55	34 913.79	44 687.50	200 000.00	5 776.40	21 314.29
Tractor use	0.00	0.24	0.08	0.00	0.04	0.03
Plow use	0.95	0.84	0.91	0.86	0.88	0.88
Livestock asset value in CFA F	1 679 665.66	754 828.50	1 009 158.72	2 492 893.52	1 750 403.56	1 809 802.76
Other assets in CFA F	304 838.18	249 460	287 532.50	350 750.00	339 280.75	340 198.29

Table 2: Descriptive statistics of the clusters in AEZs III and IV

AEZ	AEZ III			AEZ IV		
Cluster	Less poor with weak social capital (0.85%)	Poor with weak social capital (99.15%)	Total	Less poor with weak social capital (92.73%0	Poor with weak social capital (7.27%)	Total
Bush and valley bottom land in ha	8.88	4.61	4.64	2.49	2.34	2.48
Compound land in ha	1.00	0.69	0.69	0.90	1.19	0.92
Supplementary irrigated land in ha	0.00	0.01	0.01	0.00	0.00	0.00
Irrigated land in ha	2.00	0.00	0.02	0.00	0.00	0.00
Number of children	9.00	3.04	3.09	2.10	3.50	2.20
Number of men	4.00	2.48	2.49	2.76	1.00	2.64
Number of women	2.00	2.00	2.00	2.73	2.25	2.69
Yearly income from non-agricultural off-farm activities in CFA F	0.00	234 634.14	232 637.26	725 681.96	654 000.00	720 468.73
Yearly income from agricultural off-farm activities in CFA F	0.00	43 454.94	43 085.11	3 000.00	0.00	2 781.82
Financial assistance in CFA F	0.00	2 193.13	2 174.47	0.00	0.00	0.00
Value of assistance in nature in CFA F	1 875.00	1 809.45	1 810.01	2 619.81	0.00	2 429.28
Moral assistance	0.50	0.35	0.35	0.37	0.25	0.36
Rented labour use in man days	20.00	73.29	72.83	3.88	1.75	3.73
Household head validated attained school years	0.00	1.87	1.86	2.24	3.75	2.35
Household head age	49.00	40.94	41.00	41.94	30.25	41.09
Credit in CFA F	20 000.00	12 416.31	12 480.85	1 470.59	77 500.00	7 000.00
Tractor use	0.50	0.21	0.22	0.00	0.00	0.00
Plow use	0.50	0.30	0.30	0.00	0.00	0.00
Livestock asset value in CFA	2 707 536.03	942 713.63	957 733.39	74 671.57	50 604.17	72 921.21
Other assets in CFA F	724 500.00	319 026.61	322 477.45	199 827.45	424 00.00	188 378.18

3.1 Baseline scenario and model validation

The model was run first for the 2012/2013 agricultural year. The strength derived from modelling farmers' decisions is to be able to get results close to reality. Thus, any model built has to be validated. In this case, the model was validated through land allocated to each crop, through econometric regression and through mean comparison between simulated and observed land uses. The regression resulted in a slope of 0.94, which is significant at the 1% level, while the constant was not significantly different from zero (Table 3). In addition, an adjusted R-squared of 0.86 implies that there is a very good association between the simulated and observed land uses. Therefore, based on this validation test, the model can be used to simulate the impacts of climate shocks and for adaptation policy simulations. The means comparison test revealed that the difference between the means of the simulated and observed land use values (-0.004) is not significantly different from zero [Pr (|T| > |t|) = 0.72]. The model was also tested for sensitivity through changes in certain parameters. As the model does not include data from informal observations and random-generated synthetic data, there is no need to check for robustness (Yilma 2005).

Table 3: Regression results for the model validation

	Coefficients	P>|t|
$X_{observed}$	0.9354457	0.000
_cons	0.0071391	0.439

3.2 Simulation of the impacts of climate shocks

The recursive model was solved every year under the assumption that the household size remained constant during the 10 planning years. Poultry were disregarded for the simulations. The simulations showed a drop in farm income due to climate shocks (Figure 1). Farm income fell from 17.43% to 69.48% compared to the baseline scenario. These findings are in line with those of previous research. Fofana (2011) found that farm income fell by 4% to 69% due to climate change in Tunisia, depending on the scenario. Sultan *et al*. (2013) simulated the impacts of climate change on sorghum and millet yields in the Sudanian and Sahelian savannas of West Africa and found that most of the 35 scenarios developed (31/35) showed a negative impact on yield. Farmers do not change land-use patterns. They will use livestock to compensate for the fall in income, and will keep the minimum numbers of animals for reproduction and for traction purposes. They will not manage with off-farm revenue, as the labour market is not perfect. The impacts of climate shocks vary across AEZs and clusters (Table 4). On average, the poor with weak social capital farm households of AEZ II will face the greatest fall in income, whereas the poor with weak social capital of AEZ IV will experience the smallest fall in income. Actually, farmers of AEZ II will face the highest drop in income, followed by AEZs III, I and IV. Benin's trade balance will be affected, ceteris paribus, due to the fact that AEZ II is one of the two zones that produce mostly cotton.

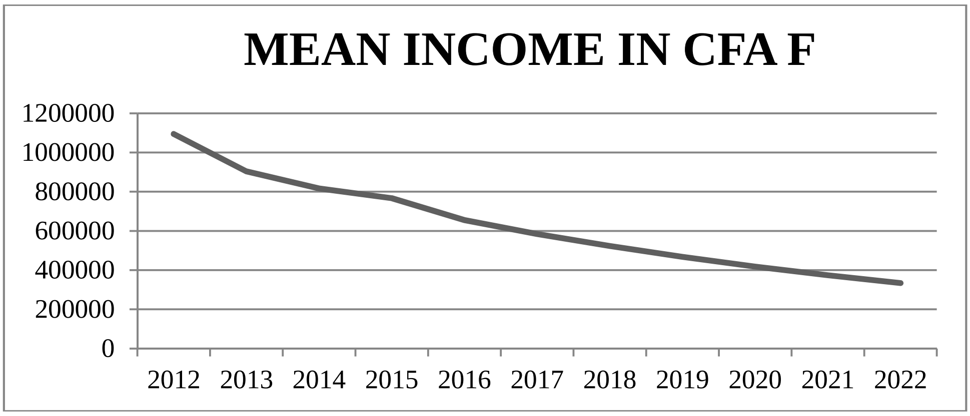

Figure 1: Simulated impacts of climate shocks on the average household's income

This study also investigated the effects of climate shocks on the shadow prices of scarce resources. However, only the results for supplementary irrigated land, irrigated land and labour are presented.[3] Indeed, investigating the effects of risk on the shadow prices of scarce resources is necessary in making decisions regarding resource development and management (Kehkha *et al*. 2005). The findings show a decline in shadow prices over years due to climate shocks. The shadow prices vary across farm types. They seem to be higher on large farms than on small farms due to increasing returns, regarding supplementary irrigated land and labour shadow prices in AEZ I only and AEZs I and II respectively. The results are in line with those of Kehkha *et al*. (2005), who found that overall, water shadow prices were greater for bigger farms. They indicated the maximum amounts by which farm cash income could be increased if an additional unit of supplementary irrigated land, irrigated land and labour was to become available. It is worth mentioning that, regarding labour, the shadow prices are relative to the peak period, specifically the period from July to September during

[3] Full details of the results are available upon request.

which farmers focus on weeding, hoeing, watering, insecticide and fertiliser application, and to a part of the harvesting period. Regarding the slack periods, labour shadow prices were equal to zero. Supplementary irrigated land and irrigated land shadow prices could be interpreted as water shadow prices due to the importance of water in irrigation.

Table 4: Percentage change in income from the baseline scenario

Years	AEZ I		AEZ II		AEZ III		AEZ IV	
	Less poor with weak social capital	**Poor with strong social capital**	**Less poor with strong social capital**	**Poor with weak social capital**	**Less poor with weak social capital**	**Poor with weak social capital**	**Less poor with weak social capital**	**Poor with weak social capital**
2013-2017 mean	-34.25	-30.69	-40.78	-168.16	-23.99	-55.56	-13.71	-11.69
2018-2022 mean	-62.84	-60.73	-65.04	-143.41	-56.48	-82.94	-51.00	-49.89
10 years' cluster mean	-48.54	-45.71	-52.91	-155.79	-40.23	-69.25	-32.36	-30.79
10 years' AEZ mean (weighted)	-46.59		-147.56[a]		-69.00		-32.25	

[a] This means that the cash income will be negative (farmers will not be able to cover the costs)

3.3 Simulations of the impacts of extreme events

This paragraph is devoted to the impacts of extreme events such as floods and droughts. It was not possible to find the forecasted probabilities of the occurrence of floods and droughts. Therefore, for the simulations, the bad rainfall conditions from the baseline scenario were converted into extreme events under the assumption that the occurrence of extreme events would increase to the detriment of the bad rainfall conditions. Indeed, the occurrence of heavy events will increase in Benin (UNDP [United Nations Development Program] 2012). First, half of the bad rainfall conditions were converted into extreme events (first scenario), and second, the overall bad rainfall conditions were transformed into these events (second scenario), and this held for floods and for droughts. The results revealed that floods and droughts negatively affect farming (Tables 5 and 6). In the case where half of the bad rainfall conditions were converted into floods, the poor with weak social capital farm households of AEZ II will be affected the most. The same category of farm households will be affected the most when all the bad rainfall conditions are converted into floods. Regarding droughts, the poor with strong social capital farm households of AEZ I will be affected the most.

As in the case of climate shocks, this study also investigated the effects of extreme events on the shadow prices of scarce resources. The results show a decline in shadow prices over the years due to extreme events. Shadow prices vary across farm types and extreme events. They seem to be higher on large farms than on small farms for the four scenarios in AEZ I, due to increasing returns regarding supplementary irrigated land and labour shadow prices. However, they are higher on small farms than on large farms regarding irrigated land shadow prices. The shadow prices obtained for the first scenarios were higher than those from the second scenarios, except for labour, in which case they were equal and followed the same path only regarding AEZ II. Thus, an increase in the occurrence of extreme events will be harmful for shadow prices.

Table 5: Simulations of the impacts of floods on the average household's income (%)

	Years	AEZ I		AEZ II	AEZ III	AEZ IV	
		Less poor with weak social capital	Poor with strong social capital	Poor with weak social capital	Poor with weak social capital	Less poor with weak social capital	Poor with weak social capital
First scenario – floods	2013-2017 mean	-32.7	-35.66	-151.14	-25.25	-39.39	-29.64
	2018-2022 mean	-61.96	-63.55	-134.63	-65.42	-65.58	-60.07
	10 years' mean	-47.3333	-49.6077	-141.963	-45.335	-52.4827	-44.8546
Second scenario – floods	2013-2017 mean	-33.38	-41.9	-152.66	2.78	-48.77	-31.41
	2018-2022 mean	-62.34	-67.09	-135.56	-49.21	-70.9	-61.08
	10 years' mean	-47.8594	-54.4957	-143.157	-23.2129	-59.8368	-46.2463

Table 6: Simulated impacts of droughts on the average household's income for AEZ I (%)

	Year	Less poor with weak social capital	Poor with strong social capital
First scenario – droughts	2013-2017 mean	-35.56	-41.67
	2018-2022 mean	-63.58	-66.96
	10 years' mean	-49.5665	-54.3166
Second scenario – droughts	2013-2017 mean	-38.51	-53.79
	2018-2022 mean	-65.24	-73.84
	10 years' mean	-51.8756	-63.812

Moreover, the irrigated land shadow prices were higher for the second scenarios than those of the first scenarios for the poor with strong social capital of AEZ I. Floods and droughts affect supplementary irrigated land, irrigated land and labour shadow prices unevenly. Indeed, the impacts of floods on shadow prices are lower than those of droughts. Thus, droughts adversely affect shadow prices more strongly than floods. This means that land and labour values decrease more when droughts occur than when floods occur. Indeed, the severity of the impacts of climate change depend on the magnitude of changes in temperature and precipitation (Fofana 2011). However, the impacts of floods and droughts are equal regarding the first scenarios and the second scenario in the case of less poor households with weak social capital in AEZ I.

3.4 Adaptation scenarios

This section contains a discussion of the management policies to be implemented by farmers and decision makers to cope with the adverse effects of climate shocks. The policies encompass four actions: (i) improve irrigation, since agriculture in Benin is mostly rain-fed and is constrained by water availability,[4] (ii) improve access to credit due to the importance of liquidity in farming, (iii) provide greater support for research and development, which is supposed to increase yield levels,[5] and (iv) ensure better access to the labour market.[6]

[4] Transform rain-fed cotton fields into supplementary irrigated fields for simplicity.
[5] A 25% improvement in maize, sorghum, millet and rice yields.
[6] Correct labour market imperfections by about 100% from the baseline scenario. This entails building roads that will enable the villages to be well connected in order to allow the mobility of labour, and also encouraging farmers through extension officers to use hired labour during the peak periods.

More time for planning and more resources are necessary for the implementation of adaptation, and farmers must increase their water availability and be ready to absorb the adjustment costs such as materials and installation costs, technician's wages and so forth (Fofana 2011). The model assumed that farmers do not face a financial constraint to implement irrigation. Farmers are assumed to face only operational charges related to additional labour need. However, in the case that the farmers will have to face high financial costs, irrigation may not be beneficial for them.

In most cases, the adaptation scenarios mitigate the negative effects of climate shocks compared to the scenarios without these measures (Table 7). The combination of supplementary irrigation in cotton production and the possibility to find available labour for hire appears to be the best measure to mitigate the adverse effects of climate shocks. This is followed by a correction in labour market imperfections of 100% combined with a perfect credit market, a correction of 100% of the imperfection in the labour market, an increase of 25% in maize, sorghum, millet and rice yields, and lastly, credit.

Although adaptation policies contribute to mitigating the adverse impacts of climate shocks, they in most cases do not compensate for the loss in income triggered by these shocks. Converting the rain-fed cotton fields into supplementary irrigated fields requires additional labour through the relaxation of the hired labour market constraint. This management technique is more beneficial to the farmers of AEZ III, especially the poor with weak social capital. It also contributes to mitigating the impacts on the less poor farmers of AEZ II with strong social capital. However, it appears costly for the remaining farmers of AEZs II and IV due to the presence of the imperfection in the off-farm labour market. The results are almost similar to those found by Fofana (2011) in Tunisia.

Even though farmers are allowed to borrow more than 500 000 CFA F, they do not like to do so. Only the less poor farmers with strong social capital of AEZ II borrow a bit more beyond the limit, and this mitigates the impacts of climate shocks by only about 0.03%. This result is similar to the finding of Sanfo and Gerard (2012), who found in Burkina Faso that credit and price stabilisation policies alone do not benefit the poorest, but rather significantly affect the wealthiest farmers. However, a correction in labour market imperfection of about 100% (hired and off-farm supply labour) leads to the same results as the combination of a correction of labour and credit market imperfection. Indeed, the labour market is important in smoothing income in the face of shocks to agricultural production (Lamb 2003).

Table 7: Simulations of the effects of management techniques on farm income

Management techniques		AEZ I		AEZ II		AEZ III		AEZ IV	
		1	2	3	4	5	6	7	8
	Cluster mean without policies	-48.54	-45.71	-52.91	-155.79	-40.23	-69.25	-32.36	-30.79
	AEZ mean without policies	-46.59		-147.56		-69.00		-32.25	
Credit	Cluster mean with policies	-48.54	-45.71	-52.88	-155.79	-40.23	-69.25	-32.36	-30.79
	Cluster impact mitigation	0.00	0.00	0.03	0.00	0.00	0.00	0.00	0.00
	AEZ mean with policies	-46.59		-147.56		-69.00		-32.25	
	AEZ impact mitigation	0.00		0.00		0.00		0.00	
Labour market	Cluster mean with policies	-46.99	-38.36	-33.88	-136.63	-63.01	27.53	-14.99	-30.20
	Cluster impact mitigation	1.56	7.35	19.03	19.16	-22.78	96.78	17.37	0.59
	AEZ mean with policies	-41.06		-128.41		26.76		-16.10	
	AEZ impact mitigation	5.53		19.15		95.76		16.15	
Credit and labour market	Cluster mean with policies	-46.99	-38.36	-33.88	-136.63	-63.01	27.53	-14.99	-30.20
	Cluster impact mitigation	1.56	7.35	19.03	19.16	-22.78	96.78	17.37	0.59
	AEZ mean with policies	-41.06		-128.41		26.76		-16.10	
	AEZ impact mitigation	5.53		19.15		95.76		16.15	
Research and development	Cluster mean with policies	-45.14	-34.38	-45.55	-111.45	-51.93	-16.90	-29.95	-29.43
	Cluster impact mitigation	3.41	11.32	7.36	44.33	-11.70	52.35	2.41	1.36
	AEZ mean with policies	-37.74		-106.18		-17.20		-29.91	
	AEZ impact mitigation	8.85		41.38		51.80		2.34	
Irrigation and labour market	Cluster mean with policies			-6.22	-209.41	-25.63	134.42	-32.62	-32.26
	Cluster impact mitigation			46.69	-53.62	14.60	203.67	-0.26	-1.48
	AEZ mean with policies			-193.15		133.06		-32.59	
	AEZ impact mitigation			-45.59		202.06		-0.34	

Note: 1: Less poor with weak social capital; 2: Poor with strong social capital; 3: Less poor with strong social capital; 4: Poor with weak social capital; 5: Less poor with weak social capital; 6: Poor with weak social capital; 7: Less poor with weak social capital; 8: Poor with weak social capital

An increase of 25% in the maize, sorghum, millet and rice yields allows farmers to mitigate the adverse effects of climate shocks. Farmers of AEZ III appear to benefit more than the rest. A deeper analysis shows that the poor farmers with weak social capital of AEZ III will gain more from the measure, followed by the poor with weak social capital of AEZ II. The less poor farmers with weak social capital of AEZ III will keep more food for self-consumption, and this will lead to a drop in income compared to the situation without adaptation measures. Indeed, the improvement of traditional crop yields leads to a significant increase in income in Ghana (Yilma 2005).

4. Conclusion

This study analysed the impacts of climate shocks on the performance of farmers' activities through a recursive dynamic mathematical programming model at the household level. Farmers were first clustered, which analysis led to two clusters in each of the four agro-ecological zones. The impacts of climate shocks on farm income were simulated up to the horizon of 2022. They show a fall in farm income of 17.43% to 69.48% compared to the baseline scenario. Moreover, farmers will not be affected evenly by climate shocks; the impacts differ across AEZs and clusters. Farmers of AEZ II will be affected the most by climate shocks, followed by those in AEZs III, I and IV. Furthermore, the impacts of extreme events (floods and droughts) were simulated and revealed that floods and droughts will have a negative effect on farming. The findings also show a decline in land and labour shadow prices over the years due to climate shocks and extreme events.

The study assumed fixed prices throughout the years. However, climate shocks could lead to an increase in prices because of shortages of crops, and the increase in output prices may outweigh the rise in input prices. The second limitation is the use of subjective evaluations of states of nature and the conditional yields of the different crops. The third limitation is the non-inclusion of interaction among economic agents. These limitations may be considered in future studies.

Some adaptation policies – (i) improve irrigation, (ii) better access to credit, (iii) research and development, and (iv) better access to the labour market – contribute to coping with the adverse impacts of climate shocks on farm income. The combination of irrigation in cotton production and the possibility to find available labour to be hired appears to be the best measure to mitigate the adverse effects of climate shocks, followed by a correction of labour market imperfection by about 100% combined with a perfect credit market, a correction of 100% of the imperfection in the labour market, an increase of 25% in the yields of maize, sorghum, millet and rice, and lastly credit. However, the success of the adaptation policies depends largely on the ability of policymakers to implement them.

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