Climate Change and Dynamic Adjustment in Agriculture: The Case in Cameroon

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Acknowledegment:

JEL Codes: C67, Q11

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Keywords: Agriculture, Climate change, Hamilthon-Bellman Equation.

***JEL Code*: C610, Q1, Q540.**

1. INTRODUCTION

Cameroon is divided into five agro-ecological zones namely monomodal forest zone, bimodal forest zone, highland area, area of the high savannas and Sudano-Sahelian zone. The share of the agricultural sector in the Cameroonian economy is important. Indeed, this sector employs almost 60 % of the active population and contributes about 20% to gross domestic product (NIS, 2016). Exports of agricultural products represent 40% of total non-oil exports. However, in Cameroon, in recent years, climate changes cause instability in rainfall leading to disruption of the agricultural calendar and a substantial decline in agricultural productivity. Thus in the north of the country in the Sahel region, these climate variabilities cause desiccation of rivers, west drought surface water; and rising sea coast with flooding. This explains why IFPRI (2009) estimates that population in the developing world, already vulnerable and exposed to food insecurity, are likely to be most seriously affected.

High temperatures and current fluctuations in precipitation, combined with population growth, are a real and permanent threat to food security through their impact on agriculture in Cameroon. Indeed, rising in temperature causes lower yields of desirable crops and the proliferation of bad harvests in the short run on the one hand, and a substantial decline in agricultural production in long run on the other hand. With this in mind, resilience to climate variability and climate change becomes imperative in order to limit their socioeconomic impacts in the sub-region and particularly in Cameroon. Moreover, Molua (2009) shows a positive relationship between adaptation measures and increasing agricultural yields. For the author, adaptation is an operational strategy to deal with climate change. According to this study , 60% of surveyed Southwest farmers adjusted their farming practices to climate variability, and about 40 % of farmers have used for agricultural strategies aiming to conserve water and soil.

Our study aims to answer the following research questions: is there a direct link between climate change and farm incomes in Cameroon? And how do farmers' expectations on climate change affect investment and production decisions and the process of inputs adjustment in Cameroon?

This study has two objectives. Firstly, it aims to assess the impact of climate change on agriculture in Cameroon. Secondly, it aims to analyze how famers' expectations on climate change affect investment and production decisions; and process of adjusting factors of production.

Ricardian approach, initiated by Nordhaws and Shaw (1994) and developed by Mendelsohn et al. (1994) is used to estimate the impact of climate variability on the production or agricultural yield in Cameroon. It is based on observation of David Ricardo that value of land would reflect its profitability in a perfectly competitive market. This method, linking regional differences in climate to value difference of land, permits to compare sensitivity to climate change in different regions (Ouedraogo, 2006). Furthermore, in order to analyze investment behavior of farmers under uncertainty and adjustment costs induced by climate variability, we build a stochastic model based on dynamic duality developed by Epstein (1981) and then developed by Vasavada Chambers (1986), Howard and Shumway (1988), and Agbola and Harrison (2005). The development of this model through the integration of expectations in the dynamic duality theory was recently done by Pietola and Myers (2000) and Krysiak (2006). Sansi and Schumway (2014) used this approach to analyze the structure adjustment of inputs and output in the US agricultural sector.

The uniqueness of this study is based on two main arguments. First, there are no studies in Cameroon, to our knowledge, on the modeling of the dynamic output supply and input demand in the cameroonian agricultural sector. In addition, our study is a contribution to the formulation of an expanded theoretical framework as well as the application of econometric models derived from the dynamic duality apporach under uncertainty. The remaining of the paper is organized as follows. Section 2 presents a review of dynamic input demand models. Section 3 presents the econometric estimation methods, while Section 4 discusses the data. The results are presented, analyzed and discussed in Section 5. Finally, Section 6 concludes.

2. Overview of the link between climate and agriculture in Cameroon

Cameroon is located in Central Africa and stretches from the Gulf of Guinea to Lake Chad. Cameroon has 475 650 km^2 of area with a long coastlines of 402km. The country is bounded on the north region by Chad lake, on the South by Congo, Gabon and Atlantic Ocean, on the east by Chad and Central African Republic and on the west region by Nigeria.

The Sudano-Sahelian zone covers North and Far North with 10 million hectares in which 0.56 million are cultured (IRAD, 2008). Regarding climate, it is characterized by a single mode type of rainfall varying between 400 and 1200 mm per year. The Temperatures vary between 28°C and 45 ° C. Given this climate the main agricultural products are cotton, sorghum, millet, rice, maize, groundnuts and cowpeas.

The Area of high Guinean savannas, for its part, covers entire region of Adamawa, a part of central region namely northern zone of Mbam and an Eastern region zone particularly Lome-et-Djerem. It has 138,000 km^2 of area; this means about 29% of total area of Cameroon. Climate is characterized by average annual rainfall which is around 1500 mm for about 150 days. Because of altitude, temperature on the other hand is moderate between 20 and 26 ° C. These climatic conditions certainly determine the quality of the soil in this area and therefore agricultural products which are primarily produced for human and animal living at the expense of trade activities. Thus, corn is the main crop followed by millet, sorghum, groundnut and yam.

The Highlands of western zone covers western and North West region with 3.1 million hectares of area. Type of climate "camerounien altitude" is structured in two seasons: a dry season from mid-November to mid-March and a rainy season extends from mid-March to mid-November. As for temperatures, they are low in average of 19 ° C and abundant rainfall ranging between 1500 and 2000 mm per year. Thus all kinds of crops (food and export) are practiced namely groundnut, banana, robusta and arabica coffee, cocoa, vegetables, corn and tea.

The Unimodal humid forest zone covers littoral and southwest regions and a coastal edge of the southern region. This zone covers 4.5millions hectares of area in which 282,000 are cultivated. The land includes the volcanic slopes of Mount Cameroon and the original rocky sediments along the coast. Under Cameroonian climate type, very wet and very hot, the rains vary on average between 2500 and 4000mm except Debunscha locality which is considered as one of the rainiest zone in the world. Indeed, in this locality, 11000 mm of rain fall per year according to a monomodal rainfall regime with a long dry season. As for the temperatures, they vary between 22°C and 29 ° C. Food crops for exports such as coffee, cocoa, tea, bananas, palm oil, etc, are also produced in this zone.

The Humid forest zone with a bimodal rainfall. It covers Cameroonian south plateau between 500m and 1500m of altitude, Central and Eastern region. Climate is Guinean, hot and humid, with 25°C of temperatures of and 1500-2000mm/year of rainfall. In this area, there are grown cocoa, robusta coffee, vegetables, various fruit trees, plantains, sugar cane, corn, tobacco and tubers.

3. Litterature review

The literature review focuses on the application of the Ricardian model and stochastic dynamic dual models. The approach used to assess the link between climate and agriculture is Ricardo approach.

3.1. Ricardian approach: review of applied models

The Assessment of impacts of climate change on agriculture began in the 1980s (Da Silva, 2009). Thus, through the Ricardian model, Molua (2002) examines impact of climate change on agricultural land in eleven African countries: Burkina Faso, Cameroon, Egypt, Ethiopia, Ghana, Niger, Senegal, South Africa, Zambia and Zimbabwe . Results of this study show that decline in rainfall and rising temperatures lead to a significant drop in farm net incomes in these countries. Furthermore, results show that farms in arid areas are particularly sensitive to climate. Global warming affects positively farms irrigated because they are in relatively cold regions of Africa. Mariara and Karanja (2006) analyze impact of climate change on agricultural net income of 816 are of Kenyan households. Authors identify three models. The first model takes into account impact of climate variables only, the second includes the hydrologic variables and soil and the third assesses impact of household characteristics. Using variables as net farm income, wage rates, rainfall, temperature and soil moisture indices, results show the effectiveness of impact of climate change on agriculture in this country. Indeed, hydrological variables significantly impact farm net income. On the other hand, even if rainfall has higher elasticity than those of temperatures, marginal effects of the former are smaller than those of the latter.

Kurukulasuriya and Mendelsohn (2008) use Ricardian approach to study impact of climate change on agricultural income of farmers following 9064 randomly selected regions of the eleven African countries. Authors also identify three models. The first takes into account all land under cultivation, the second not only integrates irrigated land and the last one integrates rainfed farms. Results show that effect of climate variables varies by model. Increasing in temperature has a significantly negative effect on net farm income of farmers operating on land depends on rainfall. By cons, this increasing temperatures positively impact net agricultural farmers' income of irrigated land. This study shows that irrigated agricultural lands are less vulnerable to climate variability. Furthermore, drylands are more sensitive to climate than irrigated land. Elasticity of temperature in arid land is 1.9, while this value is 0.6 for irrigated land.

Using the same Ricardian approach, Ouedraogo (2012) assesses impact of climate change on net farm income for 1530 Burkinabe farmers. The model includes variables such as climatic, edaphic, hydrological and socio-economic. Results show that there is a nonlinear relationship between net farm income and climate variables such as temperature and precipitations. Thus, marginal impact of temperature on net farm income is US $ -19.9 per hectare while marginal impact of precipitations on the same variable is US $ 2.7 per hectare. This shows that rising temperatures helps to reduce income of farmers while rainfall increases income in Burkina Faso.

From 184 randomly selected villages, consisting of 384 households over 8 regions namely Dioubel, Fatick, Kaolack, Kolda, Louga, Saint Louis, Tambacounda and Thies; Ahmadou (2014) analyzes impact of climate change on agricultural production, kilo-calorie consumption and lean period. Results show that climate change has significant effects that amplify vulnerability of Senegalese farmers. Indeed, rainfall has a positive impact on agricultural production and temperatures both in dry season and rainy season have a negative impact on agricultural production.

When fixed effects of villages are taken into account, negative impacts of temperature on production decrease significantly. Moreover, temperatures have a negative effect on consumption of kilo-calories while impact of rainfall on calories consumed depends on whether its term is linear or quadratic. In the first case, impact of rainfall level has a positive impact on the consumption of kilo-calories while in the second case this effect is negative. This rainfall has a negative impact on weld time.

3.2. Stochastic dynamic duality approach: review of applied models

The Adjustment costs of factor demand that arise in response to market shocks have been widely sudied and documented in the litterature. For example, works of Lucas(1967),Caballero(1994), Hammermesh and Pfan(1996), Hall(2004), Lambert and Gong(2010). But, the fact that climate change may cause adjustment costs has received very little attention(Sansi and Schumway, 2014). However, adjusment costs that arise form environmental shock can not be ignored since they are very important in investment, production and factor adjustment process. For instance, decrease in pricpitation raise demand for water which in turn raises the demand for more efficient irrigation systems. To build new irrigation infrastructure takes time and effort, and therefore causes adjsutments costs. Kelly and al.(2005) examines adjustment costs in the context of profit loss in the process when a firm with incomplete knowlegde learns about the distribution of climate change over time. However, authors did not consider the case of quasi-fixed or strictly fixed factors. They assume that all factors of production are fully variable, ignoring the fact that adjustment of inputs cannot be done instantaneously and can make it difficult in short run any change in their amount. Knowledge and information have a very important role in the magnitude of adjustment costs to climate change. Indeed, if the farmer knows or anticipates future climate conditions, induced adjustment costs will be low or zero.

Since the second objectives of this study is to examine how adjustment costs affect input and output response both to price shocks and to stochastic climate change in the cameroonian agricultural sector, we make use of dynamic dual approach which is based on results of McLaren and Cooper (1980) and formalized by Epstein (1981). Application of this model is not recent. First applications are made in the work of Epstein and Denny (1983), Taylor and Monson (1985); and Vasavada and Chambers (1986) in the US agricultural sector. The second one includes the work of Bernstein and Nadiri (1988), Howard and Shumway (1998) and Agbola (2005). The development of this approach has been made by Pietola and Myers(2000), Krysiak(2006).

Dynamic duality approach consist in transforming intertemporal value function of the firm in term of Hamilton-Jacobi-Bellman equation. This equation represents the present or discounted value of profits (or costs). The problem is therefore to maximize or minimize depending on whether we have profits or costs function. Solution obtained by hotelling lemma, is a dynamic equations describing optimal path of investment demand of quasi-fixed inputs and supply of the firm.

Pietola and Myers (1998) use dynamic duality approach under uncertainty in order to develop and assess on Finnish pork industry data, a generalized model of firm investment. In this study, effects of uncertainty on investment are estimated by making use of dummy variables. Results show that the greater the uncertainty on the prices of machinery and equipment increases, the less investment is important in this sector. Furthermore, employment decision is not sensitive to increased uncertainty. Sansi and Shumway (2014) derive and estimate a stochastic dynamic duality in order to examine adjustment structure of two types of output and three categories of inputs in the US agricultural sector under climate uncertainty. Results of this study show that, given uncertainty induced by changes in market prices and climate change, farmers gradually adjusting the two types of output and three inputs considered. For instance, crops adjust mostly toward equilibrium levels and capital adjusts most slowly.

4. Econometric Estimation Methods

According to Guerrien and Vergara (1985), the first task of econometrics is to put empirical *pulpits* around the theoretical framework. In this case, the theoretical model and their functional form have to be specified. In this section, we first specify the functional form of the the ricardian model and the firm value function as well as econometric form of input demand equations. Then hypothesis tests are performed as well as the estimation of the derived models.

4.1. Functional form of the ricardian model.

The formulation of the Ricardian model is obtained as follows:

$$\begin{aligned} RA &= \beta_0 + \beta_1 C + \beta_2 C^2 + \beta_3 S + \beta_4 E + \beta_5 SA + \beta_6 TM \\ &+ \delta_1 M + \delta_2 IR + \delta_3 ER + \varepsilon \end{aligned} \quad . \qquad (1)$$

C et C^2 represent the linear and quadratic terms of climate variable. We introduce the nonlinear term in order into account for the nonlinear effect of the relationship between net income and Climate (Ouedraogo, 2012). S represents the soil variable ,

Introduction of variables such as agricultural area, household size and irrigation allows to take into account the adjustments made directly by farmers and their effects on their income.

M market access, E is the flow of water, SA is agricultural land, TM is the household size, IR irrigation and ε error term. The irrigation and market access are dummy variables whose parameters are equal to one if the individual has used this practice and 0 otherwise.

4.2. Theoretical Model and functional form of firm value

We build an intertemporal optimization problem in order to model the adjustment path of the inputs and outputs almost fixed in time. We assume that the firm purchases its inputs in a competitive market and its expectations on climate and market prices are rational. This means that farmers hardly make forecasting errors. In addition, investment and production decisions of farmers take into account the uncertainty induced by climate change following a stochastic process. To account for this uncertainty, we introduce the climatic elements such as temperature and precipitation in the production function of the farmer. In each period, the farmer's decisions depend on their expectations on climate and market prices.

Farmers use variable factors and quasi-fixed factors. They know current prices of all inputs and outputs, but they only formulate expectations about future developments of these prices and climate conditions. However, farmers must decide on production levels to be attained, the amount of inputs to be used and the level of investment in quasi- fixed factors to be achieved without ignoring adjustment costs.

We assume also that at each base period and for a price given by the market, agricultural firm determines its optimal policy by maximizing the present value of its expected future profits. Furthermore, we assume that this firm does not face the constraint opportunities when developing its production program. Since the choice of the stock of quasi-fixed factors today affects the adjustment costs of the future, the problem becomes dynamic. Therefore, the firm must solve the problem according infinite horizon:

$$J(K_0, p_0, w_0, r, C_0) = \max_{L \geq 0, I \geq 0, C \geq 0} \int_0^{\infty} e^{-rT}(1-\tau)\left[F(L,K,I,C) - {}^{t}wL - {}^{t}pK\right]dt \quad (3).$$

s/c

$$\overset{\bullet}{K} = I - \delta K \quad (4)$$

$$\overset{\bullet}{C} = \delta(C) + \rho\varepsilon \quad (5)$$

$$K_i(0) = K_0 \geq 0, C(0) = C_0, (K, p, w) \in \Theta, \forall t \in [0;\infty[$$

$K_i(0)$ is a vector of quasi- fixed factors held by firm i at the initial period $t_0 = 0$

$\overset{\bullet}{K}_i(t)$ net investment in quasi-fixed factors, $w \in \Omega^2$ et $p \in \Omega^2$ are respectively vector prices of variable factors and quasi-fixed factors. C is climate vector that consists of temperature and precipitation indices. Its evolves stochastically and exogenously following Brownian motion with drift which is characterized by the transition equation (5). $\delta(C)$ denotes a non-random vector of drift parameters ; ρ is a vector with $\rho^t \rho = \Sigma$, ε is identically and independently distributed(iid) normal vector with , $E(\varepsilon) = 0, \operatorname{var}(\varepsilon) = dT, E(\varepsilon_i \varepsilon_j) = 0$, $i \neq j$. Θ open bounded set and domain definition of value function J , $r \geq 0$ is discount rate. It is equal to 5.5%.

Solution of the problem (2) is done by using dynamic programming, third approach of dynamic optimization problems. This approach, developed by Bellman (1957), has been successful in its application to problems in discrete and continuous time.

To derive demand functions of investment and employment, we use the dynamic duality approach. This method was initiated and developed for the first time in the theoretical work of Epstein (1981). This new duality provides a broad class of functional forms of application of inputs, which can be tested and applied to the theory of adjustment costs. The primal problem in our approach is the Hamilton-Jacobi-Bellman equation and the dual is the inverse of this equation:

$$rJ(T,K) = \max \begin{bmatrix} g(T_0, K_0, I) + {}'wL + {}'pK + J_K(T_0, K_0)\overset{\bullet}{K} \\ +J_C\delta(C) + 0,5vec(J_{CC})' vec(\Sigma) \end{bmatrix} \tag{6}$$

The above is Hamilthon -Jacobi -Bellman equation and is the primal problem. It is established as a necessary condition of equilibrium of a dynamic optimization program with a continuous time under constraint[1]. Indeed, Hamilton -Jacobi equation is a necessary and sufficient condition to maintain firm value at its maximum level in each period. It also allows transforming dynamic problem (3) in an easily handled form. This equation is a static form of the problem (3) and implies that firm value can be defined as the sum of the maximum current profit and the present value of marginal benefit resulting from the optimal adjustment in net investment. According to Epstein (1981, op.cit), firm's technology function can be determined and represents optimal behaviour firm supply as follows:

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[1] Hamilton -Jacobi – Bellman equation is different from the Euler equation, also called Euler-Lagrange equation. This equation is the necessary condition of equilibrium in a dynamic optimization program in continuous time without constraint.

$$F(L,K,I)=\min_{(p,w)\in\Theta}\begin{bmatrix} rJ(K_0,p_0,w_0,r,C_0,T_0)+{}^{t}wL+{}^{t}pK \\ -J_K(K,p,w)(I-\delta K)- \\ J_C\delta(C)+0,5vec(J_{CC})^{t}vec(\Sigma) \end{bmatrix} \tag{7}$$

$\left(L,K,I,C\right)\in\Phi$

Suppose that J is a diffeomorphisme. That means this function is bijective, différentiable on Θ an its inverse on Φ, for all (K_0,p,w,C_0).

According to envelope theorem which consist of differentiating the above equation with respect to prices w and p, and rearranging, we obtain the following system equation which represent dynamic quasi-fixed inputs and output; and variable inputs.

$$\overset{\bullet}{K}{}^{*}={}'J^{-1}_{Kw}\,(r\,'J_p+K)-J_C\delta(C)+0,5vec(J_{CC})'\,vec(\Sigma) \tag{8}$$

$$L^{*}=-rJ_w+{}'J_{Kw}\overset{\bullet}{K}-J_C\delta(C)+0,5vec(J_{CC})'\,vec(\Sigma) \tag{9}$$

The first equation describes the dynamics of quasi- fixed factors. While the second equation expresses the optimal path of variable factors.

According to Vasavada and Chambers(1982), and Sansi(2014), functional form for the Hamilton-Jacobi-Bellman equation form of value function that allows for linear homogeneity in prices and concavity in quasi-fixed inputs is a modified generalized Leontief:

$$J(K_0,p_0,w_0,r,C_0,T_0)=\left[pw\right]AK+{}'pB^{-1}K+\left[{}'p\,{}'w\right]HC+ \\ \left[{}'p\,{}'w\right]Ivec(C'C)+\left[{}'p^{1/2}\,{}'w^{1/2}\right]C\begin{bmatrix}p^{1/2}\\ w^{1/2}\end{bmatrix}+\left[{}'p\,{}'w\right]DY \tag{10}$$

This function allows taking into account the quasi- fixity of inputs and output. Then the specified form of equation (8) is:

$$\begin{aligned}
&\dot{K}^{*} = (rI - A)K + AH(rC - \delta(C)) + AI(rvec(C^{'}C \\
&-vec_{C}(C^{'}C)\delta(C) - 0,5vec(\Sigma)) \\
&+rA\left[diag(K^{1/2})\right]MK^{1/2}
\end{aligned}$$

(11)

Approximating $\dot{K}$ discretly as $\dot{K} = K_{it} - K_{it-1}$, we have the final functional form of equation (10) as:

$$\begin{aligned}
&K_{it} = (I + M_{a})K_{it-1} + AH(rC - \delta(C)) \\
&+AI(rvec(C^{'}C - vec_{C}(C^{'}C)\delta(C) - 0,5vec(\Sigma)) \\
&+rA\left[diag(K_{it}{}^{1/2})\right]MK_{it}{}^{1/2}
\end{aligned}$$

(12)

Econometric specification of demand equations is then done by adding error terms for each one of the system equations. The error term measures the difference between actual observed values of the dependent variable and the values that should have been observed if the functional relationship was strictly accurate. Specification of equations (12) is then made by adding the error terms for each of the system equations. These terms reflect also errors and optimization technology shocks

Consequently, system of quasi-fixed factors demand can be written in the following form:

$$\begin{aligned}
&K_{it} = (I + M_{a})K_{it-1} + AH(rC - \delta(C)) \\
&+AI(rvec(C^{'}C - vec_{C}(C^{'}C)\delta(C) - 0,5vec(\Sigma)) \\
&+rA\left[diag(K^{1/2})\right]MK^{1/2} + \varepsilon_{it}
\end{aligned}$$

(13)

5 . Sources and data definition

In this framework, data definition consist to neutralize price effect in the variables, and to normalize factors with respect to output price.

5.1. Data sources and identification of agricultural production units

The data used in this study come from Food and Agricultural Organisation (FAOSurveys and Agricultural Statistics Division (SASD) of Cameroon Ministry of Agriculture and Rural Development (MINADER) and the Cameroon National Institute of Statistics (NIS). Climate data including temperature and precipitation indices are collected from observation posts régionaless of the ten regions of Cameroon namely Abong-mbang, Ambam, Batouri, Ebolowa, Garoua, Lobe, Maroua, Menoua, Nkambe, Ngaoundere, Nkolbisson, Nkongsamba, Tibati and Yagooua. This is data were completed by those of World Bank (2015) and especially Climate Change Knowledge Portal. Moreover, since investment is intermittent at the firm level, we use data aggregated at the national agricultural sector. This aggregation of data is justified by the fact that the model we have derivative is a convex adjustment model. This aggregation can also be justified by reasons statistic: achieve significant results.

To assess the impact of climate change on agricultural income, we estimate Ricardo model on a sample of 13000 households identified in the Fourth Cameroonian Survey on households or Quatrième *Enquête camerounaise auprès des ménages*(ECAM4, 2014), available at the National Institute of Statistics (NIS). The number of surveyed households by enumeration area is ten in Douala and Yaoundé, twelfth in other urban strata and fifteen in semi-urban strata and rural. It should be important to note that ECAM 4 was carried out in six of the ten existing regions namely Centre, Littoral, Far North, West, Southwest and Northwest region. The reason is that in these areas, most of households practice agriculture.

Concerning the analyze of the dynamics of adjustment of inputs and outputs, we make use of data aggregated at national level provided by FAO for the period 1961-2016 STAT.

5.2. Data Definition

Variables used in this study are defined as follows:

a- The Physical capital stock which includes machinery, equipment and land.

b- The Labour. It is used taking into account degree of qualification of workers. Thus, this factor contains two categories, namely the number of workers (family labour) and the number of qualified employees. The first category perfectly fit into the variable factors, while the latter category is stored in the so-called *quasi-fixed* factors.

c- The total value of the energy. For energy, we mean fuel, electricity and water. The value is obtained by aggregating data in order to obtain the level of annual energy consumption in the agricultural sector.

d- The total value of inputs: fertilizer

The price of workforce or hourly rate of pay is relative to the number of hours worked on average

f- Price of capital.

g – The Farm net income. It is the difference between production and associated production costs (seed costs, inputs, pesticides, storage, equipment and agricultural equipment, etc.)

h-The Temperatures and annual precipitation. They are computed as the sum of monthly precipitation and temperatures. Moreover, since according to the Intergovernmental Panel on Climate Change (2007) observed changes in temperature and rainfall at the regional level are often correlated. To take into account this correlation, we use a VAR model. Im-Pesaran-Shin test (IPS) shows that the VAR model (2) better explains this temporal correlation.

We also added two dummy variables including irrigation and measures against erosion. These two variables are useful in estimating Ricardo model because they allow to capture adaptation measures undertaken by farmers under climate change. Irrigation permits to see what is the effect of the measures taken during the drought. while the second variable informs about effect of adaptation measure during rainy periods.

6. Presentation and analysis of results

The Results in this section relate to the estimation of the Ricardian model and interdependence and quasi-fixity hypothesis tests. Ricardian model informs about climate impacts on incomes of farm households. While interdependence and quasi-fixity tests inform about dynamics of production adjustment and quasi-fixed inputs to their respective optimum levels. Regression is done in two stages. In a first step, we introduce socioeconomic and climatic variables except irrigation and measures against erosion in Model 1 called model without adaptation. In the second step, especially in model with adaptation we introduce practice of irrigation and measures against erosion (both dichotomous variables) in order to assess impact of these adaptive measures on incomes of farm households. Parameters are estimated by ordinary least squares method (LSQ). Results obtained are shown in **Table 1** below.

6.1. Estimation results of Ricardian model

Table1 – Estimation results of the ricardian models

Variables	Modèle 1		Modèle 2	
	Coef.	t	Coef.	t
Climatic variables				
Temperature	-710.340**	6.08	-615.10*	4.96
Temperature squared	-10.022**	-3.15	-14.52**	-7.46
Precipitation	16.543***	6.72	17.83*	3.86
Precipitation squared	-0.893***	-7.25	-0.644**	-10.01
Socio-economic variables				
Area of holding	-7.201*	-3.44	-10.30**	-5.00
.log (Household	-8.343	-3.23	-3.56**	-2.89
size)	99.802*	5.75	78.72***	8.05
Irrigation (1/0)	41.71**	10.42	43.08**	16.32
Erosion	-41.305*	-8.230	-43.111**	-4.89
Use of hired work	-4012	-2.02	-3912	-5.32
(1/0) Constante				
Number of observations	13000		13000	
F	12.03		14.10	
R^2	0.5333		0.6207	

* Significatif au seuil de 10%; ** Significatif au seuil de 5%; *** Significatif au seuil de 1%.
Source: Authors from ECAM 3, FAOSTAT and world bank data with STATA 13 software.

The explanatory power of the two models is excellent, according to values of correlation ratio. Correlation ratio for the first model indicates that farm income fluctuations are explained at 53.33 % by different climatic and socioeconomic variables while this ratio is 62.07% for the second model. This implies that quality of equation adjustment to dependant variable is also good. Fisher-Snedecor test shows, moreover, that the two models are globally significant. As for Student test, it shows that quadratic terms of temperature and precipitation are significant at 5% level and 1% respectively. Consequently relationship between climate and farm income is nonlinear.

The Signs of parameters relating to socio-economic characteristics are those theoretically expected except agricultural area. Indeed, we found that soil quality, market access, practice of irrigation and household size positively affects net farm income. This means that the more quality of soil is good and farmers have market access, the more net farm household income is high. The Positive influence of irrigation on farm net income is explained by the fact, during dry season, irrigation allows farmers to adapt their activity to climate variations. Practice of irrigation is an important need in Central Africa in general and Cameroon in particular since country's agriculture is mainly rain-fed agriculture.

For cons, effect of agricultural area on net income is negative. This can be explained by practice of extensive farming by in order to compensate low productivity of agricultural land. In the short run, this practice increases agricultural production without improving productivity of agricultural land. In the long run, this practice lowers crop yields due to insufficient resources to maintain activity on these large areas. We assessed sensitivity of farm incomes with respect to climatic variables. Thus, **Table 2** shows that an increasing of 1% in temperature leads to lower farm revenues by 41.43 % while an increasing of 1% in precipitation leads to higher farm revenues by 17.01 %.

Table 2: Elasticity of farm incomes.

	Elasticity	**R^2**	**F-statistic**	**t-statistic**	**DW**
Temperature	-0.4143	0.72	865.11	6.10	2.10
Precipitations	0.1701	0.62	90.32	11.90	1.78

Source : Authors from MINAGRI, ECAM 4 and FAOSTAT data

Table 3: Marginal effect of climate variables on farm incomes.

	Marginal effect	**R^2**	**F-statistic**	**t-statistic**	**DW**
Temperature	-3100.05	0.44	789.45	1.76	2.00
Precipitations	3205	0 .67	77.77	11.27	1.74

Source: Authors from MINAGRI, ECAM 4 and FAOSTAT data

Looking at the marginal effects of climate change on agricultural income, **Table 3** shows that increasing 1mm rainfall leads to an increase in net farm income of FCFA 3205 per hectare. While an increase of 1°C leads to decrease of FCFA 3100.05 per hectare.

6.2. Results on Dynamics of adjustments under uncertainty.

In this sub- section, we present and analyze results on dynamic adjustment of inputs and agricultural production in Cameroonian agricultural sector based on the coefficients of adjustment matrix $M_a = rI_4 - A$. Estimation results relate to sixty seven parameters in **Table 5** in appendix.

This second part of our study is to examine dynamics of adjustment in the agricultural sector in Cameroon. This objective is achieved performing quasi-fixity and interdependence tests. The first test is performed on agricultural production, labour, fertilizer and productive capital (approximated by machinery and equipment). The second test concerns independence of adjustments between these variables. In this study, these tests are used to assess if there is relationship between two variables, even when those variables are qualitative. It is whether, at the agricultural firm level, production adjustment affects inputs adjustment and vis-versa. Independence test, for example allows controlling of interdependence between production adjustment and amount of used quasi-fixed inputs on one hand; and interdependence between quasi-fixed inputs on the other hand. According to Monson and Taylor (1985), independent adjustment rate means that each quasi-fixed input adjusts to their long-run equilibrium level regardless of the other quasi-fixed inputs. According to Howard and Shumway (1988), independence reflects the fact that in the adjustment matrix, crossed adjustment coefficients are equal to zero.

$a_{ij} = a_{ji} = 0$, avec $i \neq j$. So, a quasi- fixed variable is adjusted to long-run equilibrium level independently of each other. For example, at a certain period, firm can hire new workers without needing to vary level of physical capital (amount of equipment and machinery) or it may decide to vary level of physical capital without needing to hire new workers. Null hypothesis is the lack of interdependence and therefore independence between adjustments. According to Warjiyo and Huffman (1995), univariate partial adjustment model is then appropriate to estimate adjustment coefficients. Consequently, change in relative price of input has no effect, even indirectly on the amount of other input. Alternative hypothesis reflects interdependence between adjustments of the various quasi-fixed factors: level change in amount of an input requires change in the amount of other input and vice-versa. In this case, flexible accelerator multivariate adjustment pattern appears to be a better representation of adjustment behaviour of quasi-fixed inputs by agricultural firms, instead of univariate partial adjustment model. The following table gives results of chi-square independence test.

Instantaneity implies that in the adjustment matrix, the own and crossed adjustment coefficients are equal to 1 and 0 respectively:

$\begin{cases} a_{ii} = 1 \\ a_{ij} = a_{ji} = 0 \end{cases}$. These restrictions reflect the fact that production and quasi- fixed inputs adjust instantaneously to their optimum level of long-run and are considered to be variable inputs in short and long-run. Therefore, the current amount of inputs $K(t)$ is always at the desired level or long-term equilibrium $\overline{K}$, variation in the amount of inputs $\dot{K}(t)$ is zero for all t and the adjustment matrix is an identity matrix of order 4. In this case, any adjustment of production, fertilizer, capital, labour is done smoothly and without costs. In other words, agricultural firm adjusts these variables in one period.

Quasi-fixity test is performed as follows:

$$\begin{cases} H_0 : a_{ii} = 1, a_{ij} = 0 \\ H_1 : a_{ii} \prec 1, a_{ij} \neq 0 \end{cases}.$$

a_{ij} and a_{ji} are different from zero.

Null hypothesis reflects the fact that adjustments are instantaneous. Hence, firms adjust immediately and without costs in one period their level of output and production capacity to their optimum level. Thus, in the absence of adjustment costs, firms, facing change in relative prices adjust their output and theirs inputs freely without suffering production or revenue losses. As for alternative hypothesis, it represents the fact that changes in levels of quasi- fixed inputs are progressive: adjustment of amount of quasi-fixed inputs to their optimal level is done in several periods. Therefore, inputs are gradually adjusted to their l long run equilibrium level. In adjustment matrix, crossed and own adjustment coefficients are not only equal to zero but also strictly less than unity. They are then, in the short run, modeled as quasi-fixed inputs.

The Results of quasi- fixity test are shown in the following table:

Table 4. Tests of interdependence and instantaneity.

Hypothesis Tested	**Wald Test**	***df***	***p*-value**
Independent and instantaneous adjustment	31200.12	16	0.0020
Independent adjustment	122.00	11	0.0000
Quasi- fixity	287.07	16	0.0000
Independent and instantaneous adjustment *for*			
Crops	34.22	7	0.0100
Capital	921.40	7	0.0001
Labour	18.21	7	0.0001
Fertilizer	24.72	7	0.0000

Source: Authors from MINAGRI, ECAM 3 and FAOSTAT data and with SAS software

The Wald test we use is particularly interesting in the sense that it is possible to perform simultaneously interdependence test and instantaneous adjustments test. So, according to the results, assumptions of independence and instantaneous adjustments are rejected since adjustment matrix

M_a is different from unit matrix I_4. This confirms existence of adjustment costs in the process of adaptation and resilience to climate change and in market prices changes by farmers. Furthermore, independent adjustment test shows that production adjustment leads in capital adjustment, labour and fertilizer and vis-versa. Indeed, in Cameroon, farm households practise extensive agriculture in order to increase agricultural production affected by climate change. This practice also requires an increase in production capacity in terms of capital, labour and fertilizer. The results show that these adjustments to climate change and to changes in market prices do not happen instantly. Thus, at 10% level, quasi-fixity hypothesis is accepted for production, capital, fertilizer and labour. The fact that agricultural production is gradually adjusted can be explained by the limited adaptability of plant species. Capital which includes machinery, equipment and land, may be less flexible during certain periods (Sansi and Schumway, 2014). Since fertilizers are purchased, amount and also calendar of use are adjusted gradually. Results in the above table also show that workforce which includes paid self-employment and labour, do adjusts instantly.

The Adjustment matrix which provides information about speed of adjustment of quasi-fixed variables shows that all coefficients of this matrix are significantly different from -1 at 5% level for production, labour, and fertilizer and at 10 % for capital. This implies that in the short run and under climate change and market prices changes, production, capital, labour and fertilizer are actually quasi-fixed variables and their adjustment is not made in an annual period, but in several years. Own adjustment rate of production -0.4 implies that harvests adjust at 40% to their desired level every year in response to price shocks and climate change. While capital adjustment rate -0.0104 implies that this input is adjusted at 1.04% towards its equilibrium level in a year. In addition, labour adjustment rate -0.6666 means that workforce is adjusted at 66.66% annually. Finally, adjustment rate of fertilizers -0.9834 reflects the fact that this variable is set at 98.34% annually. It can be said that under climate change and prices shocks, Cameroonian farm households take about two and a half to adjust production at its optimum level (or desired level), about 24 years to fully adjust capital, one and a half to adjust workforce and about nine months to adjust fertilizers, each of them at their optimum level. These results show that in the Cameroonian agricultural sector, farmers are renewing more slowly their level of capital which includes machinery, equipment and agricultural land.

7. Conclusion

The first objective of this study is to understand and quantify the link between climate and agriculture in Cameroon. The second one is to examine how expectations of farmers on climate change affect investment and production decisions and inputs adjustment process. The first objective is achieved by applying two Ricardian models namely model **without adaptation** and **model with adaptation**. In the model without adaptation, irrigation and measures against erosion are not taken into account while in the model with adaptation, these measures are introduced in order to capture theirs effects on farm incomes. We found that soil quality, market access, irrigation and household size positively affect net farm income. This means that the higher the quality of soil is good, farmers have access to markets, the more the farm incomes are improved. With regard to irrigation, it permits to adapt to climate change, especially during dry seasons, since Cameroon's agriculture is mainly rain-fed agriculture. We also found that effect of agricultural area on farm income is negative. Then, estimates show that income of farm households are significantly sensitive to climate variations. Thus, an increasing of 1% in temperature leads to lower farm revenues by 41.43 % while an increasing of 1% in precipitation leads to higher farm revenues by 17.01 %. As for climate marginal effects on incomes of farm households, we found shows that increasing 1mm rainfall leads to an increase in net farm income of FCFA 3205 per hectare. While an increase of 1°C leads to decrease of FCFA 3100.05 per hectare. Finally, estimates of dynamic stochastic model show that, under uncertainty induced by climate change and in market prices changes, farmers gradually adjust production and inputs. These dynamic adjustments are justified by adaptation costs of measures implemented by farmers under uncertainty. Thus, in this uncertain environment, farmers take about two and a half years to fully adjust desired level of their crops, about 24 years to adjust capital to its desired level, one and a half to adjust work and about nine months to adjust fertilizer.

However, beyond all these results, although model allows to highlight adjustment costs induced by climate change and market prices change, it does not allow decomposition of these two effects. So in this study, changes in climate and relative price occur simultaneously.

This study contributes more to the validity of dynamic inputs demand models derived from dynamic duality approach in an uncertain environment, developed by Pietola and Myers (2000) and Krysiak (2006). In the same vein, this study shows that it is possible to model supply and demand for several quasi-fixed inputs and outputs through transformation of the value function of the firm in Hamilton-Jacobi-Bellman equations. Looking at the political contributions, interest of understanding and anticipating impacts of climate change on agriculture is very important for policy makers. It permits to implement appropriate measures to mitigate the socio-economic consequences.

Appendix

Table 5. Nonlinear Three-Stage Least squares Parameters Estimates Of Simultanous Equations

Parameter	Estimate	Standard Error	Parameter	Estimate	Standard Error
A_{11}	0.4501**	0.0272	I_{21}	0.0437**	0.0187
A_{12}	-0.1227**	0.0106	I_{22}	0.0543	0.0543
A_{13}	0.1039	0.0145	I_{24}	0.0741	0.0184
A_{14}	0.0210	0.0023	I_{31}	-0.0703	0.0349
A_{15}	-0.0027	0.0302	I_{32}	0.0267	0.0970
A_{21}	-0.6206**	0.4320	I_{34}	-0.0107	0.0111
A_{22}	0.1540*	0.1045	I_{41}	-0.0750**	0.0674
A_{23}	-0.0421	0.0376	I_{42}	-0.0201	0.0367
A_{24}	-0.0754	0.0603	I_{44}	-0.0704	0.0723
A_{25}	0.0661	0.2331	I_{51}	-0.0278	0.0403
A_{31}	0.1377*	0.0457	I_{52}	-0.0618	0.0823
A_{32}	-0.1834*	0.0324	I_{54}	-0.0343	0.0112
A_{33}	0.7166**	0.0765	C_{11}	12.1465	4.3572
A_{34}	-0.0102	0.0207	C_{12}	22.4390*	10.6563
A_{35}	-0.0732**	0.0750	C_{13}	-7.2126	11.4378
A_{41}	-0.0698	0.4509	C_{14}	-4.9347	5.1212
A_{42}	0.0310	0.3590	C_{15}	-9.2012	12.6717
A_{43}	-0.1048	0.0453	C_{22}	8.6077	8.2345
A_{44}	1.0331**	0.2370	C_{23}	-10.5123	19.1717
A_{45}	-0.4785	0.6432	C_{24}	-12.9453	7.0783
A_{51}	0.7534	0.4374	C_{25}	-17.0703*	9.9375
A_{52}	0.7903	0.4950	C_{33}	29.6520*	12.1362
A_{53}	-0.6209	0.2761	C_{34}	-8.2045	10.0028
A_{54}	0.0230	0.0532	C_{35}	-20.2304	13.2436
A_{55}	1.4351**	0.6732	C_{44}	11.3733	5.1056
H_{11}	0.0375	0.0657	C_{45}	6.7610	4.1273
H_{12}	0.1560	0.0439	C_{55}	42.4420**	31.4020
H_{21}	0.0645	0.2255			
H_{22}	0.0101	0.0448			
H_{31}	0.2014	0.2370			
H_{32}	-0.1769	0.0378			
H_{41}	0.1967	0.0265			
H_{42}	0.1345	0.0426			
H_{51}	-0.0532	0.4572			
H_{52}	-0.0730	0.0978			
I_{11}	0.0457	0.0157			
I_{12}	0.0579	0.0574			
I_{14}	0.0627	0.1122			

Sources : *By the authors from FAO STAT,MINAGRI 1961-2013 period, in the SAS software.*

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