MODELLING CLIMATE CHANGE AND AGRICULTURAL PRODUCTION IN SUB-SAHARAN AFRICA (SSA): IN QUEST OF STATISTICS

By

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ABSTRACT

Climate change is a natural and dynamic phenomenon resulting from complex interrelationships between physical, environmental and human factors. The sustainability of life on earth depends partly on the ability of mankind to maintain this natural and balanced flow of such gases such as carbon dioxide (CO2) and water vapor traping heat.

Unfortunately, human beings contribute significantly to the presence of such gases known as Green House Gases (GHGs) through agricultural and industrial activities. The implications are the excess trap of sunlight and the blocking of outward radiation.

In sub-Saharan Africa (SSA), the importance of agriculture cannot be stressed enough given that it is central to economic growth and most of economic activities in the region is still dependent on agricultural expansion. The crux of the matter is that, in Africa, the bulk of agricultural output is still produced by smallholder farmers who unfortunately continue to depend on climate variability. Hence understanding the relationships between climate variability and agricultural production is therefore critical to SSA countries.

Unfortunately, the statistics base on climate change is currently very poor and the provision of these statistics is compelling and will contribute significantly to the understanding of the impacts of these changes to agriculture, our livelihoods and economic development. Recent and upcoming events witness these concerns.

This paper attempts to provide a theoretical and empirical framework for exploring the magnitude of climate variability in the explanation of agricultural production in Sub-Saharan Africa. Despite the statistics constraints, it is expected that the design and testing of theoretical model on climate change will not only attract interests in investing in climate changes statistics but also provide better understanding of the relationships between individual and aggregate crop production performances and insights for policies directions as pertaining to SSA countries.

Keywords: Modelling, agriculture, climate change, variability, statistics, policies.

Introduction

Climate change is a natural and dynamic phenomenon resulting from complex interelationships between physical, environmental and human factors. As a slow change in the composition of the global atmosphere, climate change is caused directly and indirectly by various human activities in addition to natural climate variability over time.Despite its natural occurence, it is likely that the rate of future climate change may be more rapid than at any time in the last 10,000 years.(Toman, 2001).

The major GHGs in our atmosphere are water vapour, carbon dioxide (CO_2), methane (CH_4), halocarbons, which are used as refrigerants, and nitrous oxide (N_2O) and agriculture contributes sighnificantly to these emissions.
Since 1750, the atmospheric concentrations of carbon dioxide, methane and nitrous oxide have increased by approximately 31%, 151%, and 17%, respectively. Current rates of increase per year are 0.5% for carbon dioxide, 0.6% for methane and 0.3% for nitrous oxide. The scientific evidence for this is very solid. In a 2001 scientific assessment, the Intergovernmental Panel on Climate Change (IPCC) concluded, "the balance of evidence suggests a discernible human influence on climate change."

The sustainability of life on earth depends partly on the ability of manknind to maintain this natural and balanced flow of such gases such as carbon dioxide (CO2) and water vapor traping heat – like a greenhouse does- In fact, greenhouse gases (GHGs) trap some of this energy that the earth releases to space.In the atmosphere, these gases act as a thermostat controlling the earth's climate. Without this natural greenhouse effect, the average temperature on earth could decrease as low as $-18^{o}C$ instead of the current $+15^{o}C$ observed. Therefore, life would be impossible.

Unfortunately, human beings contribute significantly to the presence of such gases known as Green House Gases (GHGs) through agricultural and industrial activities. The implications are the excess trap of sunlight and the blocking of outward radiation.
In fact, human activities increase the GHG levels in the atmosphere by introducing new sources or removing natural sinks, such as forests. Sources are processes or activities that release greenhouse gases; sinks are processes, activities or mechanisms that remove greenhouse gases. A balance between sources and sinks determines the levels of greenhouse gases in the atmosphere.

There is a scientific belief that the accumulation of such gases in the athmosphere contribute significantly the current disturbance of climate change observed. Potential climate risks involve severe weather patterns, hobbed ecosystem of drought and floods.
On the positive side, climate change might bnefit agriculture and forestry in various locations by increasing productivity as result of longer seasons and increased fertiliszation.
The current contreversial debate surrounding climate change issues and the dificult implementation of policies is expressed as follows : climate change is one of the greatest threats facing mankind requiring immediate and strong controls on GHGs ; climate

change risks are weakly documented scientifically and that the adaptation's ability of man and the technological developments options are understated.

In sub-Saharan Africa (SSA), the importance of agriculture cannot be stressed enough given that it is central to economic growth and most of economic activities in the region is still dependent on agricultural expansion. In most of Africa, about 80 % of people work in agriculture. It is the main economic sector generating, in most countries, 30 to 60 % of Gross Domestic Product (GDP), or even more if valued properly by national accounts. The crux of the matter is that, in Africa, the bulk of agricultural output is still produced by smallholder farmers who unfortunately continue to depend on climate variability often attributed to rainfall.

Since the drought of the early 1970s, there has been extensive discussion as to whether this indicates long term changes in the climate with ensuing changes in the ecology and the advance of the desert. Present evidence provides inconclusive support for the hypothesis of secular trend in climatic conditions. Instead, there are indications that in some locations the natural population has been degraded through overgrazing, and that expansion of cleared land areas has negatively influenced evaporation and rainfall. But these were the result of acts of man-a relative overpopulation and overgrazing in semi-arid areas under the pressure of human and animal population increases-and not of autonomous changes of climate.Hence understanding the relationship between climate variability and agricultural production is therefore critical to SSA countries.

This paper explores the relationship between agricultural production and climate variability in Sub-saharan Africa for two reasons :

- The importance of agriculture in sub-Saharan Africa (SSA) cannot be stressed enough given that it is central to economic growth and most of economic activities in the region is still dependent on agricultural expansion. The crux of the matter is that, in SSA, the bulk of agricultural output is still produced by smallholder farmers who unfortunately continue to depend on climatic variability.

- It attempts to fill a theortical gap in the contribution of climate change in the long term explanation of variability of agricultural production as there have been poor treatments of climate variability in the assesment of agricultural production function.

There are two ways of investigating the relationships between agriculture and climate change. One line of investigation is to assess the contribution of agriculture to the total GHG emissions which is very common nowdays. The second line is to assess the magnitude of climate change in the explanation of agricultural production outcomes.
This paper opts for the latter and attempts to provide a theoretical and empirical framework for exploring the magnitude of climate in the explanation of agricultural production in Sub-saharan Africa.

Despite the statistics constraints, it is expected that the testing of the model will provide not only better understanding of the relationships between individual and agregate crop production performances and insights for policies directions as pertaining to SSA countries but also induce decision makers to invest in climate change statistics.

I. State of arts: Taking stock of the assessment of climate change in the explanation of agricultural production

There is a long causal link starting with economic activity, and moving to greenhouse gas emissions, concentrations of greenhouse gases, radiative forcing, climate change, market and non-market impacts, and finally to economic damages. Agriculture has several parts to play in this drama. First, agriculture has an important role in the carbon cycle. Agriculture has been associated with global land clearance that has led to substantial carbon emissions. Agriculture also affects the storage of carbon in the soils. Second, some agricultural practices have led to the direct release of greenhouse gases, specifically methane and nitrogen emissions. Third, agriculture is affected by climate change and so is an important part of impacts.

There are two ways of investigating the relationships between agriculture and climate change. One line of investigation is to assess the contribution of agriculture to the total GHG emissions which is very common nowdays. The second line is to assess the magnitude of climate change in the explanation of agricultural production outcomes. Whereas there exists an abundant litterature on the former, only few studies have documented the latter.

Impacts or effects of agriculture on climate change

According to the Intergovernment Panel on Climate Change(IPCC), the three main causes of the increase in greenhouse gases observed over the past 250 years have been fossil fuels, land use, and agriculture.

The main GHGs emitted by agriculture are carbon dioxide (CO_2), methane (CH_4) and nitrous oxide (N_2O)

As an important contributor to GHGs emissions, agriculture is a significant land user (through practices) and consumer of fossil fuel.

There are four main ways by which agriculture contributes to greenhouse gas increases:

- deforestation by releasing CO_2;
- industrial cultivation by releasing methane;
- livestock by releasing methane from enteric fermentation;
- and fertilizer application by releasing nitrous oxide.

These agricultural processes comprise 54% of methane emissions, roughly 80% of nitrous oxide emissions, and virtually all carbon dioxide emissions tied to land use.

Livestock and livestock-related activities such as deforestation and increasingly fuel-intensive farming practices are responsible for over 18% of human-made greenhouse gas emissions, including:

- 9% of global carbon dioxide emissions;
- 35-40% of global methane emissions (chiefly due to enteric fermentation and manure;
- 64% of global nitrous oxide emissions emissions mainly due fertilzer use.

Impacts or effects of climate change on agriculture

Ecological predictions of the effect that climate change might have on forests are generally based on the outputs of general circulation models (GCMs). These models predict increased overall precipitation as s result of warming, but the patterns of regional increases and decreases in precipitation is more complex. Moreover the amount of temperature change is likely to be lower at the equator and progressively higher toward the poles. However the most recent GCMs tend to indicate an expansion of forest area as a result of global warming thereby contrasting with the 1980 studies that suggested the contrary.

The works undertaken by Mendelsen (2000) shed lights on the effect of climate change on developing country agriculture. A basic integrated model was used to asses the likely impacts of greenhouse gases on developing country agriculture. The model begins with a path of greenhouse gas emissions and predicts future concentrations, global warming, a pattern of climate change, climate sensitivity, and future agricultural impacts under uncertainty.

The review of the literature on modelling agricultural climate sensitivity and agriculture reveals three set of methods: cross-sectional analysis, agronomic-economic models, and Agro-Ecological Zone (AEZ) modelling. Cross-sectional analyses compare actual farm performance across climate zones, agronomic-economic models are simulators which have been developed from agronomic experiments on major crops, and AEZ modelling uses detailed ecophysiological relationships to predict plant performance. The results suggest that developing country agricultural systems are vulnerable to climate change because they tend to be less capital and technology intensive and because they tend to be in climate zones which already border on being too hot and will likely get hotter. The agronomy results suggest that warming alone would reduce most crop yields in developing countries. However, these expected reductions in crop yields would be offset to some degree by farmer adaptations and carbon fertilization. The international community should help developing countries study these effects, identify adaptation strategies, and prepare programs for low latitude locations to help the rural poor most vulnerable to climate change (Mendelson, 2000).

Moreover, though it is recognized that climatic factors play an important role in determining agriculture, only few agricultural economists have investigated the issues. To prove the above, about 227 articles of Agricultural Economists, the Journal of the International Association of Agricultural Economists between 1991 and 2003 have consulted. Of these publications, only 30 publications (13%) dealt with environment issues in general and 14 publications (6%) with water issues. This implies that about 81% of publications were devoted to non environmental issues in the fields. More surprisingly, 6 of the total number of publications (< 3%) concern Africa, and only 4 of these publications have been published by Africans. The following table 1 depicts the situation.

Table 1: Status of series/publications of Agricultural Economics consulted between 1991-2003

Environment Issues		Non environment & Water	Geographical coverage		Nationality of authors		Total publications Consulted
Water	Water & environment		African	Non African	African	Non African	
14	30	197	6 (<3%)	24 (11%)	4	26	227

Source: Author's calculation

The crux of the matter is that not only environmental issues and for that matter water issues have not being investigated by African agricultural economists in SSA.

Moreover, out of the 227 publications, only one article has attempted to model agricultural production of small-scale farmers in sub-Saharan Africa using environmental factor. The article, based on cross-sectional data, used land fertility level as the only environmental variable as land quality can vary within a relatively small geographical area as compared with other agro-ecological factors. The mere coincidence is that the case study is derived from western Kenya. (Odulaja and Kirios, 1996).

In few cases where environment factors (climatic conditions) are estimated, agricultural economists use either ordinal scales (good/bad;high/average/weak) or average rainfall as a summative environmental indicator in estimating agricultural production function. (Odulaja and Kiros, 1996; Frisvold and Ingram, 1995).

Thus, the literature relating production to environmental factors is very scanty in SSA.

The present study built on these assets and focused on the measuring of climatic factors as crucial determinants for SSA agriculture. The methodology proposed is an attempt to improve the measurement of rainfall in the estimation of agricultural production function based on time series data in SSA. Instead of using the mean of rainfall as environmental index, it utilizes its standard of deviation. A close scrutiny of agricultural practices /agronomic sciences reveals that agricultural output is more determined by rainfall distribution than rainfall's mean. This relationship was explored in the togolese context (Koffi-Tessio,2004a).

The main hypothesis is that the growth of the agricultural sector is less associated with the mean of climatic factors than climatic variability in the explanation of agricultural performance and that climatic factors compared with than investments in physical and human capital are not significant in explaining agricultural growth in SSA.

II. The Proposed framework: Accounting for climate change in the variation of agricultural production in SSA

2.1. The conceptual framework

The proposed methodology will lead to the estimation of climate variability indicator. It stems from the following two propositions: (a) - Climate change is an interaction of precipitation, évaporation, wind speed, humidity solar radiation et other factors; (b)- Climate change may result in a “good climate variability” or “bad climate variability” as related to agriculture if climate variability is profitable (falls within the beneficial range) or damageable (falls outside the beneficial range) to the crop.

Let the above climatic factors be:

1 = Precipitation
2 = Temperature
3 = Evaporation
4 = Humidity
5 = Wind speed
6 = Solar radiation
7 = Other factors

For each of these factors, a variability index is computed:
Let it be, for example, temperature. Then the variance of temperature during a given agricultural year in a given country will be computed as follows :

Assuming in a given country there are agricultural zones Z_i, ι=1,……..,r

Considering the agricultural zones Z_i with their s_j^i Seasons during the agricultural year ($j^{\text{ième}}$ season of the zone Z_i)

j=1,……. k_i

Let t_l^{ij} be the temperature measured at the $l^{\text{ième}}$ day during the season s_j^i

So the temperature mean during the season s_j^i is :

$$t_{ij} = \sum_{l=1}^{|s_j^i|} \frac{t_l^{ij}}{|s_j^i|}$$

With $|s_j^i|$= number of days of the season, the temperature mean during the k_i saisons s_j^i of the Z_i is :

$$t_i = \sum_{j=1}^{k_i} \frac{t_{ij}}{k_i}$$

It follows from the above that temperature mean in the r-zones during the agricultural year is :

$$t_2 = \frac{1}{r} \sum_{i=1}^{r} t_i = \sum_{i=1}^{r} \sum_{j=1}^{k_i} \sum_{l=1}^{|s_j^i|} \frac{1}{r} \frac{t_{ij}}{|s_j^i|}$$

The variance of the temperature during the agricultural year is as follows :

Given V_j^i la variance of the value of temperature during the season s_j^i of the zone Z_i

$$V_j^i = \sum_{l=1}^{|s_j^i|} \frac{(t_l^{ij} - \sum_{q=1}^{|s_j^i|} \frac{t_q^{ij}}{|s_j^i|})^2}{|s_j^i|} = \frac{1}{|s_j^i|^3} \sum_{l=1}^{|s_j^i|} (t_l^{ij} |s_j^i| - \sum_{q=1}^{|s_j^i|} t_q^{ij})^2$$

If V_i is the variance of the temperature in the zone Z_i, it follows that :

$$V_i = \sum_{k=1}^{k_i} \frac{V_j^i}{k_i}$$

Gien V_2 is the mean of variances V_i in the r zones Z_i it follows that :

$$V_2 = \frac{1}{r}\sum_{i=1}^{r} V_i$$

$$= \frac{1}{r}\sum_{i=1}^{r}\sum_{j=1}^{k_i}\sum_{l=1}^{|s_j^i|}\frac{1}{|s_j^i|^3} * \frac{1}{k_i}(t_l^{ij}\,|s_j^i| - \sum_{q=1}^{|s_j^i|} t_q^{ij})^2$$

Let us consider : e_{ij}^l the quantity of evaporated water at lth day of s_j^i

- t_{ij}^l the temperature measured at lth day during the season s_j^i
- v_{ij}^l the wind speed mesured at lth day during the season s_j^i
- p_{ij}^l the solar radiation measured at lth day during the season s_j^i
- h_{ij}^l the humidity measured at lth day during s_j^i

The computation of the temperature variation during a given agricultural year is also valid for evaporation, humidity, wind speed, solar radiation and other climatic factors.

COMPUTATION OF THE CLIMATIC VARIABILITY INDICATOR

The climate being the interaction between precipitation, évaporation, temperature, wind speed, humidity and solar radiation and other factors, the climatic variability may be estimated by a constante K_{cl} as a product of variations of each of the above factors as follows :

$$K_{cl} = V_1 * V_2 * V_3 * V_4 * V_5 * V_6$$

V_1 = variance of precipitation during the agricultural year
V_2 = variance of temperature during the agricultural year.
V_3 = variance of the evaporated water during the agricultural year.
V_4 = variance of humidity during the agricultural year.
V_5 = variance wind speed during the agricultural year.
V_6 = variance solar radiation during the agricultural year.

$$V_1 = \frac{1}{r}\sum_{i=1}^{r}\sum_{j=1}^{k_i}\sum_{l=1}^{n_{ij}}\frac{1}{|s_j^i|^3} * \frac{1}{k_i}(R_l^{ij}\,|s_j^i| - \sum_{q=1}^{n_{ij}} R_q^{ij})^2$$

With n_{ij} the number of rainfall days during the season s_j^i

$$V_2 = \frac{1}{r}\sum_{i=1}^{r}\sum_{j=1}^{k_i}\sum_{l=1}^{|s_j^i|}\frac{1}{|s_j^i|^3} * \frac{1}{k_i}(e_l^{ij}\,|s_j^i| - \sum_{q=1}^{|s_j^i|} e_q^{ij})^2$$

$$V_3 = \frac{1}{r}\sum_{i=1}^{r}\sum_{j=1}^{k_i}\sum_{l=1}^{|s_j^i|}\frac{1}{|s_j^i|^3} * \frac{1}{k_i}(t_l^{ij}\,|s_j^i| - \sum_{q=1}^{|s_j^i|} t_q^{ij})^2$$

$$V_4 = \frac{1}{r}\sum_{i=1}^{r}\sum_{j=1}^{k_i}\sum_{l=1}^{|s_j^i|}\frac{1}{|s_j^i|^3} * \frac{1}{k_i}(h_l^{ij}\,|s_j^i| - \sum_{q=1}^{|s_j^i|} h_q^{ij})^2$$

$$V_5 = \frac{1}{r}\sum_{i=1}^{r}\sum_{j=1}^{k_i}\sum_{l=1}^{|s_j^i|}\frac{1}{|s_j^i|^3} * \frac{1}{k_i}(v_l^{ij}\,|s_j^i| - \sum_{q=1}^{|s_j^i|} v_q^{ij})^2$$

$$V_6 = \frac{1}{r}\sum_{i=1}^{r}\sum_{j=1}^{k_i}\sum_{l=1}^{|s_j^i|}\frac{1}{|s_j^i|^3} * \frac{1}{k_i}(P_l^{ij}\,|s_j^i| - \sum_{q=1}^{|s_j^i|} P_q^{ij})^2$$

Assume that there exists for each crop a norm for a good harvest

For example, for i^{-th} crop, i = 1, ……n assume that we must have :

$$a_1^i < V_1 < b_1^i$$
$$a_2^i < V_2 < b_2^i$$
$$a_3^i < V_3 < b_3^i$$
$$a_4^i < V_4 < b_4^i$$
$$a_5^i < V_5 < b_5^i$$
$$a_6^i < V_6 < b_6^i$$

It follows that:

$$\underset{k=1}{\overset{6}{\pi}} a_k^i < K_{cl} < \underset{k=1}{\overset{6}{\pi}} b_k^i$$

Under the hypothesis that a climatic factor may compensate another, the necessary and sufficient condition for having a good harvest of i^{-th} product is:

$$\underset{k=1}{\overset{6}{\pi}} a_k^i < K_{cl} < \underset{k=1}{\overset{6}{\pi}} b_k^i$$

Estimating the agregate translog agricultural production function with p parameters (variables)

$$\ln \gamma_t = \beta_0 + \sum_{i=1}^{p} \beta_i \ln k_i + \frac{1}{2} \sum_{i=1}^{p} \sum_{j=1}^{p} \beta_{ij} \ln k_i \ln k_j + \varepsilon_h$$

With γ_t = agregate agricultural production at time t = f (k_i, ……., k_p) a real number

Assume that γ_t is a vector of n products (crops). Let us consider γ_t = ($\gamma_t^1, \gamma_t^2, \ldots\ldots \gamma_t^n$)

With the γ_t^i being the products representing γ_t , $1 \leq i \leq n$

$$\gamma_t^i = f^i (k_1^i, \ldots\ldots k_p^i)$$

The transcendantal logarithmic disagregated function with p variables for a given crop γ_t^i , $1 \leq \mathrm{i} \leq \mathrm{n}$

$$\ln \gamma_t^i = \beta_0^i + \sum_{l=1}^{p} \beta_l^i \ln k_l^i + \frac{1}{2} \sum_{j=1}^{p} \sum_{l=1}^{p} \beta_{jl}^i \ln k_l^i \ln k_j^i + \varepsilon_h^i$$

Expression of the translog agregated function in relation to the individual or disagregated production functions of the n products.

The real agregate production function $\ln \gamma_t$ being the sum of the real individual production functions of n products $\ln \gamma_t^i$, $1 \leq \mathrm{i} \leq \mathrm{n}$, it may be deducted by extension ($\ln : \mathbb{R}^n \to \mathbb{R}$)

$$\ln \gamma_t = \sum_{i=1}^{n} \ln \gamma_t^i$$

$$= \sum_{i=1}^{n} \left(\beta_0^i + \sum_{l=1}^{p} \beta_l^i \ln k_l^i + \frac{1}{2} \sum_{j=1}^{p} \sum_{l=1}^{p} \beta_{jl}^i \ln k_l^i \ln k_j^i + \varepsilon_h^i \right)$$

$$= \sum_{i=1}^{n} \beta_0^i + \sum_{i=1}^{n} \left(\sum_{l=1}^{p} \beta_l^i \ln k_l^i \right) + \frac{1}{2} \sum_{i=1}^{n} \left(\sum_{j=1}^{p} \sum_{l=1}^{p} \beta_{jl}^i \ln k_l^i \ln k_j^i \right) + \sum_{i=1}^{n} \varepsilon_h^i$$

$$= \sum_{i=1}^{n} \beta_0^i + \sum_{l=1}^{p} \left(\sum_{i=1}^{n} \beta_l^i \ln k_l^i \right) + \frac{1}{2} \sum_{j=1}^{p} \sum_{l=1}^{p} \left(\sum_{i=1}^{n} \beta_{jl}^i \ln k_l^i \ln k_j^i \right) + \sum_{i=1}^{n} \varepsilon_h^i$$

$$= \sum_{i=1}^{n} \beta_0^i + \sum_{l=1}^{p} \left(\sum_{i=1}^{n} \beta_l^i \ln k_l^i \right) + \frac{1}{2} \sum_{j=1}^{p} \sum_{l=1}^{p} \left(\beta_{jl}^1 \ln k_j^1 \ln k_l^1 + .. + \beta_{jl}^n \ln k_j^n \ln k_l^n \right)$$

$$+ \sum_{i=1}^{n} \varepsilon_h^i$$

Let ∂ climat be the term that indicates the effects of climatic factors on the i-th product

The real value of the i-th product being

$$\ln \gamma_t^i = \beta_0^i + \sum_{l=1}^{p} \beta_l^i \ln k_l^i + \frac{1}{2} \sum_{j=1}^{p} \sum_{l=1}^{p} \beta_{jl}^i \ln k_l^i \ln k_j^i + \varepsilon_h^i$$

$s \in \{1, 2, .., p\}$. such that $k_s^i = k_{cl}^i$ where k_{cl}^i is the argument which indicates the reaction of i$^{\text{-th}}$ product to the climatic effect

Let us set : $a = \beta_s^i + \sum_{\substack{l=1 \\ l \neq s}}^{p} \beta_{sl}^i \ln k_l^i ; .....b = \frac{1}{2} \beta_{ss}^i$

$$\partial_{c\lim at} = a \ln k_{cl}^i + b\left(\ln k_{cl}^i\right)^2$$

$$\partial_{c\lim at} = \ln k_{cl}^i \left(a + b \ln k_{cl}^i\right)$$

$$\partial_{c\lim at} = 0 \Leftrightarrow \ln k_{cl}^i = 0 \text{ where } a + b \ln k_{cl}^i = 0$$

$$\Leftrightarrow k_{cl}^i = 1 \text{ where } k_{cl}^i = e^{-\frac{a}{b}}$$

Assume $a > 0, ... b > 0$

k_{cl}^i	0		$e^{-\frac{a}{b}}$		1		$+\infty$
∂_{climat}	‖	+	0	−	0	+	

Estimation of k_{cl}^i as the reaction of i-$^{\text{th}}$ product under the effect of climate in relation to the climatic indicator k_{cl}

Let us set : $K_{cl}^i = \min\left(\dfrac{\mathop{\pi}\limits_{k=1}^{6} b_k^i - \mathop{\pi}\limits_{k=1}^{6} a_k^i}{\left|K_{cl} - \mathop{\pi}\limits_{k=1}^{6} a_k^i\right|} ; \dfrac{\mathop{\pi}\limits_{k=1}^{6} b_k^i - \mathop{\pi}\limits_{k=1}^{6} a_k^i}{\left|K_{cl} - \pi\, a_k^i\right|} \right)$

In the case $K_{cl} < \mathop{\pi}\limits_{k=1}^{6} a_k^i$ **(bad harvest)**

We have $K_{cl}^i = \dfrac{\mathop{\pi}\limits_{k=1}^{6} b_k^i - \mathop{\pi}\limits_{k=1}^{6} a_k^i}{\left|K_{cl} - \mathop{\pi}\limits_{k=1}^{6} b_k^i\right|}$ and $K_{cl}^i < 1$

For $\mathop{\pi}\limits_{k=1}^{6} b_k^i - \mathop{\pi}\limits_{k=1}^{6} a_k^i < \left|K_{cl} - \mathop{\pi}\limits_{k=1}^{6} b_k^i\right|$

Studying the sign de $\partial_{c\lim at}$:

* If $e^{-\frac{a}{b}} < K_{cl}^{i} < 1$ we have $\partial_{c\lim at} < 0$

This leads to the decrease of $\ln Y_t^i$ thereby confirming **a bad harvest** of the i^{-th} product.

* Assuming the case $0 < K_{cl}^{i} < e^{-\frac{a}{b}}$ is abandonned for the moment.

In the case $\underset{k=1}{\overset{6}{\pi}} a_k^i < K_{cl} < \underset{k=1}{\overset{6}{\pi}} b_k^i$ **(good harvest)**

We have $K_{cl}^{i} > 1$ for $\begin{cases} \underset{k=1}{\overset{6}{\pi}} b_k^i - \underset{k=1}{\overset{6}{\pi}} a_k^i > \left| K_{cl} - \underset{k=1}{\overset{6}{\pi}} a_k^i \right| \\ \underset{k=1}{\overset{6}{\pi}} b_k^i - \underset{k=1}{\overset{6}{\pi}} a_k^i > \left| K_{cl} - \underset{k=1}{\overset{6}{\pi}} b_k^i \right| \end{cases}$

$$\partial_{c\lim at} = a \ln k_{cl}^{i} + b(\ln k_{cl}^{i})^2$$

$$D_{\partial_{c\lim at}} = R_{+}^{*}$$

As $$\frac{\delta\partial_{c\lim at}}{\delta k_{cl}^{i}} = \frac{a}{k_{cl}^{i}} + \frac{2b}{k_{cl}^{i}} \ln(k)$$

According to the sign of $\partial_{c\lim at}$:

We have $\partial_{c\lim at} > 0$. This leads to the increase of $\ln Y_t^i$ thereby confirming **a good harvest** of the i^{-ith} product (crop).

In the case $K_{cl} > \underset{k=1}{\overset{6}{\pi}} b_k^i$ **(bad harvest)**

We have $K_{cl}^{i} = \dfrac{\underset{k=1}{\overset{6}{\pi}} b_k^i - \underset{k=1}{\overset{6}{\pi}} a_k^i}{\left| K_{cl} - \underset{k=1}{\overset{6}{\pi}} a_k^i \right|} < 1$

For $\underset{k=1}{\overset{6}{\pi}} b_k^i - \underset{k=1}{\overset{6}{\pi}} a_k^i < \left| K_{cl} - \underset{k=1}{\overset{6}{\pi}} a_k^i \right|$

Studying the sign of $\partial_{c\lim at}$:

*If $e^{-\frac{a}{b}} < K_{cl}^{i} < 1$ we have $\partial_{c\lim at} < 0$

This leads to the decrease of $\ln Y_t^i$ thereby confirming a bad harvest of the i^{-ith} product.

The case of $0<K_{cl}^{i}<e^{-\frac{a}{b}}$ is abandonned for the moment.

The curbe of ∂_{climat} as a function of k_{cl}^{i} is as follows:

$$\partial_{\text{climat}} = a\ln k_{cl}^{i} + b(\ln k_{cl}^{i})^{2}$$

$$D_{\partial_{\text{climat}}} = R_{+}^{*}$$

$$\frac{\delta\partial_{\text{climat}}}{\delta k_{cl}^{i}} = \frac{a}{k_{cl}^{i}} + \frac{2b}{k_{cl}^{i}}\ln(k_{cl}^{i}) = \frac{1}{k_{cl}^{i}}(a+2b\ln(k_{cl}^{i}))$$

$$\frac{\delta\partial_{\text{climat}}}{\delta k_{cl}^{i}} = 0 \Leftrightarrow \ln(k_{cl}^{i}) = -\frac{a}{2b} \Leftrightarrow k_{cl}^{i} = e^{-\frac{a}{2b}}$$

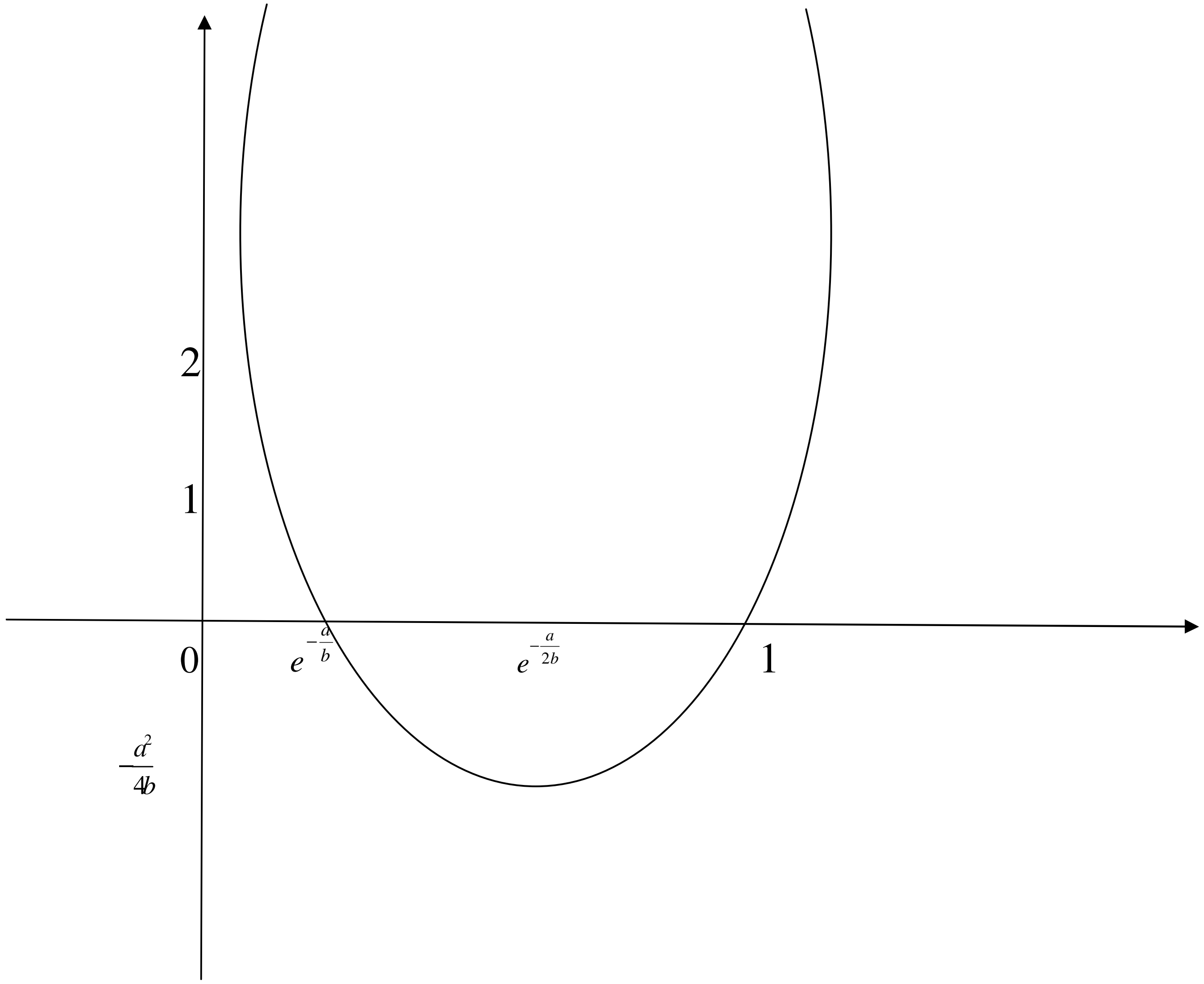
k_{cl}^{i}	0		$e^{-\frac{a}{2b}}$		$+\infty$
$\frac{\delta\partial_{\text{climat}}}{\delta k_{cl}^{i}}$	‖	-	0	+	

Limits of lim∂_{climat}

$\lim_{k_{cl}^{i}\to 0}\partial_{\text{climat}} = +\infty$; $\lim_{k_{cl}^{i}\to +\infty}\partial_{\text{climat}} = +\infty$

k_{cl}^{i}	0		$e^{-\frac{a}{b}}$		$e^{-\frac{a}{2b}}$		1		$+\infty$
$\frac{\delta\partial_{\text{climat}}}{\delta k_{cl}^{i}}$	‖	-			0	+			
∂_{climat}	‖ $+\infty$	↘		↘	$-\frac{a^{2}}{4b}=\partial_{\text{climat}}(e^{-\frac{a}{2b}})$	↗		↗	$+\infty$

Infinite Branches



2.2. The empirical framework: Testing the model using precipitation data

2.2.1. Methodology

The following steps are followed:

1. The first step is to gather a comprehensive daily rainfall data of raining seasons in the country over many years;
2. The second step is to calculate the mean of daily rainfall of a given year;

The mathematical computation of the mean of this rainfall in a given year in a country is as follows:

Suppose in a given country, there are r agro-ecological zones Z_i, with i = 1,….,r ; S_{ij} seasons in given zone j= 1,……ki ,it may be demonstrated that

The mean of daily rainfall of r zones in a given growing year in a given country is:

$\overline{m} = \sum_{i=1}^{r} \frac{m_i}{r}$ where m_i is the mean of all the zones Z_i , i = 1,…,r,

but $m_i = \sum_{j=1}^{k} \frac{m_{ij}}{k_i}$ where m_i is the mean of the given season S_j^i (k_i seasons) in the zone Z_i

with $m_{ij} = \frac{\sum_{l=1}^{n_{ij}} R_l^{ij}}{\left|S_j^i\right|}$ where n_{ij} the total number of rainfall during the season S_j^i in the zone Z and $\left|S_j^i\right|$ is the total length of the season S_j^i expressed in number of days.

By replacing the above expressions in the equation, it follows that the mean of rainfall in the country during a growing year is:

$$\overline{m} = \sum_{i=1}^{r} \frac{\sum_{j=1}^{k_i} \frac{m_{ij}}{k_i}}{r} = \sum_{i=1}^{r} \frac{1}{r} \left(\sum_{j=1}^{k_i} \frac{1}{k_i} \frac{\sum_{l=1}^{n_{ij}} R_l^{ij}}{\left|S_j^i\right|} \right)$$

$$= \sum_{i=1}^{r} \frac{1}{r} \sum_{j=1}^{k_i} \frac{1}{k_i \left|S_j^i\right|} \sum_{l=1}^{n_{ij}} R_l^{ij}$$

$$\overline{m} = \sum_{i=1}^{r} \sum_{j=1}^{k_i} \sum_{l=1}^{n_{ij}} \frac{R_l^{ij}}{r k_i \left|S_j^i\right|}$$

3. The third step is to calculate the intra-annual variation of the rainfall within a given year represented by the standard deviation of rainfall as follows:

The mean of variance of daily rainfall (V_i) of r zones Z_i in a given growing year in a given country is:

$$v = \sum_{i=1}^{r} \frac{V_i}{r}$$ with $Z_i = Z_1\ Z_2, \ldots\ldots. Z_r$ and given $V_i = V_1, V_2 \ldots.. V_r$

The variance of daily rainfall (V_i) in the zone Z_i r is computed as follows:

Given k_i seasons in the zone Z_i, if v_j^i is the variance of rainfall computed over one season S_j^i in the zone Z_i, then: $$V_i = \sum_{j=1}^{ki} \frac{V_{ij}}{k_i}$$

Vi is therefore the mean of rainfall variances of k_i seasons $S_1^i, S_2^i, \ldots. S_k^i$ in the zone Z_i.

To compute v_j^i (variance of rainfall over the season S_j^i of the zone Z_i).

Let us consider m_{ij} as the rainfall mean computed over the season v_j^i .

With n_{ij} , $\left|S_j^i\right|$, R_l^{ij} , the total number of rainfall days of the season S_j^i, the length of the season in days S_j^i and the rainfall quantity of rainfall of the l-th day during the season S_j^i

$$V_j^i = \sum_{l=1}^{n_{ij}} \frac{\left(R_l^{ij} - m_{ij}\right)^2}{\left|S_j^i\right|}$$ Or $$m_{ij} = \sum_{q=1}^{n_{ij}} \frac{R_q^{ij}}{\left|S_j^i\right|}$$

It follows that:

$$V_j^i=\sum_{l=1}^{n_{ij}}\frac{\left(R_l^{ij}-\sum_{q=1}^{n_{ij}}\frac{R_q^{ij}}{\left|s_j^i\right|}\right)^2}{\left|s_j^i\right|}$$

It can be demonstrated that:

$$V_j^i=\frac{1}{\left|S_j^i\right|^3}\sum_{l=1}^{nij}\left(R_l^{ij}\cdot\left|S_j^i\right|-\sum_{q=1}^{nij}R_q^{ij}\right)^2$$

Thus :

$$v=\sum_{l=1}^{r}\frac{1}{r}\sum_{j=1}^{k_i}\frac{1}{k_i}\cdot\frac{1}{\left|S_j^i\right|^3}\sum_{l=1}^{n_{ij}}\left(R_l^{ij}\cdot\left|S_j^i\right|-\sum_{q=1}^{n_{ij}}R_q^{ij}\right)^2$$

$$v=\frac{1}{r}\sum_{i=1}^{r}\sum_{j=1}^{k_i}\sum_{l=1}^{n_{ij}}\frac{\left(R_l^{ij}\cdot\left|s_j^i\right|-\sum_{q=1}^{n_{ij}}R_q^{ij}\right)^2}{k_i\cdot\left|s_j^i\right|^3}$$

The standard deviation of rainfall as the index of rainfall variability in a given growing year in a given country is: $IDPLU=\sqrt{v}$

4. The fourth step is to introduce the rainfall variability index into the modeling

For the present study the theoretical formulation of the food production is a function of three sets of variables: **physical capital** ($K_{p,}$)**, human capital** (K_h) **and environmental capital** (K_E) as follows:

$Y_t=f(K_p,K_h\ ,K_E\ ,\varepsilon_h)$……………………………………………………………..(4)

The empirical model is expressed as follows:

$$Y = \beta_0 + \beta_1 X_1 + \beta_2 X_2 + \beta_3 X_3 + \beta_4 H + \beta_5 SAN + \beta_6 NUT + IDPLU + \varepsilon \ldots\ldots\ldots\ldots\ldots\ldots(5)$$

where,

Y = food production index per capita (%);

H = the literacy rate index for people more than 15 years old (%), it is used as proxy as this latter is not available for the agricultural sector; (%)

X_1 = index of cultivated area in km² per capita (%);

X_2 = index of irrigated agricultural area in % of the total of agricultural areas – It represents the level of investment in rural infrastructures;

X_3 = quantity of fertilizers index per acres (%); it is a proxy of the level of agricultural technology;

SAN = index of health expenditures share in total national budget;

NUT = index of food availability per capita in kilocalories, a proxy of the nutritional status;

IDPLU= index of the rainfall variability; standard deviation (%)

ε, is the usual error term.

All the variables being expressed in natural logs, the coefficients obtained are elasticities

5. Data

Given the limited data base on climate change statistics in SSA, only rainfall data are used to test the model. Time-series data covering the period 1965-1992 are used. First, the data on production and used for explanatory variables originate from the World Bank database published in 1998. The real income (IR) per capita is a ratio of the real GNP to the total population. Second, the data on food security and availability (NU) are obtained from FAO. The data on these variables are calculated periodically by FAO on the basis of a survey conducted at household levels. Since these surveys are not carried out every year, data were generated, assuming that the food security and availability indices do not change significantly from one survey to another. The data on the literacy rate come from the national reports on sustainable human development published regularly by UNDP.

Moreover, in the absence of a comprehensive data on climate change, monthly rainfall data exist in Togo and were collected from the national Meteorology office. The availability of these disaggregated data enable the computation of intra-annual standard of deviation of the rainfall (IDPLU). Data on health indicator, SAN (share of health in national budget) come from Health Statistical Directory between 1965 and 1996.

All the data were calculated as indices (base 100 in 1987). The data processing and analysis were carried out using the econometric software EVIEWS.

The following table 2 summarizes the descriptive statistics of variables used in the study. It shows that the variables X_3 and H has the highest variability with standard deviation of 1,57 and 0,53 respectively whereas the standard of deviation of human capital and rainfall variables from 0,06(H) to 0,39 (IDPLU).

Table 2: Summary statistics for dependent and independent variables

	Mean	Median	Maximum	Minimum	Standard deviation
X1	4,84	4,84	5,25	4,46	0,23
X_2	4,36	4,47	4,62	3,39	0,33
X_3	2,82	3,14	4,72	0,00	1,57
SAN	4,83	4,78	5,33	4,42	0,26
H	3,94	3,66	4,65	3,19	0,53
Y	4,77	4,77	4,98	4,58	0,13
NUT	4,62	4,63	4,75	4,56	0,06
IDPLU	4,36	4,31	5,09	3,59	0,39

Source: Author's calculation

Validity tests

a. Unit root tests

The unit root tests show that the hypothesis of non-stationarity is accepted in level for all variables with trend and constant. In the first difference form, the tests show that non-stationarity is rejected at level $\alpha = 5\%$ for all variables included in the model (table 3).

Table 3: Results of unit root tests

Variables	In Level	In 1st Difference
SAN	-0,57 [4]	-3,98* [1]
H	-2,07 [4]	-3,64* [2]
X_2	-1,90 [1]	-3,82* [1]
X_3	-1,92 [4]	-4,00* [1]
NUT	-2,66 [2]	-2,55* [3]
Y	-2,16 [4]	-3,63* [3]
IDPLU	-2,17 [3]	-7,03* [1]
X_1	-2,44 [4]	-3,41* [3]

The values in brackets are the lags number introduced in the model. The sign (*) means that the hypothesis Ho of non-stationarity is rejected at level α*=5%. The AIC statistics was used to determine the number of lags.*

Source: Computation of the author

b. Cointegration tests

The unit roots tests (Dickey-Fuller) applied to residual show that food production (Y) is co-integrated with individual series H, X_1 et X_3 at $\alpha = 5\%$ which is not the case for SAN, NUT, IDPLU, X_2. series. However, in general all the independent variables series are co-integrated with Y at 5% level.

The results of the unit root (Table 3) and co-integration tests (Table 4) show that the long-term relations defined in the estimations are co-integrated. Thus the use of ordinary least squares estimations (OLS) are irrelevant (Engle and Granger, 1987). Instead error correction models (ECM) are therefore their best short-term specifications. The ECM of the long-term model is as follows:

$$\Delta Y_t = \theta_1 \Delta X_{1t} + \theta_2 \Delta X_{2t} + \theta_3 \Delta X_{3t} + \theta_4 \Delta H_t + \theta_5 \Delta SAN_t + \theta_6 \Delta NUT_t + \theta_p \Delta IDPLU \ (1-\lambda) ECM_{t-1} + v_t \quad \ldots\ldots (5)$$

The coefficient (1-λ) reflects the magnitude of the adjustment, which takes place in the short run in order to correct the instability of the past period.

Once the stationary properties of the series are established, the co-integrated relation of the series is tested (Johansen, 1988). This test allows to "normalize" the co-integration relation through a procedure based on the probability techniques. The co-integration techniques allow to verify the existence or not of a long-term equilibrium relation between the variables. The co-integrating relation constitutes the long-term model.

The ECM is the residual obtained through the estimation of the long-term model, represented by the equations (5). The coefficients θ, δ and π represent the short-term elasticity, while the Δ translates the fluctuations between two successive years. Due to the fact that all the variables of the three models are stationary, the error terms $\nu_{t,}$ μ_t, ω_t, are all distributed according to the normal centred reduced law.

The long-term model (5) was estimated by generalised least square (GLS) due to the presence of autocorrelations of errors. The introduction of Dum binary variables in the long-term models was made necessary due to the existence of a structural break in the two models estimations, from 1980 as shown by the Chow's test. The reasons for these breaks lie in the economic crisis experienced by the country at the beginning of the 80's. This crisis leads to the country economic setbacks and the implementation of structural adjustment programs (SAP). Moreover, Klein test did not disclose existing multicollinearity between the explanatory variables in the estimations.

The short term model (table 6) being estimated by ordinary least squares (OLS), some explanatory variables such as literacy, irrigated lands, use of fertilisers, health and nutrition index were lagged two years to assess the lagged effects of these investments.

Table 4: Results of cointegration tests or unit roots tests

Co-integration relationships	**ADF [lags]**
Y on X_1	-2,30* [4]
Y on H	-2,18* [3]
Y on X_2	-1,00 [3]
Y on X_3	-2,05* [3]
Y on SAN	-0.04 [5]
Y on NUT	-0,12 [3]
Y on IDPLU	-1,48 [1]
Y on H, X_1, X_2, X_3, NUT, SAN, IDPLU	-2,73* [3]

The values in brackets are the lags number introduced in the model.. The sign (*) means that the hypothesis Ho of non-stationarity is rejected at level α=5%. The AID statistics was used to determine the number of lags.

<u>Source</u>: Author's calculation

III. Results: Rainfall as a determinant of food production

3.1. The long run model

Statistically, the long run model is significant as shown by the (R²) which is about 98%. With respect to other variables, a distinction must be made between human capital variables and physical capital variables. First, for the human capital variables, the interactive effect of the economic crisis with literacy (H) reveals that literacy has not played any role in the explanation of food production. With respect to other variables, a distinction must be made between human capital variables and physical capital variables. First, for the human capital variables, the interactive effect of the economic crisis with literacy (H) reveal that literacy has not played any role in the explanation of food production. On the contrary, the health variable yields the expected result as its effect is not only positive but also significant as corroborated by the elasticity of SAN (0.06) and DUM. SAN (0.20). Second, the physical variables: (X_1: cultivated area; X_2: fertilizers use, X_3: irrigate area) contribute significantly to the explanation of food production between 1965 and 1992.

The short run models are satisfactory and economically significant as shown by the R² and Fisher. The results are summarized in table 6. It is important to see that the environmental indicator is not a determinant in explaining the variation of food publication as in long-term model.

Table 5: Estimation of long-term model

Variables	Dependent variable Y	
	Coef. (β)	T of Student
Constant	-6,73	-8,77*
X_1	0,96	13,88*
X_2	0,09	3,13*
X_3	0,06	6,63*
H	0,21	8,11*
SAN	0,06	2,10*
NUT	1,12	11,28*
IDPLU	-0,004	-0,35
Dum	1,55	3,93*
Dum × X_2	-0,38	-8,10*
Dum × H	-0,21	-8,07*
Dum × SAN	0,20	3,72*
	$R^2 = 0{,}975$ DW = 2,69	

** The sign (*) means that the coefficient is significant at 5% level*

<u>Source</u>: Author's calculation

3.2. The short run model

The short run model is also satisfactory and economically significant as shown by the R² and Fisher that are 70% and 7.99 at 1% level. The ECM found to be negative and significant which confirms that overall food production is co-integrated with the explanatory variables. (Table 6). The estimations yield the following results.

First, with respect to the environmental indicator, it is important to notice that the result corroborates that of long term i.e. rainfall is not a determinant in explaining the variation of food publication in Togo between 1965 and 1992.

Second, contrary to results obtained in the long term model, human capital such as literacy is negative and not significant due to the low level of investments (0.001% of the national budget and to the inadequacy of education benefited by the farmers leading to the likely flight from agriculture.

Though all the other human capital variables have the expected results, only nutrition is significant.

In conclusion, the results of short and long term models indicate that the environment variable (rainfall distribution) compared to other variables contributes less to the explanation of food production in Togo due to the continuous degradation of the ecosystems.

Table 6: Estimation of short run model

Variables	Dependent Variable ΔY	
	Coef. (θ)	T Student
ΔX_1	0,72	2,51*
ΔX_2	0,02	0,22
ΔX_3	0,05	3,29*
ΔH	0,06	1,34
ΔSAN	0,06	1,46
ΔNUT	0,63	2,86*
ΔX_2(-2)	-0,08	1,61
ΔIDPLU(-2)	-0,01	-1,42
ΔH(-2)	-0,18	-3,59*
ECM (-1)	-0,55	-2,76*
	R^2 = 0,70 F = 7,99 (0,0002) LM Test = 0,37 (0,70) White= 1,27(0,41)	

** * The sign (*) means that the coefficient is significant at 5% level*

Source: Author's calculation

Conclusion and policy implications.

First, agriculture in SSA will unfortunately continue to depend on climatic factors given the low level of capital investment and the accelerated degradation of the ecosystem. However, very few economists have devoted their research works on explaning the magnitude of climate change (variability) in the variation of agricultural performance.

Second, in the existing literature, agricultural economists often use average rainfall as a summative climatic indicator in estimating agricultural production function. This methodology is flawed. A close scrutiny of agricultural practices/agronomic sciences reveals that agricultural output is more determined not only by rainfall distribution than average rainfall but instead by a set of variable climatic factors. Consequently this climate variability may result in a "good or bad crop performance" depending on the level of variability that may be profitable or damageable to the crop.

Third, the continuous downward trends of climate change on agricultural performance needs a full assesment of climate change in the explanation of agricultural production performance. Unfortunately, current assesment is constrained by the lack of comprehensive statistics on climate change.

In the past, official statistics were confined to rather narrow traditional development agendas. There is a need for expanding the frontiers of official statistics in view of emerging issues such as climate change.

Along this concern, agricultural economists should play a more active and important role, through their investigations, in bringing to the front the strong linkages between the continuous dependency of food production to the degradation of the ecosystems in Africa. In doing so, they will not only provide appropriate information base and directions for statisticians and policy makers but also will enable decision makers to invest in climate change statistics. It is therefore recommended that climate change and development issues be one of the main concerns in the future research agenda in Africa and that African agricultural economists be given the opportunity to participate more actively in meeting these challenges.

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