Impact of climate change on household agricultural incomes in niger: spatial econometric analysis

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Impact of climate change on household agricultural incomes in Niger: Spatial Econometric Analysis[1]

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Abstract

This study aims at analyzing the impact of Climate Change on the incomes of agricultural households in Niger through the spatial econometric modeling. It is based on the "household life survey" carried out in 2018 on 3901 farm households. So, the study showed that estimating the impact of climate on the whole of Niger (global basis) without taking into account the variabilities of climatic zones hides the particular sensitivities of each zones. This is the case of the Saharan zone, which is more sensitive to temperature than the other zones, which are more sensitive to rainfall. Also, the results reveals that the reduction in precipitation appears to be more harmful to farmers' agricultural income than the increase in temperature. These results imply that the design of effective rural development programs and economic policies related to the fight against climate change, aimed at increasing household resilience, both in terms of adaptation and mitigation, must be done especially by taking into account the spatial variability of the impacts of climate change.

Keywords: Climate change, spatial econometric modeling, agriculture, climatic zones, Niger

1. Introduction

Climate change is a global challenge that requires urgent and imperative local solutions (IPCC, 2022). It poses a dire threat to human well-being and the planet's health by challenging its livability. According to Hans-Otto P. (2022), any delay in concerted global action would waste our precious and limited time to achieve a sustainable future.

The African continent, with an area of 29.8 million km², is particularly considered as the most vulnerable to climate change due to high climate variability, heavy dependence on rain-

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fed agriculture, and limited institutional economic ability to respond to respond to climate variability and change. (Sultan and Gaeti, 2016; IPCC, 2022)

The economic landscape of most African countries is critically dependent on the climate change's dynamics. The principal sectors which determine their economic performance and livelihoods such as agriculture, forestry, energy, tourism, coastal and water resources, are highly vulnerable to the climate variability and change (Abidoye and Odusola, 2015).

Niger is among the most fragile countries in Africa in terms of climate, environmental and economic context. The country ranks low on almost all human development indicators. Agriculture is the most important sector of Niger's economy, accounting for more than 40% of the country's gross domestic product and providing the main source of income for more than 80% of the population. Niger's economy and population highly depend on agricultural activities, particularly pastoral activities and subsistence crops (food crops which represent 76% of agricultural crops such as corn, sorghum ...) (Zakari et al, 2016).

Agriculture is essentially rainfed and cereal food crops are the basis of production. The major characteristics of Niger's agriculture are: the persistence of traditional extensive production systems, the gradual decline in yields, the high costs of production's means and the low level of prices for producers (FAO, 2016).

However, global warming accentuates the difficulties faced by the country in terms of the performance of the agricultural sector, which has become very unstable due to its high exposure to climate change and variabilities. Over the past 30 years, nigerien agriculture has experienced numerous droughts, floods, locust invasions and other parasitic attacks. These disasters constitute a blow to the household incomes, agricultural sector performance, government budget balances, and economic growth rates in Niger.

The country has four climate (or climatic) zones, and each zone responds differently to climate change. Temperatures in the Sahel, for example, are rising 1.4 times faster than in the rest of the world, exacerbating the already difficult climatic conditions and increasing the pressure on farming communities and resources. In the Nguigmi region, daily climate warming is twice that of Niamey, but nighttime climate warming in Niamey is twice that of Nguigmi, making very difficult the growing cash crops in these two regions. (Garba and Moussa, 2020).

So, studying the impact of climate without taking into account this spatial variability of climate change effects on zones could create a bias because farmers do not face the same climatic realities in all zones. So it would be interesting to see if there is a difference between observing the impact of climate without considering these climate zones or not. And this study is the first for Niger to address this issue with the spatial econometric modeling and is therefore an important contribution to the existing work.

And to evaluate this impact, one of the most widely used methods is the spatial Ricardian model (Mendelsohn et al., (1994)), which is potentially a good tool for measuring how climate change affects household agricultural incomes, what their direct and indirect effects are, and what their marginal impacts are.

So, in addition to the fact that this study with the spatial Ricardian model is new for Niger, the great innovation to our empirical cross-section analysis is to consider different climate zones for Niger because the country has four climate zones and each zone responds differently to climate change. Indeed, in the use of Ricardian model for most studies, estimates are made, generally, in a global way. More specifically, after detecting spatial autocorrelation in the data, a single coefficient is determined to explain the impact of climate on household agricultural income. However, this study takes into account the variability of the impact by estimating for each climate zones.

So, this research will be structured around five sections; the above introduction constituting the first one. The second one presents a brief review of the literature, the third one focus on the econometric methodology and the data used for estimation, the fourth one presents the empirical results and some discussions, and the last one concludes the study.

2. Literature review

To assess the impact of climate change on agriculture, the literature distinguishes three main approaches namely so-called production function model (agronomic approach), the Ricardian model and the new approach with panel data (termed pseudo-Ricardian) (Blanc and Reilly, (2017))

The agronomic approach is the traditional approach to estimating the impact of climate change based on empirical or experimental production functions to predict the environmental damages (hence this name production function approach).

In general, two sub-approaches have been developed based on the production function. These are the "analogous region" approach and the "crop growth models". The first one called the "analogous region" approach, examined potential changes in favorable climatic zones to particular crops. In this approach, we observed whether the regions which were previously favorable for crops will not be so after a climate change or those which were not favorable will be later.

The second approach of estimating the effect of climate change on agriculture is based on crop growth models. These are models that analyze the effects of climate change on crop yields because they incorporate daily data on temperature, precipitation, solar radiation and (often) atmospheric carbon dioxide, as well as soil data.

Several studies have used this approach to assess the climate-agriculture relationship such as Schelling (later a Nobel laureate in economics) in National Research Council report (1983), who talked about climate and agriculture (as well as other sectors) and the implications for welfare and policy. Schelling noted the obvious; that agriculture was exposed to weather more than any other sector but, given to the state of knowledge at that time, the overall impact was uncertain.

Although there have been numerous studies and reviews of climate impacts on agriculture with this model since the Changing Climate report (Decker et al. (1986), Richard Adams et al. (1988), Rosenzweig C. et al, (1994); Challinor et al. (2005)), Gornall et al. (2010) find that it's still not possible to determine with certirude the overall impact of climate change on agricultural productivity at the global scale using the production function.

So, the new model proposed by Mendelson, Nordhaus and Shaw (1994) called the Ricardian Model is born out of the criticisms made to the "production function" approach.

Indeed, according to that study of Mendelson et al. (1994), the agronomic or production function approach, while providing a useful baseline for estimating the impact of climate change on agriculture, has an inherent bias and tend to overestimate the impact of climate change on agriculture. This bias is sometimes referred to the "dumb farmer scenario" to suggest that it omits a variety of adaptations that farmers typically make in response to changing economic and environmental conditions. Most studies assume little adaptation and simply calculate the impact of temperature change on farm yields. Others allow for limited changes in fertilizer application, irrigation, or cultivation (see William Easterling et al, 1991).

These criticisms raise the Ricardian model approach, which builds on Ricardo's (1817) notion telling that the value of land reflects its productivity (determined by its intrinsic characteristics).

Developed by Mendelsohn, Nordhaus and Shaw in 1994 (MNS), it is a new technique that, in principle, corrects the bias of the production function's technique by using economic data on land values. It represents an approach in which, instead of looking at yields of specific crops, we examine how climate in different locations affects the net rent or agricultural land's value. By directly measuring farm prices or incomes, we include the direct impacts of climate on the yields of different crops as well as the indirect substitution of different inputs, the introduction of different activities, and other potential adaptations to different climates. If markets are functioning properly, the Ricardian approach will allow us to measure the economic value of different activities and thus verify if the economic impacts implied by the production function approach are replicated in the field.

Many authors examining the impact of climate change on economic variables such as farm income and revenue, have used this model (Mendelsohn et al, (1994); Kurukulasuriya and Mendelsohn (2008); Ochou, (2018); Ochou and Ouatara (2020); Lang, (2001); Molua, (2003); Dal l'Erba and Dominguez, (2016)).

Dal l'Erba and Dominguez (2016) showed, using the Ricardian model, how climate negatively affects agricultural yields and consequently farmers' income.

Kurukulasuriya, P. and Mendelsohn, R. (2008) in a paper titled: Differential Adaptation Strategies to Climate Change in African Cropland by Agro-Ecological Zones, quantify how African farmers have adapted their cropping and irrigation decisions to the current agro-ecological zone of their farm. The results indicate that farmers carefully consider climate and other conditions on their farms when making these choices. These results are then used to predict how farmers might change their irrigation and crop choice decisions if the climate changes. The model predicts that African farmers would adopt irrigation in a very hot and dry climate scenario, but less so in a mild and wet climate scenario.

Ochou and Ouatara (2020) wrote on the impact of climate change on farm income in Côte d'Ivoire, and demonstrated using World Bank CGAP survey data (Smallholder Household Survey Data 2016) that rainfall has direct and indirect effects on net farm income, while temperature has no effect. Furthermore, their predictions indicate that a decrease of the precipitation's average of 5-10% leads to a decrease of the farm income net's average of about 0.45% to 1.38%, while an increase in the same ranges leads to a decrease of the farm income net's average of about 0.02% to 0.05%.

The Ricardian model has not been spared from criticism, which can be grouped into three categories: the role of irrigation (Cline, (1996), Fisher and Hanemann(1998), Darwin(1999), Schlenker et al.(2005)), the assumption of price constancy (Cline, (1996)), and costless adaptation (Quiggins and Horowitz, (1999)). And faced with these various criticisms, the authors have sometimes tried to provide answers.

In addition to these three main criticisms that are most frequently raised in the literature and to which the authors have provided answers, the Ricardian model has been the subject of other criticisms, namely the failure to take into account livestock farming (Darwin, 1999), the effect of CO_2 (Kurukulasuriya and Mendelsohn, 2008), and the convex relationships between the value of land and climate variables (Darwin, 1999), (Quiggin and Horowitz, 1999) and aggregation bias (Fezzi and Bateman, 2015).

However, the major criticism that methodologically challenges the Ricardian model is that raised by Deschênes and Greenston(2007), who demonstrated that the Ricardian method does not yield stable results across time (the snapshot model). Thus, instead of a snapshot analysis, Deschênes and Greenstone propose to determine intertemporal variations in climate (panel data) in order to verify their impacts on agricultural profits

This criticism has prompted several authors to investigate the issue using panel data (Massetti and Mendelsohn(2011), Galindo and Reyes(2015), Blanc and Schlenker(2017), Mouleye et al (2020), Ochou and Quirion (2022)).

Concerning to the African continent, many analysis of the climate change's impact on agriculture have also used the Ricardian model. Ochou (2017) categorized these analyses into two groups, the first one focused on the African continent as a whole and the second one on specific African regions. In the first group, the author said, one of the most important analyses was that of Kurukulasuriya and Mendelsohn (2008). For the second group, Ochou (2018) adds, a dozen tests have been carried out, including one of the first concerning the African interior by Deressa et al. Similar analyses have also been carried out in Egypt (Eid et al., (2007)), in Zambia (Jain, (2007)), in Kenya (Kabubo et al, (2007)), in Zimbabwe (Mano and Nhemachena, (2007)), in Cameroon (Molua and Lambi, (2007)), in Maghreb (Nefzi and Bouzidi, (2009)), in Burkina-Faso (Ouedraogo, (2012); Ochou and Quirion (2017)), in Côte d'Ivoire (Ochou (2017); Ochou and Ouatata, (2020).

Despite this burgeoning number of studies on the African continent, Niger has never benefited any studies using this famous model with both cross-sectional and panel data. This applied research therefore aims to fill this gap for this country where agriculture is the main source of income for over 80% of the population (Zakari A et al, 2016). So, we opt for a traditional snapshot Ricardian model approach because of the lack of multi-year data that would help us use panel data.

In addition to the fact that the study is new for Niger, the biggest innovation to our empirical cross-section analysis is to consider different climate zones for Niger because the country has four climate zones and each one responds differently to climate change. Ouédraogo (2012) and Ochou (2017) also used this method for Burkina Faso and Côte d'Ivoire respectively. Indeed, in the use of Ricardian model for most studies, estimates are made, generally, in a global way. Specifically, after detecting spatial autocorrelation in the data, a single coefficient is determined to explain the impact of climate on household agricultural income. However, this study includes the variability of the impact in Niger.

3. Data and methodology

3.1. Description of the data

The data used in this study comes from two sources: the Climatic Research Unit (CRU) TS 4.05[5] for climate variables and the Harmonized Survey of Household Living Conditions (EHCVM-2018) of Niger, which is a national survey conducted by the National Institute of Statistics of Niger.

3.1.1. Climates in Niger

Niger has two types of climate: a hot desert climate (Köppen classification BWh) and a hot semi-arid climate (Köppen classification BSh) with variations of "winter" droughts (BWh and BSh).

It is characterized by a tropical Sudanian climate that alternates between two seasons, a long dry season from October to May and a short rainy season from May to September. It is located in one of the hottest regions of the world. The highest temperatures are recorded between March and April (over 40°C), while the lowest are from December to February where they can drop below 10°C. (Annuaire statistique du Niger ,2017).

Rainfall is characterized by a strong variation in space and time. We distinguish from the South to the North of the country: The Sahelo-Sudanese zone, which represents about 1% of the total area of the country and receives 600 to 800 mm of rain per year in normal years; it's conducive to agricultural and livestock production;

The Sahelian zone (350 to 600 mm per year) covers 10% of the country and is characterized by agro-pastoralism. The Sahelo-Saharan zone (150 to 350 mm per year) which

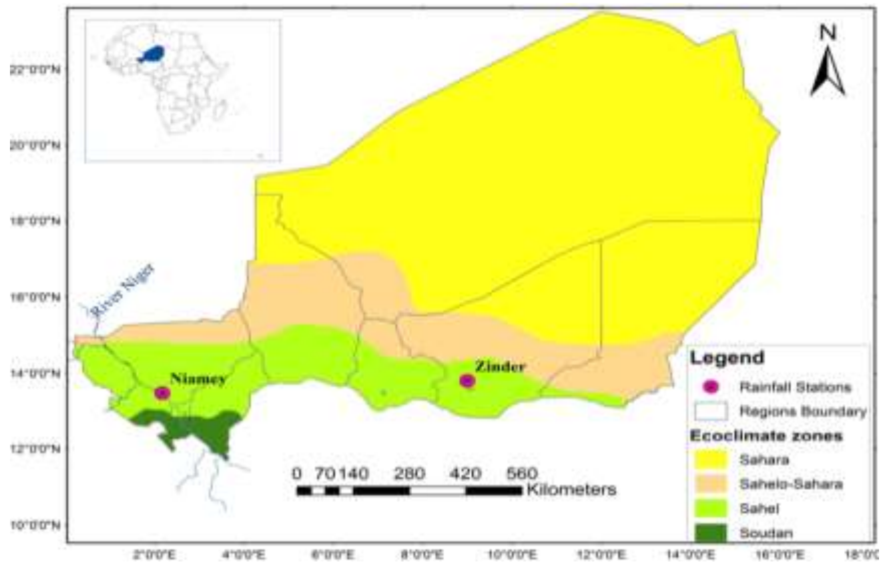
[5] The CRU data are the result of observation-derived data generated through spatialization processes (Harris et al., (2014)) for the year 2018 for each of the surveyed departments. The C.R.U data are at monthly time step and spatial resolution of 0.5°x 0.5°

covers 12% of the country and is adapted to transhumant livestock farming. The Saharan zone (0 to less than 150 mm per year) which covers 77% of the country.

Cultivated soils in Niger are generally deficient in organic matter and phosphorus. In terms of water resources, Niger, although a dry climate country, has abundant groundwater and surface water resources. The groundwater renewal rate is estimated at 2.5 billion m3 per year. Non-renewable groundwater resources are estimated at over 2,000 billion m3.

Surface water resources are estimated at about 30 billion m3 per year. (National Action Program for Adaptation to Climate Change Niger July 2019).

Figure 1: Breakdown of Niger by climate zone



Source : UNFCC

Table 1: Classification of departments in which households were surveyed according to climate zones

Climatic zones	Departments surveyed	Number of households
Saharan zone	Arlit, Diffa, Goudoumaria, Iferouane, Ingall, Maïné, Soroa, Tchirozerine	626
Sahelo-Sudanese zone	Boboye, Dioundiou, Dogondoutchi, Dosso Falmey, Gaya, Loga, Tibiri	661
Sahelo-Saharan zone	Abalak, Bagaroua, Belbedji, Birni N'Konni, Bouza, Damagaram, Takaya, Dungass, Gouré Illéla, Kantché, Keita, Madaoua, Magaria Malbaza, Mirriah, Tahoua, Takeita, Tanout	1414
Sahelian zone	Abala, Aguié, Dakoro, Gazaoua, Guidan, Roumdji, Kollo, Madarounfa, Mayahi, N'Guigmi, Ouallam, Say, Téra, Tessaoua, Tillaberi, Torodi Ville de Maradi, Ville de Niamey, Ville de Tahoua, Ville de Zinder, Balleyara, Filingué, Gothèye	1200
Total number of households		**3901**

Source : Author, based on EHCVM -Niger 2018 data

3.1.2. Agriculture in Niger

The agricultural sector occupies a central place in the Nigerien economy. It contributes over 40% of GDP and 44% of export earnings. It is, therefore, the country's leading sector of activity, employing 87% of the active population.

Agricultural activity is concentrated mainly in the south, in the Sudanian zone, on a strip of land about 200 km wide, the most watered area of the country, while the Sahelian zone in the north remains the preferred region for livestock farming. Each year, 70,000 to 80,000 hectares of new land are occupied by agriculture at the expense of forests and livestock due to the increase in population and cultivated land. The majority of agricultural production is carried out by small family farms, which are almost exclusively self-sufficient and whose techniques remain more traditional. Almost all of the cultivated land is occupied by rainfed crops, mainly millet and sorghum, cowpeas, and secondarily cassava. Most of the production, 85%, is self-consumed. Groundnuts and cotton, once important export crops, now contribute marginally to the economy. The unpredictability of rainfall, on which Niger's agriculture remains largely dependent, the persistence of drought, and poor soils are all limiting factors for agricultural productivity.

3.1.3. The variables selected for the study

a) The dependent variable

Net income per hectare is the quotient of net income by cultivated area. Net income is gross income minus the costs of hired labor, fertilizer, seed and insecticides. This variable is not directly calculated in our database, so we decided to aggregate it by the formula:

$$R = \sum Pqi * Qi(Xi, C, S, G) - \sum Px * Xi \,,$$

Where i = 1… n

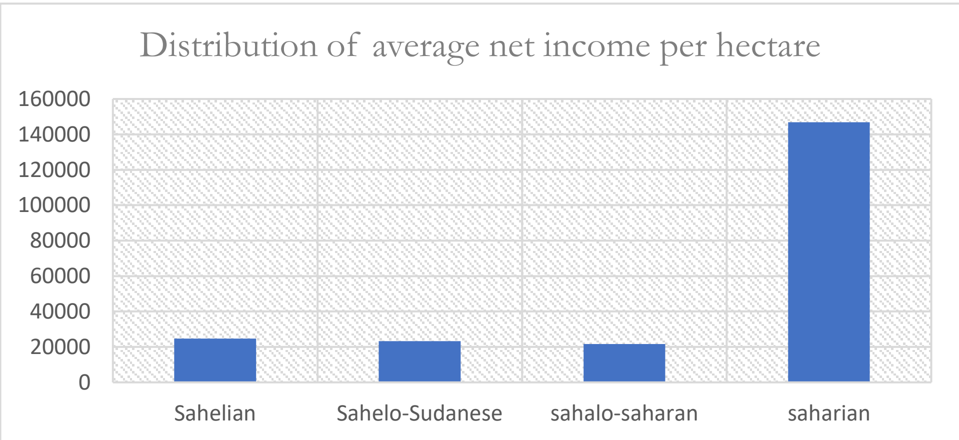
Where R is the annual income of the farmers, Pqi is the price of crop i, Qi the quantity produced for crop i, Xi is the set of inputs chosen by the farmer in this case pesticides, seeds, fertilizers, and hired labor, C the climatic factors namely temperature and rainfall, S the socioeconomic variables, G the soil types, and Px the cost of inputs.

After calculating the net income, we calculate the net income per hectare:

$Rha = \frac{R}{\sum SUPi}(1)$ where $SUPi$ is the area used for each crop i.

The variables allowed to calculate gross and net income per hectare were taken from 3901 farm households in Niger, selected from the 4 climatic regions of Niger. The figure above shows the distribution of average net income per hectare by region.

Figure 3.1.3. a: Distribution of average net income per hectare by region



Source: Author, based on EHCVM -Niger 2018 data

Looking at Figure 3.1.3.a, the average net income per hectare is highest in the Saharan climatic zone where it is above 140000 Fcfa, then is followed by the Sahelian climatic region, and very low in the Sahalo-Saharan zone where it barely reaches 20000 Fcfa/ha. The figures are summarized in Table 2.

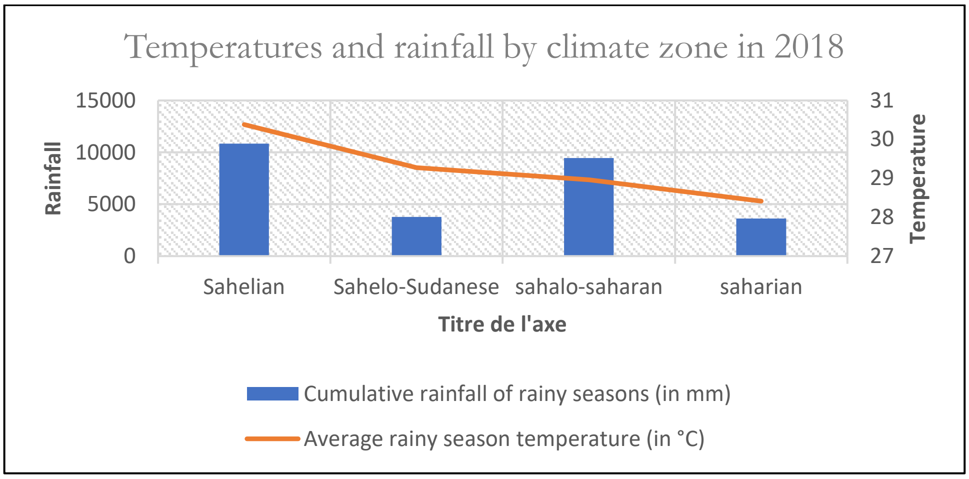
b) Climatic variables

The climatic data used in our model are those of the rainy seasons (temperature and rainfall in the rainy season). Indeed, regardless of the climatic zone, farmers' income depends on the harvest period, which depends exclusively on the current rainy season.

More specifically, for each of Niger's 04 climatic zones, we will calculate the global temperature's average. To do this, we will calculate the temperature's average for all the departments in the climatic zone under consideration.

Regarding rainfall, we will make a cumulative monthly rainfall in rainy seasons in, this to capture the amount of rainfall recorded in each area during the year. The data are summarized in Table 2

Figure 3.1.3. a: Temperature and rainfall by climate zone in 2018



Source: Author, from CRU 2018 data

Upon analysis of the graph, it can be observed that cumulative rainfall is higher in the Sahelian zone (>10000 mm and <12000 mm) and in the Sahelo-Sahelian zone (>8000 and <10000 mm). Rainfall remained low in the Sahelo-Sudanian and Sahalo-Saharan areas.

concerning the rainy season temperature's average , high temperatures are observed in all climatic zones, although temperatures in the Sahelian zones (>30 mm) are slightly higher than in the other regions and lower in the Saharan zone than in the other regions.

c) Labor force per hectare

This is the number of paid people working on the farm other than household members. The number of people employed per hectare is obtained by simply dividing the number of people employed by the area cultivated.

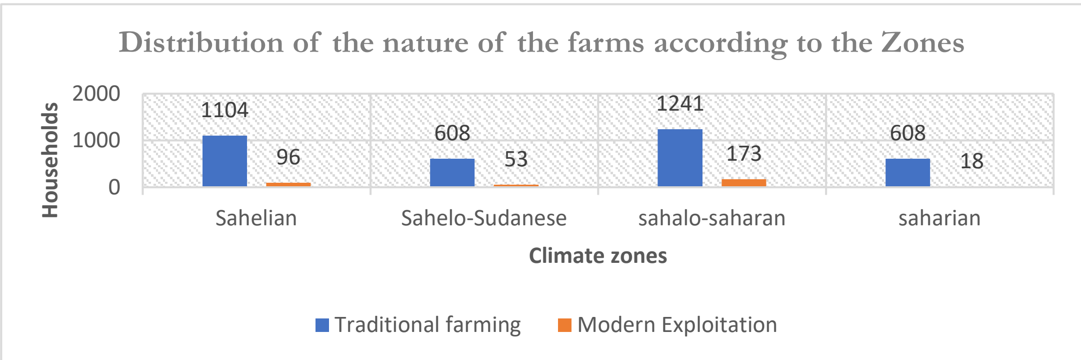
$$moh = mo/supi$$

Where mo is the labor force and $supi$ is the area of the farm.

d) The nature of the farm

The nature of the farm gives information on whether the farm is traditional (value 0) or modern (value1). We cannot know exactly all the characteristics of the traditional or modern farm in our data. Only, these terms may mean that, for modern farms, the household certainly has machinery or irrigation, whereas the opposite is true for farms in traditional farming households. Thus, we recoded to get the nature of the farm. If a farm operates manually or without l it is considered traditional and takes 0 as the value assigned to the nature of the farm and in the opposite case it takes 1 as the value associated with the nature of the farm. After recoding, we obtained 3561 traditional farms and 340 modern farms that were surveyed. The distribution of farms according to climatic regions is shown in the following figure

Figure 3.1.3. d: Distribution of the nature of farms according to climatic zones in Niger



Source: Author, based on EHCVM -Niger 2018 data

With regard to Figure 3.4 above, farms are mainly traditional in all 04 climate zones of Niger. In the Sahelian zone, they represent 92% of the farms surveyed. In the Sahelo-Sudanese zone, 91.98% of farms, 87.76% of farms in the Saharan zone, and 97.12% of farms in the Saharan zone. This can be explained by the fact that households lack the financial means to acquire modern tools and implement modern means. However, modern farms are more prevalent in the Sahelo-

Saharan zone (173) than in the other zones.

Table 2 : Summary of data used

Climate zones	Variables	Observations	Mean	Std, Dev,	Min	Max
Sahelian zone	Net income per hectare in FCFA	1200	24691,32	89303,2	-350000	1228000
	Cumulative rainfall of the rainy seasons (in mm)	22	492,2591	194,8312	81,4	849,6
	Average temperature of rainy seasons (in °C)	22	30,3803	4,15589	27,9	45,34167
	Number of people for hired labor per hectare	1200	3,390322	12,1691	0	128
	Nature of the farm (1/0)	1200				
Sahelo-Sudanese zone	Net income per hectare in FCFA	661	23339,54	51574,89	-126666,7	400000
	Cumulative rainfall of the rainy seasons (in mm)	8	471,55	145,6418	258,1	637,5
	Average temperature of rainy seasons (in °C)	8	29,275	0,7004675	28,225	30,00833
	Number of people for hired labor per hectare	661	2,06622	4,600417	0	44
	Nature of the farm (1/0)	661				
sahalo-saharan zone	Net income per hectare in FCFA	1414	21616,01	70193,24	-415000	888000
	Cumulative rainfall of the rainy seasons (in mm)	18	525,1	143,566	260,7	733,4
	Average temperature of rainy seasons (in °C)	18	28,96111	0,6879032	28,05	30,15
	Number of people for hired labor per hectare	1414	3,465201	11,55041	0	228
	Nature of the farm (1/0)	1414				
saharian zone	Net income per hectare in FCFA	626	146902,6	928235,6	-660000	2,13E+07
	Cumulative rainfall of the rainy seasons (in mm)	7	516,9429	78,17887	387,7	619
	Average temperature of rainy seasons (in °C)	7	28,4119	0,7424599	26,75833	28,95833
	Number of people for hired labor per hectare	626	5,027955	80,88722	0	2022
	Nature of the farm (1/0)	626				

Source: Author, based on EHCVM -Niger 2018 data

3.2. Methodology

Quantifying the economic impacts of climate change requires an often-complex methodology with tools drawn from economics (emission scenarios, household decision models), climate science (climate models and projections), agronomy (agronomic models), and statistics (regionalization and bias correction), each with their own share of error and limitations. (Sultan et al., 2015)

Thus, our theoretical modeling is based on the Ricardian model for which net income is used as a proxy for land value (Wood and Mendelsohn (2014)) and is regressed on climate and other variables:

$$Rev_i = \alpha_0 + \alpha_1 Clim_i + \alpha_2 Clim_i^2 + \alpha_3 MO_i + \alpha_4 NatExp_i + \varepsilon_i$$

i represents the climate zones; MO, the number of people hired on the farm per hectare; NatExp is a dummy variable that indicates the nature of the farm according to whether, it is modern or traditional. It takes the value 1 when the farm is modern and 0 when it is traditional. Clim represents the climate variables and ε the error term. α is the constant, α_i, 1...4 , the different coefficients to be estimated.

Following the procedure used by Kurukulasuriya and Mendelsohn (2008) and Ochou (2018), we determine at the mean point, the marginal impact of temperature and rainfall using the following formula :

$$E[\partial Rev_i \,/\, \partial Clim_i] = \alpha_{1,i} + 2\alpha_{2,i} E[Clim_i]$$

The quadratic term reflects the nonlinear relationship between climate variables and income.

4. Empirical Results

The descriptive statistics presented above did show us that climate zones have different characteristics, hence the theoretical motivation to perform modeling which includes these spatial differences. The calculation of the correlation between temperature and rainfall allows us to determine whether to estimate the climate variables in the same equation or to estimate different variants. We make this point to avoid the problems of convexity in the income-climate relationship detected by Quiggin and Horowitz (1999) in their critique of the Ricardian model, which would be due to problems of multico-linearity between the climate variables. In the case of a strong correlation between these two variables, we will perform two estimates (variant 1 and variant 2) with each of the climate variables taken separately. And in case of a weak correlation, we will estimate the 3 variants of equations. (With, variant 1: estimation made only with the cumulative rainfall of the rainy seasons; variant 2: estimation made only with the average temperature of the rainy season; variant 3: estimation made with the two variables simultaneously)

4.1. Analysis of correlation between rainfall and temperature

4.1.1. Sahelian Zone

The correlation coefficient between the average temperature of the rainy seasons and cumulative rainfall is 0.17. This shows that there is a very weak correlation guaranteeing the independence of these two climatic variables of interest. We therefore make estimates of net income per hectare with the 3 variants.

4.1.2. Sahelo-Sudan zone

The correlation in the Sahelo-Sudanese zone is -0.95, which reflects a very strong correlation between the two climate variables. It is therefore not appropriate to run a regression with all climate variables (Quiggin and Horowitz (1999)). We therefore estimate two variants for the Sahelo-Sudanese zone.

4.1.3. Sahelo-Saharan zone

Similarly, to the previous zone, there is a strong correlation between the two climate variables in the Sahelo-Saharan zone equivalent to 0.96. We therefore estimate two variants for the Sahelo-Saharan zone. We therefore estimate two variants for this zone as well.

4.1.4. Saharan zone

The correlation in this zone is 0.55 which is a medium or moderate correlation. Therefore, we carry out an estimation with the three variants. The first one is the regression with temperatures only. The second one with precipitation only and the last one with all the climatic variables.

4.1.5. Global

The calculation of the correlation coefficient between the average temperature of the rainy seasons and the cumulative rainfall in Niger indicates a very high correlation between these two variables, i.e., 0.998. This guarantees a strong dependence between these two climatic variables of interest leading to two regressions with the two variants.

4.2. Results

The estimations are made by bootstrap with 100 replications. We use a bootstrap because for different households from the same area, we use a single value of the climate variable. Basing on that, performing an estimation with several random draws with discounting allows us to have more accurate estimators. This method was also used by Massetti and Mendelsohn (2011) and Ochou (2017)

We first performed the Moran test to detect the presence of spatial autocorrelation. Furthermore, we suspect the presence of heteroscedasticity (which we test with the Breusch-Pagan Test) due to the difference in size of the spatial units (areas) considered.

Thus, the OLS estimation gives biased, inconsistent and/or inefficient results due to the strong spatial autocorrelation with both the adjacency matrix and the distance matrix.

After detection of heteroscedasticity in the spatial regression by Breusch-Pagan, (1979) tests, we correct for it by White's, (1980) variance-covariance matrix estimator using two-stage spatial generalized least squares (GS2SLS).

Estimates by GS2SLS yield the following results:

Table 3: Estimation results

Variables	Global		Sahelian zone			Sahelo-Sudanese zone		sahalo-saharan zone		saharian zone		
	Variant 1	Variant 2	Variant 1	Variant 2	Variant 3	Variant 1	Variant 2	Variant 1	Variant 2	Variant 1	Variant 2	Variant 3
Cumulative rainfall of the rainy seasons	200531,17*	-	10035,42*	-	17753,42*	9878,78*	-	89920,1***	-	96120,001	-	75839,89
Cumulative rainfall of rainy seasons squared	-116,51**	-	-5,9059***	-	-9,777981*	-7,5991***	-	-59,9468**	-	73,9385	-	-55,1722*
Average rainy season temperature	-	355,17*	-	835,226	744,404	-	559,05	-	222,231	-	99881,97**	91117,11*
Average rainy season temperature per square meter	-	-5,5096**	-	-11,0017	9,0017	-	7,9864	-	3,1747	-	-1664,68**	-1489,34**
Paid labor per hectare	0 ,0031*	6,2631	17,1723*	201,871*	1,02411*	784,55	77,77*	882,1***	0,1717	111,11	945,18**	0,1717*
Nature of the farm (Modern=1/ traditional=0)	-10,2153	-1,0001*	0,9582	-111,171*	0,003449	100,77	0,8971*	978,17**	1,4489	197,89	823,33	1,8639**
Intercept	182,81**	59,321	1717,72**	1003,86	444,45	832,11**	724,22*	1000,1	76,0011	890,01	1717,17**	0,7281
N	3901	3901	626	626	626	661	661	1414	1414	1200	1200	1200
Adj R-squared	0,6663	0,6201	0,6791	0,6871	0,8663	0,5189	0,5377	0,7132	0,5933	0,7717	0,7891	0,9478
Wald test of spatial terms	67,37*	58,34*	97,48*	89,38*	90,30*	77,30*	86,50*	55,05*	67,99***	101,17**	242,22**	155,89*
F-Stat	1900,5*	1824,17*	832,98*	171,59*	231,98*	332,99*	100,55*	103,09*	4,01	1,38	74,11*	917,17*
Wald chi2	12083,4*	9889,8*	888,88*	777,45*	121,33*	541,66*	99,4*	1000,98**	7,17	484,21**	888,89*	789,45

Source: Estimation of Author using stata17

Note: *, ** and *** indicate significance at the 1%, 5% and 10% level respectively.

The results from our estimations are informative or better, instructive on 3 points:

First, the model diagnosis shows us that the explanatory power of the models is well calibrated, meaning that the model is well fitted, with more than 50% of the variability of net income per hectare being explained, depending on the type of climatic zone, by the climatic variables, salaried labor per hectare and the nature of the farm. Otherwise, less than 40% of the variability in net income per hectare is explained by other factors not taken into account in these models.

In addition, the Fisher statistic reading also tells us that our famous models are globally good because the critical probabilities attached to the Fisher statistics are below the 1%, 5% and 10% thresholds, except for variants 2 and 1 for the Sahelo-Saharan and Saharan zones, respectively, which are not significant. The same is true for the Chi-square statistics (Wald test) illustrating the consideration of spatial effects, where the critical probabilities are also all below the 1%, 5%, and 10% thresholds, meaning that the existence of spatial effects in each of the variants per zone is regulated by the regression.

And finally, the Wald statistic informing the non-linearity of our regressions by zone and by variant confirms them except for variant 2 of the Sahelo-Saharan zone.

Second, the estimates with the global base (which does not take into account the climatic zones) show a high significance for our variables of interest, i.e., temperature and rainfall. We note that the Saharan zone is not sensitive to precipitation, which can be explained by the fact that this zone has an irrigation or drainage system that makes it independent of precipitation, or the zone is full of lagoon areas whose agriculture benefits greatly from its water bodies, not to mention the high rainfall present. And the other zones are not sensitive to temperature. This observation shows us that if the Ricardian model were estimated without taking into account the climatic zones and their variants, this would mask the sensitivities of certain particular zones to climate.

Furthermore, the coefficients of the quadratic terms of our variables of interest in the overall base are significant with a negative sign; this reflects a concave relationship between net income per hectare and climate (existence of the threshold). This reflects a concave relationship between net income per hectare and climate (existence of the threshold). And, singularly, all rainfall-sensitive zones have the same relationship, and the same is true for the Saharan zone, which is only sensitive to temperature.

Third, hired labor per hectare has a positive influence on net income per hectare in all cases and even for the overall base. That is, an increase in the level of hired labor per hectare also increases the level of net income per hectare. The nature of the farm has a mixed impact on net income per hectare in different cases.

4.3. Estimating direct, indirect and total effects

The results of the Spatial Durbin Error model (SDEM) regression are as follows

Table 4: Regression results of the Spatial Durbin Error model (SDEM)

Variables	Global		Sahelian zone			Sahelo-Sudanese zone		sahalo-saharan zone		saharian zone		
	Variant 1	Variant 2	Variant 1	Variant 2	Variant 3	Variant 1	Variant 2	Variant 1	Variant 2	Variant 1	Variant 2	Variant 3
Direct effect												
Cumulative rainfall of the rainy seasons	200531,17*	-	10035,42*	-	17753,42*	9878,78*	-	89920,1***	-	96120,001	-	75839,89
Cumulative rainfall of rainy seasons squared	-	-	-	-	-	-	-	-	-	-	-	-
Average rainy season temperature	-	355,17*	-	835,226	744,404	-	559,05	-	222,231	-	99881,97**	91117,11*
Average rainy season temperature per square meter	-	-	-	-	-	-	-	-	-	-	-	-
Paid labor per hectare	0 ,0031*	6,2631	17,1723*	201,871*	1,02411*	784,55	77,77*	882,1***	0,1717	111,11	945,18**	0,1717*
Nature of the farm (Modern=1/ traditional=0)	-10,2153	-1,0001*	0,9582	-111,171*	0,003449	100,77	0,8971*	978,17**	1,4489	197,89	823,33	1,8639**
Indirect effect												
Cumulative rainfall of the rainy seasons	-	-	-	-	-	-	-	-	-	-	-	-
Cumulative rainfall of rainy seasons squared	116,51**	-	5,9059***	-	-9,777981*	7,5991***	-	-59,9468**	-	73,9385	-	55,1722*
Average rainy season temperature	-	-	-	-	-	-	-	-	-	-	-	-
Average rainy season temperature per square meter	-		-	-11,0017	9,0017	-	7,9864	-	3,1747	-	-1664,68**	-1489,34**
Paid labor per hectare	0 ,7800*	7,2711	20,3331*	222,181*	2,1111*	688,43	77,77*	2,0001**	0,1717	111,12	945,23*	0,1515*
Nature of the farm (Modern=1/ traditional=0)	-7,2153	-2,6529*	0,9111	-111,171*	0,0035	111,28	0,8921*	0,7817**	1,4089	197,79	824,53	1,8755*
Total effect												
Cumulative rainfall of the rainy seasons	200531,17*	-	10035,42*	-	17753,42*	9878,78*	-	89920,1***	-	96120,001	-	75839,89
Cumulative rainfall of rainy seasons squared	-116,51**	-	-5,9059***	-	-9,777981*	-7,5991***	-	-59,9468**	-	73,9385	-	-55,1722*
Average rainy season temperature	-	355,17*	-	835,226	744,404	-	559,05	-	222,231	-	99881,97**	91117,11*
Average rainy season temperature per square meter	-	-5,5096**	-	-11,0017	9,0017	-	7,9864	-	3,1747	-	-1664,68**	-1489,34**
Paid labor per hectare	0 ,0333*	6,2622	16,1113*	201,555*	1,0251*	784,56	77,6714*	882,10*	0,1717	111,12	945,18**	0,1717*
Nature of the farm (Modern=1/ traditional=0)	-10,2221	-1,0111*	0,9666	-110,001*	0,0045	100,77	0,8555*	978,20*	1,445	197,89	823,43	1,8687*

Source: Authors based on estimates

Note: *, ** and *** indicate significance at the 1%, 5% and 10% level respectively.

The estimates of direct, indirect and total effects above show us that there is a linear direct effect of rainfall on net income per hectare in all cases except for the Saharan zone. In addition, contrary to the work of Jain, (2007); Kabubo-Mariara and Karanja, (2007) and Ouedraogo, (2012) conducted on Zambia, Kenya and Burkina Faso respectively, our estimates show that temperature does not significantly affect net agricultural income in Niger in all cases except for the Saharan zone and the global base. These results are similar to those found by OCHOU and Ouatara (2020) for Côte d'Ivoire.

The indirect effects of precipitation on neighboring areas can be explained, according to Dominguez et al. (2009), by the fact that the evapotranspiration caused by precipitation in a given locality i favors the transfer of water to the atmosphere, which is then distributed through neighboring localities, thus linking locality i to neighboring localities via atmospheric hydrological connectivity. This transfer of water increases the humidity of the air which is an important factor for photosynthesis, growth and production of plants and therefore crops. Furthermore, according to Dall'erba and Dominguez (2016), the water cycle is such that evapotranspiration from region i can lead to rainfall in neighboring region j (first-order effect), which in turn will evaporate and fall in region k (higher-order effect) or even feedback to region i.

Thus, the total effects of rainfall on farm income are nonlinear, with an inverted U shape in all cases, meaning that income increases with rainfall before decreasing from about 861 mm of rainfall, 910 mm of rainfall, 650 mm of rainfall, and 750 mm of rainfall, respectively, for the global base, Sahelian zone, Sahelo-Sudanese zone, and Sahelo-Saharan zone. And temperature has no effect on income except for the Saharan zone and the global base.

The direct, indirect, and total effects of the nature of the farm on income are mixed depending on the case. The direct, indirect and total effects of the nature of the farm on income are mixed depending on the case. And salaried labor per hectare has a positive direct, indirect and total linear impact on income in all cases. Indeed, labor is the most important input after land in rural Niger because of the low use of physical capital in agriculture. As a result, an increase in labor in a given area leads to an increase in production in that locality, and therefore in agricultural income.

4.4. Estimation marginal impacts

Table 5: Estimation of marginal impacts

Variables	Global		Zone sahélienne	Zone sahélo-soudanienne		Zone sahélo-saharienne		Zone saharienne
	Variante 1	Variante 2	Variante 3	Variante 1	Variante 2	Variante 1	Variante 2	Variante 3
Impacts marginaux (Elasticités)								
Précipitations cumulées des saisons de pluies	86221,25* (987,007)	-	8332,19* (164,490)	2385,01* (50,4619)	-	29629,14*** (690,263)	-	128470,6 (417,122)
Température moyenne de la saison des pluies	-	34,2216* (0,0233)	1286,87 (1,5889)	-	1020,56 (1,2653)	-	404,212 (0,5367)	6236,59* (1,2098)

Source: Authors based on estimates

Note: *, ** and *** indicate significance at the 1%, 5% and 10% thresholds respectively.

The marginal impacts of climate on incomes are calculated from the total effect coefficients in the previous table. The estimates show us that rainfall has a positive effect on household agricultural income in all cases and that temperatures also have the same impact, but only for the Saharan zone and the global base. These results are very telling, even though they do not take into account all of Niger's water potential, including the Niger River and the existence of groundwater that can amplify this impact. In addition, by zone, the marginal impact of rainfall is higher in the Saharan zone, followed by the Sahelo-Saharan zone, then the Sahelian zone and finally the Sahelo-Sudanese zone. Specifically, when rainfall increases by an average of 1mm, net revenue per hectare increases by about 128471 FCFA, 29639 FCFA, 8333 FCFA, and 2385 FCFA for the Saharan, Sahelo-Saharan, Sahelian, and Sahelo-Sudan zones, respectively. These differences in the total marginal effects observed in the different zones are consistent with Niger's reality and almost coincide with the division of the country into agro-climatic zones.

Indeed, two of these agro-climatic zones have extreme characteristics and rainfall has a particular impact on agriculture. The northern zone (Ténéré, Aïr) where rainfall is limited to 100-150 mm/year and the Sahelo-Sudanian zone characterized by a dry season from September to October and June with high temperatures that can reach 45-46°C. The rainy seasons here extend from June to September, only three months, making access to water very difficult and painful for some crops.

Similar results showing the positive impact of rainfall on farm income have also been found by some authors. For example, Temesgen (2007) found that increased rainfall levels also generate increased income levels in Ethiopia. Thapa and Joshi (2010) also found this for Nepal, Ajewole et al. (2010) for Nigeria; Kabuto and Karanja (2007) for Kenya; Muchena (1994) for Zimbabwe; Lee et al. (2012) for Asia. Using U.S. data on agricultural production and climate variables, Deschênes and Greenstone (2012) concluded that rainfall can increase agricultural profits by up to $1.3 billion, depending on the choice of functional form adopted for the climate variables.

Another explanation of these results comes from Kurukulasuriya and Mendelsohn (2008). In their paper concerning Differential Adaptation Strategies to Climate Change in African Cropland by Agro-Ecological Zones, they quantify how African farmers have adapted their cropping and irrigation decisions to the current agro-ecological zone. The results indicate that farmers carefully consider climate and other conditions on their farms when making agricultural choices. These results are then used to predict how farmers might change their irrigation and crop choice decisions if rainfall changes. The model predicts that African farmers would adopt irrigation in a low rainfall scenario.

5. Conclusion

Climate change currently represents an important three-dimensional issue, namely environmental, social and economic. Niger is one of the most vulnerable countries in the world due to the context of its climate, environment and economy: Niger's economy and population are highly dependent on agricultural activities (occupying more than 80% of the population and representing 40% of the GDP), particularly pastoral activities and subsistence crops (which represent 76% of agricultural crops such as corn, sorghum, etc.).

So, the desire to empirically analyze the impact of climate change on the incomes of agricultural households in Niger led us to realize this study. To do that, the study used spatial econometric techniques to analyze this impact. Thus, we performed the Moran test to detect the presence of spatial autocorrelation and after detecting heteroscedasticity in the spatial regression by the Breusch-Pagan, (1979) tests, we corrected it by the White, (1980) variance-covariance matrix estimator using the two-stage spatial generalized least squares (GS2SLS). In addition, we estimated direct, indirect, and total effects using Spatial Durbin Error Model (SDEM) regression.

Therefore, the study showed that estimating the impact of climate on the whole of Niger (global basis) without taking into account the climatic zones hides the particular sensitivities of certain zones. This is the case for the Saharan zone, which is sensitive to temperature and rainfall in particular to a greater extent than the other zones, which are only sensitive to rainfall.

Overall, the study illustrated that climate change will have negative impacts on the incomes of agricultural households in most of the country. The results reveal that agricultural incomes in Niger are more sensitive to rainfall than to temperature.

These results imply that the design of effective rural development programs and economic policies related to the fight against climate change, aimed at increasing household resilience, both in terms of adaptation and mitigation, must be done not only in a global manner but especially by taking into account the spatial variability of impacts of climate change.

To this end, the study recommends strengthening institutional factors such as access to credit, markets, extension services, group membership, and the use of crop varieties that are resistant to reduced rainfall in Sahelo-Saharan, Sahelian, and Sahelo-Sudan zones. In fact, each climate zone must be supported by local communities in order to submit viable adaptation and mitigation projects that can affect the daily lives of these farming households. For example, strategies geared towards irrigation policies could be beneficial insofar as an influx of water would play the same role as an increase in rainfall. Similarly, training in drainage or rainwater management techniques could help them increase their income.

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