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Full length Research paper

Dynamic Adjustment in Agriculture under Climate Change: Evidence from Cameroon

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This study aims at examining the dynamics of production structures in Cameroonian agricultural sector under stochastic climate change. More specifically we develop and estimate a dynamic demand system of inputs and output by using a stochastic dynamic model approach and applying the hotelling's lemma to the Hamilton-Jacobi-Bellman equations. The data are compiled from Food and Agricultural Organisation (FAO), Cameroonian Ministry of Agriculture and Rural Development (MARD) and the National Institute of Statistics of Cameroon (NSI). The model is estimated by non-linear three least squares method. We found that under climate change and market price change, food crop production, capital, labour, arable land and fertilizers are actually quasi-fixed variables and their adjustments are done progressively. Then, crops adjust each year by 56% towards their desired level in response to climate change. While the capital factor adjusts by 10.32% towards its equilibrium level in one year. Furthermore, the labour is adjusted by 68.52% each year. The fertilizer is adjusted at 44.11% per year. Finally, the arable land adjusts to 87.32% per year. To further reduce the climatic risks to which Cameroonian farmers are faced, public decision-makers can reduce directly and indirectly adjustment cost by funding research on adaptation crops and land use.

Key words : Agriculture, Cameroon, Climate change, Intertemporal Firm Choice.

JEL Code : Q1, Q540, D250.

INTRODUCTION AND BACKGROUND

The scientific evidence that climate change is a serious and urgent issue is now compelling for all the countries of the world. In Cameroon specifically, since 1960, rainfall has decreased by 2.2% per decade (or -2.9 mm each year) over the country (MINEPDEP, 2015). Since the 1980s, the frequency of droughts has been increasing. This has resulted not only in a shortening of the length of the rainy season over the country but also in high geographical variability of rainfall. In addition, the average annual temperature increased by 0.7°C from 1960 to 2007. This increase is found in all the Cameroon agro-ecological zones[1]. Moreover, climate projections then show a drier climate in the North and a wetter climate in the South of the country by 2090, with rainfall varying between -12 mm and 20 mm per month (MINEPDEP,2015). These weather forecasts also indicate an increase in the frequency and magnitude of future extreme events such as droughts, increased land erosion, floods, and land movements in all agro-ecological zones. Finally, the sea level will rise by 9 to 38 cm by 2050 and 86 cm by 2100 with inherent risks such as flooding, more frequent storms and increased sedimentation.

The need of mitigating, managing risks and to adapt to the changing climate is then urgent in this context. How do Cameroonian famers adjust or adapt their production structure under climate change given that the process of settlement in climate change is not possible without costs? According to the Intergovernmental panel on climate change (2007), adaptation is an adjustment in natural and human system in response to current or expected climatic stimuli and their effects. Its plays an important role in reducing the pervasive risks of climate change. Molua (2006) shows a positive relationship between adaptation methods and increased agricultural yields in the case of Cameroonian farm's household. According to this

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[1] Cameroon is divided into five agro-ecological zones, namely the monomodal forest zone, the bimodal forest zone, the highland zone, the high savannah zone and the Sudano-Sahelian zone.

author, since adaptation is an operational strategy to cope with climate change, 60% of surveyed farmers in the southwest have readjusted their farming practices in response to climate variability, and about 40% of them have used agricultural strategies aimed at conserving water and soil. Yet the process of settlement in climate change is not possible without costs. Thus, in the process of adjusting inputs and production amount, these costs cannot be ignored. This study aims at examining the dynamics of production structures in Cameroonian agricultural sector under stochastic climate change. Specifically we develop and estimate a dynamic demand system of inputs and outputs by using a stochastic dynamic model approach and applying the hotelling's lemma to the Hamilton-Jacobi-Bellman equations. This allows us to investigate whether adjustment costs may delay farm household's response to stochastic climate change. Furthermore, we proceed with the test of quasi-fixity inputs and outputs and the interdependence of adjustment of both types' inputs and output variables. In our study we consider a single-output but a multi-input agricultural production. The specificity of this study lies in two arguments. Firstly, there are no studies to our knowledge on the modeling of the dynamic inputs demand and outputs supply in the agricultural sector in Cameroon. Secondly, since information on climate conditions as well as market prices is incomplete at the level of decision-makers, the introducing of uncertainty into the analysis of producer behavior improves the results obtained under perfect competition, as information is treated as a risk.

The rest of the article is organized as follows. Section "literature review" reviews selected literature. In this section, the theoretical construct underlying the claimed link between the adjustment cost and the dynamics of production structure is presented. The methodological part in Section "Methodology" starts with data collection and then the model that we use is explained. Section "Results and discussion" displays the interdependence and quasi-fixity hypotheses tests that inform about the dynamics of adjustment of production and so-called quasi-fixed inputs. Finally, section "Conclusion" concludes and suggests some recommendations for policy makers.

Literature review

The fact that environmental shocks such as climate change may affect the adjustment costs and therefore affect the adjustment process of inputs and outputs has received relatively little attention (Liu and Shumway, 2015). But some works can be found such as those of Zilberman et al.(2004), Yang and Shumway(2015) and Quiggin and Horwitz (2003).

Zilberman et al. (2004) distinguish two forms of adjustments cost namely the transition costs and the settlement costs. The first one refers to the cost related to moving from one technology to another, from the cold-tolerant crop to the heat-tolerant crop, while the second reflects the costs associated with settlement of new land close to the poles. According to these authors, both of these forms of adjustment costs are likely to reduce agricultural supply and increase the social costs of climate change. These types of costs are likely to delay the process of adjusting both production and the quantity of production factors used. From the adjustment costs theory, we learn that a farmer is unable to instantly adapt to the climate change due to the fact that he does not perfectly observe the climate change, which says the farmer only realizes that the climate has changed. Once having realized that climatic conditions have changed, he forms his subjective assessment of the evolution of the weather based on currently available information and takes time to learn the new nature of the change in climate. During this time his production decisions are suboptimal and consequently his outputs or profits are incurring loss. Farmers thus incur adjustment costs when they adapt to new climatic conditions since these costs may arise both from incorrect beliefs about the state of the climate distribution and from the time taken to replace obsolete factors of production.

This adjustment can only take place in the long-run when the effect of a change in climate after both beliefs and inputs investment have been allowed to balance to the new climatic conditions. As Quiggin and Horwitz (2003) argue, the adjustment costs may be very substantial and can only represent a major element of climate change, but also can be expected to be quite pervasive, extending through complex chains technological, agrarian and demographical adaptation. These adjustment costs are high or low depending on if the net benefits of adaptation option are high or low and time-scale is long or short. In both case, these costs are non-trivial and are likely to delay the response of farm households to climate change since they involve learning costs, expansion costs, and costs of restructuring the production process or preparing equipment (Yang and shumway, 2015). According to Kolstad and Moore (2019), the adaptation process to climate change involves expectation in order to minimize its impact on the well-being of farm households in general and on their livelihoods in particular since climate change lowers welfare because of inherently worse outcomes under climate change and because farmers are initially not adapted to or even informed about the new climate.

As far as we know, systematic research has not been undertaken enough towards the modeling dynamics of the production structure under climate uncertainty. Seminal works on the dynamic duality approach have been initiated since the 1980s by authors such as McLaren and Cooper (1980) and Epstein (1981) and applied by Epstein and

Denny (1983), Taylor and Monson (1985) and Vasavada and Chambers (1986). But this model has been recently applied by Bernstein and Nadiri (1988), Howard and Shumway (1998) and Agbola (2005) even if their works are failed to account for uncertainty. The development of this approach by taking uncertainty into account is done thanks to Pietola and Myers (2000), Krysiak (2006) and Yang and Shumway (2015).

Pietola and Myers (2000) use the dynamic duality with uncertainty approach to develop and estimate a generalized investment model of the Finnish pork industry using data from the Finnish pork industry. The authors derive a stochastic model of investment under uncertainty where firms perceive state variables as geometric Brownian motion with drift. In their study, the effects of uncertainty on investment are estimated using dummy variables. They apply the resulting model to a sample of Finnish hog farms. The results show that real estate and machinery investments respond negatively to increases under uncertainty while labor decisions are insensitive to uncertainty. Labour investment is found to be asymmetric with contractions in labour usage adjusting more slowly than expansions, which is consistent with higher adjustment costs in the contraction phase than in the expansion phase. Economies of size were found for both output expansion and investment, suggesting that large one-time expansions are favored over slow gradual adjustment. Furthermore, the results show that the greater the uncertainty in the prices of machinery and equipment, the less investment is made in this sector. Moreover, the employment decision is not sensitive to the increase in uncertainty. Similar theoretical works was carried out by Krysiak (2006) when the author derived the optimal intertemporal behavior from a stochastic optimization problem in which is included models of investment under uncertainty. But only, in the two previous studies, the uncertainty in which producers invest is linked solely to changes in market prices and not to climate change as in the works of Yang and Shumway (2015).

Yang and Shumway (2015) derive and estimate a stochastic dynamic duality model to examine the adjustment structure of two aggregate output and three aggregate input categories in the U.S. agricultural sector under stochastic climate change. The results show that under uncertainty induced by market price variations and climate changes, farmers progressively adjust the two aggregate outputs and all the three inputs. In addition, the authors show that failing to anticipate climate change dramatically slows the estimated rate of adjustment for two net puts and modestly speeds the rate for two others, thus likely increasing overall adjustment costs. Failing to account for uncertainty in anticipated climate change has little impact on adjustment.

METHODOLGY

Data collection

We consider aggregate price and quantity data from 1960 to 2016 for crops and inputs namely capital, labour, fertilizer and land. These data are compiled from Food and Agricultural Organisation (FAO), the Agricultural Surveys and Statistics Division (ASSD) of the Cameroonian Ministry of Agriculture and Rural Development (MARD) and the National Institute of Statistics of Cameroon (NSI). In addition, since investment is intermittent at the farm household level, we use data aggregated at the national agricultural sector level. This aggregation of data is justified by the fact that the models we have derived are convex adjustment models. This aggregation can also be justified for statistical reasons: to obtain significant results.

The labour factor is used taking into account the degree of the workers training. Thus, this factor is divided into two categories2 : the number of workers (family labour) during a year and the number of skilled employees during a year. The first category stems for variable factors, while the second one is considered as quasi-fixed factors and will be used in our study. The public agricultural expenditure is used in order to capture change in technology and is defined as public funds allocated to the agricultural sector. This is the financing of all activity by the State. Public expenditure on agriculture refers to the budgetary expenditure of the two ministries of rural development, i.e. the Ministry of Agriculture and Rural Development (MINADER) and the Ministry of Forests and Wildlife (MINFW). Concerning agricultural production, we consider the total production in volume of the agricultural sector, particularly crop production. As for the total value of energy, it is calculated by aggregating the data to obtain the level of annual energy consumption at the level of the agricultural sector. Energy in our case consists of fuel, electricity and water. The land factor is the total amount of land allocated to agriculture. Indeed, agriculture in Cameroon is an extensive one and therefore the growth of agricultural land is likely to influence the amount of the agricultural production. The physical capital stock factor includes machinery and equipment. The amount of his capital is computed as total capital expenditure divided by the price index. This operation is useful for deflating the variables that are collected into values.

As for climate variables, even if according to Zilberman (2004), climate change can affect agricultural yields through several channels like temperatures, precipitations, atmospheric, chemistry, solar radiation, etc; in our study we focus on the temperatures and precipitations collected from the Climate Change Knowledge Portal of the World Bank. Since these data are provided monthly,

[2] This differentiation is necessary because the productivity of imported raw materials and goods is highly dependent on the absorptive capacity of the technologies incorporated in them (Augier et al., 2009).

both national-level annual data of average temperature and precipitation are computed as simple average of monthly data.

The model

We construct an inter-temporal optimization problem to model the optimal path of inputs adjustments and the optimal level of food crop production. We assume that the Cameroonian agricultural sector behaves like a firm that buys its inputs in a competitive market and that its expectations about the evolution of climate and prices in this market are rational. This means that farmers hardly make mistakes in forecasting climatic conditions and market prices. Moreover, investment decisions and production take into account the uncertainty induced by climate change in a stochastic process. By climate here we mean temperature and precipitation. Thus, these two elements are introduced into the profit function of the agricultural firm to account for uncertainty. At each period, farmers' decisions depend on their expectations about the climate and market prices. The following notations are adopted in the remaining of the paper:

$\overline{\Omega} \subseteq R^5$ is the closed positive orthant in the Euclidean space of dimension 5 and represents the set of variable factors; $\Omega \subseteq R^5$ the open positive orthant and represents the set of quasi-fixed factors; $L \in \Omega$ represents the column vector of variable factors, $K \in \overline{\Omega}$ column vector of quasi-fixed factors.

Under these assumptions, the functional which is the profit function of the agricultural firm is as follows:

$\Pi(\dot{K}, K, T, F, C, w)$ (1)

The household is supposed to revise its expectations and production plans as the base period, climate and prices change.The problem of the firm is to identify the investment plan-hence the capital path-that yields themaximum potential profit, from time 0 to infinite time. Hence

$$J(K, F, w_0, r, C_0, T) = \max_{L \geq 0, I \geq 0, C \geq 0} E\left\{ \int_0^{\infty} e^{-rt} \left[\Pi(\dot{K}, K, T, F, C, w) + p^t K \right] dt \right\} \quad (2)$$

s/b

$\dot{K} = I - \delta K$ (3)

$\dot{C} = \mu(C) + \rho\varepsilon$ (4)

$K_i(0) = K_0 \geq 0, C(0) = C_0, (K, p, w) \in \Theta, \forall t \in [0; \infty[, K_i(0)$ is the quasi-fixed factor vector held by firm i at an initial time $t_0 = 0$, $Q(0) = Q_0, F(0) = F_0, T(0) = T_0$, $w(0) = w_0$, $p(0) = p_0$. Π stems for the short-run profit function.

$\dot{K}_i(t)$ Net investment in quasi-fixed factors, $w \in \Omega^5$ et $p \in \Omega^5$ are respectively the price vectors of variable and quasi-fixed factors. is the climate vector in terms of temperature and precipitation. Its evolution is assumed to be stochastic and exogenous and following a Brownian process characterised by the transition equation (4). $\mu(C)$ is a non-random vector of the parameters; ρ is such that $\rho^t \rho = \sum$ ε vector normally, identically and independently distributed (iid). ρ is a vector that allows to capture the variance of climate change. $E(\varepsilon) = 0, \text{var}(\varepsilon) = dT, E(\varepsilon_i \varepsilon_j) = 0, i \neq j$

Θ is a bounded open set and constituting the domain of definition of the value function, is the discount rate fixed at 5.5%.
The solution to problem (2) is obtained using the dynamic duality approach. This method was first initiated and developed by Epstein (1981, op. cit.). This new duality makes it possible to have a large class of functional forms of input demand, which can be tested and applied to the theory of adjustment costs. The primary problem in our approach is the Hamilton-Jacobi-Bellman equation; and the dual is the inverse of this equation:

$$(K,F,w_0,r,C_0,T)=\max\begin{bmatrix}\Pi(\dot{K},K,T,F,C,w)+p^tK+J_K\dot{K}\\+J_C\mu(C)+0,5vec(J_{CC})^t vec(\Sigma)\end{bmatrix} \quad (5)$$

The latter equation, which is the Hamilthon-Jacobi-Bellman equation, is the primal problem. It is established as a necessary condition of equilibrium of a dynamic optimization problem in continuous time with a constraint. Indeed, the Hamilton-Jacobi equation is a necessary and sufficient condition to maintain the firm's value function J at its maximum value at each period. It also allows to transform the dynamic problem (2) into an easily manipulated form. This equation is a static form of problem (2) and implies that the value of the firm can be defined as the sum of the maximum value of the current profit and the present value of the marginal profit resulting from the optimal adjustment in net investment.

According to the envelope theorem which consists in differentiating equation (5) with respect to prices p and w . By rearranging, the following equations are obtained:

$$\dot{K}^*={}^tJ_{Kw}^{-1}(r\,{}^tJ_p+K)-J_C\mu(C)+0,5vec(J_{CC})^t vec(\Sigma) \quad (6)$$

$$L^*=-rJ_w+{}^tJ_{Kw}\dot{K}-J_C\mu(C)+0,5vec(J_{CC})^t vec(\Sigma) \quad (7)$$

The first equation describes the dynamics of the quasi-fixed factors, while the second equation reflects the optimal trajectory of the variable factors. As Vasavada and Chambers (1986),and Sansi (2014), the functional form of the firm's value function is the modified generalized Leontief form as follows:

$$J(K,F,w_0,r,C_0,T)={}^twAK+{}^tpB^{-1}K+\left[{}^tp\,{}^tw\right]HC+$$
$$\left[{}^tp\,{}^tw\right]Ivec(C\,{}^tC)+\left[{}^tp^{1/2}\,{}^tw^{1/2}\right]G\begin{bmatrix}p^{1/2}\\w^{1/2}\end{bmatrix}+\left[{}^tp\,{}^tw\right]DE+\left[{}^tp\,{}^tw\right]KN \quad (8)$$

This function makes it possible to take into account the quasi-fixity of inputs and outputs. Hence the specified form of the following equation (6):

$$\dot{K}^*=(rI-A)K+AH\begin{bmatrix}rC-\mu(C))+AI(rvec(C\,{}^tC\\-vec_C(C\,{}^tC)\mu(C)-0,5vec(\Sigma)\end{bmatrix} \quad (9)$$
$$+rA\left[diag(p^{1/2})\right]Gp^{1/2}+rAHN$$

The discrete approximation of $\dot{K}$ is $\dot{K}=K_\tau-K_{\tau-1}$. The final functional form of (6) is obtained as follows:

$$K_\tau=(I+M_a)K_{\tau-1}+AH(rC-\delta(C))+AI\left[rvec(C\,{}^tC-vec_C(C\,{}^tC)\delta(C)-0,5vec(\Sigma)\right] \quad (10)$$
$$+rA\left[diag(p^{1/2})\right]Gp^{1/2}+PN$$

$M_a=rI_5+A^{-1}$ is an 5×5 adjustment matrix which includes own adjustment a_{ii} costs and interrelated adjustment costs a_{ij} . This matrix is computed from the estimated parameters found in table 1 in the appendix.

RESULTS AND DISCUSSION

The results, in this section, relate to the interdependence and quasi-fixity hypotheses tests that inform about the dynamics of adjustment of production and so-called quasi-fixed factors to their respective optimal levels. We present and analyze the results on the dynamic adjustment of agricultural production and factors of production in the agricultural sector in Cameroon based on the coefficients of the adjustment matrix $M_a = rI_5 + A^{-1}$.We thus perform a simultaneous test including the quasi-fixity of agricultural production, productive capital (approximated by machinery and equipment), labour, fertilizer and arable land on one hand; and the independence of adjustments between these variables in the other hand. This testisperformed in order to assess whether or not the adjustment of production influences the adjustment of a production factor and vice versa. The interdependence test, for example, then allows to control for the interdependence of adjustments between output and quasi-fixed factors on the one hand, and the interdependence between factors of production on the other.
According to Taylor and Monson (1985), the rate of independent adjustment means that each quasi-fixed input adjusts to its long-run equilibrium level independently of the level of other quasi-fixed inputs. According to Howard and Shumway (1988), independence is reflected by the fact that in the adjustment matrix, the cross-adjustment coefficients are zero:
$a_{ij} = a_{ji} = 0$, avec $i \neq j$.

The nullity of these coefficients means that each quasi-fixed factor adjusts towards its long-term equilibrium level independently of the level of the other. For example, at a certain period of time, the firm may hire new workers without the need to vary the level of physical capital (amount of equipment and machinery) or it may decide to vary the level of physical capital without the need to hire new workers, use fertilizer or increase arable land.

According to Warjiyo and Huffman (1995), the univariate partial adjustment model is then appropriated for estimating adjustment coefficients. The consequence is that a change in the relative price of one factor has no effect, even indirectly, on the quantity of the other factor. The alternative hypothesis, whereas, means that there is an interdependence between the adjustments of the various quasi-fixed factors: the variation in the level of one factor requires the change in the level of the other and vice versa. In this case, the multivariate flexible accelerator adjustment model appears to be a better representation of the adjustment behaviour of quasi-fixed factors by agricultural firms, compared to the representation of univariate adjustment.

Instantaneity means that, in the adjustment matrix, the eigen and cross adjustment coefficients are equal to -1 and 0 respectively. These restrictions reflect the fact that output and quasi-fixed inputs adjust instantaneously to their long-run optimal level and are then considered as variable inputs in the short and long term. Therefore, the current quantity of net inputs is always at the desired or long-run equilibrium level. In this case, any adjustment of output, fertilizer, capital, labour and area is smooth and cost-free. In other words, farmers adjust these variables in a single period. Indeed, the null hypothesis reflects the fact that adjustments are instantaneous. In this case, farmers adjust the level of production and production capacity to their optimal level immediately and without costs in a single period. Thus, in the absence of adjustment costs, outputand inputs are adjusted hence freely without incurring losses. Thus, no short-run imbalances exist in their use. As for the alternative hypothesis, it represents the fact that changes in quasi-fixed factor levels are gradual,that says the adjustment of quasi-fixed factor quantities only reaches its optimal level over several periods.
Based on the above, the results of the quasi-fixity and interdependence test are given in the following table 1:

Tableau 1. Interdependence test and instantaneity tests

Tested hypothesis	Wald test	Dl	Prob.
Independent et instantaneous adjustment	25876.01	28	0.0010
Independent adjustment	302.59	22	0.0000
Quasi- fixity	421.09	28	0.0030
Independent and instantaneous adjustment for Crops	40.20	8	0.0021
Capital	933.92	8	0.0001
Labour	21.10	8	0.0001
Fertilizer	32.43	8	0.0000
Land	154.19	8	0.0020

Source : Authors

The Wald test that we use here is particularly interesting in that it simultaneously checks the interdependence and immediacy of adjustments. Thus, with regard to the results, the hypotheses of independence and instantaneity of adjustments are rejected since the adjustment matrix. M_a is different from the unit matrix. This confirms the existence of adjustment costs in the process of adaptation and resilience to climate change and variations in market prices by farmers. Furthermore, the independent adjustment test shows that adjustment in food crop production leads to adjustment in capital, labour, arable land and fertilizer and vice versa.

Indeed, in Cameroon, farm households practice 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, arable land and fertilizer. The results show that these adjustments to climate change and market price changes do not take place instantaneously that says in a single annual period. Thus, at the 10% threshold, the assumption of quasi-fixity is accepted for output, capital, fertilizer, arable land and labour. The fact that agricultural production adjusts gradually can be explained by the limited adaptive capacity of some crop species. Capital that includes machinery and equipment may be less flexible during certain periods (Sansi and Schumway, 2014). Since fertilizers are purchased, both the quantity and the timing of their use are adjusted gradually. The results in the above table also show that labour that includes paid labour does not adjust instantaneously.

The adjustment matrix that provides information on the speed of adjustment of the quasi- fixed inputs shows that all the coefficients of this matrix are significantly different from -1 at the 5% threshold for food crop production, labour, fertilizer and arable land and 10% for capital. This means that in the short run and under climate change and market price variations, food crop production, capital, labour, arable land and fertilizers are actually quasi-fixed variables and their adaptation is not carried out in an annual period, but over several years. The own adjustment rate of food crop production -0.56 implies that crops adjust each year by 56% towards their desired level in response to price shocks and climate change. While the capital adjustment rate -0.1032 implies that this factor adjusts by 10.32% towards its equilibrium level in one year. Furthermore, the labour adjustment rate -0.6852 means that labour is adjusted each year by 68.52% each year. The fertilizer adjustment rate -0.4411 reflects the fact that this variable is adjusted at 44.11% per year. Finally, the arable land adjustment rate -0.6800 means that the arable land area adjusts to 87.32% per year. This last result confirms the fact that farmers practice extensive agriculture. In other words, under climate change and variations in market prices, it takes Cameroonian farmers more than a year and a half to adjust the level of production to its optimum (or desired) level, about nine years to adjust capital, a year and a half to adjust labour, about two and three months to adjust the level of fertilizer, and a year and a half to adjust the arable land, each to its optimum level. These results show that in Cameroon's agricultural sector, farmers renew their level of capital (machinery and equipment) very slowly.

CONCLUSION

According to IPCC (2007), adaptation is an adjustment in natural and human systems in response to actual or expected climatic conditions and their effects. This adaptation cannot be implemented without costs for farm producers trying to learn about the new climatic conditions. These adjustment costs arising from environmental shocks are non-trivial and cannot be ignored as they are important for determining the level of investment, output and factor adjustment. This study examines the dynamics of farm production structures in Cameroon under stochastic climate change. For this purpose, we developed and estimated a dynamic demand system of inputs and output by using a stochastic dynamic model approach and applying the hotelling lemma to the Hamilton-Jacobi-Bellman equations.

We found that under climate change and market price variations, food crop production, capital, labour, arable land and fertilizers are really quasi-fixed variables and their adaptation is not carried out in smoothly, but over several years or more than one year. Crops adjust by 56% each year towards their desired level in response to price shocks and climate change. While capital factor adjusts by 10.32% towards its equilibrium level in one year. Furthermore, the labour is adjusted by 68.52% each year, fertilizer is adjusted at 44.11% per year. Finally, the arable land area adjusts to 68.00% per year. However, although the model allows the identification of adjustment costs induced by climate change and the change in market prices, it does not allow the decomposition of these two effects. Therefore, in this study, changes in climate conditions and relative prices occur simultaneously. This is a limitation of this study.

Moreover, the interest in understanding and anticipating the impacts of climate change on agriculture is very important for policy makers. This allows appropriate measures to be taken in order to limit the socio-economic consequences. To further reduce the climatic risks to which Cameroonian farmers are faced, public decision-makers can reduce directly and indirectly adjustment cost by funding research on adaptation crops and land use.

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Appendix

Adjustment matrix $M_a = \begin{bmatrix} -0,5602 & -0,4511 & -0,8012 & -0,6971 & -0,7011 \\ -0,5660 & -0,1032 & -0,7521 & -0,7521 & -0,6290 \\ -0,8610 & -0,6610 & -0,6852 & -0,8238 & -0,5721 \\ -0,76234 & -0,8723 & -0,6201 & -0,4411 & -0,4002 \\ -0,5934 & -0,7822 & -0,4951 & -0,6667 & -0,6800 \end{bmatrix}$

Table 1. Non Linear-Three Least Square parameters

Parameter	Estimate	StantardError	Parameter	Estimate	StantardError
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	G_{11}	12.1465	4.3572
A_{34}	-0.0102	0.0207	G_{12}	22.4390***	10.6563
A_{35}	-0.0732**	0.0750	G_{13}	-7.2126	11.4378
A_{41}	-0.0698	0.4509	G_{14}	-4.9347	5.1212
A_{42}	0.0310	0.3590	G_{15}	-9.2012	12.6717
A_{43}	-0.1048	0.0453	G_{22}	8.6077	8.2345
A_{44}	1.0331**	0.2370	G_{23}	-10.5123	19.1717
A_{45}	-0.4785	0.6432	G_{24}	-12.9453	7.0783
A_{51}	0.7534	0.4374	G_{25}	-17.0703*	9.9375
A_{52}	0.7903	0.4950	G_{33}	29.6520*	12.1362
A_{53}	-0.6209	0.2761	G_{34}	-8.2045	10.0028
A_{54}	0.0230	0.0532	G_{35}	-20.2304	13.2436
A_{55}	1.4351**	0.6732	G_{44}	11.3733	5.1056
H_{11}	0.0375	0.0657	G_{45}	6.7610	4.1273
H_{12}	0.1560***	0.0439	G_{55}	42.4420	31.4020
H_{21}	0.0645	0.2255	P_{11}	-0,0013**	0,00101
H_{22}	0.0101	0.0448	P_{12}	0,0020**	0,00908
H_{31}	0.2014	0.2370	P_{21}	0,0145	0,00010
H_{32}	-0.1769	0.0378	P_{22}	-0,0037*	0,00003
H_{41}	0.1967	0.0265	P_{31}	-0,0011	0,00122
H_{42}	0.1345	0.0426	P_{32}	0,0322	0,00402
H_{51}	-0.0532	0.4572	P_{41}	0,0258**	0,00028
H_{52}	-0.0730	0.0978	P_{42}	0,0063	0,00820
I_{11}	0.0457	0.0157	P_{51}	0,0233	0,00005
I_{12}	0.0579	0.0574	P_{52}	0,0088**	0,00105

I_{14}	0.0627	0.1122

Note : *p<0,1**p<0,05 ***p<0,01