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Research Article

ECONOMIC IMPACT OF CLIMATE CHANGE ON AGRICULTURE IN BURUNDI: AN APPLICATION OF THE RICARDIAN MODEL

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Abstract

For several years, climate change has been at the center of both political and scientific concerns. Burundi is one of the countries which is very much concerned because its economy is mainly based on the rainfall agriculture. The aim of this study is to examine interactions between agriculture and the climate and assess the economic impact of climate change on agricultural production using a Ricardian approach applied to Burundi data from 1961 to 2020.The results show that climate has a non-linear and significant effect on agricultural production. However, any temperature above 18.6°C or rainfall above 1359.5mm would reduce agricultural production. Forecasts of estimated marginal impacts suggest that global warming of 1.5% and 2.5%would lead to an overall drop in agricultural production of about 0.93% to 2.27%per hectare. These findings call on policymakers and development planners to propose necessary climate change adjustment measures and adaptation options to reduce climate change negative impact.

Keywords: Climate change, Agriculture, Ricardian model, Burundi.

INTRODUCTION

Climate change affects several life areas such as water resources, agriculture, fisheries, forestry, human health, infrastructure, ecological systems, etc. It causes significant disturbances perceived as natural systems with both direct and indirect implications for economic policies (Huong *et al.,* 2019). These impacts can be dramatic in some countries than others because of great spatial variability of the climate and socio-economic development of the country (Ouedraogo, 2012). The communities mostly affected by climate change are farmers, especially those in developing countries as they are involved in agricultural production and their farming systems are largely dependent on the nature of the climate. Their living conditions are negatively affected since they depend on rainfed agriculture as their main and sole source of income, but they are also the main consumers of their own production. Climate change affects the entire agricultural value chain as it causes major changes in the way food is produced, traded and consumed around the world, subsequently resulting in persistent food insecurity, nutritional and health challenges. Consequently, the number of malnourished people keeps increasing over time (FAO *et al.,* 2023). However, scientific advances and consensus on adverse climate change effects have trigged interest at the level of decision-makers. Although there have been, in the last ten years, several economic analyses on the impact of climate change on American agriculture, European and Asian agriculture, there have been few such studies on Africa and almost nothing on Burundi. Yet, Burundi like other subsaharan african countries, agricultural is a key sector of the national economy, both in terms of the number of people it employs and the amount of wealth it generates (Ouedraogo, 2012).

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In addition to its major role in food supply, the agricultural sector occupies a prominent place in the country's economy as it contributes up to 30% to the GDP formation, provides more than 90% of export earnings and employs more than 85% of the working population in rural areas. This is why increasing agricultural productivity would be both a strategic necessity and an opportunity for the Government of Burundi. The analysis of climate data for the past 30 years shows that the climate is marked by irregularities in the temporal and spatial distribution of rainfall, in the beginning and end of rainy seasons, high frequencies of extreme climatic events as well as more frequent drought episodes, particularly in the North-East. According to the degree of sensitivity to climate change, Burundi can be divided into 5 eco-climatic regions. From the West to the East, we distinguish the lowlands of Imbo, the steep region of Mumirwa, the mountainous region (the Congo-Nile Ridge), the central plateaus and the depressions of Kumoso and Bugesera. Natural disasters that have occurred since 2005 show how vulnerable the agricultural sector is, which strongly influences national economic growth. In addition to the variability of production, other impacts can be observed, including reductions in food crops' yields, disruption of cropping seasons, disappearance of certain crop varieties following the extension of the dry season, proliferation of plant diseases and reduction in the production of industrial crops including coffee and palm oil. As a result, the income from this sector drops, which leads to a drop in the purchasing power of necessities, and consequently a reduction in access to food (Solaymani, 2018). Meanwhile, predictions of future climate change consequences are unfavorable for Burundi. The projection of climatic parameters in different parts of the country shows an upward trend in rainfall and temperatures. Indeed, climate models with RCP4.5 and RCP8.5 scenarios (Van Vuuren *et al.,* 2011) show an increase in annual rainfall of between 12% and 13.15% for the 5 meteorological stations by 2030 and 2050. They also show an increase in the maximum annual temperature of between 0.80° and 0.91°C by

2030 and an increase of between 1.89 and 2.02°C by 2050. In general, rainfall is characterized by strong inter-annual and spatio-temporal irregularities, with a direct impact on returns and agro-pastoral production. The resulting climatic hazards affect the stability of agro-pastoral production in general as well as that of export earnings in particular, and therefore weaken the country's economy. They also affect smallholder farmers, and their vulnerability is particularly likely to be worsened given their technological and resource constraints. This situation will be exacerbated in the perspective of global climate change, hence the interest in Burundi to know the impact of possible climatic variability on agricultural production. The analysis of the impact of climate change on the incomes of smallholder farmers requires special attention given their importance in the labor force. Nevertheless, although the consequences of climate variability on agriculture are real, no study has been conducted in Burundi to quantitatively assess the economic impact of climate change on agriculture to identify the implications of economic policies in household resilience. Thus, this study aims to analyze the economic impact of climate variability on the income of smallholder farmers in Burundi.

Most studies on the impact of climate change on agriculture use the Ricardian model because it allows to take farmers' adaptation strategies into account. This study is part of the dynamics of the literature using the Ricardian model to understand the vulnerability of the agricultural sector to exogenous pressures. This is very important in the development of agriculture for policy makers and development planners. Despite the importance of the agricultural sector in Burundian economy, knowledge of the extent of climate change impacts on agriculture is still limited. This study aims to contribute to the knowledge of present and future impacts as it assesses the projected impacts of climate change (changes in rainfall and normal temperature) on agricultural performance using a Ricardian model. Considering claims made above, it is hypothesized that climate variability has an ever-increasing negative effect on the agriculture production in Burundi. Hence, the objective of this paper is to analyze the economic impact of climatic variability on agricultural production in Burundi using the Ricardian model. Specifically, the study aims to: (i) assess the impact of temperature and rainfall variations on agricultural income; (ii) carry out a forecast analysis to assess the future effects of climate on agricultural income in Burundi. The rest of the study is structured in the following way: the second section concerns an overview of Burundian agriculture. The third section reviews the literature on the impact of climate change. The fourth section concerns the methodology and the fifth the types of data used as well as their sources. The sixth section presents and discusses the results. The seventh section concludes the study and suggests policy options.

Economic overview of the agricultural sector in Burundi

Burundi has eleven different agro-ecological zones and extends over a total area of 27,834 km² with 23,500 km² of potential agricultural land. It is located between 29.00° and 30.54°in the East and 2.20° and 4.28° parallels in the South. Despite its modest dimensions, Burundi is unique by its relief diversity and landscapes thus enjoying a tropical climate tempered by the relief. The annual average temperature varies between 12°C and 24°C and strongly influenced by the altitude. The highland regions have on average lower temperatures than the lowlands. Concerning the hydrology, Burundi belongs to two large African hydrographic basins, namely the Nile basin with an area of 13,800 km² and the Congo River basin with an area of 14,034 km². In most parts of Burundi, there is a dense network of permanent watercourses and numerous drainage axes. Burundi is very rich in natural lakes including Tanganyika, Cohoha, Rweru and Rwihinda lakes. With an estimated population of 16.3 million in 2023, its density is one of the highest in Africa and even in the world with 442 inhabitants/km². The Burundian economy is dominated by the primary sector. The current structure of production, dominated by subsistence agriculture, renders the economy very vulnerable and fragile because of its dependence on climatic conditions.

Stylized facts

Graph 1 shows some evolution in the opposite direction between agricultural income and the average annual temperature in Burundi. When the temperature increases, the agricultural income decreases and vice versa. The same is true for rainfall. This symmetrical joint evolution shows the existence of a correlation between various climate indicators and agricultural income in Burundi. However, it is worth noting a U-shaped and an inverted U-shaped evolution due to the quadratic relationship between crops productivity and climatic variables (Schlenker & Roberts, 2009; Tun Oo *et al.,* 2020). This would mean that there is a level from which temperature and rainfall could be beneficial or not to increase agricultural production. We would be interested to know this average temperature and rainfall which favor agricultural production. The FAO considers the period from 1951 to 1980 as a reference climatology, corresponding to 18.68°C of temperature and 1341.6 mm of rainfall for Burundi. In addition, there has been global warming over the period from 1961 to 2020 because the temperature has increased while the rainfall has varied in the opposite direction. While the agricultural system is heavily rainfed, any unforeseen variation in climatic parameters has serious repercussions on agricultural production (Kurukulasuriya and Mendelsohn, 2007).

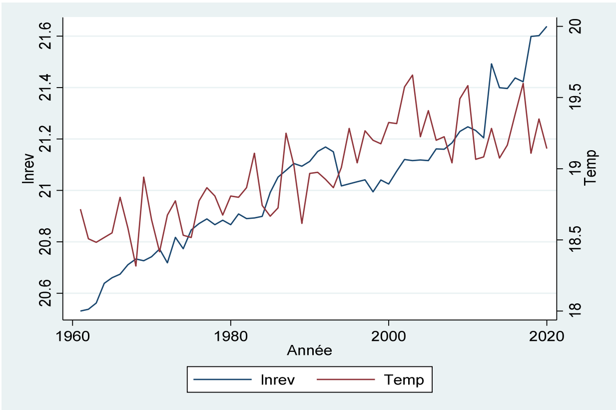
Nevertheless, agriculture in Burundi is very complex because of the number of seasons, the multiplicity of crop cycles, the diversity of crops and the number of associated crops per plot (Cochet, 1993). Agro-ecological conditions enable farmers to grow food crops three times per agricultural year, with distinct food crops according to agricultural seasons.

Agricultural seasons

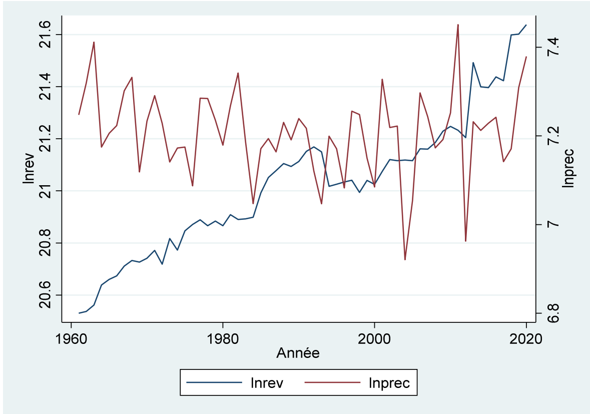
In general, the country has two main seasons per year: a rainy season which lasts eight months (October to May) and a dry season which lasts four months (June to September). However, a small dry season of about two weeks is observed between January and February. There are three agricultural seasons in Burundi: (i) Season A which runs from mid-September to mid-February. It is the short rainy season. This season’s production represents on average a quarter (23.7%) of the annual production; (ii) Season B which corresponds to the main rainy season, covering the period from mid-February to mid-June. It provides more than half (52.5%) of the total crop production; and (iii) Season C which extends from mid-June to mid-September and provides about a quarter (23.8%) of the annual production of food crops.

Graph 1. Evolution of agricultural income and agricultural income per hectare according to average temperatures and average annual rainfall in Burundi from 1961-2020

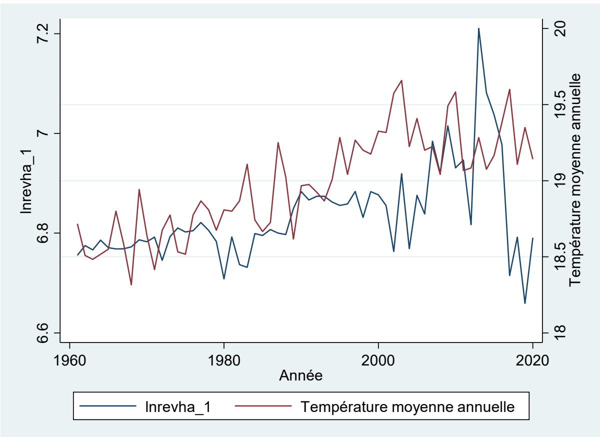
a) Average annual temperatures and agricultural income



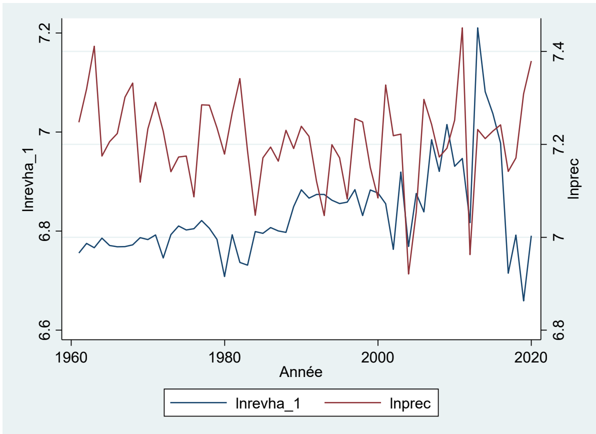
b) Average annual rainfall and farm income



c) Average annual temperatures and agricultural income per hectare



d) Average annual rainfall and agricultural income per hectare



This production is mainly attributable to cassava and bananas, which are known to be perennial crops. However, rainy and/or drought periods that condition seasons have been affected by successive climatic disturbances that have prevailed from the 1998-1999 agricultural year to date and have caused a severe blow to agricultural production. As a result, there has been a shift in seasons so that season A now begins in mid-October at the best, and tends to overlap with season B. In addition, since the month of September in 2015, Burundi was severely affected by the El Niño weather phenomenon. Therefore, two main shocks related to natural hazards, namely drought and hail damage continue to affect the livelihoods of rural households.

Crops and their associations

In each agricultural season, Burundian farmers can produce different combinations of rainfed crops. The main food crops grown in Burundi that are dealt with in this study are cereals (maize, rice, wheat, sorghum, finger millet), legumes (kidney beans, climbing beans, peas, Cajun peas), beer banana, cooking banana, fruit banana), tubers or roots (sweet cassava, bitter cassava, sweet potatoes, potatoes, colocase) and oilseeds (peanuts, soya, sunflower). Industrial crops, vegetable and fruit crops are not concerned by this study. Except for industrial crop plots, crop cycles on the same plot with diversified crops are numerous, monoculture plots being rare. Most of cultivated fields and/or plots include several associated crops at the same time.

Many farmers combine cereals and legumes and add cuttings of sweet potatoes and/or cassava here and there. One may find about five associated crops in the same plot. For example, plots with pure crops during season A, represent 32.1% of the plots with food crops, 39.5% in season B and 59.9% in season C. Among plots with associated crops in season A, 26.2% have two crops, 23% three crops, 14.2% four crops and 4.5% five crops. During season B, 29.3% of plots have two crops, 18.8% three crops, 9.5% four crops and 2.9% five crops. As for season C, 28.5% of plots have two crops, 8.9% three crops, 2.4% four crops and 0.4% five crops.

Economic constraints of the agricultural sector

Burundian agriculture faces several constraints that significantly hinder its performance. These constraints are mainly political, geographical, social, demographic and economic. In fact, agriculture faces the constraint of small arable land linked to the agrarian system in place (Cochet, 1998). Agricultural land is traditionally transmitted by inheritance and commercial transactions are uncommon. As a result, the average size of a plot owned by households is very small. For example, the total developed area for farms amounted to 803,422 ha in 2012, with an average of 0.5 ha per farm. The gradual fragmentation of agricultural holdings is also the result of population growth and the low availability of non-agricultural jobs in rural and urban areas. This high population density and high dependence on the agricultural sector, associated with sensitive land due to its geomorphology. All these factors have simultaneously caused and aggravated degradation of the environment. Most of farms (82%) are located on hills, most of which (75%) have no anti-erosion device, with the result that erosion is a serious problem. Erosion control programs are insufficiently promoted, especially in provinces that are much more exposed to soil erosion and landslides due to heavy rainfall. However, soil degradation in Burundi is in some cases caused by anthropogenic effects, in particular uncontrolled urbanization, uncontrolled exploitation of minerals and deforestation. Heavy exploitation of non-renewable natural resources not accompanied by measures to mitigate negative effects exposes farmers to effects of climate change. For example, in 2018 the exploitation of ores and quarries took place on a total area of 37,993.8 hectares and 576.2 ha respectively, while the area devoted to research and prospecting perimeters of mines is only 178,099.9 ha. At the same time, evolution of 34.1% of peat production (in) has been observed during the last 6 years, ranging from 11,367 tons in 2014 to 15,248 tons in 2018. However, in the same year, only 0 .98 ha were rehabilitated for mines against 4.7 ha for quarries.

In addition, widespread poverty limits farmers' access to inputs and other basic needs. The use of chemical fertilizers and improved seeds remains extremely low. Fertilizer use in sub-Saharan Africa is 8 kg/ha/year compared to a global average of 93 kg/ha/year. The same situation is true for the use of phytosanitary products, with subsequent perpetual attacks of plant diseases and pests (e.g. cassava mosaic, fusarium and banana bacteriosis, armyworms, etc.). The Burundian agricultural sector also suffers from the low intensification of farming systems. It neither uses animal traction nor mechanization. It is limited by the lack of technical and technological innovations related to water control, development, processing, and conservation of agricultural, livestock and fisheries production. It is exclusively based on traditional agricultural practices, mostly manual with rudimentary equipment such as the hoe. Agriculture is generally practiced by a young, predominantly female population with a low level of education and very few farmers belonging to a producer association or organization. This limits the sharing of knowledge and good practices. In addition, there is poor performance of the farmer supervision system. Coverage of agricultural extension and advisory services is very low in rural areas of Burundi. Financial services in Burundi are not accessible to farmers due to the lack of valuable guaranties that can be used to obtain credit and financial loans. The weak technical capacities, the lack of infrastructure and the difficulties of access to credit limit the potential linked to diversification and increase in added value of food products and block the process of diversification of rural income. The low supply of electrical energy hampers the development of agricultural processing enterprises. The large amount of energy produced, is made up of more than 92% firewood, and 5.7% for charcoal and other types of fuel such as peat, bagasse and electrical energy share the remaining 2.3% left over from production. This national production represents 95.6% of national energy consumption supplemented by imports. Moreover, this exploitation of forest resources is at the root of erosion, which leads to degradation or loss of soil fertility, endemic species, and increased climate variability. These factors significantly increase the exposure of the most vulnerable social strata to the risks of food insecurity. Food production has a low but also cyclical growth rate because farmers are vulnerable to adverse weather conditions and price shocks.

Theoretical Framework and Literature Review

Various models are used to assess the impact of climate change on agriculture, but the impact is not fully understood as not all environmental indicators are included in the impact assessment. According to Husnain *et al.,* (2018), the best-known models in the literature are crop simulation models, production function models, the Ricardian approach (Mendelsohn *et al.,* 1994; Ouedraogo, 2012; Sodjinou & Hounkponou, 2019), general or partial equilibrium models (De Salvo *et al.,* 2013; Deressa, 2007; Solaymani, 2018), integrated assessment models and panel data (Deschênes & Greenstone, 2007). The studies evaluating the impact of climate change on agriculture found in the literature use two types of climatic variables: annual temperature averages and total annual rainfall over the entire agricultural campaign with their squares; other models use degree-days during the growing season, and total rainfall (annual or covering the same growing season) inspired by more agronomic arguments (Vaitkeviciute *et al.,* 2019). More recently, Husnain *et al.,* (2018) used the Latitude and the Longitude as instrumental temperature variables, considering the added value of the agricultural sector as an endogenous variable.

Nevertheless, all these studies agree on the existence of a quadratic relationship between crops' productivity (or land values) and climatic variables. Results from these studies show that climate change is likely to have both positive and negative impact on agriculture, depending on the region and the type of agriculture practiced (Antle, 2008). On one hand, the productivity of most food crops decreases following average annual increase in temperature. On the other hand, excessive rainfall has a positive effect, but which is unfortunately absorbed by the negative effect of excessive increase in temperature (Praveen & Sharma, 2020). For example, India registers a negative impact on agriculture with a loss of about 3% to 26% of the production at a temperature increase of around 2 to 3.5 degrees Celsius (Ninan & Bedamatta, 2012) while in Burkina Faso the marginal impact of temperature on agricultural income is -19.9 US dollars per hectare while that of rainfall is +2.7 US dollars per hectare (Ouedraogo, 2012).

According to Deressa (2007), Ricardian approach is subject to weaknesses such us that it is not based on controlled experiments between farmers. Farmer responses vary spatially not only because of climatic factors, but also due to many socio-economic conditions. Another weakness is that Ricardian analyses suffer from a systematic bias in the case of Africa, due to the spatial variability of agricultural prices. Ricardian cross-sectional or even panel studies assuming constant prices underestimate the impact of climate change using income or the value of production. Another weakness of the model is that it does not consider the effect of fertilization, carbon dioxide concentrations (a higher concentration of $CO2$ can improve crop yield by increasing photosynthesis and allow more efficient use of the water).

However, despite these weaknesses the Ricardian model is still used to analyze the impact of climate change on agriculture by considering farmers' adaptations. Moreover, this model has been used all over the world (Bozzola *et al.,* 2018; Gebreegziabher *et al.,* 2020; Huang & Sim, 2021; Martin &

Vaitkeviciute, 2016; Mendelsohn *et al.,* 1994; Mishra *et al.,* 2018; Tun Oo *et al.,* 2020). Also, according to De Salvo *et al.,* (2013), all models present common difficulties: the availability of data and analysts-oriented expertise. While data is frequently available, it is often not disaggregated to the necessary temporal and/or spatial scales. Another reason is that research on climate change effects involves multidisciplinary skills and competences because analyses of the effects of climate change involve many factors such as the consideration of: (i) climate and other environmental aspects induced by climate change, (ii) biological aspects and plant physiology, (iii) technical and socio-economic factors, (iv) strategies to deal with the climate change effects, (v) impacts on/of the main economic adjustment mechanisms at national and international levels, (vi) feedback of modified conditions on climate.

METHODOLOGICAL APPROACH

Foundation of the Ricardian model

The starting point of the model is the assumption that the farmer chooses the optimal allocation of input quantities in his profit maximization problem. This model aims to determine the direct impact of climate change not on crop yields but on the gross margin of the farm or the value of the land. The value of land reflects the sum of discounted future benefits that can be derived from its use. The most used variable in empirical studies is the net agricultural income (Dall'erba & Domínguez, 2016; Issahaku & Maharjan, 2014). By regressing land values on a set of environmental inputs, the Ricardian model makes it possible to measure the marginal contribution of each input to agricultural income capitalized in land value. The Ricardian model also has the advantage of considering farmers' adaptations to mitigate adverse effects of climate change either by using cross-sectional or panel data (Deschênes & Greenstone, 2007; Mendelsohn *et al.,* 1994).

Thus, farmer *i* of commune *j* maximizes his profit in crop year *t* under the constraints given by exogenous conditions to his farm (soil, climatic, socio-economic and factor price conditions). He therefore chooses the quantities of inputs and outputs (agricultural production) denoted *k* which maximize:

$$max\, \pi_{ijt} = \sum_k^n P_{ijkt}\, Q_{ijkt}[X_{ijkt}/(F_{ijt}Z_{ijt}G_{ijt})] - \sum_k^n R_{ijkt}X_{ijkt} \quad (1)$$

where is the profit of farmer *i* of municipality *j* in campaign *t*, and being respectively an exogenous vector of output and input prices, designates the quantities resulting from the production function at the campaign t, is an endogenous vector of the choice of inputs such as seeds, fertilizers, pesticides, labor or capital,..., is a vector designating exogenous socio-economic variables, represents the exogenous climatic characteristics and those of the soil, all in the agricultural countryside *t*.

The total number of inputs that maximize the profit of farmer *i* in municipality *j* in campaign *t* is then a function of exogenous variables only. They are obtained by deriving the previous equation with respect to each of the inputs:

$$\pi_{ijt}^* = \pi_{ijt}^*[(F_{ijt}Z_{ijt}G_{ijt})/P_{ijkt}] \quad (2)$$

Thus, the value of agricultural land, , will be a function *f* (.) of the present value of each farmer's maximum profit:

$$f(V_{ijt}) = \int_0^\infty \pi_{ijt}^* e^{-\delta t} dt + \varepsilon_{ijt} \quad (3)$$

where δ is the discount rate and the error term.

Climatic variables play an important role in crop production. To ensure good crop growth, it is necessary to have an effective combination of various climatic factors. Otherwise, crop development may not be assured. Following the work of Schlenker & Roberts, (2009), all studies using the Ricardian model confirm the existence of a quadratic relationship between crop productivity or land value and climatic variables (Massetti & Mendelsohn, 2020).

Thus, to identify the impact of the climate on agricultural income at the national level, the following equation was estimated:

$$V_{jt} = \beta_0 + \beta_1 F_{jt} + \beta_2 F_{jt}^2 + \beta_3 Z_{jt} + \beta_3 G_{jt} + \varepsilon_{jt} \quad (4)$$

where and capture the linear and quadratic terms for temperature and rainfall. The introduction of quadratic terms for climate variables reflects the nonlinear effects of the relationship between temperature and crop yields (Schlenker & Roberts, 2009).

The expected marginal impact of a climatic variable on agricultural income evaluated at its average is given by the following expression:

$$E[dV/df_i] = \hat{\beta}_{1,i} + \hat{\beta}_{2,i} * E[f_i] \quad (5)$$

The change in welfare, ΔU, resulting from a climate change from C0 to C1 can be measured as follows:

ΔU= C (V1) −C(V0) (6)

Data

The data used are taken from the FAO database. The present study also used administrative data from the Geographical Institute of Burundi (IGEBU) on the climate. The detailed description of the variables is given in the following lines.

Dependent variable

In the literature, net agricultural income is the most widely used indicator for assessing the vulnerability of the agricultural sector in general and agricultural households in particular to shocks induced by climate change (Gebreegziabher *et al.,* 2020; Huong *et al.,* 2019). Other authors use land value or land productivity (Martin & Vaitkeviciute, 2016; Mendelsohn *et al.,* 1994).

Independent variables

Several climate databases are used in the empirical literature to assess the impact of climate change on different social outcomes. These databases use different measurement methods: some use a mixture of surfaces and satellites (rainfall and temperature at the spatial level) while others are based only on the surface (Husnain *et al.,* 2018). This study used both sources. Preferred data on temperature (expressed in degrees Celsius) and rainfall (expressed in mm) are provided by the Geographical Institute of Burundi (IGEBU) and are based only on the surface. These data are collected in various meteorological stations located in the country. The observations are entered daily at a given frequency and are reported to the IGEBU, which compiles them each month for each station. Temperature data includes minimum, maximum and average temperatures during the given month and/or year. The rainfall series are constructed from readings collected at various meteorological stations. Collection agents fill in the data by simply reading the volume of rainwater on the rain gauges each time it rains. These data are then aggregated monthly to obtain total monthly and/or annual rainfall. Missing data is replaced by satellite data from the Climate Research Unit (CRU). The data used are both annual climatic data and variations in temperature and rainfall compared to a reference climatology, corresponding to the period 1951-1980

Other Coping and Control Variables

Fertilizer consumption: Agricultural productivity and fertilizers' use are closely linked; therefore, the impact of fertilizers was controlled by including fertilizer consumption in the Ricardian model for the national level. This set contains nitrogen, potassium and phosphate fertilizers used per unit of arable land. It excludes traditional nutrients such as animal and plant manure.

Agricultural area: A country with a larger land area is expected to have a higher agricultural added value. To control this potential bias, the area of agricultural land is included in the regression equation. According to the FAO, agricultural land refers to the share of the area (in square kilometers) that is arable and includes land devoted to temporary crops (double-cropped areas are counted once), temporary grassland for mowing or pasture, market garden land or vegetable gardens and temporarily fallow land but exclude tree land cultivated for timber.

Total population: Population can affect agricultural added value through different channels. It counts mid-year estimates for all residents, regardless of legal status or citizenship, except for refugees, based on the definition of the world development indicators. Different household and farm characteristics, infrastructure and institutional factors influence the use of adaptation methods by farmers (Deressa 2007). Variables relating to household characteristics, farm characteristics, institutional factors, infrastructure characteristics are not available and are captured in the error term. We note that the expected effects for most of these variables are positive. Table 1 presents respectively the description of the explanatory variables used and their descriptive statistics. For reasons of scales between units of different variables, some variables have been converted into logarithms.

RESULTS AND DISCUSSION

In this section, we present the results of the Ricardian model estimated using macroeconomic data. Each time, we will try to explain the existing relationships between the dependent variable and explanatory variables introduced into the models.

Results of the Ricardian model

We tested various regression specifications to capture the effect of climatic variables on agricultural income in Burundi. Table 2 presents the coefficients of the estimates of eight models obtained using the generalized least squares (GLS) method to correct the autocorrelation of the errors identified. To identify the influence of each of the climatic variables on agricultural income, models (1) and (2) are estimated using the average of annual temperature and his square as a climatic variable and then with its interaction with rainfall. Models (3) and (4) are estimated using the average of annual rainfall and his square as a climatic variable and then with its interaction with the average annual temperature. Model (5) considers only the interaction of the two climatic variables, while Model (6) considers them without interaction between them to manage possible collinearity. The addition of control variables shows the overall sensitivity of income to climatic variables. In fact, the results of the Ricardian model show that, whatever the model used, the effects of climatic variables (rainfall and temperature) on agricultural income are globally significant. Rainfall and temperature coefficients and their quadratic terms have almost the same level of significance of 10%, 5%, and 1% in the different models. The significant quadratic terms indicate that the relationship between climatic variables and farm income is not linear. Indeed, the signs of the linear and quadratic terms are opposite. This means that temperature and rainfall positively affect income up to a certain level, beyond which each of these variables becomes harmful for crops. Therefore, the relationship between farm income and climatic variables (temperature and rainfall) is inverted U-shaped. In contrast to the results of studies by Sodjinou and Hounkponou (2019), Tun Oo et al. (2020), and Ouedraogo (2012) conducted respectively in Benin, Myanmar in the Southeast Asian region, and Burkina Faso, the present study shows that temperature does not negatively affect agricultural income in Burundi. This can be explained by the fact that the country has plenty of water resources in such a way that the current temperature does not significantly affect the growth and yield of food crops. It may also be due to the use of adaptation strategies put in place by farmers, such as the use of animal fertilizers, which contribute to the conservation of soil fertility. However, this result hides certain realities that can be revealed if we consider the production and/or yield of the crops taken individually, since there are crops that are sensitive to heat.

Table 1. Description of the variables used and their descriptive statistics

Variable	Descriptions	N	Mean	Std. Dev.	Min	Max
Temp	Annual average temperature (°C)	60	19.0	0.3	18.3	19.7
Temp2	Annual squared average temperature (°C*°C)	60	360.3	12.5	335.5	386.5
Prec	Rainfall (mm)	60	1356.5	130.3	1013.2	1721.4
Prec_2	Rainfall squared (mm*mm)/100000	60	1856.7	355.5	1026.6	2963.2
PrecTemp	Rainfall x Temperature (mm x°C)	60	25737.6	2445.9	19478.8	32821.4
PrecTemp2	Rainfall x Temperature squared (mm x°C)^2/100000	60	6683.0	1266.8	3794.2	10772.4
Lnpop	Population Logarithm (number)	60	15.5	0.4	14.9	16.3
Lnsup	Harvested area Logarithm (number)	60	13.9	0.2	13.6	14.7
F_K2Okgha	Potassium fertilizers (kg/ha)	60	0.5	0.8	0.0	3.5
F_Nkgha	Nitrogen fertilizers (kg/ha)	60	1.2	1.6	0.1	8.7
engranim	Animal fertilizer (T/ha)	60	0.1	0.0	0.1	0.2

Table 2. Results of regression models of climatic and control variables on income per hectare

Variables	(1)	(2)	(3)	(4)	(5)	(6)
Temperature (°C)	6.662*	4.991***				4.590***
	(3.798)	(1.185)				(1.643)
Annual squared average temperature (°C x°C)	-0.174*	-0.134***				-0.123***
	(0.101)	(0.0316)				(0.0432)
Rainfall * Temperature	0.0109**	0.0113***	-0.0261	-0.0315*	0.00917***	
(mmx°C)	(0.00524)	(0.00288)	(0.0268)	(0.0170)	(0.00339)	
Rainfall x Temperature squared (mm x°C)2	-0.000216** (0.000106)	-0.000218***	0.000604	0.000490	-0.000181***	
		(5.30e-05)	(0.000508)	(0.000315)	(6.45e-05)	
Population (Log)		0.378***		0.376***	0.278***	0.427***
		(0.0517)		(0.0526)	(0.0405)	(0.0637)
Harvested area (ha)		-0.342***		-0.347***	-0.243***	-0.463***
		(0.0757)		(0.0833)	(0.0887)	(0.109)
Potassium fertilizers		-0.0554**		-0.0412	-0.0376	-0.0473*
(kg/ha)		(0.0259)		(0.0250)	(0.0269)	(0.0253)
Nitrogen fertilizers		0.00163		0.00297	-0.00324	0.00453
(kg/ha)		(0.0144)		(0.0151)	(0.0161)	(0.0134)
Animal fertilizer (T/ha)		0.891***		0.755**	1.372***	0.623*
		(0.289)		(0.319)	(0.306)	(0.360)
Rainfall (mm)			0.00536	0.00812**		0.00259***
			(0.00483)	(0.00316)		(0.000453)
Rainfall squared			-0.00234	-0.00256**		-0.00095***
(mm x mm)			(0.00173)	(0.00110)		(0.000163)
Constant	-58.03	-42.14***	6.863***	4.607***	4.924***	-37.64**
	(35.84)	(11.56)	(0.726)	(1.071)	(0.939)	(15.75)
Observations	60	60	60	60	60	60
R-squared	0.189	0.895	0.239	0.773	0.757	0.787

Notes: * indicates significance at the level of 10%, ** at the level of 5%, *** at the levelof 1%. Robust standard errors are in parentheses.

The harvested area has a negative effect on farm income. This corroborates results found in Burkina Faso by Ouédraogo (2012). This is explained by the fact that farmers tend to increase cultivated areas to increase production to compensate land's low productivity. This strategy certainly increases production, but generally does not improve the productivity of the land. Instead, it leads to a drop in yield because of the lack of resources for the maintenance of large areas. Researchers have different views on the effect of population on agriculture. The positive relationship between population and agricultural income, also found by Husnain et al. (2018), may explain the abundance of family labor on the national territory of Burundi, which should lead to increased agricultural production. However, this workforce, generally female and peasant practices subsistence agriculture. Moreover, this relationship may not be warranted as there are serious and growing concerns about the impacts of rapid population growth on natural resources. Nevertheless, the positive relationship between population and agriculture found in this study has been supported by Boserup (1965) who demonstrates that population growth generates intensification of agricultural production to respond to demand increase by letting markets reveal real prices which express the relative scarcity of production and products factors. Increase in production occurs "naturally" through the adaptation of techniques.

However, this relationship contradicts the Malthusian view that demographic pressure would result in increasing food dependence and population regulation either through famines, migrations, or wars. In the modern version of the "neo-Malthusian" thesis, it is believed that exodus replaces famine when there is a greater imbalance between the productive capacity of an environment and the needs of populations. As expected, the results of this study also show that animal manure has a positive effect on farm income. Indeed, the application of compost and manure (and green straw) is one of the climate change adaptation measures. The application of compost and manure improves soil fertility and structure and, therefore, increases crop productivity (Tun Oo *et al.,* 2020).

Sensitivity of agricultural income to climate change

To assess the sensitivity of agricultural income to climate, we calculated the marginal impact of temperature and rainfall. The coefficients from model 6 were used to estimate marginal impacts of the climate on net incomes (Table 2). According to model 6, the marginal effect of temperature on farm income is 4.59. This means that an increase of 1°C in temperature would lead, *ceteris paribus*, to an increase in agricultural income of 459 Burundian Francs per hectare. Similarly, the marginal effect of rainfall on farm income is 0.0025. This means that an increase in rainfall of 1mm would lead, *ceteris paribus*, to an increase in net agricultural income of 0.25 Burundian Francs per hectare. However, any temperature higher than 18.6°C would lead to a drop in agricultural income. Similarly for an increase in rainfall of more than 1359.5mm would lead to a decline in agricultural income.

Projected impacts of climate change on farm income

Future climate change scenarios could have a significant effect on cropping patterns and crop productivity in Burundi. According to various IPCC reports, the forecast temperature is supposed to increase all over the planet. In this section, we have used estimated response functions to explore how climate change scenarios might affect farm income. Like the RCP2.6 and RCP2.8 scenarios, we tested six uniform climate scenarios, namely changes of +1.5°C, +2.5°C, +5°C in temperature and -5 %, -7% and -10% of rainfall. Model (6) in Table 2 was used to estimate how climate affects farm income per hectare. The effects of changes in the predicted temperature and rainfall scenarios on agricultural income per hectare (marginal value changes) are shown in Table 3 below:

In line to different forecast scenarios, results in Table 3 show that any variation (increase or decrease) in rainfall leads to a drop in agricultural income. The situation will become increasingly serious with global warming (temperature increase). In fact, a drop of between 5% and 10% in rainfall leads to an overall drop of about 0.17% to 0.86% in agricultural income, while an increase of 5% to 10% in future rainfall will lead to an overall drop of about 0.32% to 1.16% in agricultural income. A global warming of between 1.5% and 2.5% leads to an overall drop of about 0.93% to 2.27% in agricultural income, while a future global warming of 5% will lead to an overall drop of about 8.145% in agricultural income.

Table 3. Variations in average income according to the different climate scenarios

Scenarios		Changes in farm income
Reduction in Rainfall	- 5%	-0.177%
	- 7%	-0.391%
	- 10%	-0.863%
Increase in Rainfall	+ 5%	-0.329%
	+ 7%	-0.603%
	+10%	-1.167%
Increase in temperature	+1,5	-0.933%
	+2,5	-2.27%
	+5,0	-8.145%

However, these global results hide a difference between the effects of future variations in rainfall according to the different areas of the country. The next research will deal with these variations from a disaggregated point of view.

Conclusions and policy implications

This study examined the effects of climate change on agricultural income in Burundi. This study's empirical results showed that agriculture income per hectare was sensitive to marginal changes in climatic variables (temperature and rainfall). Estimated coefficients by the Generalized Least Squares (GLS) method were pretended to show the effects of climate change variables and other control variables on farm income per hectare. The results showed that the climate has a non-linear and significant effect on agricultural income in Burundi. However, contrary to the results of certain studies, current temperature and rainfall do not negatively affect agricultural income, though any variation in these climatic parameters would lead to a drop in agricultural income. Indeed, any temperature higher than 18.6°C or a rainfall of more than 1359.5mm would lead to a drop in agricultural income. There has certainly been an increase in temperature in the last sixty years. But increase in temperature prompts farmers to adopt adaptation strategies which, according to Huang & Sim (2021) can reduce climate damage in agriculture by two-thirds. The adaptation strategy implemented by Burundian farmers described in this study is the use of animal manure which has a positive and highly significant effect on farm income. The use of compost and manure improves soil fertility and structure and, therefore, increases crop productivity (Tun Oo *et al.,* 2020). The results also show that harvested area has a negative effect on farm income. This is explained by the fact that farmers tend to increase the cultivated areas to increase production to compensate for the low productivity of the land. This strategy certainly increases production, but generally does not improve the productivity of the land. It leads to lower yields due to a lack of means to maintain large areas (Ouedraogo, 2012). The positive relationship between population and agricultural income, also found by Husnain *et al.,* (2018) can be explained by the abundance of family labor on the Burundian national territory which should lead to an increase in agricultural production. Nevertheless, this workforce, generally female and peasant, practices subsistence agriculture. However, this relationship may not be warranted as there are serious and growing concerns about the impacts of rapid population growth on natural resources. Forecasts of the marginal effects of climate on agricultural incomes suggest that climate change could have negative effects in Burundi. The results of the scenarios used confirm that global warming will have a substantial impact on agricultural income. Indeed, a decrease in rainfall of between 5 and 10% would lead respectively to an overall drop in agricultural income of approximately 0.17 to 0.86% of agricultural income per hectare, while an increase in future rainfall of 5 to 10% would lead respectively to an overall drop in agricultural income of about 0.32 to 1.16% of agricultural income per hectare. However, these results may somewhat be biased by our specification of farm income in which assumptions have been made about constant prices or full adjustment, or which do not consider the annual cost of capital and labor costs used such as family work. In addition, the Ricardian model widely used to analyze the effect of climate change on agriculture has been subject to several criticisms, one of the most important being the assumption of spatial constancy of agricultural products' prices. Moreover, it is also recognized that this model does not consider the possible spillover effects that may exist between the different spatial units, which could lead to underestimation or overestimation of climate change effects on agriculture. Despite the limitations mentioned above, this study managed to show the positive contribution of certain adaptation factors to the improvement of agricultural income, such as the use of animal origin fertilizer, which can serve as niches for the development of adaptation strategies in a sustainable manner.

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