Spatial Analysis of Climate Effect on Agriculture: Evidence from Smallholder Farmers in Côte d'Ivoire

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Research Paper 508

Bringing Rigour and Evidence to Economic Policy Making in Africa

AFRICAN ECONOMIC RESEARCH CONSORTIUM
CONSORTIUM POUR LA RECHERCHE ÉCONOMIQUE EN AFRIQUE

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AERC Research Paper 508
African Economic Research Consortium
June 2022

THIS RESEARCH STUDY was supported by a grant from the African Economic Research Consortium. The findings, opinions and recommendations are those of the authors, however, and do not necessarily reflect the views of the Consortium, its individual members or the AERC Secretariat.

Published by: The African Economic Research Consortium
P.O. Box 62882 - City Square
Nairobi 00200, Kenya

ISBN 978-9966-61-208-3

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Acknowledgements

We are grateful to the African Economic Research Consortium (AERC) for financial support, and to all resource persons for their valuable comments and suggestions, with particular thanks to Professor Théophile Anzoumahou, the main resource person of this study. Any opinions expressed in the paper are those of the authors and should not be attributed to their respective institutions.

Abstract

Climate change has been affecting the agriculture sector over the past few decades. This impact could have serious consequences for farmers in developing countries. This paper applies the spatial approach to assess the response of agricultural net revenue to climate change in Côte d'Ivoire. It first uses a simple static comparative approach, to show that market imperfection induces spatial heterogeneity in agricultural product prices and hence spatial autocorrelation. Taking these findings as a point of departure, empirical analysis uses a Spatial Durbin Error Model based on 2016 World Bank Smallholder Household Survey Data from Côte d'Ivoire. Results reveal that rainfall has a non-linear direct effect and positive linear spillover effects on agricultural net revenue. In addition, the paper shows that the total marginal effect of rainfall is positive in the central, eastern and northern regions of the country and negative in the coastal and western regions. Moreover, predictions indicate that a decrease in average precipitation of between 5% and 10% leads in general to a decrease in the average net agricultural income from about 0.45% to 1.38%, while an increase in the same ranges leads to a decrease in the average net agricultural income from about 0.02% to 0.05%.

Keywords: Climate change; Spatial autocorrelation; Spatial Durbin Error Model; Net revenue; Côte d'Ivoire
JEL Code: Q54 ; C21

1. Introduction

Agriculture is an economic activity subject to various sources of risk (such as fluctuating markets, government policies, invasion of pests). Among these, climate risk seems to be the most significant, according to literature from recent decades. Indeed, climate appears as a direct input to agricultural production which escapes the control of farmers. Any unforeseen variation in climate parameters likely leads to significant losses in agricultural production and, therefore, exacerbates the vulnerability of the poorest populations, especially in countries where agriculture is heavily dependent on rainfall.

For example, rainfall disturbances observed in Côte d'Ivoire since the 1960s have exposed Ivorian agriculture to many problems, including lower yields, loss of seeds, desertion of crops and modification of agricultural calendars (Dibi Kangah and Mian, 2016; N'da, 2016). Climate parameters, in particular rainfall and temperature, experience different variations between localities and over the years, partly due to climate change. The temperature rises gradually while the water supply decreases over the long term in response to climate change. The subsequent instability in agricultural production creates economic and social disruption in several regions of the country (Brou et al, 2005). Furthermore, forecasts indicate that future changes in temperature and precipitations will lead to changes in land and water regimes that will subsequently affect agricultural productivity in Côte d'Ivoire (Ahossane et al, 2013; Läderach et al, 2013). These production losses may have profound consequences for smallholder farmers for whom the vulnerability is particularly liable to be acute, given technological and resource constraints. Their incomes are likely to experience significant variations. Therefore, the analysis of the effects of climate change and/or climate variability on the incomes of smallholder farmers in Côte d'Ivoire requires special attention. Thus, our study aimed to analyse the effect of climate change on the incomes of smallholder farmers in Côte d'Ivoire.

From a general point of view, the concerns induced by climate change regarding the agriculture sector have given rise to several studies which have attempted to show the relationship between climate and agriculture in order to assess the effect of climate variability or climate change on the sector. These studies generally fall into four categories: (i) the agronomic model (Rosenzweig, 1985); (ii) the traditional Ricardian model using cross-section data (Mendelsohn et al, 1994; Kurukulasuriya and Mendelsohn, 2008a; Wood and Mendelsohn, 2014; Khan et al, 2021); (iii) the

Ricardian model with panel data qualified as "pseudo-Ricardian" (Deschênes and Greenstone, 2007; Baylie and Fogarassy, 2021); and (iv) controlled agricultural laboratory experiments, which carefully isolate the effect of temperature and carbon dioxide (CO_2) on agricultural yields (Adams et al, 2001). In addition to these four groups defined in the literature, there is a new trend which uses the Ricardian model with the econometrics of spatial data (Dall'erba and Domínguez, 2016; Vaitkeviciute et al, 2019).

Most of the studies conducted in Africa use either the traditional Ricardian model or pseudo-Ricardian models. The studies generally show that climate change has non-linear and significant effects on net agricultural income per hectare with greater sensitivity to future increases in temperature (Jain, 2007; Kabubo-Mariara and Karanja, 2007; Ouedraogo, 2012). However, the Ricardian model has been the subject of many criticisms (Darwin, 1999; Polsky 2004; Schlenker et al, 2005, 2006; Deschênes and Greenstone, 2007), among which the price constancy hypothesis is recognized as a source of bias (Cline, 1996). This criticism constitutes a major gap in studies on African countries using this approach. Indeed, this hypothesis suggests that markets are perfect and therefore crop prices are spatially identical. This could not be realistic, especially for cross-sectional data on developing countries such as Côte d'Ivoire. In these countries, transaction and/or transportation costs act as a brake for the mobility of agricultural products so that price equilibrium after an imbalance in a given locality cannot be achieved instantly. What is more plausible is to assume that prices are balanced locally, within a small perimeter. The idea is that a price increase in a given locality ii can only immediately attract products from the nearest localities, and not from the remote localities due to transportation costs. As a result, in the short-term, price can only be constant within a given area. Furthermore, the classic Ricardian model ignores the interactions that may exist between different localities. For example, Rogers (1995) and Polsky (2004) explain the influence that some farmers in one area can have on others when they are in contact. These criticisms have recently led some authors to consider the spatial approach in the analysis of the relationship between agriculture (Schlenker et al, 2006; Dall'erba and Domínguez, 2016; Vaitkeviciute et al, 2019) and climate in addition to the other methods still in use in the literature.

Studies carried out in Côte d'Ivoire focused on the analysis of variance (A::NOVA) which relates climatic parameters and a specific crop production through the correlation coefficient (Dibi Kangah and Mian, 2016; N'da, 2016). However, this approach is limited insofar as it does not enable the capture of the marginal effects of climate parameters on agricultural production. In addition, it omits both the spillover effects induced by some variables on the variable of interest and the possible non-linear effects of climatic parameters on agricultural production.

Our study is more in line with the dynamics of the spatial Ricardian model and aims to analyse the effect of climate change on agricultural income in Côte d'Ivoire. We adopted the empirical model specification, Spatial Durbin Error Model, which captures both the direct and indirect marginal effects of climate as well as those of other explanatory variables responsible for spatial dependence. In addition, this specification accounts for the spatial autocorrelation induced by omitted variables.

The analyses are made using survey data from the World Bank database (Anderson, 2017) on small agricultural households in Côte d'Ivoire and satellite data from the Climate Research Unit (Harris et al, 2020). In general, the results show that rainfall has a total non-linear effect (in the shape of an inverted U) on the net agricultural income in Côte d'Ivoire as shown by previous studies (Kurukulasuriya and Mendelsohn, 2008a; Ouédraogo, 2012). However, this total effect is broken down into two effects: a direct non-linear effect and a positive and linear spillover effect within a radius of 50 kilometres. In addition, the analysis of the marginal effects shows that all the regions of Côte d’Ivoire are not affected by rainfall in the same way. Furthermore, some variables such as cooperatives and average household size also have spillover effects on net agricultural income in Côte d'Ivoire. These latter results are not reflected in the previous literature. The absence is probably because previous studies did not consider the spatial autocorrelation induced by these variables.

In view of the above, this study advances the existing literature in several directions. First, it provides theoretical proof of the questioning of the hypothesis of spatial constancy of prices in the classical Ricardian model, and then adopts a spatial approach instead. In addition, it establishes a clear distinction between the direct and indirect effects of climate variables as well as those of other explanatory variables on net agricultural income in Côte d'Ivoire. Finally, it assesses the marginal effects of climate variables on each of the studied localities, and then carries out a forecast analysis to assess the future effects of the climate on net agricultural income in Côte d'Ivoire.

The remainder of the paper is organized as follows: Section 2 presents the structure of agricultural markets in rural areas of Côte d’Ivoire; Section 3 provides theoretical proof of the questioning of the price constancy assumption that supports the classic Ricardian model, and presents the empirical model of analysis; Section 4 gives the different results, while Section 5 analyses the effect of the future climate on net farm income in Côte d'Ivoire. Finally, Section 6 concludes the study and offers some policy recommendations.

2. Market structure for agricultural products in rural areas of Côte d'Ivoire

Agricultural activity is mainly motivated by self-consumption and income. This last objective naturally depends on agricultural production, and also on the prices of products, which are themselves strongly influenced by the structure of agricultural markets. Indeed, the size of the market, the barriers to market access and the flow of information are all factors that define the price formation mechanism and the direction of product flows from one market to another. In developing countries in general, the type of product (cash crop or food crop) also defines how the market works. In Côte d'Ivoire the agricultural market may be subdivided into two main groups: the market for cash crops and that of food crops. In the cash crop market, the government sets prices for producers (farm gate price). However, the effective exchange of products is most often done through negotiations between producers and agricultural cooperatives, which act as intermediaries between farmers and buyers. These negotiations usually result in prices lower than those at farm gate, and are different across localities. The argument in favour of cooperatives is that the difficulty of accessing some of the production areas results in significant transportation or transaction costs that these cooperatives will have to bear.

Food crops are sold in local markets (rural and urban), where prices are set by the law of supply and demand. Rural markets are characterized by an extreme asymmetry of relations between many small producers and/or consumers and a few buyers and/or sellers. Such market relations are inequitable, often uncompetitive and generally to the disadvantage of the small-scale producer. They result from several factors. The first is the physical aspect, which is characterized by a total lack of roads or impassable roads at crucial times of the year. This results in high transportation and/or transaction costs for both buyers and sellers. The second aspect relates to the scale of the market. In many rural communities, especially those in more remote areas where population density is low, limited demand for factors of production and the resulting minimal production attracts very few buyers. As a result, the markets are mostly held once a week and the prices remain very low and vary significantly from one locality to another, depending on the volume of produce. These disparities in the prices of agricultural products in rural markets lead to rural producers moving to the nearest towns, according to market day. However, this movement of products is limited by several factors that prevent mobility, the most significant of which is the transportation cost, positively correlated with distance and road conditions. Therefore, the decision of households to sell their produce on a given market results in a trade-off. The following section gives a theoretical analysis and the consequences of this phenomenon to the traditional Ricardian model.

3. Methodology

Theoretical rationale of the spatial approach to the Ricardian model

The traditional Ricardian model is a cross-sectional approach that assesses the effect of climate and other exogenous variables on the value of agricultural land considered as the expected present value of future rents. However, due to lack of data on land values, several studies instead use annual net income per hectare as a dependent variable (Kurukulasuriya and Ajwad, 2007; Mendelson et al, 2007). This is because net agricultural annual income is assumed to reflect net productivity and crop prices. Moreover, just like land value, agricultural net annual income is assumed to depend on climate and a set of other exogenous variables following the equation:

$$RN = \sum_k p_k q_k(X,F,Z,G) - WXRN = \sum_k p_k q_k(X,F,Z,G) - WX \qquad (1)$$

where p_k represents the market price of crop; k, q_k the production of crop k; F the vector of climate variables; Z Z the vector of soil characteristics; G the vector of socio-economic characteristics of the household; $X X$ the vector of inputs; and W the vector of input prices (Mendelson et al, 2007). The farmer is supposed to choose the vector of inputs X and crops k which maximize net income per hectare under the constraint of soil and market characteristics. That is:

$$\max_{X,k} RN = \sum_k RN_k = \sum_k p_k q_k(X,F,Z,G) - WX \qquad (2)$$

This action is before production. Farmers, ignoring the prices of agricultural products, choose the vector $X^* = X\,(P,F,Z,G,W)$ (demand function of agricultural production factor) and crops $k^* k^*$ which give them the maximum net income given climate and other socioeconomic and land characteristics. They then obtain the optimal net income $RN^* = RN\,(P,F,Z,G,W)$ which in reality is purely theoretical. Indeed, it is the expected income that motivates farmers to choose inputs and crops by getting an idea of the future price of agricultural products and the climate. This income differs from the effective net income, which is the product of the effective quantity and the effective prices that prevail after the harvest.

The traditionally used Ricardian model is based on theoretical net income and, therefore does not reflect price effects. It does not take into account the spatial variations in production prices that result from changes in the structure of local markets which could affect adaptation decisions at the farm level. Rather, this study assumes that prices differ from one locality to another and that after the harvest farmers have the option of choosing the price of the locality that gives the highest possible income.

From this assumption, we stand after production assuming a farm household that produced n distinct agricultural products. For each product, the farmer has the choice between m markets (the market here being the physical place where buyers and sellers of agricultural products meet); that is, the markets of m distinct localities. It is assumed that each locality has only one market. This last assumption is based on the fact that transportation costs within the same locality are negligible so that the prices of agricultural products are identical in all the markets of a locality with more than one market. By choosing market i for a given product k, the household bears a transportation cost:

$$C_{ki} = d_i \psi_{ki}(k, q_k^*, e_i) \quad (3)$$

where d_i represents the distance between the locality of residence of the household and that where the market i is located (in other words, it is the distance between the local market and the market ii); and $\psi_{ki} > 0$ is a function which depends on the nature the product k (perishable or not, breakable product etc.), the quantity of product to be carried q_k^* (resulting from problem stated in Equation 2) and the state of the road e_i. $e_i \in]\,0,1\,[$ is a continuous variable indicating the road condition. The closer e_i is to zero, the worse the road is and the higher the transport cost. So,

$$\frac{\partial \psi_{ki}}{\partial x_i} > 0; \quad \frac{\partial \psi_{ki}}{\partial e_i} < 0\,; \quad \lim_{e_i \to 0} \psi_{ki} = +\infty$$

Therefore, the farmer’s second problem (after production) is given by:

$$\begin{cases} RN^e = \sum_k RN_k^e \\ RN_k^e = \sup_i \{RN_{ki}^* = p_{ki}^e q_k^* - C_{ki}\} \ (i = 1, .., m) \end{cases} \quad (4)$$

where $q_k^* = q\ (P, F, Z, G, W)$ represents the agricultural supply function of crop k obtained in problem (2); and p_{ki}^e is the effective price of product k prevailing in market i different from the price p_k which is the farmer's expected price of crop k at the planting period. The price p_k depends on the beliefs of the farmer and therefore on his/her socioeconomic characteristics, and is consequently not observable. What is observable is the effective price in each market (at the harvesting period) and this price directly affects net income. This means that:

$$RN^e = RN\ (P^e, F, Z, G, W) \quad (5)$$

where P^e is the vector of effective prices.

The effective agricultural net income from the sale of product k on market i is therefore given by:

$$RN_{ki} = p^e_{ki} q^*_k - C_{ki} \quad (6)$$

From the above hypotheses, the following results are obtained.

Proposition 1

The household chooses the market *i* instead of the market *j* if the price gap between the two markets is greater than the gap in average transport costs between the household's locality of residence and each of the two markets.

Proof proposition 1

The proof is straightforward, based on the assumption that household chooses market i over market j if the profit made on market i is greater than the profit made on market j, that is:

$$RN_{ki} \geq RN_{kj}$$

Substituting each member of the equation by its expression as shown in Equation 2 and rearranging gives:

$$p^e_{ki} - p^e_{kj} \geq \frac{1}{q^*_k}\left(\psi_{ki} d_i - \psi_{kj} d_j\right) \quad (7)$$

Corollary 1

The household chooses market *i* instead of the local market if and only if the resulting sum of local market price and the average cost of transport is lower than the price prevailing on market *i*.

Proof of corollary

Choosing local market l implies that $d_l = 0$. Substituting this in Equation 7 we deduce that the household chooses market ii for product k instead of local market l if and only if:

$$p^e_{kl} + \frac{\psi_{ki}}{q^*_k} d_i \leq p^e_{ki}$$

$\frac{\varphi_{ki}}{q^*_k} d_i$ represents the average cost of transportation (cost per unit of product))

Proposition 2

Whatever the price of market ii, there is a distance (respectively a road condition) beyond which (respectively below) the household always chooses the local market.

Proof of proposition 2

Consider the Equation 7 and suppose that:

$$h(d_i) = p^e_{kl} + \frac{\psi_{ki}}{q^*_k} d_i \text{ and } g(e_i) = p^e_{kl} + \frac{d_i}{q^*_k} \psi_{ki}(k, q^*_k, e_i).$$

This arises:

$$\lim_{d_i \to \infty} h(d_i) = +\infty \Longrightarrow \forall p_{ki}, \exists \bar{d}, \forall d_i \geq \bar{d}, h(\cdot) \geq p^e_{ki}$$

$$\lim_{e_i \to 0} g(e_i) = p^e_{kl} + \frac{d_i}{q^*_k} \lim_{e_i \to 0} \psi_{ki} = +\infty \Longrightarrow \forall p^e_{ki}, \exists \bar{e}, \forall e_i \leq \bar{e}, g(e_i) \geq p_{ki}$$

Proposition 2 shows that a rise or fall in price does not necessarily rebalance. In the short term, the price variation in locality i can affect agricultural net income of nearby localities, but not those of remote localities because of the transportation cost, which increases when the distance increases or when the road conditions deteriorate. Thus, a price increase induced by unfavourable climate conditions in a locality i can only be offset by a decrease in prices induced by favourable climate conditions in a given region j if this locality is close enough to the locality i or if the road leading to this locality is in an acceptable condition to allow the movement of products from j to i.

Empirical approach to assessing the effect of climate on agricultural income

From Equation 5, the standard empirical Ricardian model expresses income as a quadratic function of climate variables as follows (Mendelsohn et al, 1994):

$$RN^e = \beta_0 + \beta_1 F + \beta_2 F^2 + \beta_3 Z + \beta_4 G + u \quad (8)$$

In the previous section, we showed that variables such as distance and road condition create barriers to the mobility of agricultural products from one market to another. This leads to price heterogeneity in the different markets, and therefore to spatial heterogeneity of agricultural income for the same quantity of a given agricultural product. However, climate variables could induce indirect effects due to the proximity of the regions considered. Similarly, there are technology transfers between neighbouring localities. All these factors create a spatial autocorrelation that is not taken into account by the traditional Ricardian model (Equation 8). However, in the presence of spatial autocorrelation, ordinary least squares (OLS) estimators are biased, inconsistent and/or inefficient (Anselin, 1988). To correct this limit Schlenker et al. (2005, 2006) recommend a Spatial Error Model (SEM) given by:

$$RN^e = \alpha\iota_n + X\beta + u \quad (9)$$

with $\boldsymbol{u} = \lambda W u + \varepsilon$ and $\varepsilon \sim N(0, \sigma^2 I_n)$

where $\boldsymbol{W}$ is a $n \times n$ matrix called a weight matrix containing the elements measuring the distance (or indicating the neighborhood relationship) between the different localities studied; $\boldsymbol{X}$ the vector of explanatory variables; and $\boldsymbol{\beta}$ the vector of the parameters to be estimated.

However, according to Dall'erba and Dominguez (2016), the problem with this specification (Equation 9) is that the estimated parameters capture the average marginal effect of the explanatory variables on the dependent variable as if there were no spillover or spatial effects. Indeed, in this case, the direct and the indirect effects remain the same. This is because the disturbances do not come into play when considering the partial derivative of the dependent variable with respect to changes in the explanatory variables. Like Dall'erba and Dominguez (2016), we believe this assumption is unrealistic, at least in rural areas of Côte d'Ivoire. Undeniably, as shown above, a strong variation in rainfall, for example, or the influence of a cooperative in an area, can cause a variation in prices, which would in turn lead to a shift of agricultural products from the closest areas to this locality. This attraction gradually decreases as the distance increases due to increased transportation costs and reduced earnings for producers. This shows that in the short term, there is an indirect effect of some of the explanatory variables on agricultural income via the pull effect induced by prices, which cannot be measured by the model described in Equation 9. Thus, in the presence of spatial autocorrelation, the above model gives consistent, but biased, estimators. To correct this bias, we adopt in this study, a Spatial Durbin Error Model (SDEM) specified as follows:

$$RN^e = \boldsymbol{\alpha \iota_n} + \boldsymbol{X_1 \beta_1} + \boldsymbol{X_2 \beta_2} + \boldsymbol{W X_2 \theta} + \boldsymbol{u} \qquad (10)$$
$$\boldsymbol{u} = \boldsymbol{\lambda M u} + \boldsymbol{\varepsilon}$$

where $\boldsymbol{X_1}$ is a set of explanatory variables assumed to have no spatial effects; $\boldsymbol{X_2}$ is the set of explanatory variables assumed to be responsible for spatial dependency; and $\boldsymbol{W}$ and $\boldsymbol{M}$ represent weight matrices capturing respectively the indirect (spillover) effects of explanatory variables and the spatial autocorrelation of the error term induced by missing variables. These matrices can be equal or different depending on the phenomenon studied. The advantage of the SDEM is that it makes it possible to measure both the direct and the indirect (spillover) effects of the explanatory variables on the dependent variable.

The direct and indirect effects of the explanatory variable $x_i x_i$ on the agricultural income $\boldsymbol{RN^e}$ are given by:

$$\frac{dRN^e}{dx_i} = \beta_{2i} + \theta_i \qquad (11)$$

where β_{2i} represents the direct effect; and θ_i the spillover effect of x_i on $\boldsymbol{RN^e}$.

Data sources and description

Data sources

We used two types of data: socioeconomic and climate. Socioeconomic data were derived from the World Bank database survey (CGAP, 2016) on small agricultural households in Côte d'Ivoire. This survey was carried out using three questionnaires. The first questionnaire dealt with basic household information (property and characteristics of the home) and was addressed to the head of the household or an informed adult. The second is addressed to all household members over 15 years old, participating in household agricultural activities. This questionnaire dealt with demographic data, agricultural activities and economic data of the household. The third questionnaire was addressed to an adult randomly chosen from the household, and dealt with overall agricultural activities, and formal or informal financial tools. We therefore reconciled these three databases using the household identifier. This allowed us to obtain a database with all the questions (answers) of the unique respondents for each household, in this case the heads of households. From the question relating to the municipality of residence, these households were then distributed over 510 localities covering the entire country (municipalities), and which constituted the analysis sample. In other words, data were aggregated so that each locality represented the average agricultural household living in this locality.

As for the climate data, it comes from the C.R.U. TS 4.03 data (Climate Research Unit of University of East Anglia). The C.R.U. are the result of data derived from observations, generated through spatialization processes (Harris et al, 2020) for each of the regions surveyed. C.R.U. data are at monthly time step and at a spatial resolution of 0.5° × 0.5°.

Description of variables

Socioeconomic variables

The socio-economic variables used in this study are the average agricultural net income per year by locality (REV), the percentage of male heads of household by locality ($SEXE$), the average agricultural experience of the head of household by locality (EXP_AG), the average land area owned by households by locality (SUP_POS), the average number of family labour by locality (MOF), and the rate of household membership in an agricultural cooperative by locality ($COOP$).

The annual net income per household is obtained by multiplying the monthly net income by 12, the monthly net income being equal to the gross monthly income less the monthly production costs. This information was obtained based on household declarations. To ensure that the income reported by farmers was farm income, we only considered households that had exclusively agriculture as their source of income. The average annual income by locality was obtained by aggregating the average income per household for each locality. This choice is justified by the fact that the agricultural households in each locality have similar socioeconomic characteristics. They also face the same climate conditions. The dependent variable considered here is the logarithm of average monthly agricultural income by locality ($ln(REV)$).

(EXP_AG), (SUP_POS), MOF and ($COOP$) are obtained following the equation $Z = \frac{1}{n_i}\sum_{j=1}^{n_i} z_{ij}$, where $Z \in \{EXP_{AG}, SUP_{POS}, MOF, COOP\}$, where n_i is number of observations in locality ii and z_{ij} is the value of the related variable of household j in locality i.

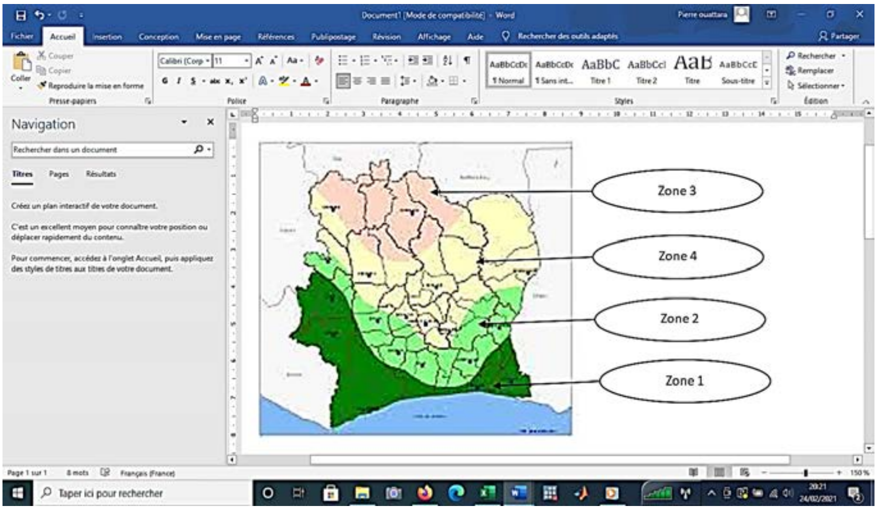
Apart from the membership rate of agricultural cooperatives, the other socioeconomic variables are those usually used for the analysis of the effects of climate on agricultural income. The inclusion of the membership rate of agricultural cooperatives as an explanatory variable of agricultural income stems from the fact that in rural areas of Côte d'Ivoire, agricultural cooperatives are very important. Indeed, they strongly influence production through the facilitation of access to certain inputs such as land, fertilizers, pesticides and also prices through their strong negotiating power. In addition, family labour can strongly affect agricultural income through its effect on production.

Climate variables

We used temperature and precipitation as climate variables to assess the impact of climate change. The climate data considered in this study are those of the rainy seasons (average temperatures and cumulative precipitations in the rainy season). In fact, whatever the zone, farmers' income depends on the period from sowing to harvest, and this depends exclusively on the current rainy season. Since the survey period covers April to May 2016 (corresponding to the start of the rainy season for most localities), we assume that the income declared by households is the income obtained from the year's harvests. We, therefore, use the rainy season periods of 2015 for each of the 510 localities. More precisely, for the localities of the south, this period goes from March to July and from September to November. For the localities of the central region, the period runs from April to October, and for those of the north, from May to October. The seasons of each locality are determined by their respective climatic zone (Ochou et al, 2005; Kouadio et al, 2007)).

To take into account the types of crops in each locality, we introduced dummy variables for each locality belonging to each of the four agroclimatic zones covering the entire country. Côte d'Ivoire is subdivided into four agroclimatic zones (see Figure1) within which farmers cultivate almost the same types of crops, given the climatic conditions and the physical properties of the soils.

Figure 1: Agroclimatic zones in Côte d'Ivoire



Source: Adopted from Yao et al (2013)

Weight matrixes

We used two different weight matrices to estimate Equation 10, namely a contiguity matrix and a distance matrix. This double consideration is justified by the fact that, as presented in the theoretical model developed in Chapter 3, transport costs are strongly correlated with distance. To capture this effect, we consider a normalized inverse weight matrix $\boldsymbol{W_d}$ whose elements w_{ij} is given by:

$$w_{ij} = \frac{1}{d_{ij}/r_{0,max}}$$

Where $r_{0,max}$ indicates the largest eigenvalue of the distance matrix before normalization $\boldsymbol{W_0}$ and of which each element d_{ij} represents the distance between the localities i and j. This standardization is preferred to row normalization because according to Elhorst (2001), and Kelejian and Prucha (2010), row normalization is likely to lead to specification problems insofar as the normalized weight matrix is no longer symmetrical, meaning that the effect of locality ii on locality j is different from the effect of j on i.

Inverting the normalized coefficient of the matrix allows us to capture the fact that the closer the localities are, the greater the spillover effect, and it decreases as the distance increases. In addition, we considered distance matrix $\boldsymbol{W_0}$ because, like Dall'erba and Dominguez (2016), we believe that constructing spatial offsets based on physical distance (distance from the great circle) is a better way to account for the continuous nature of the landscape physical and climate conditions as adjacencybased matrices that are based on political boundaries. To account for the fact that the distance reduces the attraction of other markets with respect to a given locality and because of the small size of the localities studied, we assumed the effect of spillover of the markets fade beyond 50 kilometres.

To capture the indirect effect of the omitted spatial variables such as the type of soil or the state of the roads (variable not available) we used a contiguity matrix of order 2 ($\boldsymbol{W_c}$). That is, we assumed both the effect of the immediate neighbours and that of the neighbours of the immediate neighbours. The neighbourhood is defined by the localities sharing a common border. The summary of the data is given in Appendix 1.

4. Results and interpretations

The distribution of agricultural net income by locality shows that income seems to be clustered (Appendix 2). This suggests a possible presence of spillover effects between the different localities. To be convinced of this, we tested for the presence of spatial autocorrelation using the Moran I test. In addition, we suspected a presence of heteroscedasticity (which we were testing) due to the difference in size of the spatial units (localities) considered. Table 1 gives the results of the spatial autocorrelation test and that of the test for the constancy of variance of the error term (Breusch-Pagan/ Cook-Weisberg test).

Table 1: Spatial autocorrelation and heteroscedasticity tests

	Moran I test		Breusch-Pagan/Cook-Weisberg test
	Matrix W_c	Matrix W_d	
$\chi^2(1)$	5.58	4.74	6.68
$Prob > \chi^2$	0.0182**	0.0295	0.0098***

$***\, p < 0.01***\, p < 0.01$ $**\, p < 0.05**\, p < 0.05$ $*\, p < 0.1*\, p < 0.1$

Source: Authors' calculations

The Moran I test shows that the null hypothesis of normality and independence of the distribution of the error term is rejected using the contiguity matrix. However, this hypothesis cannot be rejected when using the distance matrix. This indicates the presence of strong spatial autocorrelation induced by several unobserved independent variables and supports the specification of Equation 1. This proves our initial hypothesis: The OLS estimate therefore gives biased, inconsistent and inefficient results. This justifies the use of a spatial model. Furthermore, the Breusch-Pagan/ Cook-Weisberg test rejects the null hypothesis of constancy of error variance, thus indicating a high heteroskedasticity of errors. This leads us to estimate the two-step generalized least squares of Equation 10, which is the appropriate method for cross-sectional data with spatial autocorrelation and heteroscedasticity of errors.

Table 2: Spatial Durbin Error Model (SDEM) model estimation results

Variables	SDEM – Option gs2sls heteroscskedastic		
	Direct effects	Indirect effects	Total effects
$lnREV$			
$CONST$	-51.64 (0.276)	–	–
$CONST$			
$SEXE$	0.1874* (0.098)	–	0.1874* (0.098)
EXP_AG	0.0001 (0.993)	–	0.0001 (0.993)
$COOP$	0.1843** (0.045)	-6.14** (0.022)	-5.96** (0.028)
SUP_POS	- 0.0018 (0.799)	–	-0.0018 (0.799)
SUP_POS			
MOF	0.0781** (0.014)	-0.97* (0.073)	-0.8978* (0.099)
TM	4.65 (0.192)	–	4.65 (0.192)
TM^2TM^2	-0.089 (0.177)	–	-0.089 (0.177)
$PREC$	0.0064715*** (0.003)	0.0042* (0.053)	0.0107*** (0.001)
$PREC^2$	-3.35e-06*** (0.000)	-1.91e-06 (0.159)	-5.26e-06*** (0.002)
$ZAGR1ZAGR1$	0.3133* (0.053)	–	0.3133* (0.053)
$ZAGR2ZAGR2$	0.0874 (0.424)	–	0.0874 (0.424)
$ZAGR3ZAGR3$	0.0205 (0.885)	–	0.0205 (0.885)

Source: Authors' calculations

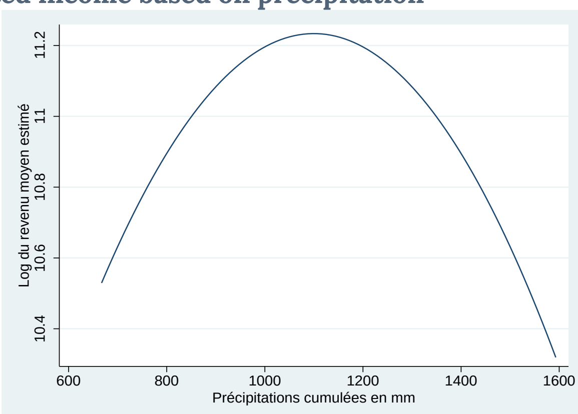
*** $p < 0.01p < 0.01$ ** $p < 0.05p < 0.05$ * $p < 0.1p < 0.1$; values in parentheses represent p-values

Results of the Spatial Durbin Error Model (Equation 10) are summarized in Table 2. Unlike in studies carried out in Zambia (Jain, 2007), Kenya (Kabubo-Mariara and Karanja, 2007) and Burkina Faso (Ouedraogo, 2012), our results show that temperature does not significantly affect agricultural net revenue. In addition, the results show both non-linear direct effect and linear positive indirect effect of rainfall on agricultural income. This indirect effect can be explained by the fact that the evapotranspiration caused by the precipitation of a given locality i promotes the transfer of water to the atmosphere, which is then distributed through the neighbouring localities, connecting the locality i to neighbouring localities via atmospheric hydrological connectivity (Dominguez et al, 2009). This transfer of water increases the humidity of the air which is an important factor in photosynthesis, growth and production of plants (and therefore crops). Moreover, according to Dall'erba and Dominguez (2016), the water cycle is such that the evapotranspiration from region ii can lead to rains in neighbouring region j (first order effect), which, in turn, will evaporate and fall into region k (higher order effect) or even feedback to region ii.

This last explanation can be seen in Appendix 3, which shows that the distribution of precipitation across the different localities studied is clustered. Thus, the total effect of rainfall on agricultural income remains non-linear, with an inverted U-shape as shown by previous studies using the Ricardian model. In terms of total effects, income increases with precipitation before decreasing from about 1,150mm.

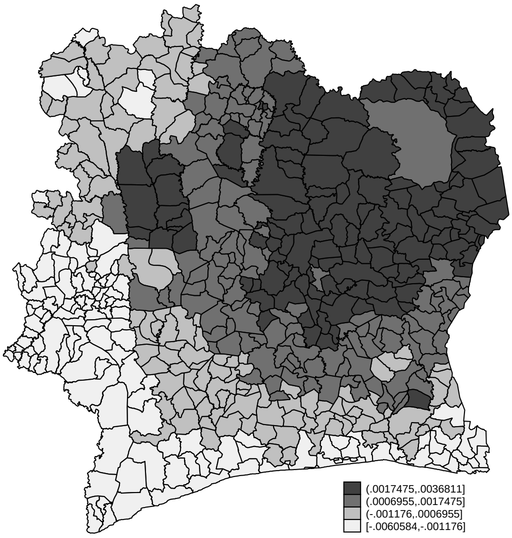
Figure 2 shows the total marginal effect of climate on the different localities studied. This impact is calculated from the derivative of Equation 10 with respect to precipitation. That is, $\frac{dRN^e}{dPREC} = (\beta_{PREC} + \theta_{PREC}) + 2\beta_{PREC^2}PREC$ (Vaitkeviciute et al, 2019). We then used the coefficients of the total effects from Table 2 to estimate the marginal impact of rainfall on agricultural net revenue. The result indicates that the total marginal effect of precipitation is positive in the central and northern regions and ranges between 0.0007 and 0.004 but negative in the coastal and western regions (it ranges between -0.006 and -0.001). However, it remains mixed in the intermediate zone between the coast and the centre (between -0.001 and 0.0007) (Figure 2). This means that a decrease (respectively increase) in precipitation in the centre and the north (coast and west respectively) would lead to a drop in the income of farmers in these localities.

Figure 2: Estimated income based on precipitation



This result is in line with the Ivorian reality since the north naturally records low levels of rainfall unlike the coastal and western areas. The differences in the total marginal effects observed in the different zones almost coincide with the division of Côte d'Ivoire into agroclimatic zones (see Figure 1). For example, in the coastal and western zones (agroclimatic zone 1), agricultural activity is more geared towards perennial crops such as coffee, cocoa or rubber, which constitute the main export crops. This could explain why the income in this area is statistically higher than that of the others (see Table 2).

Figure 3: Total marginal effect of climate on net revenue



Furthermore, cooperatives positively and significantly affect agricultural income within the localities where they operate, but they have a negative and significant spillover effect on neighbouring localities within a radius of 50 kilometres. Indeed, an average increase in the number of cooperative members of 1% in a given locality ii creates an increase in average agricultural income of 0.18% in this locality, but leads to a 6.14% drop in income in neighbouring localities. Thus, the resulting effect (total effect) of this increase on overall agricultural income remains negative and significant.

The contrary signs of the direct and indirect effects of agricultural cooperatives on agricultural income between localities can be explained by the fact that cooperatives allow farmers to increase their production in the localities where they operate by facilitating access to land, finances and inputs. This increased production creates an increase in the supply of agricultural products in these localities. The result is, therefore, a fall in prices, which in turn creates a movement of agricultural products to neighbouring localities. This shift creates an increase in supply of agricultural product in the neighbouring localities and leads to lower prices. The phenomenon spreads like a shock wave, the effect of which gradually decreases with distance (due to transport costs), until prices stabilize within a radius of 50 kilometres. At equilibrium, the resulting price is relatively lower than it was initially. But the effect of this price drop is offset by the increase in production in the localities where the cooperatives operate. In this locality, average agricultural income increases while the neighbouring localities suffer from the drop in prices, which reduces their income.

A similar phenomenon can be observed with the family workforce in each locality. Indeed, family labour is the most important input after land in rural areas of Côte d'Ivoire due to the low use of physical capital in agriculture. Therefore, an increase in family labour in a given locality leads to an increase in production in that locality. This increased production causes the same phenomenon described in the paragraph above, thus creating opposite direct and indirect effects.

Robustness check

According to spatial econometric theory, spatial models result may be sensitive to spatial weight matrix. In this section, we check for stability of results using an alternative spatial weight matrix. This matrix is built based on the principle of gravity models. The idea here is that there is a mutual attraction between two distinct localities, which is an increasing function of the population densities of the two localities, but a decreasing function of the distance. Thus, the elements of the gravity matrix are given by: $M_{ij} = \frac{D_i D_j}{d_{ij}}$, where D_i and D_j are densities of locality i and j respectively. The elements of the corresponding spectral normalized matrix are given by: $m_{ij} = \frac{M_{ij}}{w_{max}}$, where w_{max} is the largest eigenvalue of the gravity matrix. This last matrix is therefore used instead of the distance matrix to estimate the SDEM. Results are summarized in Table 3. The direct effects remain unchanged to a few decimal places for all variables, while the indirect effect of rainfall becomes non-linear with the gravity matrix. In addition, the indirect effects of cooperatives and family labour become insignificant. This affects the total effect of these two last variables in such a way that they are no longer significant.

This difference in results using the two different matrixes is not surprising, as they do not measure the same reality. The gravity matrix measures the power of attraction between different localities. It does not reflect the effect of transportation cost on people's decisions to move from one place to another. Indeed, using the population density in the calculation of the weights of the gravity matrix, we reduce the effect of distance and therefore the effect of transportation cost. Indeed, a locality i located at a great distance from a locality j can have a strong attraction because of its high population density compared to a locality k located a short distance from j with a low population density.

Table 3: Estimates of the Spatial Durbin Error Model (SDEM) using gravity matrix

Variables	SDEM – option gs2sls heteroscskedastic Direct Effects	Indirect Effects	Total Effects
lnREV			
CONSTCONST	-12.842 (0.805)	–	-12.842 (0.805)
SEXE	0.198* (0.060)	–	0.198* (0.060))
EXP_AG	0.006 (0.628)	–	0.006 (0.628)
COOP	0.094** (0.004)	0.503 (0.540)	0.771 (0.348)
SUP_POS *SUP_POS*	-0.0018 (0.799)	–	-0.0018 (0.799)
MOF	0.0789** (0.010)	-0.202 (0.331)	-0.124 (0.556)
TM	1.609 (0.669)	–	1.609 (0.669)
TM^2TM^2	-0.031 (0.669)	–	-0.089 (0.177)
PREC	0.0055** (0.013)	0.002* (0.075)	0.007*** (0.003)
$PREC^2$	-2.69e-06*** (0.006)	-1.11e-06 (0.037)	-3.80e-06*** (0.001)
ZAGR1ZAGR1	0.259 (0.105)	–	0.259 (0.105))
ZAGR2ZAGR2	0.096 (0.370)	–	0.096 (0.370)
ZAGR3ZAGR3	0.044 (0.739)	–	0.044 (0.739)

Source: Authors' calculations

However, all other things being equal, the cost of transport from j to i must logically be higher than that of j to k. Subsequently, a farmer located at j is more attracted to locality k than locality i if the price of agricultural products is equal in these two localities, as he supports lower transportation cost.

Therefore, the consideration gravity matrix in the regression of SDEM gives biased results in the spatial case of this study, as one of the main hypotheses is that the transportation cost affects the farmer decisions. Consequently, the results obtained with the inverse distance matrix are more appropriate for this study.

5. Impact of future climate on agricultural net revenue

The work of Janicot (2012) on the attribution of recent decadal variability in West Africa predicts a slight decrease in rainfall by between 5% and 10% by 2090–2099. Despite difficulties in making forecasts, especially for rains, the 5th report of the IPCC (2014) forecasts for West Africa and more precisely near the Gulf of Guinea, (where Côte d'Ivoire is located), a 10% decrease in rainfall under the RCP2.6 scenario to a 10% increase under the RCP2.8 scenario for the period 2081–2100 compared to the period 1986–2005.

Table 4: Variations in average income according to the different climate scenarios

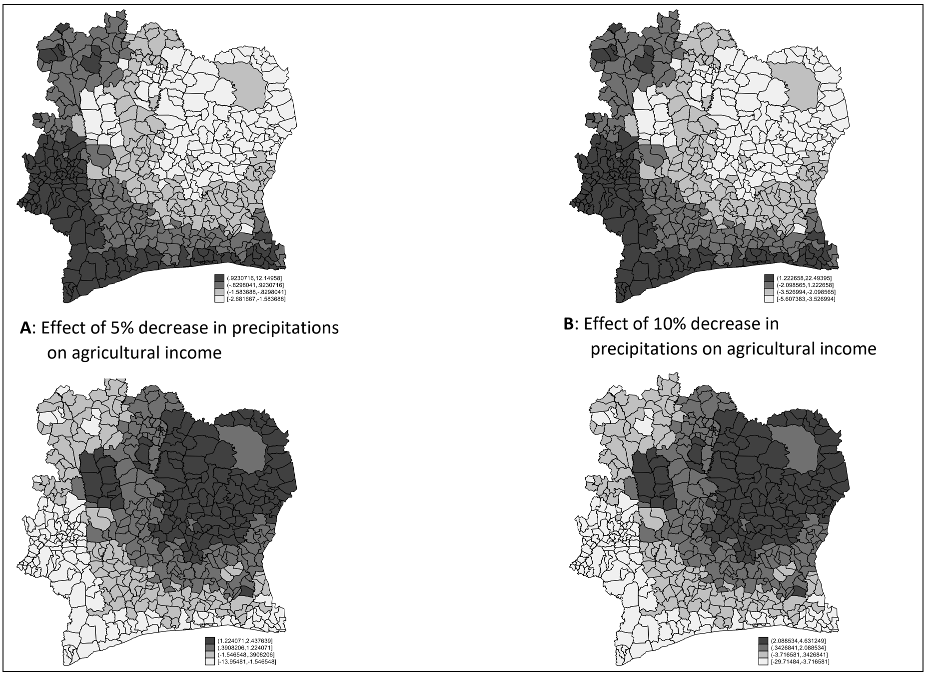
Scenarios	Variations in average income
−10%	−1.38%
−5%	− 0.45%
5%	−0.02%
10%	−0.05%

Source: Authors' calculations

Based on the Intergovernmental Panel on Climate Change (IPCC) forecasts, Table 4 shows that a decrease in rainfall of between 5% and 10% leads to an overall decrease in the average income of Ivorian agricultural households of around 0.45% to 1.38%, while an increase in future rainfall from 5% to 10% will lead to an overall drop in agricultural income of around 0.02% to 0.05%.

However, these overall results hide a difference between the effects of future variations in rainfall across different areas of the country. Indeed, a future decrease in rainfall of 5% to 10% will lead to an increase in the income of agricultural households on the coast and in the west, of about 0.92% to 22.50%, while this decrease will lead to a drop in income in the centre, north and east, from around 0.83% to 5.61% (A and B in Figure 4). However, the effect of a future increase in precipitation of 5% to 10% will lead to a drop in income on the coast and in the west of about 1.55% to 29.71% and an increase in income of about 0.39% to 4.63% in the centre, north and east (C and D in Figure 4). These effects will be mitigated in the intermediate zone between the coast and the centre and also in the north-west (Figure 4). The negative signs of the overall effects are due to the fact that the overall losses are greater than the overall gains. These results are explained by the fact that the coastal and western zones correspond to the forest areas (agroclimatic zone 1) where the average precipitation level is 1,234mm of rain, 6.3% above the threshold precipitation level estimated at 1,150mm (that is 84mm more). Thus, any decrease in precipitation of less than 168mm would lead to an increase in income, while any increase in precipitation would result in a decrease in income on the coast and in the west. The centre, north and east zones correspond to savannah area (agroclimatic zone 4) where the average precipitation level is about 848.36mm, corresponding to 26.23% lower (that is 301.64mm less) than the threshold precipitation level. This means that any increase in rainfall of less than 603.28mm of rain (or 52.46%) would lead to an increase in income in this part of the country.

Figure 4: Effect of future climate on agricultural income



A: Effect of 5% decrease in precipitations on agricultural income

B: Effect of 10% decrease in precipitations on agricultural income

C: Effect of 5% increase in precipitations on agricultural income

D: Effect of 10% increase in precipitations on agricultural income

These results suggest different adaptation policies from one region to another. The north, centre and east are more sensitive to droughts, while the littoral and west regions are more sensitive to floods. Thus, the regions of the north, the centre and the east should benefit from irrigation policies or rainwater management to manage potential droughts, while the coastal and western areas would benefit from rainwater drainage policies to prevent flooding.

6. Conclusion and recommendations

Climate disturbances resulting from the gradual warming of the planet affect the agriculture sector and lead to economic, technological and social changes that differ from one country to another. In Côte d'Ivoire, climate variability, observed since the 1960s, has led to instability in agricultural production, which in turn has created economic and social disruptions in several regions of the country. Given the strong dependence of populations on agricultural production, this study assessed the effect of climate variability on the incomes of smallholder farmers in Côte d'Ivoire.

From a simple theoretical model, the study shows that in presence of market imperfection, the hypothesis of spatial constancy of agricultural products prices does not hold. Indeed, the study shows that several factors, such as distance and road condition, affect the mobility of agricultural products, thus creating spatial heterogeneity in their prices. This in turn results in spatial autocorrelation. These results lead to the adoption of a spatial approach to empirically analyse the effect of rainfall and temperature on the agricultural income of smallholder farmers. The empirical results show that temperature does not affect agricultural income, while rainfall in a given locality induces both a direct non-linear effect on that locality, and a positive linear spillover effect on agricultural income of neighbouring regions. In addition, the distribution of the total marginal effect of climate on income indicates that an increase in precipitation leads to a rise in the income of farmers in the north and centre while this same effect would lead to a fall in income in the coast and in the western part of the country. Furthermore, the impacts of the future climate, based on IPCC forecasts, indicate that an average decrease or increase in rainfall of between 5% and 10%, leads to a drop in the average income of Ivorian agricultural households. Moreover, the results also show that agricultural cooperatives as well as family labour have direct positive effects on household income, but indirect negative effects on the same in neighbouring localities.

These results, especially those of the total marginal impacts, suggest economic policies linked to the fight against climate change. Indeed, current policies, both adaptation and mitigation, are addressed comprehensively. Of course, they take into account vulnerable sectors, but do not make an objective difference between the populations that could be the most vulnerable, especially in the agriculture sector. Thus, we suggest that given the strong influence of climate on household income in the centre and north, policies to support farmers in terms of subsidies for the availability of seedlings and information on climate forecasts be more accentuated in these regions. In addition, the central, northern and eastern regions must benefit from support at the level of local communities to enable them to submit viable adaptation projects that could affect the daily lives of these agricultural households. For example, strategies geared towards irrigation policies could be beneficial insofar as water supply would play the same role of increased rainfall. For coastal and western farmers, training in drainage techniques or rainwater management, could help them increase their income. Finally, a better organization of agricultural cooperatives must be undertaken, especially for small agricultural households.

References

Adams, S.R., K.E. Cockshull and C.R.J. Cave. 2001. “Effect of temperature on the growth and development of tomato fruits”. *Annals of Botany*, 88(5): 869–77.

Ahossane, K., A. Jalloh, G.C. Nelson, T.S. Thomas, R.B. Zougmoré and H. Roy-Macauley, H. (Eds.). 2013. “Côte d’Ivoire”. In *West African Agriculture and Climate change: A Comprehensive Analysis*. Research Monograph. Washington, D.C.: International Food Policy Research Institute (IFPRI).

Anderson, J. 2017. *National Survey and Segmentation of Smallholder Households in Cote d'Ivoire: Household Level Data.* Washington, D.C.: CGAP. Ref: CIV_2016_SHS_v01_M.

Anselin, L. 1988. *Spatial Econometrics: Methods and Models*. Dordrecht: Kluwer Academic Publishers.

Baylie, M.M. and C. Fogarassy. 2021. “Examining the economic impacts of climate change on net crop income in the Ethiopian Nile Basin: A Ricardian fixed effect approach”. *Sustainability*, 13(13): 7243.

Brou, Y., F. Akindès and S. Bigot. 2005. “La variabilité climatique en Côte d'Ivoire: Entre perceptions sociales et réponses agricoles”. *Cahiers Agricultures*, 14(6): 533–40.

Cline, W.R. 1996. “The impact of global warming on agriculture: Comment”. *The American Economic Review,* 86(5): 1309–01.

Dall'erba, S. and F. Domínguez. 2016. “The impact of climate change on agriculture in the southwestern United States: The Ricardian approach revisited”. *Spatial Economic Analysis*, 11:1, 46–66.

Darwin, R. 1999. “The impact of global warming on agriculture: A Ricardian analysis: Comment”. *The American Economic Review*, 89(4): 1049–52.

Deschênes, O. and M. Greenstone. 2007. “The economic impacts of climate change: Evidence from agricultural output and random fluctuations in weather”. The American Economic Review, 97(1): 354–85.

Dibi Kangah P.A. and K.A. Mian. 2016. “Analyse agro-climatiques de la zone cacaoyère en Côte d’Ivoire”. *Revue de géographie de l’Université Ouaga/RGO*, 5(1): 45–68.

Dominguez, F., D. Breshears and J.C. Villegas. 2009. “Spatial extent of the North American monsoon: Increased cross-regional linkages via atmospheric pathways”. *Geophysical Research Letters*, 36(7): L07401.

Elhorst, J.P. 2010. "Applied Spatial Econometrics: Raising the Bar." *Spatial Economic Analysis,* 5:1, 9-28, DOI: 10.1080/17421770903541772

Harris, I., T.J. Osborn, P. Jones. 2020. Version 4 of the CRU TS monthly high-resolution gridded multivariate climate dataset. Sci Data 7, 109. https://doi.org/10.1038/s41597-020-0453-3

IPCC. 2014. "Climate Change 2014: Synthesis Report." Contribution of Working Groups I, II and III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change [Core Writing Team, R.K. Pachauri and L.A. Meyer (eds.)]. IPCC, Geneva, Switzerland, 151 pp.

Jain, S. 2007. "An empirical economic assessment of impacts of climate change on agriculture in Zambia". *World Bank Policy Research Series Working Paper 4291*. (The World Bank Development Research Group, Washington, D.C., 2007)

Janicot, S. 2012. "État des recherches sur l'attribution de la variabilité décennale récente en Afrique de l'Ouest". *Les Cahiers d'Outre-Mer*, 260: 463–77.

Kabubo-Mariara, J. and F.K. Karanja. 2007. "The economic impact of climate change on Kenyan crop agriculture: A Ricardian approach". *World Bank Policy Research Series Working Paper 4334*. (The World Bank Development Research Group, Washington, D.C., 2007)

Kelejian, H. H., and I.R. Prucha. 2010. "Specification and estimation of spatial autoregressive models with autoregressive and heteroscedastic disturbances." *Journal of Econometrics,* 157(1), 53-67.

Khan, A.U., A.H. Shah and M. Iftikhar-Ul-Husnain. 2021. "Impact of climate change on the net revenue of major crop growing farmers in Pakistan: a Ricardian approach". *Climate Change Economics*, 2150006.

Kouadio, K.Y., K.E. Ali, E.P. Zahiri and A.P. Assamoi. 2007. "Étude de la prédictibilité de la pluviométrie en Côte d'Ivoire durant la période de Juillet à Septembre". *Revue. Ivoirienne des Sciences et Technologies,* 10: 117–34.

Kurukulasuriya, P., and M.I. Ajwad. 2007. "Application of the Ricardian technique to estimate the impact of climate change on smallholder farming in Sri Lanka." *Climatic Change*, 81(1), 39-59.

Kurukulasuriya, P. and R. Mendelsohn. 2008a. "A Ricardian analysis of the impact of climate change on African cropland". *African Journal of Agricultural and Resource Economics,* 2: 1–23.

Läderach, P., A. Martinez-Valle, G. Schroth and N. Castro. 2013. "Predicting the future climatic suitability for cocoa farming of the world's leading producer countries, Ghana and Côte d'Ivoire". *Climatic Change,* 119(3–4): 841–54.

Mendelsohn, R., A. Basist, P. Kurukulasuriya, and A. Dinar. 2007. "Climate and rural income." *Climatic Change*, 1:101–118. https://doi.org/10.1007/s10584-005-9010-5

Mendelsohn, R., W. Nordhaus and D. Shaw. 1994. "The impact of global warming on agriculture: A Ricardian analysis". *American Economic Review*, 84: 753–71.

N'Da, K.C. 2016. "Variabilité hydroclimatique et mutation agricole dans un hydrosystème anthropisé: l'exemple du bassin versant du Bandama en Côte d'Ivoire". Thèse de doctorat, IGT, Université Felix Houphouët-Boigny.

Ochou, A. D., A. Aman, K.Y. Kouadio and P. Assamoi. 2005. "Zonage climatique basé sur la variabilité pluviométrique en Côte d'Ivoire et au Ghana." *Revue Géog Trop Envir,* 5: 34-46.

Ouedraogo, M. 2012. "Impact des changements climatiques sur les revenus agricoles au Burkina Faso". *Journal of Agriculture and Environment for International Development* (JAEID), 106(1): 3–21.

Polsky, C. 2004. "Putting space and time in Ricardian climate change impact studies: the case of agriculture in the U.S. Great Plains". *Annals of the Association of American Geographers,* 94(3): 549–64.

Rogers, E. 1995. *Diffusion of Innovations*. (4th ed.). New York: The Free Press.

Rosenzweig, C. 1985. "Potential CO_2-induced effects on North American wheat producing regions." *Climatic Change*, 7: 367–89.

Schlenker, W., W.M. Hanemann and A.C. Fisher. 2005. "Will US agriculture really benefit from global warming? Accounting for irrigation in the hedonic approach". *The American Economic Review*, 95(1): 395–406.

Schlenker, W., W.M. Hanemann and A.C. Fisher. 2006. "The impact of global warming on US agriculture: An econometric analysis of optimal growing conditions". *Review of Economics and Statistics*, 88(1): 113–25.

Vaitkeviciute, J., R. Chakir and S. Van Passel. 2019. "Climate variable choice in Ricardian studies of European agriculture". *Revue économique*, 70(3): 375–401.

Wood, S.A. and R. Mendelsohn. 2014. "The impact of climate change on agricultural net revenue: A case study in Fouta Djallon, West Africa". *Environment and Development Economics*, 20(1): 20–36.

Yao, N., A. Oulé and K. N'Goran. 2013. "Etude de Vulnérabilité du secteur agricole face aux changements climatiques en Côte d'Ivoire." PNUD Côte d'Ivoire. 105p.

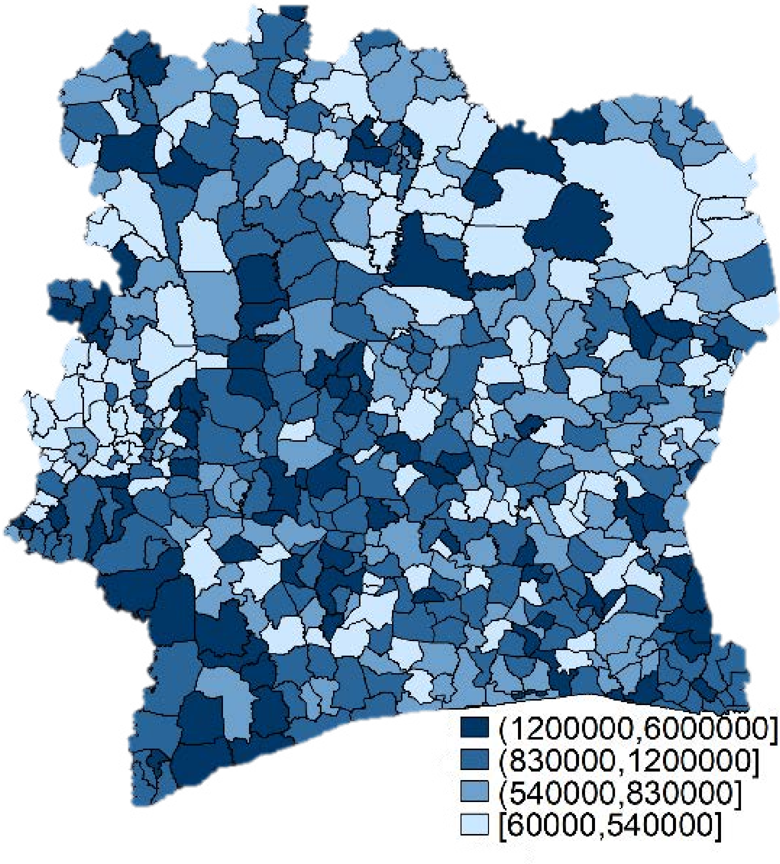
Appendixes

Appendix 1: Summary of statistics

Variables	Description	Units	Observations	Mean	SD	Min	Max
lnREV	Logarithm of average annual net income per locality	FCFA	510	11.056	0.693	8.517	13,122
TM	Average temperature in wet season per locality	°C	510	26.890	0.62	24.78	28.33
TM²	Square of average temperature in wet season per locality.	°C	510	723.910	33.232	614.210	803.010
PREC	Cumulated rainfall in wet season per locality	mm	510	994.650	189 .3806	667.2	1593
PREC²	Square of cumulated rainfall in wet season	mm2	510	1025141	414735 .300	445155.800	2537649
MOF	Average number of people of working age in the household per locality	Persons	510	2.200	1.152	1	11.500
SUP_POS	Average area of household farm per locality	Hectare	510	5.145	4.782	0.250	40
EXP_AG	Average agricultural experience per locality	Year	510	8.078	2.579	0	10
SEXE	Percentage of male heads of household per locality	%	510	0.873	0.291	0	1
COOP	Percentage of households belonging to an agricultural cooperative per locality	%	510	0.153	0.309	0	1
ZAGR1	Agroclimatic zone 1	–	510	–	–	0	1
ZAGR2	Agroclimatic zone 2	–	510	–	–	0	1
ZAGR3	Agroclimatic zone 3	–	510	–	–	0	1
ZAGR4	Agroclimatic zone 4	–	510	–	–	0	1

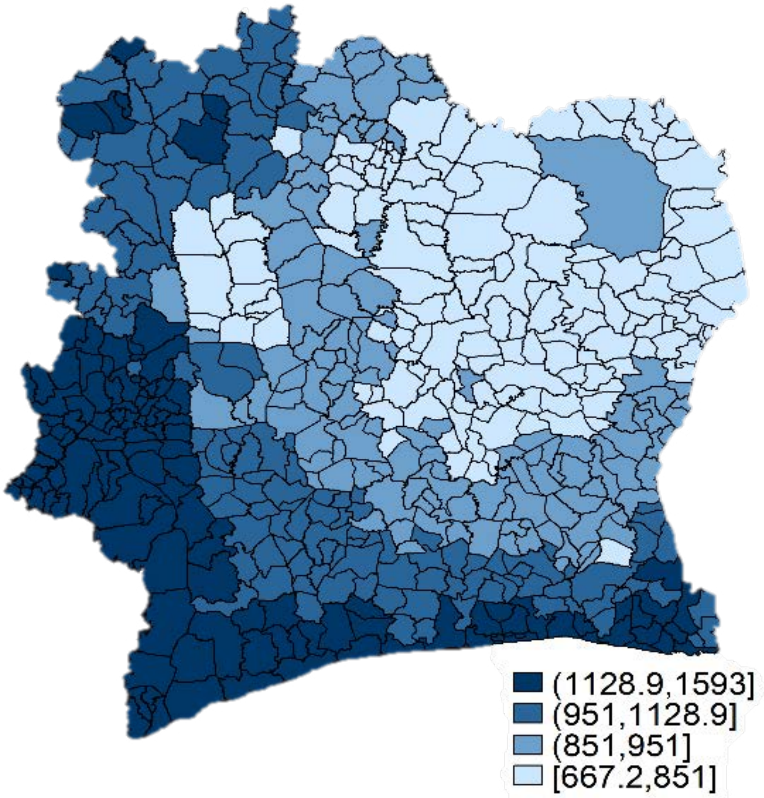
Source: Authors’ calculations

Appendix 2: Distribution of agricultural net revenue per locality



Source : Authors, from CGAP, 2016

Appendix 3: Distribution rainfall per locality



Source : Authors, from C.R.U data ; Harris et al, 2020

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