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The Economic Impact of Climate Change on Agriculture in Cameroon

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Abstract

This study examines the impact of climate change on crop farming in Cameroon. The country's economy is predominantly agrarian and agriculture and the exploitation of natural resources remain the driving force for the country's economic development. Fluctuations in national income are due not merely to the decline in world demand for Cameroon's traditional agricultural exports or to mistakes in economic policy making, but also to the vagaries of the weather. Based on a farm-level survey of more than 800 farms, the study employs a Ricardian cross-sectional approach to measure the relationship between climate and the net revenue from crops. Net revenue is regressed on climate, water flow, soil, and economic variables. Further, uniform scenarios assume that only one aspect of climate changes and the change is uniform across the whole country. The analysis finds that net revenues fall as precipitation decreases or temperatures increase across all the surveyed farms. The study reaffirms that agriculture in Cameroon is often limited by seasonality and the availability of moisture. Although other physical factors, such as soil and relief, have an important influence on agriculture, climate remains the dominant influence on the variety of crops cultivated and the types of agriculture practiced.

This paper—a product of the Sustainable Rural and Urban Development Team, Development Research Group—is part of a larger effort in the department to mainstream climate change research. Policy Research Working Papers are also posted on the Web at http://econ.worldbank.org. The author may be contacted at emolua@yahoo.com.

THE ECONOMIC IMPACT OF CLIMATE CHANGE ON AGRICULTURE IN CAMEROON[1]

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SUMMARY

Cameroon's economy is predominantly agrarian and agriculture and the exploitation of natural resources remain the driving force for the country's economic development. Fluctuations in national income are due not merely to the decline in world demand for Cameroon's traditional agricultural exports or to mistakes in economic policy making, but also to the vagaries of weather. Farming is a vital sector involving 80% of the country's poor and contributing about 30% of Cameroon's GDP, so changes in temperature and precipitation could seriously damage the nation's economy.

This study examines the impact of climate change on crop farming in Cameroon. It is based on a farm-level survey of over 800 farms. We employ a Ricardian cross-sectional approach to measure the relationship between climate and the net revenue from crops. Net revenue is regressed on climate, water flow, soil and economic variables. The resulting regression explains the role that each variable plays today. We find that net revenues fall as precipitation decreases or temperatures increase across all the surveyed farms. We also examined some simple climate scenarios to see how Cameroon would respond to climate change. These 'uniform' scenarios assume that only one aspect of climate changes and the change is uniform across the whole country. The empirical analysis reveals that a 2.5℃ increase in temperatures would cause net revenues from farming in Cameroon to fall by $0.5 billion. We also examined a 5℃ increase and found that it would cause net revenues to fall by $1.7 billion. A 7% decrease in precipitation would cause net revenues from crops to fall by $1.96 billion and a 14% decrease in precipitation would cause them to fall by $3.8 billion. Increases in precipitation would have the opposite effect on net revenues.

In addition to the uniform scenarios, we also examined 15 climate change scenarios. These reveal that net revenues could rise by up to $2.9 billion if future climates are mild and wet but could fall by up to $12.6 billion if they are hot and dry. This study reaffirms that agriculture in Cameroon is often limited by the seasonality and amount of moisture availability. Although the other physical factors such as soil and relief have an important influence on agriculture, climate remains the dominant influence of the variety of crops cultivated and the types of agriculture practiced. Climate cannot be dissociated from agriculture since its various elements (rainfall, sunshine, humidity and temperature) are essential for the survival of crops and of man. The climate problems that plague agriculture in Cameroon must be factored into production plans and catered for, if agricultural output is to be maximized.

1. Background information

1. 1 Introduction

Climate is a dynamic phenomenon that changes continually, with long-term warming and cooling cycles. However, recent rapid and extensive changes are too extreme to be dismissed as 'normal', and have been shown to be closely correlated to changes in atmospheric carbon as a result of human activity (see IPCC 2002a,b,c). The subject of this study is the effect of climate change on the vulnerable tropical farming systems in Cameroon.

We have established in a review of crop and livestock systems in Cameroon that the links between agriculture and climate are quite pronounced and often complex (Molua & Lambi 2005a,b). Crops need nutrients, water and heat to drive the photosynthetic process and produce edible products. Clearly, water and heat are factors affected by climate, but so are nutrients. Increased atmospheric carbon dioxide concentrations can be beneficial to crop productivity; but changes in temperature and precipitation can have mixed results, as can be seen in the CROPWAT analysis for Cameroon (Molua & Lambi 2006). This is compounded by the high sensitivity of crops to extreme events such as floods, wind storms and droughts, and seasonal factors such as periods of frost, heat spells, and rainfall patterns.

For Cameroon, agriculture is truly important.[3] The agriculture and forestry sectors provide employment for the majority of the population. About 80% of the country's poor live in rural areas and work primarily in agriculture. About 35% of Cameroon's GDP comes from agriculture and related activities, 22% from industry and mining, and 36% from services. Close to 70% of the national labor force is employed in agriculture, 10% in industry and mining, and 20% in services. Cameroon's economy is therefore predominantly agrarian and agriculture and the exploitation of natural resources remain the driving force for the country's economic development.

Agriculture in Cameroon is moderately productive, extensively managed, and semi market-based. Farms and the associated input (storage, transportation and processing subsectors) provide low-cost, high-quality food for domestic consumers and contribute substantially to export earnings for the country as a whole. Farmland has been increasing steadily over the last five decades and the total annual value of the Cameroon agricultural sector's output is greater than $4 billion. Crop production, dominated by cereals, tubers and bananas, is worth over $2.5 billion.[4]

While Cameroon's agriculture is on a long march to productivity, the system is still highly dependent on climate, because temperature, light, and water are the main drivers of crop growth.

[3] The importance of agriculture in the African economy as whole and the Cameroon economy in particular includes both micro and macro economic issues. Agriculture contributes to household food supply, provides raw materials for local industries, contributes to the growth in GDP and employs three-quarters of the population. It is the powerful driving force in the economic growth of the nation.

[4] While issues such as access to markets, poor infrastructure and use of modern productive inputs demand different solutions, government has to battle food insecurity, hunger and malnutrition. Agricultural practices in most parts of the country remain predominantly traditional and too outmoded to produce enough to cope with the runaway demands of the rapidly increasing population.

Plant diseases and pest infestations, as well as the supply of and demand for irrigation water, are also influenced by climate. The key uncertainty, therefore, for agricultural outlook in the country is the weather, despite relative improvements in technology and yield potential. Given the pronouncements of climatologists on the evidence of global warming, there is now concern that climatic impacts on food production and its costs will be exacerbated in Cameroon and beyond the Central African sub-region. Current climate variation is already altering the types, frequencies, and intensities of crop and livestock pests and diseases, the availability and timing of irrigation water supplies, and the severity of soil erosion.

Low rainfall in 1997 in northern Cameroon directly affected crop yields and caused livestock deaths, leading to hunger and triggering the need for food aid from the World Food Programme (WFP). In 1998 the WFP organized an emergency operation to provide about 9500 tonnes of food aid to Cameroon, largely to compensate for the shortfall in production in the northern Sahelian areas. In March 2005 northern Cameroon was again hit by food shortages, requiring external intervention from international aid agencies. In addition to directly affecting crop yields, drought has triggered an increased migration of pastoralists and nomads from the northern part of the country to the south. The observed decline in rainfall in the region is thought to contribute to the increasing desertification in northern Cameroon, leading to shifts in the ecological zones and an increasing exploitation of marginal ecosystems. Global climate change may therefore be one of the major challenges that will confront agricultural policy makers in Cameroon.

In addition to climatic factors, human and market influences also affect agriculture in Cameroon. The agricultural systems in the country are managed; that is, there is active human influence in contrast to natural or unmanaged systems. Agricultural production patterns respond not only to biophysical changes in crop and livestock productivity brought about by climate change or technological change, but also to changes in agricultural management practices, crop and livestock prices, the cost and availability of inputs, and government policies. All of these are dynamic and changing within the national economy, even if climate remains constant, and make the assessment of the effects of climate change on production and food supply complex and challenging.[5] Although there is uncertainty in each step of the assessment of climate change on agriculture, from economic activity to final climate change damages, more is now understood about the entire process. In order to understand how much to spend on mitigating damage and supporting appropriate adaptation, it is critical to understand to the possible effects of long-term climate change. This section of the study therefore examines the microeconomic impact of climate and projected changes on agricultural production in Cameroon.

1.2 Climate and agriculture

1.2.1 Climate distribution in Cameroon

With a total land area of about 475,440 sq km and a coastline of 402 km, Cameroon's climate varies with the terrain. Cameroon lies between 2° and 13° north latitude and between 8° and 16° east longitude in west central Africa. It is characterized by high year-round temperatures and the

[5] Major uncertainties remain, even though much has been learned about the magnitude of the climate threat. The major factor contributing to these uncertainties is the lack of precise forecasts of climate change at geographic and time scales relevant to agricultural decision makers. Thus, numerical estimates presented in impact studies should be interpreted only as illustrative of the possible consequences of climate change.

weather is controlled by equatorial and tropical air masses. The country has two distinct climatic regions: the humid equatorial region in the south and the semi-arid northern portion extending into the Sahel. In the humid southern region annual rainfall often averages 1500mm, while in the north it averages 500mm. The remainder of the country, as shown in Figure 1, lies between these rainfall zones, with distinct wet and dry seasons.

Cameroon's daily weather conditions[6] and climatic factors are both a blessing and curse to the nation's quest to feed its people and its industries. To the south of the sixth parallel, the south Cameroonian plateau and the coastal plain have a four-season equatorial climate and forests. To the west, throughout a territory stretching from the mouth of the River Sanaga to the northern frontier of Northwest Province, the Guinean monsoon brings about a pseudo-tropical climate by the suppression of the short dry season which should occur during July to August. To the north, there is a two-season equatorial climate with a savanna showing some variations. The plateau of Adamawa has a Sudano-Guinean climate and a savanna with gallery forest; the Benoue Basin has the usual Sudanese climate with wooded savanna and to the north of the tenth parallel there is Sudano-Sahelian climate with a low savanna.

The country has two major seasons, dry and wet. The winds which influence the climate of Cameroon are the north-east trade wind that blows from North Africa, and the south-west monsoon from across the Atlantic Ocean. The north-east trade wind which begin to blow across the country from about October marks the beginning of the dry season. It sweeps down across the country as a dry wind known as the harmattan, which continues to blow for about nine months in the north, and for about six months in the south. Temperatures during this period are often very high, ranging from 26.6℃ to over 32℃ as we move northwards. The weak prevailing south-west winds continue to blow in the coastal areas, leading to occasional rainfall along the coast during this season. The prevailing south-west winds begin to blow strongly across the Atlantic Ocean in about mid-March, marking the beginning of the wet season. The effect is stronger in the south than in the north, thus the southern region of the country experiences a longer wet season than the northern region.

Most of the rains in Cameroon fall between April and October, with rainfall highest at the coast but diminishing steadily northwards. Two factors are responsible for this phenomenon: first the nearness to the sea, which means the winds blowing across the coast are moisture laden, and second the fact that the coastline is at right angles to the rain-bearing wind, which means that the influence of the south westerly winds is not only concentrated along the shores of this gulf, but is felt for a longer period.

Temperatures decrease as latitude and altitude increase. Southern Cameroon has an average temperature of about 25℃. In the extreme north of the country daily temperatures are very high, usually between 25℃ and 34℃, with large amount of sunshine. Two main factors influence temperature in Cameroon: the amount of cloud and rain, and the altitude.

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[6] Weather is the atmospheric condition of a place observed over a short period of time with respect to temperature, humidity, rainfall sunshine, pressure, cloud cover and wind direction. Weather is mainly a day–to–day or even hour-to- hour phenomenon. Weather therefore is never static, and as such cannot be generalized. Unlike weather, climate is the average atmospheric condition of a place within a long period of time, say 35 years. Therefore climate is the statistics of weather of a place for a fairly long period of time. Once the climate of a place has been established, it is static (see Leong 1984).

1.2.2. The inherent relationship between climate and agriculture

The basic climatic elements directly influence the spatial distribution of crop types and agricultural systems, because different crops require different amounts of rainfall, humidity, warmth and sunshine. In Cameroon's rainfed agriculture, climate is the main factor determining crop types and yields. Beyond certain climatic limits, it becomes impossible or disadvantageous to cultivate certain types of crops.

The forest zone of Cameroon (Figure 2), with its high temperatures, heavy rainfall fairly distributed throughout the year and consequently abundant amount of soil moisture favors the cultivation of tree crops and tubers. The western highland region is conducive to the cultivation of all types of crops because its mountainous character influences the prevailing climate conditions. The different climate conditions that exist at different altitudes affect agriculture production differently. Lowland areas such as the Mbaw plain, the Ndop plain and the Bafut lowland are areas favorable for tree crops, especially oil palm. The increasing length of the dry season in this region despite the abundant precipitation favors the cultivation of cereals, especially maize. At very high altitudes, especially around the Santa, Bui and Ndu regions, temperatures are quite low, making it possible to cultivate temperate crops such as potatoes and various vegetables.

Cereals are mostly cultivated in the north. Since rainfall decreases towards the north, only crops which are capable of withstanding drought conditions can do well. Crops such as millet, sorghum and guinea corn are cultivated in the drier northern region since they are able to complete their production cycles within the short rainy season. Millet, which is also cultivated in this region, can tolerate a mean annual rainfall as low as 400mm. Cotton is also cultivated here because of the moderate humidity, low rainfall and plentiful sunshine.

Plantations are concentrated in the southern region of the country, especially along the coast. The various plantation crops such as bananas, oil palm, rubber and cocoa require abundant moisture as well as high temperatures, averaging 21^oC to 27^oC. The shifting cultivation practiced in the southern plateau is an adaptation to the climatic conditions. The heavy rainfall experienced in this region contributes to a high degree of leaching in the soil. This soil therefore easily loses its fertility within a short period of cultivation. In order to maintain soil fertility without necessarily making use of artificial fertilizers, the piece of land under cultivation is left fallow to regenerate its fertility.

The spatial pattern of livestock farming is also explained by the variation in climatic conditions. For example the north and part of the western region, where rainfall totals range between 700mm and 1200mm. support pastoral nomadism. The climate in these regions produces extensive grass cover for grazing, and does not favor tsetse flies, which are harmful to the cattle. The humid southern climatic conditions, on the other hand, with rainfall of more than 1500mm, supports pig farming.

1.2.3 Climate as an exogenous constraint in agriculture

Rainfall variability and unreliability, floods, frost, wind storms and droughts often have devastating effects on agriculture. Increasing rainfall variability results in droughts, reduction in soil moisture, and consequently a decline in agricultural productivity. Northern Cameroon is noted for intermittent droughts. Periods of drought which have severely affected Sahelian northern Cameroon include the 1972–1973, 1982–1983 and 1987–1988 dry spells. Though these droughts may be natural in occurrence and origin, it is important to note that their severity is as a result of over-grazing, farming on marginal lands and deforestation from wood gathering. Droughts have led to hunger and famine, as cereal productions dropped. Many herders and thousands of cattle were seriously affected during the 1972–1973 and 1982–1983 droughts. In Cameroon's chequered agricultural history, the effects of droughts have spilled over to the high savanna region in the southern parts of the country. The output of tea, a major export, dropped badly during the 1982–1983 drought whose ramifications serious affected the tea plantations in Ndu.

Besides droughts, northern Cameroon also has to cope with periodic floods which are common between August and September. Some of these floods, especially the 1988–1989 ones, destroyed thousands of hectares of cereal farms. Long dry seasons are followed by short rainy seasons that come with torrential downpours that destroy food, property and life.

In the southern regions of the country another weather hazard, frost, affects agricultural productivity. Frost occurs in the mountainous regions of the Northwest and Western Provinces. During the dry season, night-time cold dense air from mountain slopes drains down the valleys, displacing the warm air that accumulated in the valley during the day. This process leads to very low temperatures at the bottom of the valleys, where legumes, grains and plantains are grown. The biting frost kills budding fruits as well as leaves of plants.

In the coastal zones of Kribi, Campo, Douala and Limbe, storms and wet season floods destroy coastal infrastructure and agricultural resources and reduce production. Whenever such storms occur, large acreages of farmland, notably the banana plantations whose products are destined primarily for export, are destroyed. Rubber plantations, pineapple fields and oil palm estates are inundated, causing massive destruction.

1.2.4 Trends in agriculture and climate in Cameroon

The movement of the inter-tropical convergence zone (ITCZ) influences Cameroon's rainfall patterns and their variability. When rainfall does not meet the crop requirements, the country's limited capacity for irrigation and its high population growth rates will increase the probability of food shortages. Climatically speaking, only about 56% of land in the country is assumed to be suitable for agricultural activities. Inter-annual climate variability affects agriculture in a number of ways and threatens food security in Cameroon. Figure 3 shows changes in real agricultural GDP and changes in rainfall for 1961–2000. We observe an interesting relationship between GDP swings and precipitation anomaly. Years of good performance in agriculture are preceded by years of adequate rainfall (e.g. 1969, 1976 and 1995). The reverse is true for 1973, 1979 and in most of the 1990s. Given that Cameroon's agriculture is principally rainfed, it is possible that fluctuations in rainfall significantly account for observed changes to the returns in agriculture.

The variability and unreliability of rainfall in particular, implies high risks in agriculture, possible deterioration of sectoral growth and hindrance to overall economic progress. This raises an important question: What will be the consequences for the agricultural sector under changed global climate?

1.3 Research questions and objectives

Considering the findings of global warming research in other regions of the world, some pertinent questions can be asked about climate variability and change in Cameroon and the response of agriculture: (1) What factors explain the vulnerability of the agricultural system? What is the farm level agricultural risk associated with climate change? (2) What is the impact of climate variability on agricultural profitability? Will agriculture in Cameroon be profitable under future climate change scenarios? (3) Which policies and conditions (taxes, subsidies and regulation) are necessary to minimize the negative impact of climate change on agriculture? (4) What long-term approaches should be recommended to maintain the adaptive mechanisms?

The specific objectives of the research are to (i) assess the impact of climate change on agriculture in Cameroon, (ii) estimate how climate affects the current agricultural systems, and (iii) project how climate change might affect these systems in the future. Overall, it therefore assesses the potential economic impact of climate change and the options for adaptation in Cameroon's agriculture, in order to provide meaningful insight and contribute to efforts aimed at ensuring increased food availability through sustainable domestic production and increased income from agricultural production. The study therefore conducted cross-district analysis and extrapolated the results to national districts, and extended these to a national level economic analysis of the impacts of climate change on agricultural production and adaptation strategies.

1.4 Rationale for agro-climatic research

Most of the empirical work to date on the impact of climate change on agriculture has focused on Europe, the United States, Canada and Australia. Most of the physical and economic modeling and analysis has focused on the northern latitudes and high income countries and although experts have extrapolated their findings worldwide little research has focused on developing regions such as those in the tropics and sub-Saharan Africa where the poor who may be most vulnerable to adverse changes live, even though scientists fear that the most adverse effects are likely to occur in these poorer countries, such as Cameroon.[7] In these countries, agriculture is the mainstay of the

[7] Effects are likely to be worse because the tropical regions differ significantly from the temperate ones in their biophysical characteristics of climate and soil and the vulnerability of their agricultural systems to climate change. The risks of changing weather conditions such as higher temperatures, changes in precipitation, increased climate variability and extreme weather events can result in significant impacts on agriculture, forestry and rural areas. Increased atmospheric carbon dioxide concentrations may directly affect the growth of crop plants and weeds and also induce changes in climate, altering levels of temperature, rainfall and sunshine, and affecting plant productivity.

economy, contributing up to 60% of total value of exports. This makes them vulnerable to inter-annual climate variability and climate change. It is both academically and morally appropriate to place such areas high on the research agenda as a matter of urgency.

Cameroon is attractive for this kind of study because its wide range of agro-ecological conditions, the result of its two distinct climatic zones which affect plant life, wildlife, human population and the economy of the regions in varying proportions, ensure that the findings of such research are broadly applicable. Most of its farmers rely on traditional systems, such as slash-and-burn rainfed mixed cropping and multiple cropping, for their subsistence and income. Agricultural production in the country is characterized by low levels of input (quality seed stock, fertilizer, pesticides and herbicides). Many farmers cannot afford modern inputs and government subsidies are low compared with those allocated to European agriculture. The semi-extensive farming systems are particularly sensitive to small changes in climate. Traditional farming methods such as multiple cropping and terracing act to buffer the system against climate variability, conserve soil fertility and increase yields. In general, irrigation is an important buffer against climate variability and climatic change. However, only about 20% of Cameroon's cropland is irrigated, producing about 30% of annual crop production.

Desert encroachment in the northern part of the country and a possible southward progression of the harsh dry conditions are likely to have effects on the terrestrial ecosystem and land use practices that will result in environmental degradation and human misery. The intermittent droughts in the north and vagaries of weather in the south are reducing agricultural output and productive activity. As a result, the agricultural sector finds it increasingly difficult to perform its traditional roles of meeting domestic food needs, raw materials for industry and earning foreign exchange through export. Given the fundamental role of agriculture in human welfare, concern has been expressed by international agencies and some non-governmental organizations about the potential effects of climate change on agricultural productivity. Interest in this issue has motivated the need for this study for Cameroon.

2. Theoretical framework

Statistical and econometric techniques can be employed to establish a logical association between climate variation and change. Multiple regression methods were used to estimate the impact of meteorological variables on corn yield. The econometric approach is based on a 'black box' or 'reduced form' statistical relationship between output (e.g. income) and input (weather). By regressing agricultural sector performance on a set of climate variables (rainfall and temperature), traditional inputs (land and labor) and support systems (infrastructure such as irrigation), it is possible to measure the contribution of each factor to the outcome and project the effects of long-term climate change on the agricultural sector.

2.1 Estimating the economic impact of climate change on agriculture

A substantial amount of research has been conducted on the potential impacts of climate change on agricultural productivity (Parry et al. 1988; Parry 1990; Leemans & Solomon 1993; Rosenzweig & Iglesias 1994). Attempts are made to link the state-of-the-art models developed by researchers in disparate disciplines, including climatology, agronomy and economics, in order to project future impact. Some studies have used climate induced changes in crop yields to estimate potential global economic impacts (Kane et al. 1992; Rosenzweig et al. 1993; Rosenzweig & Parry 1994; Reilly et al. 1996) while others have examined the indirect impact on economic variables such as farm revenue and income, e.g. Mendelsohn et al. (1994) and Lang (2001).[8] Schimmelpfennnig et al. (1996) present a simple taxonomy that classifies the methods of analysis as either structural (Kaiser et al. 1993; Easterling et al. 1993; Adams et al. 1990, 1995, 1998b) spatial-analogue (Mendelsohn et al. 1994; Darwin et al. 1999). These analyses can be applied at either farm level (low order) or national/international level (higher order).

2.1.1 The structural approach

The *structural approach* is interdisciplinary, linking models from atmospheric science, crop science and economics. It starts with crop simulation models (as in Rosenzweig & Parry 1994), to model yield changes by crop. The crop biophysical simulation models embed parameters drawn from crop experiments. After measuring crop yield changes (crop response model) under different climates, for example by using forecasts from General Circulation Models (GCMs[9]), the yield estimates are then incorporated into economic models of the agricultural sector to estimate changes in acreage and supply and consequent changes in market clearing price (Adams et al. 1998a). The economic models seek to either minimize costs or maximize consumer and producer welfare subject to climatic constraints. This approach is applied in Kaiser et al. (1993), Easterling et al. (1993) and Adams et al. (1998b, 1995), and clearly described and employed in Rosenzweig & Parry (1994). The crop yield projections are then employed as inputs into a world food trade model.

The advantage of this approach is that it provides a detailed understanding of the physical and economic responses, and adjustments. A caveat from Kaiser et al. (1993) is that economic impact studies of climate change must model the role of adjustments by agriculture over time, otherwise the negative impacts will be overstated. Failure to account for human adaptation to climate (or expected weather) will result in overestimation of the damages. To illustrate the importance of even minor farm-level adjustments, Kaiser et al. (1993) calculate the differences in net farm revenue for the 'with' and 'without' adaptation scenarios. In the with adaptation scenario, it is assumed that farmers could adapt to climate change by changing crop varieties and timing of

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[8] A number of studies have estimated the costs of climate change to agriculture by modeling changes in yield on the assumption that the existing pattern of land use will remain unchanged. Mendelsohn et al. (1994), call this the 'dumb farmer' scenario and observe that costs derived in this way represent an upper bound estimate for the costs of climate change. As an alternative, Mendelsohn et al. propose a Ricardian approach, based on comparative static estimates of the change in equilibrium rents to land associated with a one-time change in climatic conditions.

[9] The GCMs are mathematical representations of the atmospheric, ocean, and land-surface processes involving mass, momentum, energy and water. They calculate the temporal and spatial transports and exchanges of heat and moisture throughout the earth's surface and atmosphere, predicting changes in temperature, precipitation, radiation and other climatic variables caused by greenhouse gases in the atmosphere. Although the models have some limitations, they provide facility for studies of climate and climate change. They are usually employed for investigating the sensitivity of climate to internal and external factors and for predicting climate change. The models are then verified against the observed climate and used for examining and assessing the subsequently modeled climate changes.

planting and harvesting, while in the without adaptation scenario it is assumed that farmers do not make any adjustments over time. Under the without adaptation scenario, simulated crop yields, and therefore net farm revenues, for all the climate warming scenarios are drastically lower than those in the with adaptation scenario.

2.2.2 The spatial-analogue approach

The *spatial-analogue approach* involves 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 to analyze changes in spatial patterns of production. The inference of this approach is based on how farmers have adapted across a transect of climate. These models include the Ricardian analysis in Mendelsohn et al. (1994), the use of computable general equilibrium (CGE) and Geographic Information System (GIS) models in Darwin et al. (1999) and Restricted Profit Function in Lang (2001) and Molua (2002). Both the Ricardian and the Restricted Profit Function methods measure the economic impact of climate on farm values. Otherwise referred to as the cross-sectional approach, the spatial-analogue approach fundamentally examines farm performance across climate zones (Mendelsohn et al. 1994; 1996; Sanghi 1998; Sanghi et al. 1998; Kumar & Parikh 1998; Mendelsohn & Dinar 1999; Lang 2001; Molua 2002). As reviewed by Adams et al. (1998a: 22), the strength of the spatial-analogue approach is that structural changes and farm responses are implicit in the analysis. However, a significant limitation is that, unlike the structural approach, it not only ignores likely changes in input and output prices that result from global changes in production but also assumes a long-run equilibrium that ignores short- and medium-term adjustment costs for a possible gradually changing climate. In other words, this approach cannot fully disentangle agricultural and economic adjustments made in response to climate from those induced by other processes.

In a brief review, Mendelsohn and Dinar (1999) observe that one of the shortcomings of the Ricardian Method is that the experiment is not carefully controlled across farms. In addition to climate variables, farms may vary for many reasons. In an attempt to control for this problem in the Ricardian model other important extraneous variables such as soil quality, market access and solar radiation are included. This is, however, the strength of the agronomic model which relies on carefully controlled farm experiments and avoids the influence of extraneous variables. In addition, the Ricardian method does not consider price variation, as all farms are assumed to face the same prices. According to Cline (1996), assuming that prices are constant across farms leads to a bias in the welfare calculations. This highlights the strength of the restricted profit function in Lang (2001) and Molua (2002). Unlike the Ricardian approach, the restricted profit function measures both the loss to individual producers and any loss in consumer surplus if supply changes due to price variation.

Although both the structural and spatial analogue approaches highlight varying levels of farmer adaptation, they are based on the assumption that adaptation to climate is costless. Either the potential damage from climate change is overestimated or its potential benefits are underestimated. Unlike the approaches discussed above, Molua (2003) used time series data for a 40-year period of real-time climate, agricultural production, land use and irrigation allocation, hinged on the premise that ‘dynamics matter’, to examine the impact of gradual climate change and unexpected weather events on Cameroon's agricultural sector. Using recent developments in time series econometrics, testing for stationarity and cointegration of climate and agriculture, a long-run equilibrium model is formulated and studied to ascertain the impact of climate variation on over four decades of agricultural production. Overall, the structural model and spatial analogue methods are complementary. Reconciling the differences in results between the two methods enables a better understanding of the role of climate change on agriculture.

3. Measuring the impact of climate on Cameroon's agriculture

3.1 Analytical framework: The Ricardian theory

To evaluate the effect of climate variation and climate change on Cameroon's agriculture, this study uses the Ricardian analysis, which is based on the assumption of a direct cause and effect relationship between climate events and farm value. The technique is named the Ricardian method because it draws heavily on an observation by Ricardo that land values would reflect land productivity at a site (under competition). The approach has been used to evaluate the contribution of environmental conditions to farm income. By regressing land value on a set of environmental inputs, one can measure the marginal contribution of each input to farm income. The presupposition is that farm value reflects the present value of the sum of all future net profits. Generally, the analysis of land related resources is complex in that it requires the consideration of spatial contiguity, externalities and the durability of buildings and other infrastructure on land (Case & Fair 1999). Land value has been perceived as a residual value, as a factor of production, as scarcity rent, as a differential rent, as a structural rent or even a quasi-rent. Rent, nonetheless, is measured on the intensive potential of the resource/asset attributes or as a reflection of the differences between the resource and capital attributes (Evans 2004).

With a focus on the issues of scarcity and productivity, the measurement of land value can be identified by using two approaches that have evolved out of established economic thought. The Ricardian approach takes rent to be a residual return. This return is measured as a price-determined surplus in excess of the cost required for employing the asset (land). Another approach is based on marginal economics, i.e. marginal physical product (MPP) or the marginal value product (MVP), which are prime elements of Marshallian microeconomic theory. This approach focuses on land rents as determined by the marginal productivity of the fixed land resource. In this context land is an input in the productive or development process in the short run. However, the format of the Ricardian rent is a dynamic analysis of a price-determined residual measure of the return to land, such that the price is set in a perfectly competitive market as a function of the interaction of supply and demand (Alonso 1968). Ricardo's theoretical construct hinges on land rents reflecting the net productivity of land. Thus, the Ricardian rent in a marginal context links to the Marshallian economic construct and allows the analysis of land from the perspective of marginal value production as well as the traditional residual format (Hollander 1979). With a consideration of marginal productivity, economic rent as defined by Ricardo is based on the difference in the excess return over marginal cost. The cost is based on the supply price (land rent) required to employ the external margin of land capacity. The economic rent measure is based on the comparative difference in the excess capacity between grades/qualities or types of land.

In measuring farmland value, we assume agricultural producers to be profit maximizers within a competitive environment. Agricultural producers within the country take the geographical and geophysical variables as given, and adjust production inputs and outputs accordingly. We hypothesize that climate shifts the production function of agriculture, and we then study the yields of specific crops and livestock and estimate a short-run equilibrium relationship between climate and agricultural sector output. This is thus a microeconomic analysis that examines how climate in various regions in Cameroon affects agriculture.

By directly measuring farm level agricultural income as a proxy for farmland value, the approach accounts for the direct impact of climate on yields of the different agricultural components as well as the indirect substitution of various inputs, introduction of various activities and other potential adaptations to varying climatic conditions. Mindful of the limitations of the GCMs, this research is hence a complementary effort that links climate projections and black box statistical evidence.

3.2 Empirical model: The Ricardian specification

We assume that the primal production function depicting the production possibilities and resources that are available to farmers in Cameroon is a non-linear continuously differentiable function (possesses continuous first-order and second-order derivatives which are different from zero for 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. The output function for farms in the country is implicitly specified as:

$$q_i = f(x_i; \beta) + \varepsilon_i \tag{1}$$

where outputs are denoted by q_i and inputs by x_i. Equation 1 is assumed to be an increasing function with respect to output levels and a decreasing function with respect to input levels. The agricultural sector's production capability is assumed to be restricted by exogenous climate variables and other socio-economic variables. The farmers' objective is thus to maximize returns based on critical inputs (x*) and environmental factors (E):

$$\pi(x^*, E) = p_q q(x^*, E) - p_x x^* \tag{2a}$$

Estimating the profit maximizing level of inputs and yields for farm enterprises and activities enables us to estimate net revenues, given the employed technology (T). That is;

$$\pi\left(p_q, p_x\right) = \max_{q,x}\left\{p_q q - p_x x : (x,q) \in T; p_q, p_x > 0\right\} \quad (2b)$$

where q represents the vector of outputs, x the vector of inputs, T the set of production possibilities, and p_x and p_q the vectors of the prices of inputs and outputs respectively that generate the farm values. The climate effects on farm returns may then be ascertained based on producer welfare (*w*), specified as;

$$w = \pi(x_1^* E_1) - \pi(x_0^*, E_0) \quad (2c)$$

This implicitly implies that farmers' behavior and the short-term and long-term decisions they make on production and input employment are guided by the market prices of inputs and outputs;

$$x_n = f(p_q, p_{x,} E) \quad (2d)$$

The profit function is explicitly a function of output prices, input prices, and possibly exogenous variables. It is concerned with the maximum value that a given input endowment can generate, combining the effects of output and input prices. On estimating the profit function, the estimated parameters of the input variables will be shadow prices of these inputs, because they give the increase in profit associated with an expansion of the input endowment.[10]

However, this analytical framework only works when we can expect producers to be 'price-takers' in all the markets. This is thus the basic assumption of this study. If this assumption is violated, the estimates of the function are meaningless from an economic point of view. Given the statistical confidence in the dataset generated throughout the country, we rely on this approach and estimate the farm values. Farm value is regressed on climate and other socio-economic variables in a non-linear function of the form:

$$V = \beta_0 + \beta_1 F + \beta_2 F^2 + \beta_3 Z + \beta_4 G + \beta_5 S + \beta_6 W + \beta_7 W^2 + \beta_8 W * F + \varepsilon \quad (3)$$

[10] The profit function requires data in all input and output prices, and sufficient variation in these prices. This information was obtained from the nationwide field survey in Cameroon that was undertaken for this study.

where V is farm value, F is a vector of climate variables, Z is the set of soil variables, G relates to the set of economic variables such as market access and access to capital, S is a vector of social variables, W is a vector of relevant hydrological variables, and ε is the statistical error term.

The inherent relationship between climate and production activities allows us to derive important economic information from Equation 3. To give a sense of the importance of the climate variables in the model, we begin with a general model that contains typical input variables (acreage, fertilizer and labor). Then, in the remainder of the regressions, climate variables are excluded. Though irrigation is an endogenous reaction to climate that may have a long-term response, we include it in the regression and examine the response. It is expected to be a strongly positive variable increasing agricultural output substantially, indicating the crucial importance of irrigation as an adaptation option in Cameroon and in many parts of the dry tropics.

The relationship in Equation 3 between farm value and climate stems from the influence of the prevailing or average weather conditions (e.g. minimum and maximum temperature, precipitation and solar radiation) on agricultural activities (crop and livestock production, cropping systems, field hours, i.e. time spent on agricultural activities during favorable weather). Such agricultural variables contribute to and determine the farm enterprise combinations and the net income. Whatever the climate-induced changes in agricultural production may be, they will inevitably lead to overall changes in production in the national economy for countries such as Cameroon where agriculture contributes about 30% of national income. However, these economy-wide impacts will depend on (a) the magnitude of production changes in agriculture, (b) the importance of agriculture to the rest of the economy and (c) the capacity of national industries linked to agriculture to adjust to changes in agricultural production.

3.3 The marginal impact of climate on farm value

In order to interpret the climate coefficients, it is apt that we calculate the marginal impacts of a change in each climate variable. The marginal values depend on the regression equation that is being used and the climate that is being evaluated. The expected marginal impact of a single climate variable on net revenue, the proxy of farm value, evaluated at the mean is:

$$E[dV/df_i] = b_{1,i} + 2*b_{2,i} *E[f_i] \qquad (4)$$

While the signs of the linear terms indicate the uni-directional impact of the independent variables on the dependent variable, the quadratic term reflects the non-linear shape of the net revenue of the climate response function. When the quadratic term is positive, the net revenue function is U-shaped and when the quadratic term is negative the function is hill-shaped. There is a known temperature for which tropical crops grow best across seasons. Agronomic studies reveal that crops consistently exhibit a hill-shaped relationship with annual temperature, although the maximum of that hill varies with each crop.

3.4 Nature and source of data

To understand the impact of climate on agriculture, we studied agrarian households in the country. Primary data is thus employed. The data was obtained from the nationwide field survey conducted between January and April 2005. The research objectives were translated into questions, and heads or representatives of farming households were interviewed face to face. The objectives of the household survey were threefold: (i) to generate reliable representative sample quantitative data on output prices costs, net revenue, farmland values, and other socio-economic determinants of agricultural performance in Cameroon; (ii) to generate qualitative information on farmers' perceptions of the nature of long-term changes in temperature and rainfall in farm locations and the short- and long-term adaptation strategies they employ to mitigate potential adverse effects of climate change; and (iii) to achieve substantial variation in the dataset, covering all the agro-ecological zones in the country, as well as the major and minor crops, rainfed and irrigated agriculture, small- and large-scale production, and traditional and improved technology-based agriculture. All the selected divisions and villages/towns were covered during the survey in eight agro-ecological zones.[11] A sample comprising 800 households was interviewed from 50 out of the 58 administrative divisions in Cameroon. The farm-level and household information collected was for the 2002/2003 farming season.

Data on climate for this study were obtained from two sources: weather stations and satellite data from the United States Department of Defense. The satellite data includes measures of temperature and soil moisture which are critical determinants of crop vegetative growth and development (Basist et al. 2001). On examining the effectiveness of satellite data versus weather station data for analyzing the role that climate plays in agriculture, Mendelsohn et al. (2004) reveal that although weather stations give accurate measures of ground conditions they provide only sporadic observations that require interpolation into areas where observations are missing. In contrast, satellites have trouble measuring some ground phenomena such as precipitation but provide complete spatial coverage of various parameters over a landscape. The differences between the two measurement sources are small. However, except where precipitation is key, the satellite weather data provides more accurate accounts of agricultural performance across the landscape than the weather station data. In addition to these two sources, supplementary data was obtained from the Africa Rainfall and Temperature Evaluation System (ARTES). This data is generated by the National Oceanic and Atmospheric Association's Climate Prediction Centre based on ground station measurements of precipitation and temperature. Soil data was obtained from the FAO (2003) database which provides information on the major and minor soils in the sampled districts in the country. Complementary data on hydrology was obtained from simulations and estimations through the collaborative effort of teams of researchers from the International Water Management Research Institute (IWMI), Pretoria and the University of Colorado, USA, who generated, for watersheds and river basins in the country, important information on surface water runoff and river flows.

[11] These zones are the Sahel, the Sudan savanna, the low savanna, the high savanna (savanna-montane), the forest-savanna eco-zone, the Guinea savanna, the humid equatorial zone and the littoral moist equatorial forest. This classification is based on the differences in precipitation, average temperature, vegetation, relative humidity, reference evapotranspiration, wind speed and total solar radiation.

4. Empirical findings and discussions

4.1 Farm incomes

The farming system in Cameroon, though founded on rudimentary traditional technology, is resilient, providing food and income to millions of households in the country, and contributing to the nation's agricultural exports. An important incentive that explains the supply response from Cameroon's agriculture is the cumulative income from the sector.

Based on the household survey, the following crop gross returns are estimated: gr4crha [gross revenue per ha (of crops) based on mean annual cropland]; gr3crha [gross revenue per ha (crops) based on maximum seasonal cropland]; gr2crha [gross revenue per ha (crops) based on the sum of cropland]; gr1crha [gross revenue per ha (crops) based on farmland]. The gross revenues compare as shown in Figure 4. Farms on average record gross returns of US $750 per hectare per household to about US $950 for crop enterprises in Cameroon. A comparative analysis of various measures of gross revenue reveals that revenues are highest at gr4crha and lowest when measured at gr2crha. Overall, however, the four different measures of revenue reveal it to be about US $800 per hectare in Cameroon. Given the average household size of eight persons, this finding has important implications for household welfare and food security in the country.

The estimated net revenues for farms are shown in Figure 5. The following definitions of net revenue are computed: nr1_1 [household crop gross rev(US$) less fertilizer & pesticide costs per ha of farmland]; nr1_3 [household crop gross rev(US$) less fertilizer & pesticide costs per ha of cropland]; nr2_1 [nr1_1(US$) less hired labor costs per ha of farmland]; nr2_3 [nr1_3(US$) less hired labor costs per ha of cropland]; nr3_1 [nr2_1(US$) less machinery costs per ha of farmland]; nr3_3 [nr2_3(US$) less machinery costs per ha of cropland]; nr4_1 [nr3_1(US$) less other farm costs per ha of farmland]; nr4_3 [nr3_3(US$) less other farm costs per ha of farmland]. The measurements indicate different definitions and measurements of net revenues based on the manipulation of costs, particularly household labor costs. When household labor costs are valued at the market wage rate or the reported amounts households claim to pay for family labor, the net revenues sag, and turn negative for some households. This highlights the dilemma of measuring household labor in developing country agriculture. In general, the farms are averagely profitable, indicating that they meet both their variable and fixed costs of production.

4.2 Adaptation strategies

The climate's direct impact on sustainable livelihood forces farmers to adopt new practices and coping strategies in response to the altered conditions. Farms and rural households adapt in various ways to lessen the adverse effects of climate variation on crop yield, farm profit and household income. In general, the repertoire of strategies to confront unstable changing climate includes the following: (i) shifting crop mix to more drought tolerant and short season varieties, (ii) reducing the area planted initially, then increasing it gradually, depending on the nature of the season, (iii) staggering planting dates (early or late planting), (iv) increasing plant spacing, (v) maximizing the use of clay soils where these are available, since clay soils have a high water holding capacity, (vi) implementing soil water conservation techniques (pot-holing, weeding), (vii) adjusting level and timing of fertilizer, and (viii) undertaking traditional and religious ceremonies.

4.3 Econometric estimation

Market prices are observed to vary across the country because of geographic, ecological and infrastructure differences between the regions. Agricultural products fetch good prices in the dense humid forest zones, better prices in the savanna grasslands and the best prices in the dry areas; this is partly explained by supply and demand issues. The variation in farm product prices across the country allows us to econometrically test the impact of climate on farm returns based on the hypothesis that climate could be contributing to variations in farm value. Relying on the function specified in Equation 3, climatology variables and hydrological and agronomic variables are regressed on farm values. The dependent variable is net revenue (profit) defined as the gross revenue minus production costs. We rely on the nr1_3 definition of net revenue. We avoid using the definitions of net revenue that include the cost of labor, as the estimates of labor costs were problematic.

The results in Table 1 show that spring and summer temperatures are moderately significant. Winter and spring precipitations are strongly significant. Both linear and squared terms are significant in certain seasons, implying that climate has a non-linear effect on net revenues. Surface water runoff appears to have a strongly significant influence on farm returns.

Results for the socio-economic variables (e.g. farmers' age, education, access to subsidies and extension services, adaptation, etc.) provide important information on the influence of farm values in Cameroon. Cameroon's farmers adapt the agricultural systems and practices to changing economic and physical conditions, by adopting new technologies and changing crop mixes and cultivated acreage. The economic significance of such flexibility is revealed by the econometric estimates which reveal the adaptation dummy to be significant, and dummies for various groups of adaptation (crop and soil management options) are moderately significant.[12] Crop and soil management techniques include pruning, staking, plant spacing, multiple cropping per year, monocropping, growing solely perennial crops, and zero tillage. These are suggestive of significant potential for Cameroonian farmers to adapt to climate variation and future climate change. More interestingly, the dummy variable for irrigation though positive is not statistically significant. Few farmers in the country can afford the costs of modern irrigation systems. However, a plethora of rainwater harvesting strategies is employed to cushion the negative impacts of short rainy seasons and long dry seasons in some parts of the country.

However, based on the adjusted R^2 we observe that climatic, hydrological and agronomic variables explain about 19% of variation in farm value. Statistical tests on the signs of the parameter

[12] In addition to adaptation in general, we specifically identified clusters of farmers who relied predominantly on crop management techniques or soil management strategies as their primary mode for adapting to changing climate, and tested the statistical significance of these options.

estimates, the F-statistic and the diagnostic tests for multicollinearity and heteroscedasticity (Durbin-Watson, Breusch-Pagan tests) reveal the functions to be well behaved.[13]

To ascertain deeper meaning on the climate coefficients, we calculate the marginal impacts of a change in each climate variable. Table 2 displays the results of using the various regressions from Table 1. In each case, the marginal effect of temperature and precipitation is evaluated at the mean for each sample. Relying on the sample results evaluated at the national mean climate (23.5℃ and 283.44mm/mo), the marginal temperature effect ranges from -$25/℃ to -$5/℃ and the marginal precipitation effect ranges from $5.3 to $9.4/mm/mo.

5. Global climate change scenarios and agrarian impact

5.1 Uniform Climate scenarios

Using the estimated regression coefficients in Table 1 for nr1_3 (gross revenue less the total costs incurred per farmland), we examine how changes in climate change net revenue per hectare in each province in Cameroon. We multiply the change in net revenue per hectare by the number of hectares of cropland in each province to get an aggregate impact in each province. This value is summed across all the provinces to get a total impact for the country.[14] The results of the uniform climate scenarios are presented in Table 3. Four uniform climate scenarios are tested: changes of +2.5℃, +5℃, -7% and -14% changes in precipitation.

The 2.5℃ warming results in predicted losses of $0.65 billion and doubling warming to 5℃ increases the losses to $1.8 billion. Reducing precipitation by 7% reduces net revenue by 6.5% on a per hectare basis. Without doubt, 14% reduction in precipitation is predicted to cause much larger losses of about $4.56 billion. This significantly demonstrates Cameroon's dependence on rainfed agriculture.

5.2 Global Climate Model scenarios

This study employs 15 scenarios derived from five different well tested models (CSIRO2, HadCM3, CGCM2, ECHAM and PCM[15]) in conjunction with two different emission scenarios (A2, B2) (see Strzepek & McCluskey 2006). Strzepek and McCluskey (2006) used these scenarios to modify real-time climate information in Cameroon. In each scenario, climate changes at the grid

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[13] Even though the results are not reported here, the effects of the seasonal climate on variables are robust across the various definitions of net revenue.

[14] Aggregate climate impact$_p$= Sum(ΔY_i*W_j), where ΔY_i = change in net revenue per hectare from a climate change; W_j =hectares of cropland; p= province d.

[15] The Parallel Climate Model (PCM) is a coupled climate model comprising an atmospheric component from the National Center for Atmospheric Research (NCAR) Community Climate Model. The ocean component is the Parallel Ocean Program and the sea ice component is the Naval Postgraduate School model. The components are interfaced by a flux coupler that passes the energy, moisture and momentum fluxes between components. This model has higher-resolution ocean and sea ice components than are used in previous coupled climate model simulations.

cell level are summed to predict climate change in the country. This develops for 100 years (2001–2100) about 1200 monthly values. Table 4 summarizes the results of analyzing the climate change scenarios for Cameroon. The consequences of these country level climate change scenarios on farm income in 2020, 2050 and 2100 are examined in Table 5.

The decadal average values (monthly) for precipitation, temperature and streamflow fitted into the Ricardian framework to ascertain the impact of future climate change on farm incomes. Though the mean rainfall in Cameroon may increase or decrease depending on the scenario, there is substantial variation in rainfall across provinces, as noted in the diverse ecologies. The levels of net revenue for each climate scenario are estimated by modifying farm net revenue under current conditions. The net revenues are predicted using the estimated regression coefficients from Table 1. The change in net revenue is then multiplied by the hectares of cropland in each province. These impacts are then summed across all provinces in the country. The predicted changes in net revenues are observed to be different depending on the climate scenario.

In Table 5, we present the results of the 15 scenarios for the five models in three time periods. The PCM results suggest that with a significant increase in rainfall and minor increase in temperature the net effect on farms in Cameroon would be a gain of from $1.6 to $2.9 billion/yr. The HadCM3 results suggest that substantial drying and warming together would generate losses of $5.8 billion beyond 2100. The CSIRO results suggest that a large increase in temperature and a large decrease in precipitation would lead to substantial losses across farms equal to $20.3 billion by the year 2100.

6. Policy implications of findings, recommendations and conclusion

Given that Cameroon, like most developing countries, depends heavily on agriculture, the effects of global warming and climate change on the agricultural sector are likely to threaten both the welfare of the population and the economic development of the country. This is particularly important for prudent agricultural policies. Agricultural policy must have an important role in influencing Cameroon's agricultural sector's ability to adapt successfully to climate change. The review of the literature reveals significant potential for climate change to affect crop and livestock production, hydrologic balances, input supplies and other components of the agricultural systems. The nature of these biophysical effects and human responses are complex and uncertain. For instance, crop and livestock yields are directly affected by changes in climatic factors such as temperature and precipitation and the frequency and severity of extreme events such as droughts, floods and wind storms. To add to this, Cameroon is faced with difficult socio-economic conditions, insufficient institutional framework and inadequate infrastructure. Inadequate research, training and credit limit farmers' capacity to adapt to climate variation and change. The necessary adjustments such as changing crops, introducing irrigation or modifying farm management methods are too costly for many farmers to implement. These changes entail costly capital investments, and the resulting lower yield potential (production) from drought tolerant crops does not compensate for the direct costs incurred. Desertification in the north is also strongly linked to food insecurity. Combating desertification and promoting development are virtually one and the same owing to the social and economic importance of natural resources and agriculture. Food security can be put at risk when people already living on the edge face severe drought.

Projected changes in rainfall, both in annual totals and in its distribution, may pose greater threats. The risks of waiting for unambiguous signals are real, since neither climate change nor its impacts can be reversed quickly, if at all. And as climate evolves beyond the bounds of natural variability there is a greater chance of 'surprises and unanticipated rapid changes'. Delaying actions by governments and the society might increase both the rate and magnitude of damage from climate change and hence the costs of adaptation and repairing damage. The lack of risk management policies has been due to inadequate means to predict climate conditions with sufficient skill and lead time. A seasonal forecast of rainfall has not been properly developed in Cameroon. With a marked record of droughts in the north, high inter-annual variability of rainfall in the south and its largely agricultural economy, Cameroon could benefit immensely from seasonal forecasting. Building institutional capacity to provide medium-term forecasts to enhance adaptive resource management in the country would be a major step forward both in achieving present development goals and in preparing for potential climate change. Research on how to disseminate information and ensure its applicability both at the farm and household level would be crucial. There is need to ensure good forecasts on climate and production. This will ensure early responses to climate problems, bolster sustainable livelihoods, and promote adaptations. Building institutional capacity to provide medium-term forecasts to enhance adaptive farm management measures would be a major step in achieving the present development aims and in preparing for climate change. (This could be coupled with an intensification of effort to disseminate other information, for example, price forecasts and technology and management information, and ensure it is disseminated at the farm level.)

For smallholder farmers to enjoy the potential benefits of long range forecasts, they would have to contain the following information: (a) the date of onset of the rainy season, (ii) the quality of the rainy season, and (c) the date of the end of the rainy season. Explicit information would enhance the nature and speed of the farmers' response. This forecast would promote both agricultural production and household food security. At present, there is a need to incorporate climate change considerations into agricultural development plans, and the clearest policy objective should be to prepare for the hazards of climate change by (a) reducing vulnerability, (b) developing monitoring capabilities and (c) enhancing the responsiveness of the agricultural sector to forecasts of production variations by reducing vulnerability through improvements in agricultural research and infrastructure.

Although this study does not examine the role of technological change over the next century, and does not consider changes in trade policies or taxes, it does suggest some important conclusions. In particular, agriculture in Cameroon is a risky business, not only because of inadequate infrastructure, under-capitalization and farming returns that barely exceed costs, but in large part because an essential input – climate – is variable and unpredictable. Declining growth rates in yields, losses of land from production and environmental constraints are powerful indicators for a difficult future. Since agricultural activities are sensitive to climate and weather conditions, agriculture decision makers in the country are at the mercy of these natural factors or attempting to benefit from them. The only way to profit from natural factors is to take them into account and understand their influence. Since very little land is irrigated, climate variables translate into variable production levels. There is an overwhelming and urgent need to put in place mechanisms that will promote societal adaptation to the current climate variation, and future climate change.

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Table 1: Regression coefficients of climate and hydrology on farm net revenue (nr1_3) in Cameroon

Variable	Parameter estimates	t-stat
Temp-winter	374.26	1.04
Temp-spring	-43.73	-1.88*
Temp-summer	18.93	2.11**
Temp-autumn	-23.58	-0.25
Temp-winter sq	-6.45	-0.08
Temp-spring sq	5.83	1.36
Temp-summer sq	-4.61	-2.42**
Temp-autumn sq	48.27	0.80
Precip-winter	0.71	1.89**
Precip-spring	0.23	2.03**
Precip-summer	1.02	1.28
Precip-autumn	0.09	1.09
Precip-winter sq	2.62	2.33***
Precip-spring sq	-3.22	-2.61***
Precip-summer sq	4.29	0.72
Precip-autumn sq	5.25	0.93
Log (household size)	18.46	1.69*
Adapt (1/0)	0.23	1.67*
Irrigate (1/0)	0.06	1.14
Adapt through crop mgt (1/0)	0.31	1.98**
Adapt through soil mgt (1/0)	0.15	1.57*
Household head education (1/0)	0.08	1.00
Extension service (1/0)	0.03	1.59*
Total flow	1.75	0.68
Flow variance	-8.31e-10	-1.07
Perci	507.95	0.73
Percend	236.27	0.40
Constant	405.322	1.59*
Adj. R-squared	0.17	
F-stat	19.95	
Observations	719	

Notes: The values in parentheses are t-values. T-values denoted * are significant at 10%, ** significant at 5%, and *** significant at 1%. Season based on three-month average with December , March, June and September as middle months of winter, spring, summer and autumn respectively.

Table 2: Marginal impacts of climate net revenue (US$/ha)

Variable	Estimate
Temperature	-15.4 (-2.77)**
Precipitation	5.65 (3.39)***

* Significant at 10% level, ** significant at 5% level and *** significant at 1% level

Table 3: Impacts from Uniform Climate Scenarios

Impacts	2.5℃ warming	5℃ warming	7% decreased precipitation	14% decreased precipitation
ΔNet revenue (USD per ha)	-7.3 *(-5.5%)*	-19.5 *(-11.3%)*	-26.8 *(-6.5%)*	-45.3 *(-15.3%)*
ΔTotal net revenue (billion USD)	-0.65	-1.82	-2.95	-4.56

Note: Using coefficients in Table 1 for nr1_3 (gross revenue less the total costs incurred per farmland). The numbers in brackets represent the percentage change in net revenue per hectare relative to the mean of the sample.

Table 4: Summary results of analyses of Climate Change Scenarios

	CGCM2 (cg)		CSIRO2 (cs)		ECHAM (ec)		HadCM3 (ha)		PCM (pc)	
	2050	2100	2050	2100	2050	2100	2050	2100	2050	2100
Precipitation										
A2-Scenario	100%	99%	99%	96%	106%	116%	101%	104%	104%	110%
B2-Scenario	100%	99%	99%	96%	106%	116%	101%	104%	104%	110%
Temperature										
A2-Scenario	3.4	8.3	3.4	8.3	3.1	7.9	3.7	9.2	2.2	5.2
B2-Scenario	2.9	5.1	3.5	6.3	3.1	5.6	3.7	6.5	2.2	3.8
Streamflow										
A2-Scenario	89%	77%	89%	76%	110%	127%	93%	88%	99%	99%
B2-Scenario	91%	85%	87%	79%	115%	128%	93%	90%	102%	104%

Source: Strzepek & McCluskey (2006)

Table 5: Climate change impacts on agriculture in Cameroon

	CGCM2 (cg)			CSIRO2 (cs)			ECHAM (ec)			HadCM3 (ha)			PCM (pc)		
Impacts	2020	2050	2100	2020	2050	2100	2020	2050	2100	2020	2050	2100	2020	2050	2100
A2-Scenario															
ΔNet revenue (US$ per ha)	12.5 (5.8%)	15.3 (12.5%)	21.5 (20.5%)	-75.5 *(-23%)*	-90.7 *(-34%)*	-105.6 *(-45%)*	20.8 (10.7%)	26.4 (14.5%)	32.3 (22.6%)	10.5 *(11.3%)*	-15.2 *(-21.4%)*	-35.1 *(-25.9%)*	25.5 (20.2%)	35.5 (26.4%)	40.2 (30.1%)
ΔTotal net revenue (billion US$)	1.2	0.4	-1.5	-5.4	-8.5	-12.6	2.4	1.8	1.3	1.2	-2.9	-3.7	1.6	2.3	2.9
B2-Scenario															
ΔNet revenue (US$ per ha)	5.6 (9.3%)	12.4 (17.6%)	16.5 (28.3%)	-80.3 (-26.2%)	-103.5 (-42%)	-115.2 (-50%)	12.5 (17.3%)	15.5 (23.5%)	20.1 (27.4)	6.5 (15.5%)	-17.4 (-10.3%)	-47.5 (-19.%)	19.3 (27.3%)	26.5 (31.3%)	30.2 (37.5%)
ΔTotal net revenue (billion US$)	0.9	-1.3	-2.5	-13.5	-15.5	-20.3	1.6	1.1	0.5	0.5	-2.3	-5.8	0.3	1.5	2.2

Note: Using coefficients in Table 1. The numbers in brackets represent the percentage change in net revenue per hectare relative to the mean of the sample.

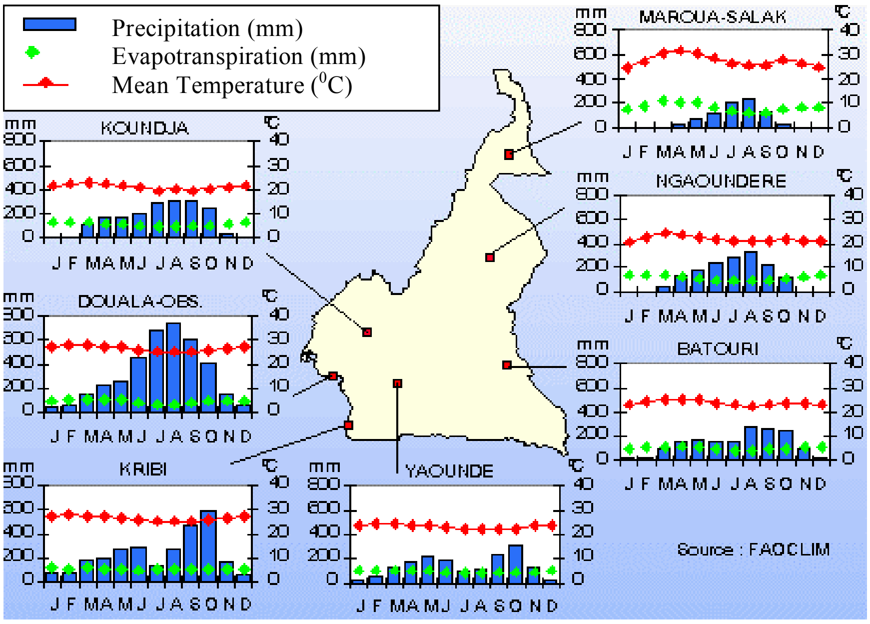

Figure 1: Temperature and precipitation distribution across Cameroon

Source: FAOCLIM

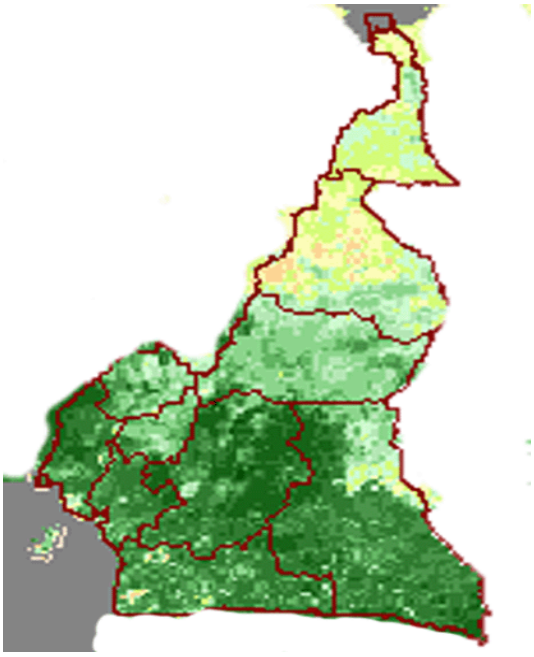

Figure 2: Cameroon's contrasting ecological zones

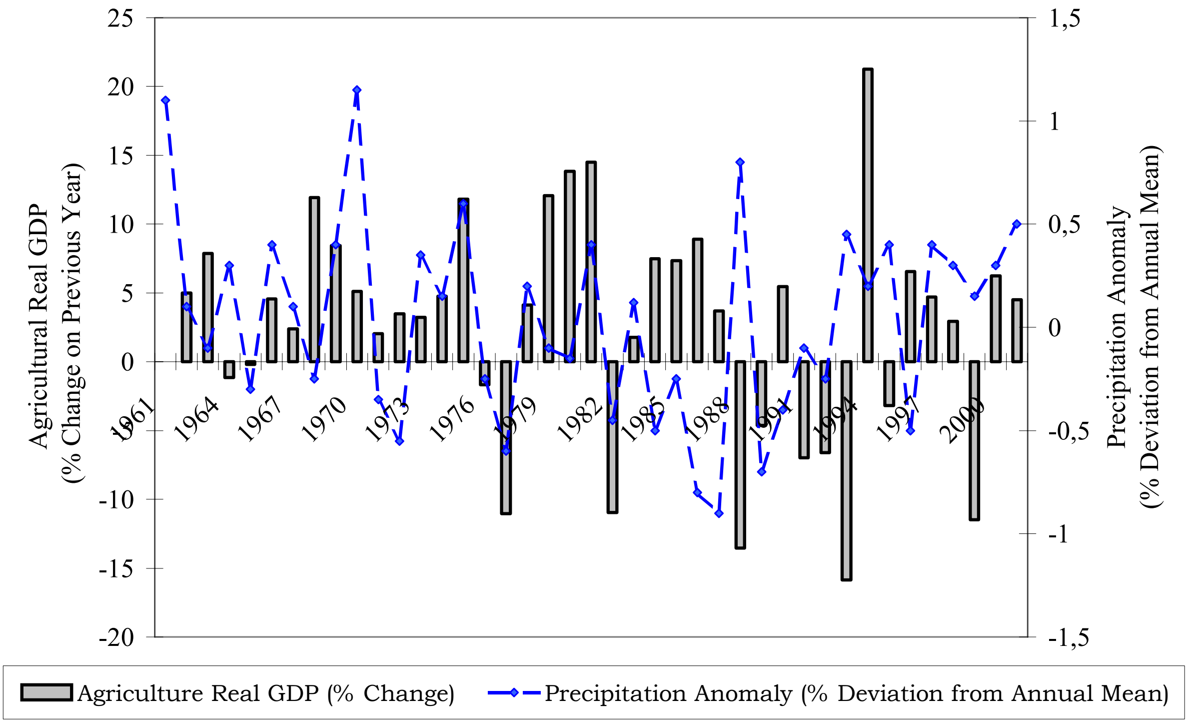

Figure 3: Agricultural sector performance and rainfall in Cameroon

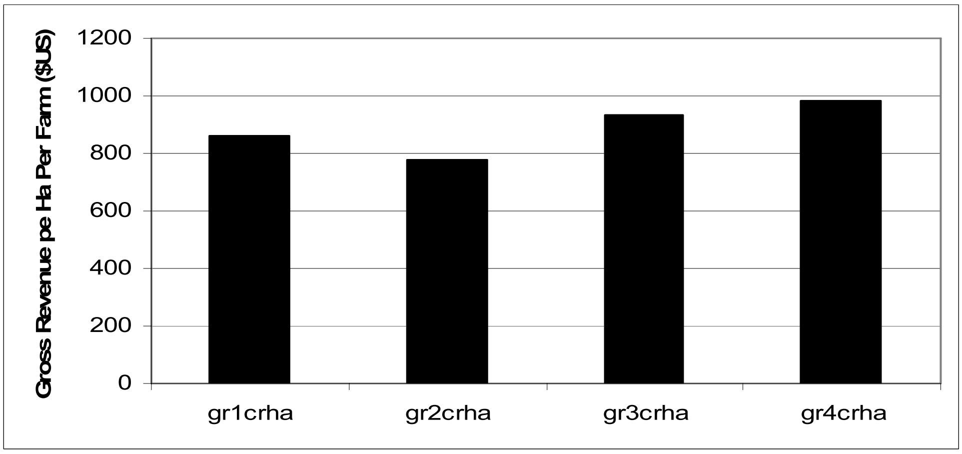

Figure 4: Gross revenue for farms in Cameroon

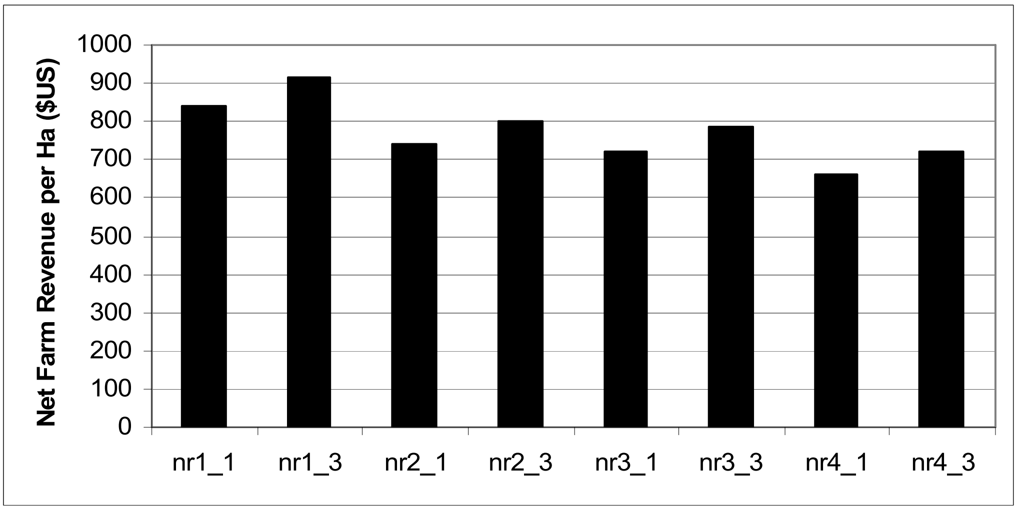

Figure 5: Net revenues of farms in Cameroon