Turning up the heat on African agriculture: The impact of climate change on Cameroon's agriculture

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Abstract

This paper examines the effect of changes in climatic averages on agricultural production at the national level in Cameroon. The empirical results reveal that Cameroon's agriculture is influenced by climate variables. The economic value of the projected output in 2050 ranges from USD3.5 billion (41% less than the 1961–2001 mean value at 2.5°C increase in temperature and 8.5% increase in precipitation) to US$ 7.1 billion (18.5% greater than the 1961–2001 mean, for a 1.5°C increase in temperature and a 15% increase in precipitation). A 3.5% increase in temperature associated with a 4.5% increase in precipitation in the absence of irrigation facilities would be detrimental to Cameroon's agriculture, leading to a loss of almost 46.7% in output value. This would negatively affect the economy as a whole, since close to 30% of Cameroon's national GDP comes from agriculture.

Keywords: Cameroon; Agriculture; Climate variation; Global warming; Econometric methods

JEL codes: O3 ; Q10 ; Q20

Résumé

Cet article examine, au niveau national, les effets du changement dans les moyennes climatiques concernant la production agricole au Cameroun. Les résultats empiriques révèlent que l'agriculture du Cameroun subit l'influence des variables climatiques. La valeur économique du résultat projeté pour 2050 varie entre 3,5 milliards USD (41% de moins que la valeur moyenne pour la période 1961–2001 avec une augmentation de la température de 2,5°C et une augmentation des précipitations de 8,5%) et 7,1 milliards USD (18,5% de plus que la moyenne pour la période de 1961–2001, pour une augmentation de la température de 1,5°C et une augmentation des précipitations de 15%), Une augmentation de 3,5% de la température associée à une augmentation de 4,5% des précipitations, cela en l'absence de systèmes d'irrigation, représenterait un préjudice pour l'agriculture du Cameroun et entraînerait une perte de presque 46,7% de la valeur de sortie. Ceci affecterait l'ensemble de l'économie de manière négative puisque près de 30% du PIB du Cameroun est issu de l'agriculture.

Mots clés: *Cameroun; Agriculture; Variation climatique; Réchauffement planétaire; Méthodes économétriques*

Catégories JEL : *O3 ; Q10 ; Q20*

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1. Introduction

Climate variation and change can have significant impacts on agricultural production, forcing farmers to adopt new practices in response to altered conditions. Higher temperatures, changes in precipitation and increased climate variability can affect agriculture, forestry and rural areas. Considerable progress has been made in studying the concept and issues of global climate (Bryant 1997; and see IPCC 2001a,b,c and the references cited therein), and evaluating the potential effects on global agriculture (Rosenzweig & Parry, 1994; Mendelsohn & Williams, 2004; Kurukulasuriya et al., 2006). The presence of significant uncertainties has led researchers to emphasize the analysis of regional and national effects (Mendelsohn & Dinar, 2003; Deressa et al., 2005; Gbetibouo & Hassan, 2005). The issue of climate change is without doubt important for developing countries with an agrarian economy, such as Cameroon.

Agriculture is the lifeblood of Cameroon and its people, with about 70% of the labor force employed in this sector. Its agriculture is often limited by the seasonality and magnitude of moisture availability (Molua, 2006). Production is characterized by low levels of input use and many farmers are unable to afford modern inputs (quality seed stock, fertilizer and pesticides). Traditional technology such as multiple cropping and terracing act to buffer the system against climate variability, conserve soil fertility and sustain yields (Molua, 2005). In general, irrigation is an important buffer against climate variability and change. However, Cameroon's crop lands are sparsely irrigated, irrigation being done mostly in the drier north that produces about 30% of the annual crop production (Molua, 2003).[1]

The aim of this study is to assess the potential economic impacts of changes in climate on agriculture in Cameroon and the options for adaptation, in order to provide meaningful insight and contribute to efforts aimed at ensuring both increased food availability through sustainable domestic production and increased income from agricultural production. Specifically, we estimate and analyze whether there exists a relationship between climate and agricultural sector output. This analysis is *macro* in nature, supplementing the previous microeconomic household and farm-level analysis (Molua & Lambi, 2007) and painting a bigger picture.

2. Analytical framework

A substantial amount of research has been conducted on the potential effects of climate on agricultural productivity (Parry, 1990; Leemans & Solomon, 1993; Mendelsohn et al., 2001; Seo et al., 2005). Some studies have used climate induced changes in crop yield to estimate potential global economic impacts (Kane et al., 1992; Rosenzweig & Parry, 1994), while others have examined the indirect impact on economic variables such as farm revenue and income (Lang, 2001; Molua, 2003). Schimmelpfennig et al. (1996) present a simple taxonomy that classifies the method of analysis as either structural (Kaiser et al., 1993; Adams et al., 1990, 1995, 1998)[2] or spatial analogue (Mendelsohn et al.. 1994; Darwin et al., 1999; Kurukulasuriya & Ajwad, 2007).[3]

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[1] The main commercial agriculture crops in Cameroon are cocoa, coffee, cotton, sugarcane, sorghum, groundnuts, millet, sweet potato, cassava, rice, maize, wheat, soybean, potato and field beans.

[2] This method of analysis is interdisciplinary, linking models from atmospheric science, crop science and economics. It links the output of global climate models from the GDFL, GISS and UKMO with crop growth models. The crop yield projections are then employed as inputs into a world food trade model.

[3] The *spatial-analogue* approach involve models that estimate the effects of climate change on agriculture based on observed differences in agricultural production and climate between regions, using either statistical or programming methods. These include the Ricardian analysis in Mendelssohn et al. (1994), the use of computable

2.1 Empirical model

This study inherently combines features of both the structural and spatial analogue approaches. The unifying model that examines the distribution of the impact of climate change on Cameroon's agrarian economy thus consists of three key components: climatic, agronomic and economic. The output of the climatic component includes temperature and precipitation. The study considers the effects of climate change shocks on farm-level output (enterprise level effects), changes in regional production (regional effects) and aggregate changes in the level of national agricultural (national effects). The secondary impacts are associated with changes in the level of national income (GDP), especially in Cameroon where agriculture contributes significantly to national income and employment.

In the current experiment, we assume that the primary production function depicting the production possibilities and resources of Cameroon's agricultural sector is a non-linear continuously differentiable function (it possesses continuous first order and second-order derivatives which are different from zero in all its non-trivial solutions). The production technology for the sector is represented by a differentiable, quasi-concave and monotonic production function of n-input elements (Chambers, 1994: 9). The output function for the sector is implicitly specified as:

$$Q_{it} = f\left(X_{it};\beta\right) + \varepsilon_{it} \tag{1}$$

where output is denoted by Q_{it} and inputs by X_{it}. The agricultural sector's production possibility is assumed to be restricted by exogenous climate variables and other socioeconomic variables. The relationship in equation (1) could be represented by a Translog[5] production function of the form:

$$\ell nQ_t = a_o + a_t T + \sum_{i=1}^{n} a_i \ell nX_i + \frac{1}{2}\sum_{t=1}^{n} \gamma_{ij} \ell nX_i \ell nX_j + \sum_{i=1}^{m} \Phi_{it} \ell nX_i T + \frac{1}{2}\Phi_{tt} T^2 \tag{2}$$

where Q_t = agricultural output, T = time trend and X_i= inputs. These inputs include rainfall (RF_t), temperature (TP_t) acreage under cultivation (AC_t), labor (LB_t), fertilizer (FT_t), pesticides (PS_t), capital durable equipment (K_t) and irrigation (IG_t).

Traditionally, the specification of economic climate models has been based on theoretical considerations (Mendelsohn et al., 1994; Lang, 2001), while less attention is given to the statistical properties of the data. Indeed, though economic theory relies heavily on long-run assumptions and suggests identifying economically well-founded restrictions on the long-run structure, much less is usually known, however, about the short-run structure or adjustment to

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general equilibrium (CGE) and Geographic Information System (GIS) models in Darwin et al. (1999) and the Restricted Profit Function in Lang (2001).

[5] The translog has proven the most popular form in recent applied production economics and can approximate arbitrary twice continuously differentiable functions (Chambers, 1994).

equilibrium. This study differs from previous climate impact studies in that it employs an estimation procedure which draws on advances in time series econometrics (Thomas, 1997). We test the statistical properties of the variables in equation (2) before employing them for the structural analysis. Importantly, if the time series are non-stationary, statistical inference based on the conventional t- and F-test is invalid and the results obtained may be subject to the ‘spurious regression’ problem.

2.2 Impact forecast and predictions

In formulating policy decisions it is essential for a study of this nature to be able to forecast the value of economic magnitudes as a result of climate change. These forecasts will enable policy makers to judge whether it is necessary to take corrective measures to influence the relevant economic variables. The classical technique for forecasting agricultural output has been the extension of a regression line from an ordinary least squares equation to fit past actual output values. While such a technique has lacked theoretical support, it has captured historical output surprisingly well. Based on the economic model in equation (2), a forecasting system is developed for this study. Two forecasts are obtained from the model, based on the following restrictions: (i) the climate environment is without any relevance to Cameroon’s agriculture, and (ii) adaptation is irrelevant to climatic constraint. Climate conditions would, therefore influence output in the absence of mitigating measures to combat the negative impacts. The forecasting performance of the economic model is judged on the basis of the difference between predictions and realization. The smaller the differences between prediction (P_i) and the actual values (A_i) of the dependent variables, the better the forecasting performance of the econometric model (Theil, 1966).

3. Database development and estimation procedures

This study relies on secondary data. The data used consist of three parts: (1) economic variables, measuring national output quantities, (2) real-time data measuring the past and current climate, and (3) projections about the future climate conditions. The historical data used covers the period 1961 to 2001. The agriculture and economic data for Cameroon is obtained from Food and Agriculture Organization statistics (FAO, 2002), and data for other economic variables from various issues of the National Statistical Accounts (MINEFI, 1998). Real-time data, information on precipitation and temperature for each month from 1961 to 2001, is obtained from meteorological stations in Cameroon. We focus on year-to-year variations in climate from the monthly temperature and precipitation data for eight selected meteorological stations and calculate the 40-year average temperature and precipitation.

3.1 Estimation of input variables

Output (Q_t) is the quantity index of permanent and arable crops, from 1961 to 2001. While there are regional disparities in crop types grown in the different agro-ecological zones in the country, data limitation on regional and sub-regional aggregate production hampers the possibility of estimating regional production functions and/or analyzing individual crops. Hence we proceed to estimate an aggregated production function for the national crop subsector. The acreage under cultivation (AC_t) is the quantity index of land (arable crops and permanent crops). Labor (LB_t) is the quantity index of the male and female economically active population in the agricultural sector. Fertilizer (FT_t) is the quantity index of manufactured and organic fertilizers. Pesticides (PS_t) is the quantity index of herbicides, insecticides, fungicides and rodenticides. Capital (K_i) is the quantity index of durable equipment (tractors), animal capital and replacement inventories. Irrigation (IG_t) is the fraction of agriculture area irrigated. The input data is for the period 1961 to 2001. Data for the following variables are from the FAO statistical database: Q_t, AC_t, $FT_,$ PS_t, and IG_t. The remaining variables (LB_t and K_t) are from Cameroon's National Statistical Account. Table 1 presents a brief summary of the input and output structure of Cameroon's agricultural sector.

Table 1: Selected agriculture output and input estimates for Cameroon, 1960 –2001

Item	Mean	Standard deviation
Output (crops)		
Cereals (mt)	910,779	219,885
Roots and tubers (mt)	2,075,845	538
Bananas (mt)	511,875	285
Output (Livestock)		
Meat (mt)	129,374	48,262
Milk (mt)	110,489	56,386
Eggs (mt)	8,922	3,433
Inputs		
Cultivated land area (1000 ha)	8,616	600
Fertilizer (mt)	26,173	14,613
Herbicides (mt)	86	133
Insecticides (mt)	209	326
Irrigated area (1000 ha)	16	11
Agric. population (1000)	6,248	1,074

Notes: mt = metric tons, ha = hectares

3.2 Generation of climate data

3.2.1 Processing of precipitation and temperature data

Mean monthly and mean annual precipitations are computed from weather stations across Cameroon. We employ the area-average normalization developed by Kraus (1977) and employed in studies such as Landsea & Gray (1992). To obtain the best picture of the regional aspect of precipitation variations, Kraus attempted to combine stations without inducing a bias toward any station or any sub-grouping of stations. The monthly regional precipitation data is estimated, and then the anomaly is computed. The rainfall anomaly is essentially the departure from the mean divided by the standard deviation. That is:

$$\Delta RF_j = \frac{RF_j - R\overline{F}}{\sigma} \tag{4}$$

where ΔRF_j is the rainfall variation and $\overline{RF}$ is the mean. To obtain the monthly mean for each station, the daily average temperature is calculated. The average temperature per month is then computed and the annual deviations (anomalies) from the mean (TP) are obtained.

3.2.2 Climate change scenarios

According to IPCC projections (1998), equatorial countries (for example, Cameroon, Uganda, and Kenya) may be about 1.4°C warmer by 2050, a rate of warming of about 0.2°C per decade. Sea surface temperatures in the open tropical oceans surrounding Africa will rise by less than the global average (i.e. about 0.6–0.8°C); the coastal regions of the continent therefore will warm more slowly than the interior (IPCC, 1998). According to the IPCC (1998), equatorial Africa could experience a 5% increase in rainfall. These rainfall results are, however, not consistent. Different climate models or different simulations with the same model yield different patterns.

The UNEP/GEF (2000) study on Cameroon examined two regions to assess impacts and adaptations: the coastal zone, which is the most densely populated area of Cameroon, and the Sudano-Sahelian zone, which is the region most affected by extreme events, including droughts and floods. To explore the implications of climate change for Cameroon, the study uses the results from MAGICC[4] to project mean global temperature and sea level rise. Using the IPCC IS92a emissions scenario, MAGICC (version 2.3) generated projections of mean global temperature and sea level rise to the year 2100. It is observed that for the coastal zones average changes in annual temperature range from 1.58°C to 3.33°C, with a mid-value of 2.31°C. Temperature increases are higher in northern Cameroon, where the MAGICC results range from 2.13°C to 4.53°C (UNEP/GEF, 2000). For precipitation changes, the GCM results fall within present-day variability, thus no dramatic changes are expected. This compares to small positive changes generated, ranging from a 4% to an 8% increase, depending on climate sensitivity.

Projections from leading climate research centers' climate scenarios yield mean temperature changes of between 1.3°C and 4.6°C by the year 2050, representing global warming rates of between 0.2°C and 0.4°C per decade. Therefore assuming that the rate of change in the global climate is an indicator of the rate of change in local climate and in line with the findings of UNEP/GEF (2000), we comfortably rely on these projections for assumptions of future climate change in Cameroon. We assume that future annual temperatures across Cameroon will rise by 1.5°C (scenario A), 2.5°C (scenario B) or 3.5°C (scenario C). For future changes in mean seasonal rainfall in Cameroon we assume that rainfall will increase by 15% (scenario A), 8.5% (scenario B) or 4.5% (scenario C). Despite possible limitations, the climate scenarios cover a reasonable range of the likely climate change distribution. We therefore use them to explore the sensitivity of Cameroon's agriculture. Due to uncertainties, long-term projections may have little practical meaning. Hence the years under consideration are limited to 2010, 2020, 2030, 2040 and 2050. These changes are applied to the econometric model (equation 2) and forecasts aimed at revealing the potential impact of global warming on Cameroon's agricultural sector.

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[4] MAGICC is a simple climate model developed by the Climate Research Unit (http://www.cru.uea.ac.uk) at the University of East Anglia in the UK (Hulme et al., 1995).

4. Empirical results: The impact of climate on agriculture's potential

The performance of Cameroon's agriculture sector depends largely on the return of good rains and the timely and adequate provision of agricultural inputs. Figure 1 captures changes in the crop production index and changes in rainfall for 1961–2001. The diagrammatic observations reveal a possible relationship between rainfall and agricultural sector performance in Cameroon.[5] Years of improved rainfall are associated with improved agricultural output and, conversely, years of decreased agricultural output can be explained by poor rainfall. Variability and unreliability of rainfall in particular imply high risks for agriculture, possible slowing down of sectoral growth and hindrance to overall economic progress.

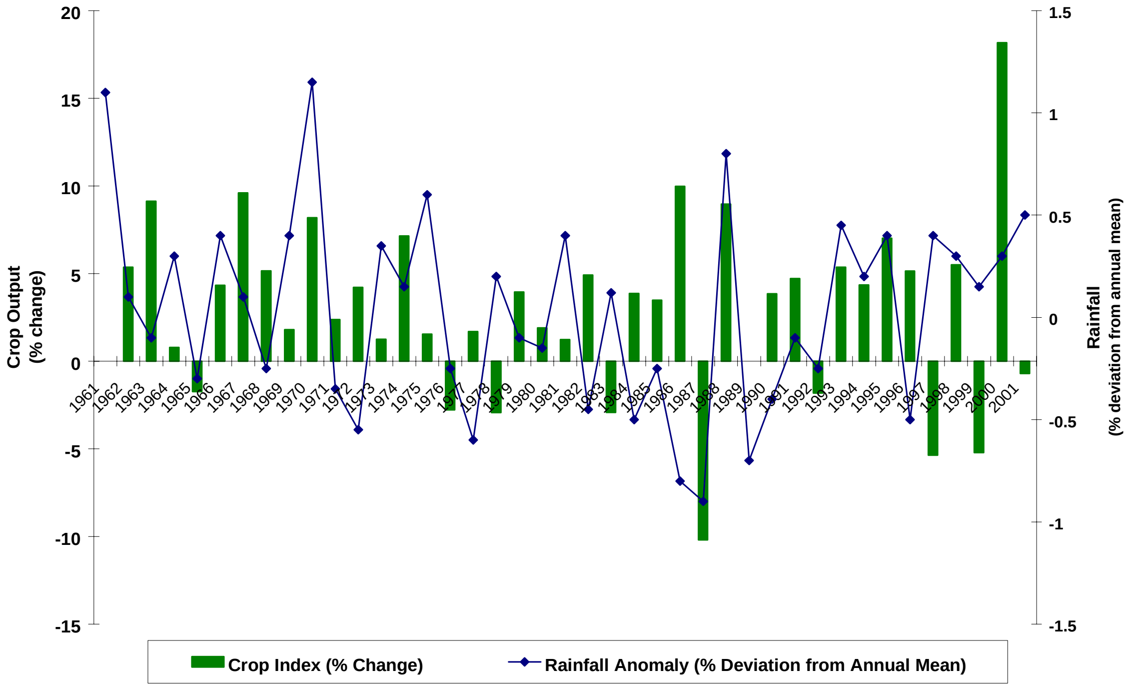

Figure 1: Crop production variation and rainfall anomaly relationship in Cameroon

Though there have been substantial periods, for example 1969–70 and 1988–90, that were much wetter than average, changes in rainfall patterns have had pronounced effects on food availability and the income of agriculture dependent households (Molua, 2002; Molua & Lambi, 2007). The late 1980s witnessed probably the driest period, with two episodes of mild drought being registered in northern Cameroon, leading to lower agricultural returns, malnutrition and deaths.

Farmers in Cameroon are, however, not passively submitting to climate variation. Detailed information generated though rapid rural appraisal and discussions with farming groups across the country on the farming situation, farming practices and farm-level decision making reveals a plethora of adaptation options. Information about the basis for farmers' decisions about the cropping pattern, the management options available to them, and their assessment of associated costs and benefits reveals that their main strategy for reducing climate risk is to diversify production and livelihood systems. Soil and water management measures and plant

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[5] The rainfall is an average for all Cameroon. The monthly totals, monthly averages and annual deviations in rainfall recorded in weather stations across Cameroon are estimated, rather than the episodic or seasonal effects. The crop index is for all crops grown in the country.

protection measures are varied to maintain yields. While some farmers are acquiring more livestock to cushion income, others are increasingly engaged in various non-farm activities (crafts and trade). It is increasingly difficult to know what to plant, how much, where, when, and how. As shown in Table 2, in addition to farming options, farmers use a range of consumption, investment or income generating strategies to cope with expected shortages. While these observations are important, we acknowledge that the current exercise is a macro-sectoral study aimed at complementing farm-level and household impact studies in Cameroon (Molua & Lambi, 2007) that take into account the economic costs and benefits of adapting to climate vagaries. This current experiment is thus limited in scope in ascertaining producer welfare impacts. Notwithstanding, an important research question we seek to answer is: What is the numerical significance of observed climatic variation for Cameroon's agriculture sector and what will be the consequence for the sector under a changed global climate? Successfully answering this paves the way for further analysis of the rationale for adaptation and the welfare impact of observed management practices.

Table 2: Farm level decision making in response to climate anomaly in Cameroon

Management options	Decisions	Expected outcomes
Soil & water management	Implement water conservation techniques	Ensure water supply during farming season
	Increase or reduce area planted by crop, by location, by topo-sequence	Keep farm output and food production constant
Protection measure	Change row orientation with respect to slope	Reduce soil erosion, trap surface water, retain soil nutrients
	Apply soil amendments, e.g. farmyard manure	Improve soil structure and soil fertility
	Increase fertilizer application three days prior to sowing	Increase soil fertility and ensure yield increases
Plant s	Adjust planting time and planting order among crops, locations, topo-sequence	Maximize crop yield
	Choose certain crops and crop varieties (with different growth cycle, water requirements)	Optimize farm output
	Treat seed with fungicides before sowing	Reduce seed rot incidence, increase germination rate
	Late leaf spot spray of fungicide, one week after incidence	Improve crop vegetative growth
Farming operations	Early harvest when dry soil is expected	Minimize crop losses
	Apply more or fewer inputs	Minimize production costs
Household livelihood	Undertake non-farm economic activities	Increase off-farm income
	Disinvest household and personal assets	Smooth household consumption
	Avoid selling remaining food stocks	Safeguard food reserves
	Reduce expenditures	Increase savings
	Ration food	Safeguard nutrition intake
	Migrate	Save lives and family continuity

Source: Authors' observation and notes, 2003

4.1 Dynamic impact analysis

To analyze the impact of rainfall and temperature variation (anomalies) on agriculture we must subject the generated data to a rigorous time series analysis. The ADF testing procedures (unit roots test) performed in Table 3, on both level and first difference, seek to determine whether the individual production input series are stationary and exhibit similar statistical properties. The tested ADF equation allowed for the presence of non-zero mean and constant deterministic drift. The number of lags was determined by the general-to-specific method, whereby a generous lag structure is allowed and the insignificant lags are eliminated sequentially. For two of the variables in their level forms (K_t and PS_t) the ADF statistics are more negative than the critical values at 1%, 5% and 10%. Thus we reject the null hypothesis for non-stationarity and establish that the series are I(0). For the output (Q_t), fertilizer (FT_t), rainfall (RF_t),[6] temperature ($TP_{t,}$) acreage ($AC_{t,}$) labor (LB_t) and irrigation (IG_t) variables in their level forms, the ADF statistics are not more negative than the critical values at either 1%, 5% or 10%. Thus we fail to reject the null hypothesis for non-stationarity and establish that the series are not I(0). That rainfall variation ($RF_{t,}$) is not I(0) corroborates anecdotal evidence. As regards temperature, the findings appear incongruous to available evidence where the temperature variation series is trending upwards – hinting that it could be a trend stationary variable. This finding is illuminating. It highlights the sensitivity and better exploratory nature of the mechanics in the ADF tests. A parsimonious explanation for the revelation that the climate anomaly series exhibits a stochastic trend is embedded in both the physics of atmospheric processes and the nature of our data manipulation for the derivation of the climate anomalies. The normalization procedure may have led to the resultant effect of a low signal-to-noise ratio in the anomaly series, thus causing the failure to reject the null hypothesis of a stochastic trend. Exploring the nature (cyclic, seasonal etc.) of the trend is not our immediate objective in the current study.

In general the ADF test confirms the obvious finding that most economic time series are possibly I(1), only becoming stationary on first differencing. The series of respective independent variables in equation (2) is denoted I(0) when it is stationary already in levels and non-stationary and integrated of order d (I*(d)*) when it must be differenced d times in order to achieve (weak covariance) stationarity (Banerjee et al., 1993). As shown in Table 3, the first-difference series are found to be significant at 1% critical value, indicating that the differenced series are 1(1). Since Q_t~I(1), K_t~1(0) and PS_t~I(0), then $Q_t = \alpha_1 K_t + \alpha_2 PS_t + \varepsilon_t$ is possibly an unsuitable regression, implying that this type of aggregate data is not suitable for the current analysis. Therefore these two variables (K_t and PS_t) are dropped. The remaining variables, FT_t, RF_t, TP_t, $AC_{t,}$, LB_t, and IG_t, which are all I(1), are used for further analysis. An interesting observation concerns the climate variables, rainfall and temperature. That they are both I(1) implies they can explain both short-run deviations and a long-run relation with the agricultural sector. It is also possible that there are cointegrating vectors among the I(1) variables. However, exploring the nature of cointegration and identifying the possible vector error correction equations is beyond the scope of the current study.

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[6] Recall that the temperature and precipitation anomalies rather than mean values are used in this study.

Table 3: Univariate stationarity property of the series with constant term and time trend

Variables (log)	Optimal lag length	ADF statistic	Variables (log) (differenced)	Optimal lag length	ADF statistic
Output (Q_t)	0	-1.37	Output (Y_t)	0	-3.64
Rainfall (RF_t)	0	-1.99	Rainfall (RF_t)	0	-4.21
Temperature (TP_t)	0	-2.46	Temperature (TP_t)	0	-3.73
Acreage (AC_t)	0	-1.56	Acreage (AC)	0	-5.61
Labor (LB_t)	0	-2.52	Labor (LB_t)	0	-3.02
Fertilizer (FT_t)	0	-2.42	Fertilizer (FT_t)	0	-2.97
Pesticides (PS_t)	1	-3.66	Pesticides (PS_t)	1	-3.74
Irrigation (IG_t)	0	-1.65	Irrigation (IG_t)	0	-6.01
Capital (K_t)	1	-3.96	Capital (K_t)	1	-4.06

Notes: ADF t-statistics at 1% critical value = – 3.57, 5% critical value = –2.94, and 10% critical value = –2.62.

4.2 Impact analysis and robustness of climate on agriculture

In an attempt to capture adjustments in output in relation to deviations of the climate determinants from their equilibrium relation with agriculture, we proceed to the estimation of the long-run relation using equation (2). The variables that are integrated of the same order I(1) are used in the analysis. First, using a general-to-specific approach, the translog production function (TRLM1) with two climate inputs (rainfall and temperature) and four aggregate inputs (land, labor, fertilizer and irrigation) is estimated. Equation (2) is thus estimated as a dynamic long-run reaction of climate and agro-economic variables measuring the response of Cameroon's agriculture. Two other possible relationships are estimated based on the following hypotheses:

(i) The climate environment is without any relevance to Cameroon agriculture (TRLM II). This somewhat strong hypothesis is identical with the restriction α_{ij} = 0; $\gamma_{ij} = 0, \ \forall i = 1,......, n$ in which i and j will denote climate variables.

(ii) Irrigating farmlands to adjust to climate constraint is irrelevant. Climate conditions would, therefore, influence output in the absence of cushioning measures to combat the negative impacts (TRLM III). This less restrictive hypothesis is identical with the restrictions $\alpha_{ij} = 0; \gamma_{ij} = 0, \ \forall i = 1,.....n$ in which i and j will denote the irrigation variable.

Parameter estimates for production function are obtained by maximum likelihood estimation. The detailed regression results are presented in Tables 4a, 4b and 4c. The likelihood ratio tests are performed to highlight the statistical relevance of the climate variables. The summary presented in Table 5 below allows for clear interpretation. Both hypotheses posited above are rejected. This indicates that climate influences Cameroon's agricultural sector. In addition, increased investment in irrigation as an option for adaptation is significant.

Table 4a: Regression model (TRLM 1) explaining the impact of climate on Cameroon's agriculture

Serial no.	Parameters	Coefficients	Estimates	t-statistic	Serial no.	Parameters	Coefficients	Estimates	t-statistic
0	Constant	α_0	40.3333	3.8124**	21	*ln* AC_t x *ln* FT_t	γ_{35}	0.1313	2.0610*
1	*ln* RF_t	α_1	-0.0877	-2.0205*	22	*ln* AC_t x *ln* IG_t	γ_{36}	0.3125	2.1888*
2	*ln* TP_t	α_2	-0.0656	-2.0167*	23	*ln* LB_t x *ln* RF_t	γ_{41}	0.0010	1.0045
3	*ln* AC_t	α_3	0.2270	4.0801***	24	*ln* LB_t x *ln* FT_t	γ_{45}	0.2503	1.7320
4	*ln* LB_t	α_4	0.1880	2.1603*	25	*ln* LB_t x *ln* IG_t	γ_{46}	0.1140	1.3200
5	*ln* FT_t	α_5	0.0620	2.7710**	26	*ln* FT_t x *ln* RF_t	γ_{51}	-0.0081	-1.0630
6	*ln* IG_t	α_6	0.0453	4.7207***	27	*ln* FT_t x *ln* IG_t	γ_{56}	0.0499	2.0200*
7	T	$\alpha_t T$	0.0090	5.3302***	28	*ln* IG_t x *ln* RF_t	γ_{61}	0.0090	1.0061
8	*ln* RF_t x *ln* RF_t	γ_{11}	-0.1153	-2.3501*	29	T_{RF}	Φ_{1t}	-0.0002	-2.0171*
9	*ln* TP_t x *ln* TP_t	γ_{22}	-0.0902	-2.1800*	30	T_{TP}	Φ_{2t}	-0.0001	-1.0010
10	*ln* AC_t x *ln* AC_t	γ_{33}	0.3071	2.7896**	31	T_{AC}	Φ_{3t}	0.0085	5.2300***
11	*ln* LB_t x *ln* LB_t	γ_{44}	0.0927	2.6603**	32	T_{LB}	Φ_{4t}	0.0006	3.3402**
12	*ln* FT_t x *ln* FT_t	γ_{55}	0.0670	2.0231*	33	T_{FT}	Φ_{5t}	0.0002	2.5220*
13	*ln* IG_t x *ln* IG_t	γ_{66}	0.0601	2.0158*	34	T_{IG}	Φ_{6t}	0.0006	2.2132*
14	*ln* TP_t x *ln* RF_t	γ_{21}	-0.1311	-2.0420*	35	T_{tt}	Φ_{tt}	0.0003	2.0912*
15	*ln* TP_t x *ln* AC_t	γ_{23}	0.0010	1.7200	36	Adj. R. sq.	R^{-2}	0.6187	
16	*ln* TP_t x *ln* LB_t	γ_{24}	0.0002	1.0071	37	F-statistic	F (35,4)	145.62	
17	*ln* TP_t x *ln* FT_t	γ_{25}	0.0001	1.0980	38	Durbin-Watson	DW	1.49	
18	*ln* TP_t x *ln* IG_t	γ_{26}	0.0001	2.0166*	39	White statistic	W	13.32	
19	*ln* AC_t x *ln* RF_t	γ_{31}	0.0110	1.4620	40	Jarque-Bera	JB	2.44	
20	*ln* AC_t x *ln* LB_t	γ_{34}	0.2338	2.0550*	41	----	----	----	

Notes: Rainfall is the value of monthly rain deviation from annual mean. Temperature is the value of monthly temperature deviation from annual mean. *** is significant at 1% level of confidence (c.v. = 4.032), ** at 5% level of confidence (c.v. = 2.571), * at 10% level of confidence (c.v. = 2.015) (using the two-tailed t-test). The F-test (critical value = 13.8 at 1%) supports the hypothesis that all coefficients are jointly significant (i.e. rejects the null hypothesis that all are zero). Diagnostic tests using White statistic ($W \sim \chi^2$ critical value = 55.8) heteroscedasticity test, Durbin-Watson (DW) autocorrelation test and Jarque-Bera ($J\text{-}B \sim \chi^2$ critical value = 5.99) test on normality of residuals, reveal no evidence of serial correlation or heteroscedasticity. The normality assumption of the error term is not violated. In all the diagnostic tests, none of the obtained statistics exceeds its critical value. The coefficient of multiple determination (R^{-2}) indicates that 61% of the variation in sectoral output in Cameroon can be attributed to the changes in the independent variables examined. The residual variations could be explained by the variables not existing in the model. Overall, the model is statistically significant at the 95% probability level as the F-test for the joint significance of the explanatory variables indicates.

Table 4b: Regression model (TRLM II) Explaining the IMPACT OF CLIMATE on Cameroon's agriculture (Hypothesis: The climate environment is irrelevant.)

Serial no.	Parameters	Coefficients	Estimates	t-statistic	Serial no.	Parameters	Coefficients	Estimates	t-statistic
0	Constant	α_0	67.7540	6.2311***	21	*ln* AC_t x *ln* FT_t	γ_{35}	0.4200	1.7613*
1	*Ln* RF_t	α_1	----	----	22	*ln* AC_t x *ln* IG_t	γ_{36}	0.7001	1.2110
2	*ln* TP_t	α_2	----	----	23	*ln* LB_t x *ln* RF_t	γ_{41}	----	----
3	*ln* AC_t	α_3	0.2750	3.9802***	24	*ln* LB_t x *ln* FT_t	γ_{45}	0.0711	1.2280
4	*ln* LB_t	α_4	0.2130	2.5601**	25	*ln* LB_t x *ln* IG_t	γ_{46}	0.0956	1.7412*
5	*ln* FT_t	α_5	0.0830	2.1372**	26	*ln* FT_t x *ln* RF_t	γ_{51}	----	----
6	*ln* IG_t	α_6	0.0657	3.0333***	27	*ln* FT_t x *ln* IG_t	γ_{56}	0.0720	1.0092
7	T	$\alpha_t T$	0.0100	1.9600*	28	*ln* IG_t x *ln* RF_t	γ_{61}	----	----
8	*ln* RF_t x *ln* RF_t	γ_{11}	----	----	29	T_{RF}	Φ_{1t}	----	----
9	*ln* TP_t x *ln* TP_t	γ_{22}	----	----	30	T_{TP}	Φ_{2t}	----	----
10	*ln* AC_t x *ln* AC_t	γ_{33}	0.5061	2.9800***	31	T_{AC}	Φ_{3t}	0.0050	2.8712***
11	*ln* LB_t x *ln* LB_t	γ_{44}	0.1556	1.9713*	32	T_{LB}	Φ_{4t}	0.0008	1.7706*
12	*ln* FT_t x *ln* FT_t	γ_{55}	0.1043	1.2100	33	T_{FT}	Φ_{5t}	0.0003	2.0201*
13	*ln* IG_tx *ln* IG_t	γ_{66}	0.0912	1.8251*	34	T_{IG}	Φ_{6t}	0.0009	2.2890**
14	*ln* TP_t x *ln* RF_t	γ_{21}	----	----	35	T_{tt}	Φ_{tt}	0.0001	1.7316*
15	*ln* TP_t x *ln* AC_t	γ_{23}	----	----	36	Adj. R. sq.	R^{-2}	0.3906	
16	*ln* TP_t x *ln* LB_t	γ_{24}	----	----	37	F-statistic	F (20,19)	89.68	
17	*ln* TP_t x *ln* FT_t	γ_{25}	----	----	38	Durbin-Watson	DW	1.64	
18	*ln* TP_t x *ln* IG_t	γ_{26}	----	----	39	White statistic	W	10.24	
19	*ln* AC_t x *ln* RF_t	γ_{31}	----	----	40	Jarque-Bera	JB	3.28	
20	*ln* AC_t x *ln* LB_t	γ_{34}	0.8071	2.6762**	41	Likelihood ratio	LR	188.70	

Notes: *** is significant at 1% level of confidence (c.v. = 2.831), ** at 5% level of confidence (c.v. = 2.080), * at 10% level of confidence (c.v. = 1.721) (using the two-tailed t-test). The F-test (critical value = 3.00 at 1%) supports the hypothesis that all coefficients are jointly significant (i.e. rejects the null hypothesis that all are zero). Diagnostic tests using White statistic (W ~ χ^2 critical value = 31.4) heteroscedasticity test, Durbin-Watson (DW) autocorrelation test and Jarque-Bera (J-B ~ χ^2 critical value = 7.81) test on normality of residuals, reveal no evidence of serial correlation or heteroscedasticity. The normality assumption of the error term is not violated. In all the diagnostic tests, none of the obtained statistics exceeds its critical value. The coefficient of multiple determination (R^{-2}) indicates that 39% of the variation in sectoral output in Cameroon can be attributed to the changes in the independent variables examined. The residual variations could be explained by the variables not existing in the model. Similarly, overall, the model is statistically significant at the 95% probability level as the F-test for the joint significance of the explanatory variables indicates.

Table 4c: Regression model (TRLM III) Explaining the impact of climate on Cameroon's agriculture (Hypothesis: Adaptation using irrigation is irrelevant.)

Serial no.	Parameters	Coefficients	Estimates	t-statistic	Serial no.	Parameters	Coefficients	Estimates	t-statistic
0	Constant	α_0	41.3103	4.2201***	21	*ln* AC$_t$ x *ln* FT$_t$	γ_{35}	----	----
1	*ln* RF$_t$	α_1	-0.1724	-1.7333*	22	*ln* AC$_t$ x *ln* IG$_t$	γ_{36}	----	----
2	*ln* TP$_t$	α_2	-0.0711	-1.7800*	23	*ln* LB$_t$ x *ln* RF$_t$	γ_{41}	0.0340	1.3126
3	*ln* AC$_t$	α_3	0.2410	2.7911**	24	*ln* LB$_t$ x *ln* FT$_t$	γ_{45}	----	----
4	*ln* LB$_t$	α_4	0.1563	1.7322*	25	*ln* LB$_t$ x *ln* IG$_t$	γ_{46}	----	----
5	*ln* FT$_t$	α_5	----	----	26	*ln* FT$_t$ x *ln* RF$_t$	γ_{51}	----	----
6	*ln* IG$_t$	α_6	----	----	27	*ln* FT$_t$ x *ln* IG$_t$	γ_{56}	----	----
7	T	α_tT	0.0050	2.2630**	28	*ln* IG$_t$ x *ln* RF$_t$	γ_{61}	----	----
8	*ln* RF$_t$ x *ln* RF$_t$	γ_{11}	-0.1872	-3.3433***	29	T_{RF}	Φ_{1t}	-0.0001	-1.7155*
9	*ln* TP$_t$ x *ln* TP$_t$	γ_{22}	-0.0978	-2.8991***	30	T_{TP}	Φ_{2t}	-0.0001	-1.0055
10	*ln* AC$_t$ x *ln* AC$_t$	γ_{33}	----	----	31	T_{AC}	Φ_{3t}	0.0075	1.9187*
11	*ln* LB$_t$ x *ln* LB$_t$	γ_{44}	0.2343	1.8870*	32	T_{LB}	Φ_{4t}	0.0005	2.1300**
12	*ln* FT$_t$ x *ln* FT$_t$	γ_{55}	----	----	33	T_{FT}	Φ_{5t}	----	----
13	*ln* IG$_t$ x *ln* IG$_t$	γ_{66}	----	----	34	T_{IG}	Φ_{6t}	----	----
14	*ln* TP$_t$ x *ln* RF$_t$	γ_{21}	-0.0900	-2.6556**	35	T_{tt}	Φ_{tt}	0.0001	1.7834*
15	*ln* TP$_t$ x *ln* AC$_t$	γ_{23}	0.0001	0.8109	36	Adj. R. sq.	R^{-2}	0.5348	
16	*ln* TP$_t$ x *ln* LB$_t$	γ_{24}	0.0001	0.2002	37	F-statistic	F (19,20)	96.44	
17	*ln* TP$_t$ x *ln* FT$_t$	γ_{25}	----	----	38	Durbin-Watson	DW	2.32	
18	*ln* TP$_t$ x *ln* IG$_t$	γ_{26}	----	----	39	White statistic	W	8.52	
19	*ln* AC$_t$ x *ln* RF$_t$	γ_{31}	- 0.0310	-1.7800*	40	Jarque-Bera	JB	5.23	
20	*ln* AC$_t$ x *ln* LB$_t$	γ_{34}	0.3192	1.7322*	41	Likelihood ratio	LR	343.46	

Notes: Rainfall is the value of monthly rain deviation from annual mean. Temperature is the value of monthly temperature deviation from annual mean. *** is significant at 1% level of confidence (c.v. = 2.807), ** at 5% level of confidence (c.v. = 2.069), * at 10% level of confidence (c.v. = 1.714) (using the two-tailed t-test). The F-test (critical value = 3.00 at 1%) supports the hypothesis that all coefficients are jointly significant (i.e. rejects the null hypothesis that all are zero). Diagnostic tests using White statistic (W ~ χ^2 critical value = 30.1) heteroscedasticity test, Durbin-Watson (DW) autocorrelation test and Jarque-Bera (J-B ~ χ^2 critical value = 7.81) test on normality of residuals, reveal no evidence of serial correlation or heteroscedasticity. The normality assumption of the error term is not violated. In all the diagnostic tests, none of the obtained statistics exceeds its critical value. The coefficient of multiple determination (R^{-2}) indicates that about 53% of the variation in sectoral output in Cameroon can be attributed to the changes in the independent variables examined. The residual variations could be explained by the variables not existing in the model. Overall, the model is statistically significant at the 95% probability level as the F-test for the joint significance of the explanatory variables indicates.

With crop output (permanent and arable) as the dependent variable, on examining the parameters and related statistical test results of the independent variables obtained from the 'general' regression (equation 2), denoted model (TRLM I), most of the signs of the coefficients of the variables simulated are as expected. The t-statistics show that most of the variables are statistically meaningful at the 1%, 5% or 10% significance level. The model registers a significant influence for land, labor, fertilizer and irrigation, confirming a priori expectations. However the rainfall and temperature anomalies are significant at a low level (though having the expected a priori negative sign), while their squared terms are highly significant. The findings indicate that output decreases by 8.1% for a 1 standard deviation (SD) of rainfall from the mean value. Temperature anomaly decreases output by 3% for a 1 SD of temperature from the mean value. Furthermore, the impact on output significantly increases with the squared terms. That the squared terms are strongly significant implies that the observed relationships are non-linear. The squared term for precipitation is negative, implying that there is productive level of precipitation anomaly and beyond the acceptable and required level of precipitation such deviations may be bad for agriculture, and negative outcomes are observed.

Table 5: Likelihood ratio tests on simplified model structures

Hypothesis	λ_{LR}	Degrees of freedom	$X^2_{0.10}$	$\chi^2_{0.01}$	Result
Climate conditions are irrelevant (TRLM II)	188.70	15	22.3	30.6	Reject
Irrigation is irrelevant (TRLM III)	343.46	17	24.8	33.4	Reject

Notes: λ_{LR} is the likelihood ratio statistic. χ^2 indicates the critical chi-square value.

The interactive term rainfall x temperature also has a negative coefficient, albeit marginally significant. In other words, increase in temperature variation has an increasingly large effect of about 13% decline in production as rainfall variation also increases. The interactive term rainfall x acreage, though significant, is expected to have a negative sign to indicate that increasing climatic variation has a stronger negative impact on agriculture by limiting agricultural response and the acreage under cultivation. However, the fact that this interactive term is positive implies that more land is exploited for agriculture despite increased climate variation. It could therefore be that more marginal lands are exploited for agricultural use. Similarly, irrigation is a strong positive variable that substantially increases output, which is expected given the crucial importance of irrigation in many areas of the dry tropics. Since irrigation and its squared terms are positive, it is therefore possible that modern irrigation practices, traditional methods of rainwater harvesting and other adaptation options make it possible to expand the acreage in production despite the limiting climatic conditions. Labor, fertilization and irrigation are observed to have increasingly large effects of about 18.8%, 6.2% and 4.5% respectively, as the inputs are increased. The positive parameter estimates for fertilizer, labor and irrigation highlight the potential resilience of farm-level response to climate variation. And it is worth observing that, while increasing precipitation anomaly and an increase in temperature will have a negative impact, irrigation is highly significant. This tells us that with a potential increase in temperature with global warming and drier conditions, irrigation would be needed to cushion the detrimental effects.

Overall, the equations are found to be robust as they satisfy almost all the relevant diagnostic tests. The diagnostic test statistics (Durbin-Watson, White test and Jargue-Bera) show no evidence of functional misspecification and no significant serial correlation. The correlation for each model (not reported here) reveals that the explanatory variables constitute near-orthogonal regressors and therefore multicollinearity is assumed to be less serious. This allows for the conclusion that the relationship between agriculture and climate is structurally stable and the findings in the model equations valid.

Interestingly, in all the regressions in Table 4 (a, b and c) the time trend (T) is positive and significant, particularly for the critical inputs of land, fertilizer and irrigation. This suggests that the variables in question do exhibit a trend in the period under review, with the possibility that for given sub-periods they follow a mixed process (stochastic and deterministic). However, the trend term being positive and significant also implies that with the passage of time there may have been marginal technological changes; that is, improvements and the adoption of new scientific methods of agriculture that shift the production function. The time trend parameters α_t and Φ_{tt} indicate the direction of shift of the production function and the rate of change of this shift, respectively, at the point of approximation.[7] Technological progress occurs at an average annual rate of 0.9%, 1% and 0.5% respectively (measured at the point of approximation for each of the models), and these rates are increasing slowly over time. Technological adoption would give Cameroon's farmers increased flexibility and the adoption of modern farming methods may free them from previous environmental constraints with the use of new crop varieties, irrigation technologies and chemical controls (Dinar et al., 1998).

4.3 Forecasts of climate change impact on agriculture's potential

The climate change impact for Cameroon is computed using the future climate scenarios. The results are presented in Table 6. Projections of the other inputs in the model are based on FAO projections on the growth rate of input use for Cameroon.[8] Comparing all the models, the estimates suggest that TRLM I is robust to the inclusion of climate variables. Therefore, TRLM I and III are selected for the projections, with TRLM III allowing for predictions in the absence of irrigation and some modern inputs. While irrigation and artificial fertilization have been dropped in TRLM III, they still maintain their specification as production functions given the presence of the two variables, land and labor, which are key dominant inputs in African agriculture. On evaluating the impact of climate change on current agricultural conditions the values indicate a gain in all the three climate change scenarios. The estimates diverge depending on the global warming scenario used.

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[7] Most economic studies of technical change focus on the time trend variable as a (residual) indicator of technical progress.

[8] See FAOSTAT at www.fao.org

Table 6: Predicted impact of climate change on the agricultural sector in Cameroon by the year 2050

Scenario	TRLM I		TRLM III	
	Predicted output (USD billion)	Percent dev. from 1960–2000 mean	Predicted output (USD billion)	Percent dev. from 1960–2000 mean
A	7.11	+18.5	7.51	+25.17
B	6.30	+5.0	5.22	-13.00
C	3.50	-41.2	3.20	-46.67

Notes: The predicted agricultural output values are in billions of USD, 1998 value. The 1960–2000 mean output value is USD 6 billion.

The economic value of the projected output in 2050, at 1998 prices, will range from US$3.5 billion (41% less than the 1961–2001 mean) to US$ 7.1 billion (18.5% greater than the 1961–2001 mean). Reviewing the TRLM I model, positive outcomes are obtained from the scenario A simulations, as expected – with the lowest temperature increase (1.5°C) and the wettest scenario (15%). This highlights the beneficial effects of more rainfall. The results indicate that by 2050 the output from Cameroon's agriculture will be 18.5% (scenario A), or 5% (scenario B) more than the mean value observed from 1961–2001. The projection based on scenario C emphasizes the unattractiveness of warmer drier climates, especially for low input agriculture such as Cameroon's. The results indicate that by 2050 the output from Cameroon's agriculture will be 41% (TRLM I) less than the mean value observed for 1961–2001. The results of scenarios A and B imply that, global warming notwithstanding, Cameroon could see a nominal increase in crop production and possibly an overall increase in agricultural production. It is therefore possible that under global warming scenarios the agricultural economy would grow, albeit more slowly than in the absence of any warming. However, an increase in global temperature in the absence of irrigation and other adaptation options would be detrimental to Cameroon's agriculture, leading to almost a 46% loss in crop output (scenario C).[9] Broadly, this could be detrimental to the economy as a whole, given that close to 30% of Cameroon's national income comes from agriculture.

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[9] However, we have to be cautious when interpreting the findings of this study, since market conditions may mask potential physical yield losses (Molua & Lambi, 2007). Negative outcomes may appear as gains when associated with a product price rise that accompanies declines in supply, ceteris paribus. On examining climate variability, risk coping and agrarian policies in Mali, Ruben et al. (2000) demonstrate that input and output prices tend to influence welfare. Consumers typically suffer a welfare loss when supply is reduced, while producers gain. However, in a scenario where about 70% of the population are agricultural producers, as in Cameroon, it could be that gains will be broadly distributed. In sum, the presented evidence highlights serious implications for Cameroon's economy.

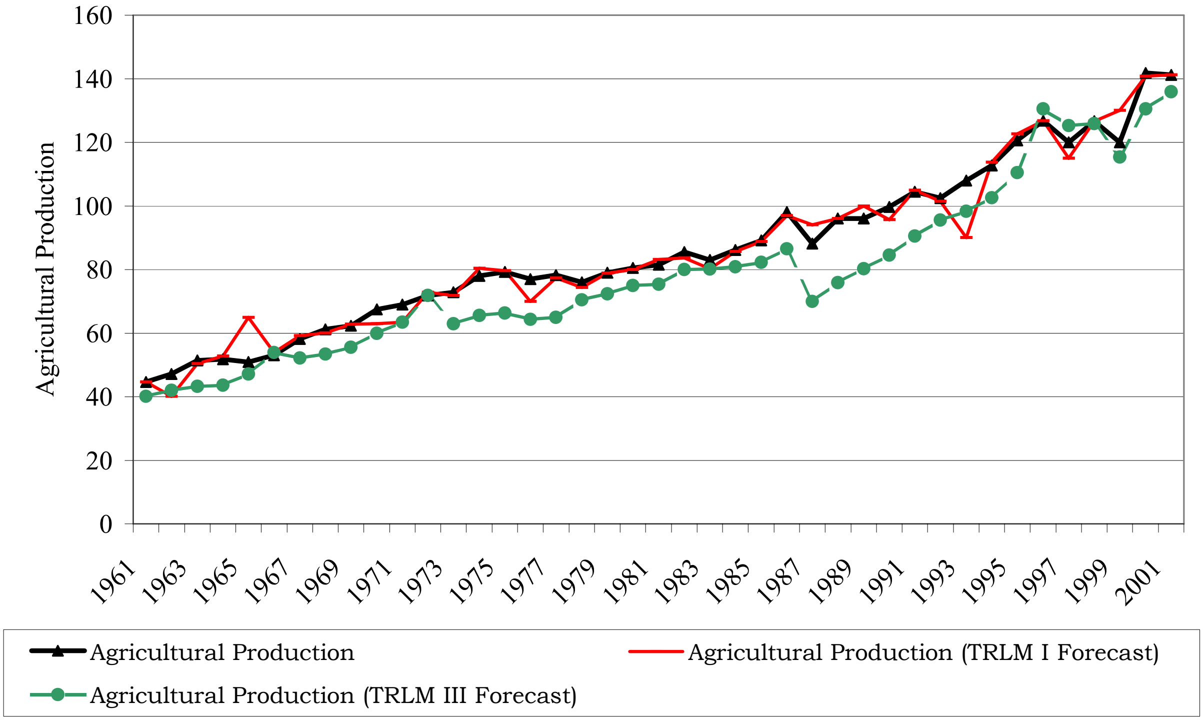

Figure 2: Production index in Cameroon, 1961–2001, tracked by the econometric models

Figure 2 highlights the performance of the econometric model (equation 2) used in the analysis. These regression lines are extended to obtain the forecasts presented in Table 6. The Theil inequality coefficients obtained from the historical simulations of production equations TRLMI and TRLM III are shown in Table 7.[10] In general the forecasting power of a model is deemed to be relatively good if the inequality coefficient (θ) is below 0.3. The results meet the performance criterion, as θ values of 0.132 and 0.164 are obtained for TRLM I and III respectively.

Table 7: Evaluation of forecasting performance of the regression models using Theil's inequality coefficient

	TRLM I	TRLM III
Root mean square error (RMSE)	0.013	0.015
Mean absolute error (MAE)	0.010	0.012
Theil inequality coefficient (θ)	0.132	0.164
Bias proportion (BP)	0.000	0.010
Variance proportion (VP)	0.021	0.023
Root mean square error (RMSE)	0.013	0.015

Notes: Forecast evaluation estimates generated with SAS 6.12

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[10] In addition to the Theil test, in-sample and out-of-sample tests (ex-post analysis) produced satisfactory results for the TRLM I and the coefficients appear to be robust across a variety of specifications.

While it is prudent to acknowledge the inherent limitation of our current experiment, in not factoring farm-level adaptation into the analysis, it is, however, plausible that induced innovation and endogenous technical change will arrest the negative impacts of gradual climate change.

5. Concluding remarks

This study suggests the effects of climate change. With semi-extensive farming systems being sensitive to small changes in climate, it is reasonable to expect that agriculture-dependent countries such as Cameroon will be vulnerable to this change. The overall aim of adaptation should be to make the best use of climate as a resource for agriculture by enhancing the sectors' capabilities for responding to variations and change. There is thus an urgent need to incorporate climate change considerations into agricultural development plans. The clearest policy objective should be to prepare for change by (a) reducing vulnerability, (b) developing monitoring capabilities and (c) enhancing the responsiveness of the agricultural sector to forecasts of production variations and possible food crises. It is important that farm programs be instituted to encourage farmers to use adaptive farm management strategies to respond to changing climate. Unless such programs are accessible to farmers, the socioeconomic costs will probably increase as climate change occurs.

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