EFFECT OF CLIMATE CHANGE ON MAIZE SUPPLY IN GHANA, 1970 – 2002

BY

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DEDICATION

This work is dedicated to my mother, Akosua Otubea (O.T).

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DECLARATION

I, Ama Asantewah Ahene, author of this M.Phil thesis do hereby declare that the work presented in this thesis titled, "Effect of Climate Change on Maize Supply in Ghana, 1970-2002" was done entirely by me in the Department of Economics, University of Ghana, Legon from October 2002 to August 2003.

This work has never been presented either in whole or in part for any other degree in this University or elsewhere.

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All Power, Glory and Honour belong to God. Thank you Jesus.

ABSTRACT

Societies which depend upon agriculture for their livelihood may face the perils of climate change (Global Warming), especially developing countries in the tropics and subtropics where some crops are already near their maximum temperature tolerance and where dry land and non-irrigated agriculture predominate. Yields will tend to decrease with even nominal amounts of climate change. Agriculture in Ghana is largely rain fed, therefore changes in climate in the form of changes in rainfall for example, may affect agricultural supply especially crops, maize inclusive. This study examines the effects of climate change, using rainfall and temperature as climate variables, on maize supply in Ghana. Annual time series data on temperature, rainfall, and output of maize, prices of maize, rice, cassava and fertiliser covering the period 1970-2002 are used. The error correction model and Granger Causality Test were employed in the analysis. The results of the study show that climate change in the form of change in rainfall exerts a statistically significant effect on supply of maize. The study further confirms that rainfall is essential during crop growth, and the critical major period of rainfall is the best time to plant to avoid water stress and pest infestation. The study closes with some policy recommendations and suggestions for future research.

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LIST OF ABBREVIATIONS

ADF	Augmented Dickey-Fuller
AIC	Akaike Information Criterion
CERES	Crop Environment Resource Synthesis
CFC	Chlorofluorocarbon
ECM	Error Correction Model
ECT	Error Correction Term
EPA	Environmental Protection Agency
FAO	United Nations Food and Agriculture Organization
GDP	Gross Domestic Product
GHG	Greenhouse Gas
GNP	Gross National Product
IEA	International Energy Agency
IPCC	Intergovernmental Panel on Climate Change
OECD	Organization for Economic Cooperation and Development
OLS	Ordinary Least Square
SBIC	Schwartz-Bayes Information Criterion
UNEP	United Nations Environment Programme
UNFCCC	United Nations Framework Convention on Climate Change

CHAPTER 1

INTRODUCTION

"Continued global warming is in nobody's interest, but the simple facts of the matter are that developing countries will suffer the most damage, and their poor will be at an even greater disadvantage. I see the Bank's role in climate change as providing every opportunity to developing countries to benefit from the huge investment OECD must make in reducing climate change."

James Wolfensohn, World Bank President
United Nations General Assembly, June 1997

1.1. Background and Problem Statement

Climate is the average weather that describes the condition of different weather variables for a specified area during a specified time interval (van der Geest, 2002). Many natural factors influence climate and have the potential to change it. One of these factors is the greenhouse effect. Climate has always been changing throughout the history of the Earth. Between 2500 B.C. and 2300 B.C., for example, the climate in the present Sahara changed rapidly from a situation in which wheat, barley, millet and guinea corn could be cultivated into a situation in which only livestock could be kept (Curtin et al., 1978). Climate change is a normal phenomenon (Ribot *et al.*, 1996). Natural changes in climatic conditions have resulted in Ice Ages, relatively warm periods in temperate regions and dry, intermitted with wet periods in Africa (Kemp, 1994). Hence, climate change is not new.

The average global temperatures will increase by 1.4 to 5.8 degree Celsius over the next 100 years if no action is taken globally to control it (World Bank, 1996). The earth's temperature has been rising progressively for the past 25 years (Ibid). The increase in the earth's temperature recently has a more drastic consequence than all other natural climate changes that have been documented over the last 100,000 years due to the intensity of human activities (World Bank, 1996; Lean and Mahlman, 1999).

The term "climate change" is sometimes used to refer to all forms of climatic inconsistency, but because the Earth's climate is never static, the term is more properly used to imply a significant change from one climatic condition to another. In some cases, climate change has been used synonymously with the term, global warming. Scientists, however, tend to use the term in the wider sense to also include natural changes in climate. The progressive rise of the earth's surface temperature and changes in global climate patterns is thought to be caused by the greenhouse effect. Global warming has occurred in the distant past as a result of natural influences, but the term is often used to refer to the warming predicted to occur as a result of increased emissions of greenhouse gases (van der Geest, 2002).

According to The Intergovernmental Panel on Climate Change (IPCC), global climate change is a rise in temperature caused by emissions of greenhouse gases (IPCC, 1990). The IPCC, composed of hundreds of scientists worldwide, released a scientific assessment of climate change in the early 1990s. The IPCC was jointly set up by the United Nations Environment Programme (UNEP) and the World Meteorological Organisation to provide an authoritative international statement of scientific opinion on climate change.

The mechanism of the greenhouse effect is that, the sun is the driving force behind the weather and climate. By heating the Earth's surface, the sun provides the energy for the cycle between oceans, atmosphere, glaciers, surface water, groundwater and vegetation through precipitation and evapotranspiration. Solar radiation is absorbed by the Earth's surface and it later leaves the Earth as outgoing radiation. Part of the outgoing radiation is, however, absorbed by greenhouse gases in the atmosphere and re-emitted to the earth's surface (Arrhenius, 1896). This makes the earth warmer. Without the natural greenhouse gases, the earth would presently be approximately 33 degrees Celsius colder (Ibid). Current life on Earth could not be sustained without the natural greenhouse effect. The earth's temperature is

affected by numerous natural factors, such as variations in solar radiation and emissions from volcanoes, among others. However, the scientific community generally agrees that human activity has intensified the greenhouse effect, and it is to blame for the recent increase in global average temperature (Houghton *et al.* 1990; Ribot *et al.* 1996; Lean and Mahlman, 1999).

Some human activities increase the concentrations of greenhouse gases in the atmosphere. Consequently, more outgoing radiation is re-emitted and this is how humanity is capable of increasing the global temperature. This is called the *enhanced* greenhouse effect (Houghton *et al.*, 1990), or the *anthropogenically* enhanced greenhouse effect (Ribot *et al.*, 1996). The speed with which greenhouse gases are emitted through human activities like deforestation and industrialisation are predicted to cause an accelerated climate change that has no precedent (Ibid). Changes in land use patterns such as the clearing of forests also release carbon dioxide that has been stored in trees into the atmosphere. According to Lonergan (1998), there is a strong relationship between atmospheric levels of carbon dioxide and temperature.

Temperature alters precipitation patterns, triggers extreme weather conditions which could alter forests, crop yields, and water supplies, as well as disrupt farming, fishing, and many other industries reliant on weather and the natural world (IPCC, 1990; Downing, 1992). Climate change is likely to have numerous negative effects on human development and welfare. The per capita fossil energy use (greenhouse gas emitter) by Sub-Saharan Africa in general and Ghana in particular is very low; yet the region is most susceptible, due to poverty and inability to adapt to continuing climate change.

Although the issue of global warming has been debatable, the following could be argued in favour of its occurrence. One, anthropogenic releases of greenhouse gases are increasing at a constant rate (van der Geest, 2002). Second, these gases, in the absence of

other changes, will result in general global warming (Ibid). Third, there will be regional variation in the amount of warming and changes in other climate parameters, such as precipitation (Ibid). Finally, the consequences of such warming could be very great, depending on the ability of systems to adapt to these potential changes. Governments, environmentalists and many scientific bodies are also calling for severe reduction in the emissions of these gases with the interests of future generations in mind. The response was the signing of the United Nations Framework Convention on Climate Change (UNFCCC) by over 150 countries in June 1992. The signing of the convention indicates widespread recognition that climate change is potentially a major threat to the World's environmental and economic development. A key objective of the convention is the stabilisation of Green House Gas (GHG) concentration in the atmosphere at a level that would prevent dangerous anthropogenic interference with the climate system (UNEP/OECD/IEA/IPCC, 1995).

Ghana covers about 238,539 square kilometres and lies between latitude 4.5°N and 11.5°N and longitude 3.5°W and 1.3°E. The country shares borders on the West with Cote d'Ivoire, East with Togo, North with Burkina Faso and to the South lies the Gulf of Guinea. Three main agro-ecological zones can be found in Ghana. These are the Coastal Plain, the Middle Semi-equatorial Forest and the Northern Savannah. There are two major types of crops grown in Ghana, cash crops and food crops. Agriculture contributed about 36 percent of the Gross Domestic Product (GDP) in Ghana in 2001 and 2002 (GSS, 2002a).

The Environmental Protection Agency (EPA) in Ghana has observed a 20 percent decrease in annual total rainfall and a 1 degree Celsius increase in temperature over the thirty-year period of 1961-1990 (EPA, 2000). There is also a general perception of climate change in Ghana by both farmers and non-farmers especially the elderly who, by memory, recall higher rainfall in their days (Ofori-Sarpong, 2001; van der Geest, 2002).

The agricultural sector in Ghana is likely to suffer, most adversely, from climate change because of its high dependence on rainfall, temperature and soil type. Maize is a staple in Ghana and it is cultivated in virtually all the regions in Ghana. This raises the following issues: What has been the nature of climate change in Ghana? What have been the effects of climate change on maize supply in Ghana during the period 1970-2002? These are the issues which the present study addresses.

1.2. Objectives of the Study

The primary objective of this study is to analyse the effects of climate change on maize supply in Ghana over the period 1970-2002. The specific objectives are the following:

a. To describe the time profiles of rainfall and temperature in Ghana during the period 1970 - 2002.
b. To describe the time profile of maize supply in Ghana over the period 1970-2002.
c. To quantify the effect of climate change on maize supply in Ghana during the period 1970-2002.

1.3. Relevance of the Study

Climate change would indeed affect agricultural supply and hence the economic development of the country. There is not much empirical analysis done in this area, especially in Africa in general and Ghana in particular. The present research therefore contributes to narrowing this gap in knowledge.

Ghana is an appropriate country for the research since it is a developing country with different agro-ecological regions and climatic zones, which would clearly depict the impact of climate change in the country. Also, the country cultivates diverse crops with varying temperature tolerance levels, so that farmers and policy makers could identify which crops to

fall on when temperature increases. This could also be a model for other countries in Africa which have similar agro-ecological conditions.

The agricultural sector in Ghana is the focus of this research because it contributes about 36 percent to GDP and employs about 60 percent of the labour force (GSS, 2002). Furthermore, it is highly dependent on rainfall and temperature and it is likely to be the hardest hit when climate changes. Also, agriculture is an appropriate sector for this analysis because it could be the most important market impact from warming (Mendelsohn and Neumann, 1998, Mendelsohn and Schlesinger, 1999; Mendelsohn et al., 2000). Hence, policy makers must be made aware, through rigorous research, of the adverse effects of climate change and suitable measures taken to mitigate these adverse effects.

Maize is the crop studied in this research because it is a crop which can be found in all the agro-ecological zones in Ghana (GSS, 2000). Maize accounts for about 52 percent of the total output of cereals in Ghana and occupies about 44 percent of the total area devoted to cereals. It is grown on more than 500,000 hectares of land in Ghana and has a national average yield of about one ton/ha (Marfo and Read, 1985). Maize is also the staple food of a majority of the population in Ghana, and government has sometimes imported large quantities of this cereal periodically to supplement local production for both human and animal consumption (GOG, 1982).

1.4. Organisation of Study

This study is organised into five chapters. In Chapter 2, a review of the existing relevant literature on the theme of the study is presented. Chapter 3 outlines the methodology employed to accomplish the objectives of the study. Empirical results of the study are presented in Chapter 4. Summary and policy recommendations are made in Chapter 5.

CHAPTER 2

LITERATURE REVIEW

This chapter reviews the theoretical and empirical studies done on the subject of climate change and its effects on agriculture globally, in sub-Saharan Africa and Ghana. It highlights the conclusions drawn by earlier researchers concerning how a change in climate would or does affect developing countries under limited capital and technology.

The Intergovernmental Panel on Climate Change (IPCC) reports that the impact of climate change on people's livelihood will be greatest in the tropics and subtropics, particularly in Africa due to the high dependency of many poor smallholders on agriculture (IPCC, 2001b). According to Watson (2001), 800 million people are already malnourished and food production has to double in the next thirty-five years to meet future needs. These statistics coupled with the event of climate change pose a great threat to development and food security. In an increasingly interdependent world, developing countries cannot avoid being strongly influenced by what happens in the rest of the world, particularly in the industrialized (Organization for Economic Cooperation and Development - OECD) countries (Killick, 1989). This view can be strongly related to climate vis-a-vis development of the world. In the process of developing, the Developed World destroys the environment through increasing CO_2 levels in the atmosphere (global warming) and developing countries bear the consequences of their actions.

In identifying possible causes of the observed warming of the earth's climate over the 20th century, a series of model calculations were used to examine the differing effects of natural variability, carbon dioxide and other greenhouse gases, sulphate particles, and changing solar output on the climate of the 20th century (Lean and Mahlman, 1999). In general, these calculations made it clear that it is scientifically very difficult to construct an explanation for the 20th century warming that does not include a major role for the added

greenhouse gases resulting from human activities (Ibid). Based on the model calculations and the observational records of climate change for the 20th century, the conclusions are that added greenhouse gases provide, by far, the most plausible hypothesis for explaining the warming of the 20th century (Ibid). Solar irradiance variations are large enough to shape, but not dominate, the observed warming. Natural variability plus added greenhouse gases and added greenhouse gases plus increased solar irradiance can explain the extended warming period between 1910-1940 (Ibid).

2.1. General Effects of Climate Change

Rising global temperatures are expected to raise sea level and change precipitation and other regional climate conditions. Changing regional climate could alter forests, crop yields and water supplies. It could also affect human health, animals, and many types of ecosystems (IPCC, 1996).

A French scientist first described the natural greenhouse effect, drawing the parallel between the actions of the atmosphere and the effect of glass in a greenhouse (Fourier, 1824). The sun's radiation reaching the earth is in the shorter wavelength whereas outbound radiation from the earth is in the infrared long-wave bands. Clouds, water vapour and natural greenhouse gases such as carbon dioxide (CO_2), methane, nitrous oxide and ozone are more opaque to long-wave than short-wave, trapping 80 to 90 percent of the outbound radiation from the earth's surface. This trapping influence is called the greenhouse effect. Without the greenhouse effect, the average surface temperature on earth would be -18°C instead of the 15°C observed today, and this would be too low for any sort of life (Ibid).

The Swedish scientist Svante Arrhenius introduced the possibility of an enhanced or man-made greenhouse effect one hundred years ago. Arrhenius hypothesized that the increased burning of coal would lead to increased concentration of carbon dioxide in the

atmosphere and warms the earth (Fleming, 1998; Arrhenius 1896). Since Arrhenius' time, the emissions of greenhouse gases have increased dramatically. The concentration of carbon dioxide in the atmosphere has increased by 25 percent over pre-industrial levels (Ibid). In addition to increased burning of fossil fuels such as coal, oil and natural gas, man-made chemical substances such as Chlorofluorocarbons (CFCs) as well as methane and nitrous oxide emissions from agriculture and industry contribute to the greenhouse effect (Cline, 1992; Frankhauser, 1995).

With respect to the greenhouse effect from human activity, the IPCC noted that "there has been a real, but irregular, increase of global surface temperature since the late nineteenth century" amounting to 0.45°C on average (IPCC, 1996). Current emission trends will lead to a doubling of greenhouse gas concentration over pre-industrial levels around the year 2050. The IPCC projects a global average temperature increase of 1 - 3.5 degrees Centigrade, or 2 - 6 degrees Fahrenheit, which would have significant impact on climate throughout the world.

Average global surface temperature has increased by approximately 0.6°C since the late 19th century, with 95 percent confidence that it lies between 0.4 and 0.8°C (IPCC, 1990; 1996). Most of this increase has occurred in two periods, from about 1910 to 1945 and since 1976; the largest warming in recent period has been recorded in the winter extra-tropical Northern Hemisphere (Ibid). The warming rate of 0.17°C per decade since 1976 has been slightly larger than the rate of warming during the 1910 to 1945 period (specifically, 0.14°C per decade), although the total increase in temperature is larger for the 1910 to 1945 period (IPCC, 1990). The most recent periods of warming also recorded a faster rate of warming over land compared with the oceans (IPCC, 1990; 1996).

According to the IPCC, Third Assessment Report (Scientist Assessment), warming from 1910 to 1945 was initially concentrated in the North Atlantic and nearby regions. During 1946 to 1975, the Southern Hemisphere was warm whilst the Northern Hemisphere

showed cooling. Temperature trends in the Twentieth Century exhibit a broad pattern of tropical warming with extra-tropical trends being more variable. The El-Nino event in 1997/1998 is associated with the high global temperature in both surface and tropospheric temperature. Warming was emphasised in the Northern Hemisphere in winter and spring with all year-round cooling in the Southern Hemisphere oceans and the Antarctica between 1976 and 2000 (IPCC, 2001). The North Atlantic/Arctic Oscillation Westerly phase and the Pacific variability are recognised to have caused global temperature change since the 1970s (Ibid).

2.2. Future Effects of Climate Change

It is projected that the equivalent of doubling atmospheric CO_2 will occur by 2050 and this will lead to a global temperature rise of between 2.4 and 10.5 degrees Fahrenheit by 2100 (IPCC, 1990; 1997). The longer it takes humanity to begin reducing greenhouse gas emissions, the greater the rise in global temperature will be. Land surfaces and higher latitudes will experience larger increases (Ibid). Temperature will continue to rise long after emissions are reduced and greenhouse gas concentrations stabilise (Ibid).

Sea level will rise 10-30 inches by 2100, and will continue to rise thereafter (Ibid). Wetlands will be flooded. Many low-lying regions and small island states will have to be evacuated due to storm surges and saltwater intrusion (IPCC, 1996). Evaporation and precipitation will increase about 1 percent for every 1 degree Fahrenheit temperature rise, and their distribution will be increasingly uneven and unpredictable (Ibid). There will be more frequent and severe heat waves and droughts, and heavier storms and floods. Rapid climate change will limit the ability of many plant and animal species to adapt. However, insects, rodents, disease organisms, and other species which reproduce rapidly will increase in population (Ibid).

2.3. Effects of Climate Change on Agriculture

Recent literature suggests that, in the tropics and subtropics where some crops are already near their maximum temperature tolerance and where dry land, non-irrigated agriculture predominates, yields will tend to decrease with even nominal amounts of climate change (IPCC, 1998). The literature tends to project further that positive effects on agriculture would be concentrated in high latitudes and negative effects in lower latitudes, precisely where problems of hunger already exist (Ibid).

The effects of climatic variations on agriculture (especially in Africa) have been well established through decades of field experiments, statistical analyses of observed yields, and monitoring of agricultural production (IPCC, 1997; Akong'a et al, 1988). The most important climatic element is precipitation, particularly seasonal drought and the length of the growing season. The distribution of rainfall within the growing season also may affect yields. Low temperatures and radiation limit production in some high-elevation regions; frost is a hazard in Southern Africa (IPCC, 1997). High temperatures can negatively affect yields and yield quality in semi-arid and arid regions, although water is more important. Sea-level rise and coastal erosion will affect groundwater through increased salinity, irrigated agriculture, and low-lying coastal land in some areas on the basis of the extent of land liable to inundation and the population being at risk (IPCC, 1997).

Based on experimental research, crop yield responses to climate change vary widely, depending upon species and cultivars, soil properties, pests and pathogens, the direct effects of carbon dioxide (CO_2) on plants, and interactions between CO_2, air temperature, water stress, mineral nutrition, air quality, and adaptive responses (IPCC, 1996). Even though increased CO_2 concentration can stimulate crop growth and yield, this benefit may not always outweigh the adverse effects of excessive heat and drought (IPCC, 1997).

Yields of some crops in tropical locations would decrease generally with even minimal increases in temperature, because such crops are near their maximum temperature tolerance and dryland/rainfed agriculture predominates (Reilly et al, 1996). Where there is also a large decrease in rainfall, tropical crop yields would be even more adversely affected. Most studies indicate that global mean annual temperature increases of a few degrees Celsius or greater, would prompt food prices to increase due to a slowing in the expansion of global food supply relative to growth in global food demand (Ibid).

Changes in temperature and in the level and timing of precipitation may influence the yield of crops (Adams et al, 1990; Parry, 1990). It is expected that in some areas, crop production will generally suffer from the changes whereas in other areas crop production will benefit from the changes (Parry, 1990). In some areas, heat or water stress will reduce the yields of certain crops, whereas other crops will benefit from the changes in climate, implying that the relative productivity of different crops will change (Ibid). Some of the crops which may be affected negatively are wheat, maize and rice to mention but a few (Ibid). Furthermore, the frequency of extreme meteorological events may change, causing higher yield variability. Increased levels of CO_2, technological changes, plant breeding, inter alia., will also influence the future crop productions (Ibid).

Higher temperatures may increase the need for plant protection (Chen and McCarl, 2001). The conditions are more favourable for the proliferation of insects and pests in warmer climates. Temperature as well as increased levels of CO_2 influence the growth of weeds, implying that control of weeds may be more difficult (Rosenzweig and Liverman, 1992). However, the effects of climate change on the need for plant protection will vary from case to case. In addition to temperature and precipitation changes, climate change may also impact agriculture through greater competition from weeds, increased plant and animal disease, changes in soil nutrients and pests, and increased conflicts for available water. While these

damaging effects are probably controllable, no conclusions have been drawn yet as to what they may do to the cost of agricultural production and how they will affect agricultural resources and the environment.

Since rain-fed agriculture is the main source of livelihood for most people in Africa, the combination of decreasing annual amounts of rainfall, increasing rainfall variability, increasing temperature and population growth could cause a serious decline in the population's capacity to secure its food and other needs. Agricultural droughts would occur more frequently and without a dramatic shift in agricultural and non-agricultural production strategies, the region would become much more prone to famine. That is why climate change in Sub-Saharan Africa, albeit being an age-old phenomenon, has to be taken seriously. The Sahelian droughts of the 1970s and the early 1980s may have been a first warning. They were much more extreme than the 'normal' oscillating pattern (Hulme 1994). Although precipitation levels have partly recovered in the 1980s and 1990s, they are still well below the average of the first part of the century.

Where certain varieties of crops are grown near their climatic limits, extreme weather events may have dramatic effects on agricultural production (Parry, 2000). This may consequently influence the variability of the economic outcome of farming and increase the risk of agricultural investments. The economic and social impacts of climate change include changes in the optimal farming systems, relocation of farm processing industries, increased economic risk and changes in the rural income and heritage (Kane et al, 1992; Molua, 2002). Changes in the economic performance of different farming systems due to, for example, changes in crop growth conditions, may lead to substantial changes in the farming systems and with agriculture being the main income generator, the economic welfare of the society would be affected.

Changes in rainfall and temperature could have direct effects on biological productivity, crop yields and economic welfare. These effects depend on the importance of the climatic controls of production relative to other controls such as provision of plant nutrients, availability of labour and availability of capital, technology and know-how. Climatic control of productivity is of crucial importance in certain agricultural zones in developing countries. Climatic 'marginal' zones, such as the semi-arid savannas are particularly susceptible to climate-driven changes in productivity. Even though many scientists fear that the most adverse effects are likely to occur in poorer countries, few attempts have been made to explore climate change (global warming) in the developing world (Schelling, 1992; Nordhaus, 1993). Most of the research has focused on the U.S and Europe (Ibid).

Rasmussen (1999) noted that the effects of climate change on human lives and national economies are likely to be greater in the tropical and subtropical developing countries than in the industrialised (and typically temperate) countries. This is not necessarily due to differences in the size and severity - in purely physical terms - of the projected climate changes in itself, but rather it is due to the greater importance of the primary sector in these countries in terms of contribution to the GNP. This underlines the need to look at climate change, supposedly mainly related to greenhouse gas emissions caused by human consumption as a problem affecting food security, quality of life and economic development in developing countries in particular. Not only the climatic changes, but also the economic and political mechanisms applied to limit these changes, have implications for developing countries.

2.4. Empirical Literature on Effect of Climate Change on Agriculture

Most empirical studies undertaken focus mostly on the impact of climate change on agriculture in the United States. Some of the existing studies are Nordhaus (1993), Cline (1996), Dinar and Mendelsohn (1999) and Mendelsohn et al (2001). These researchers concluded that agriculture systems in the US would readily adapt to climate change, by introducing new technologies, new crop varieties, and cultivation practices so that there would be minimal changes in yields and net profits. These results would likely extend to other Organization for Economic Cooperation and Development (OECD) countries, suggesting that agriculture in developed countries is less sensitive to climate change. However, less is known of the effects of climate change in developing countries, especially Africa in general and Ghana in particular.

Molua (2002) observes that an increase in rainfall during crop growth is a positive covariate of income in Southwestern Cameroon. This implies that, for a region whose agriculture is rain-fed, an increase in rainfall coupled with improved tillage practices could enhance farm economic return. Therefore irrigation in the growth period especially during dry spells would be valuable for stimulating increases in production. He used an econometric function which directly relates farm income and precipitation in order to statistically estimate the significance of farm-level adaptation methods. Similarly, agroclimatic studies by Akong'a et al. (1988) considered the effects of climatic variability on agriculture, with an emphasis on coping with drought. Drought episodes in sub-humid and semi-arid zones were observed to have led to the failure of crop production and dependency on other sources of income to buy food, or on famine relief.

Schulze et al. (1996) used the ACRU/CERES hybrid model to evaluate the impact of climate change on maize in South Africa. The investigators divided the diverse geography of South Africa into 712 relatively homogeneous zones, each associated with a specific type of

vegetation, soil, and climate. Daily values of temperature (minimum and maximum), rainfall, wind speed and solar radiation were used in crop evaluation, based on the CERES-Maize model. For three scenarios of climate change, yields tend to decrease in the semi-arid west. For most of the country, CO_2 enrichment effect tends to counteract the relatively modest changes in temperature and precipitation and potential yields tend to increase. In parts of the eastern highlands, particularly in Lesotho, dramatic increases in yields tend to result from higher temperatures.

Endrody-Younga (1968) observed that insects increase during the season of crop growth. However, maize planted early in the major season tended to escape heavy infestation and mature before insects could cause severe damage. Therefore, yield reduction due to greater plant damage normally occurs when cultivation is done late in the major season or in the minor season when insects are on the increase.

Liverman and O'Brien (1991) observed that global warming may present a threat to local and national food security in Mexico, especially if farmers are unable to adapt to a drier climate and as food imports from other regions become more costly.

Muchena (1994) and Muchena and Iglesias (1995), explained that climate change may lower maize yields in Zimbabwe due to shortening of the favourable growing period and increasing water stress. Furthermore, climate change is likely to cause significant spatial shifts in agricultural capability and land-use zones, with wet zones diminishing and dry zones expanding due primarily to rises in potential evapotranspiration. A large portion of African agriculture is rain-fed, but heat-related plant stress may reduce yields in several key crops, such as wheat, rice, maize, and potatoes (Burke et al, 1988). These crops most often are located in warmer, dryer climates and are quite susceptible to water stress.

The type of land preparation before planting affects the development and yield of maize (Takyi, 1970). Furthermore, planting maize in ridges have greater yields than maize in

flat seed beds since there are higher concentrations of fertiliser in the root zone as a result of ridging (Ibid). He came to this conclusion by examining the planting of maize in ridges, flat seed beds and soil not ploughed in central Ghana. Clarke (1962) observed that soil structure and climate strongly influenced the nutrient holding capacity of soils. Also, soil management and cultural practices such as fallowing affect the fertility of soils.

According to Davis and Porter (1936), Doneen and MacGillivray (1943) and Delouche (1953), adequate moisture availability is important for good growth and yields of plants.

From a review of various studies on the impact of climate change on agriculture, Dinar and Beach (1998) concluded that the relative lack of information and insufficient economic analysis of the impact of and adaptation to climate change in developing countries, suggests that an important task is to initiate empirical research in developing countries, since these countries are likely to be subject to a negative impact of climate change in the future. They were of the view that, appropriate measures which might be used to deal with the climate change phenomenon are complicated due to a great deal of controversy surrounding the issue; that is, different interpretations of the evidence, different interests of policy makers and different evaluation of intervention options.

Using cross-sectional data, Zekri (2002) regressed regional net revenue on climate, geographical, soil, economic and demographic variables to determine the intrinsic value of climate change. He noted that in the coming fifty years, global temperature will rise by 2 °C to 5°C if nothing is done in terms of reducing CO_2 and other gases responsible for the Green House Effect. Negotiations between the major industrialized countries have taken place to set acceptable standards concerning CO_2 gas emissions. Nevertheless, many pieces of the puzzle are still missing to come to a reasonable compromise. In effect, decision-makers cannot accept any alternative in the lack of quantitative information about the economic impacts of

climate change on the world economy, which sectors will benefit, what countries will benefit and who will lose and so on. It is obvious that the reduction of emissions will mean either decreases in the industrial activities or adoption of new technologies resulting in increases in production costs and shifting part of the investments in pollution abatement to this sector. On the other hand, part emissions reduction should lead to benefits or costs to other sectors such as health, agriculture, landscape and water. Thus, what decision-makers should ensure is that the stream of benefits would be greater or equal to the costs of reducing emissions (Zekri, 2002).

Adams et al. (1990) conducted an integrated study for the US, linking models from atmospheric science, plant science and agricultural economics. While the outcomes depend on the severity of climate change and the compensating effects of carbon dioxide on crop yields, the simulations suggest that irrigated acreage will expand and that regional patterns of US agriculture will shift with predicted global warming. With the more severe climate change scenario tested, the movement of US production into export markets is substantially reduced.

Rosenberg and Crosson (1990) integrated the Missouri, Iowa, Nebraska, and Kansas (MINK) study, both within the agricultural sectors and across other sectors. The study incorporated both the physiological effects of CO_2 and adaptation by farmers to the climatic conditions of the 1930s. Even with the relatively mild warming (1.1°C) of the 1930s and with farmer adaptation and CO_2 physiological effects taken into account, regional production declined by 3.3 percent. Given the IPCC (1990a) estimate of 2.5°C warming for doubled CO_2 conditions, these results imply agricultural losses of about 10 percent for equilibrium warming of doubling of carbon dioxide-equivalent (Cline, 1991).

According to Hulme (1996), the coefficient of variation for annual maize yields due to the effects of the 1984–85 and 1991–92 droughts varies from about 10 percent in Central Africa to almost 50 percent in drier countries such as Botswana and Swaziland. A significant

component of the variability is likely to be related to rainfall, although prices and market policies are influential. Hulme (1996) presents an integrated view of climate impacts in Southern Africa. Prospects for agriculture depend critically upon changes in precipitation. A "dry" scenario suggests less-suitable conditions in semi-arid and sub-humid regions. With little decreases (or increases) in precipitation, agriculture should be able to cope with the average changes. However, shifts in drought risk need to be considered.

Mendelsohn and Williams (2002) concur that tropical nations will be hurt, temperate nations will be barely affected, and polar nations will benefit from climate change; since these effects are offsetting, the net global impact of climate is relatively small. Compensation is clearly called for but only a modest abatement programme appears warranted at this time. The large uncertainty surrounding these forecasts further suggests that continued monitoring of both the climate and impacts is worthwhile.

The empirical results of Sanghi et al (1998) indicated that climate change would have an overall negative impact on Indian agriculture, with varying seasonal and regional implications. A warming scenario of 2°C increase in mean temperature and a 7 percent increase in mean precipitation levels exerted a 12.3 percent reduction in net revenues for India as a whole. When the increases in temperature and precipitation were calculated differently, it was realised that a rise in temperature was damaging, whereas an increase in precipitation levels was beneficial. However, the positive precipitation effect was dwindled by the negative temperature effect. There was a suggestion that, in order to adapt to these climate changes, there was the need to develop increased heat tolerance in high-value temperature sensitive crops. Also, minimizing run-offs to capture benefits from increased rainfall was expected to be a beneficial strategy.

Dinar and Mendelsohn (1999) using a Ricardian Analysis argue that, the damages of climate change will be greater in developing countries because their levels of capital and

technology are lower. For example, the results cited in Pearce et al. (1996) predict that OECD countries will suffer damages of 1.4 1.6 percent of GDP but less-developed countries will have damages between 1.6 percent and 2.7 percent. Economies with less capital and technology could be more vulnerable to climate change as they have less control over their environments, due to the fact that more of their economy is in vulnerable sectors, and they have warmer climates to begin with.

Although it is commonly believed that vulnerable sectors in developing countries are more climate sensitive (Nordhaus, 1991; Schelling, 1992), it has never been rigorously tested empirically particularly in Africa. Mendelsohn et al (2001) in their study of sensitivity of climate and development arrived at the conclusion that, development does have an important effect on climate sensitivity. Furthermore, farmers in developing countries are currently more climate sensitive than farmers in the more-developed countries. Combining this climate sensitivity with the higher temperatures at low latitudes suggests that low-latitude agriculture would be hurt if warming occurred today (IPCC, 2001). Whether this is the case or not is unknown in Africa in general and Ghana in particular. The present study will contribute to narrowing this gap in knowledge.

2.5. Literature on Climate Change and Agriculture in Ghana

In Ghana, global warming has precipitated climate change (EPA 2000). For example, over the thirty year period covering 1961-90, annual total rainfall declined by 20 percent and stream flow or runoff in all the river basin systems declined by 30 percent, as temperature increased by 1°C (EPA 2000). Furthermore, it is estimated that mean daily temperature will increase by 2.5-3.2°C by the year 2100, whereas annual total rainfall will decline by 9-27 percent by the same year. Stream flows in all the river basins are expected to decline by 15-20 percent by 2020 and 30-40 percent by 2050. Notably, Ghana has been experiencing long

periods of drought and erratic rainfall, particularly in the arid north (savannah) and along the coast. Irregular climatic conditions like untimely onset of rainfall and untimely cessation of rainfall during the crop-growing season have also been experienced. Erratic rainfall has also been observed during the minor crop season (namely, during September and November) in the forest-savannah transition zone. Sometimes excessive rainfall causes floods. The current levels of temperature and evaporation rates are high in Ghana, particularly in the Guinea savannah, Sudan savannah and coastal savannah zones.

Climate change could exert adverse effects on agriculture in Ghana. For example, it has been argued that the current high temperatures and high evaporation rates have tended to increase water stress and ultimately precipitated declines in crop yields (EPA, 2000). Furthermore, high temperatures and declines in surface water resource availability due to temperature effects on river discharges or runoff values, as well as declines in groundwater resource availability due to climate-induced declining rates of recharge of aquifers have also occurred in Ghana. It has been estimated, for instance, that climate change is likely to cause 22 percent, 17 percent and 5 percent declines in groundwater (aquifer) recharge by the year 2020 in the Volta basin system, the Pra system and the Ayensu system respectively (EPA, 2000).

Adverse climate change could lead to total crop failure. For example, farmers in the Upper East Region have lamented the failure of the millet crop, whereas farmers in the Northern Region have recorded rice crop failure due to change in climate (Ofori-Sarpong, 2001). Farmer perceptions concerning climate change indicate that farmers are aware of climate changes like the delayed onset of rains, increase in day length, and intermittent droughts during the relevant crop growing season and crop failure due to adverse climate change (Ibid).

Evidence of climate change (specifically, reduction in rainfall amount) in the Sekyere-West District of Ghana has been provided by Owusu (2002). Similarly, the impact of climate change on agriculture and farmers' coping strategies in Navrongo and Bawku (the arid regions of Ghana) have been analysed by Ofori-Sarpong (2001). The mean annual rainfall for the 30-year period 1931-1960 was 1087.6 mm while the mean for the second 30-year period 1961-1990 was 986.1 mm, which is an indication that the first 30-years were wetter than the latter 30 years in the arid Upper East Region (Ofori-Sarpong, 2001). Of the sixty years, thirty-six are drought years (drought is here defined as a period during which rainfall falls below the mean). This confirms the fact that in the Upper East Region, drought is endemic (Ofori-Sarpong, 2001). Furthermore, over the last 30-40 years, a decrease in annual and monthly rainfall figures in the Upper East Region occurred (Ofori-Sarpong, 2001). Also, the annual mean and monthly temperatures have increased, which could also be an indication of climate change (Ofori-Sarpong, 2001). The study, however, was performed only in the Upper East Region, with a particular climatic condition (hot and dry weather). The present study contributes to narrowing this gap in knowledge by extending the analysis across the country, which would capture the effects of different climatic conditions; hence, contributing to analysing the effects of climate change on agriculture in Ghana.

Owusu (2002) observed that rainfall totals in the Sekyere-West District decreased from 1493.1 mm in 1960 to 1164.0 mm in 1999. He further noted evidence of drought conditions in the monthly rainfall distribution in some wet years (the growing seasons) and that in 1992, which was a typical drought year, all the months except May recorded rainfall below the long-term mean, while water balance recorded an eight-month instead of a five-month drought period in the long-term mean water balance. Moreover, in 1998, the humid periods were reduced to only five months instead of the mean seven months (Owusu, 2002).

In Owusu's study, rainfall was the only climatic factor considered. The present study includes an additional climatic factor, specifically, temperature.

Hamid (1984) concluded in his study in the Upper West area of Ghana that rainfall seasonality is the major factor which controls the calendar of agricultural activities in the area. He said the struggle for sufficient food supply by the people of this area is controlled by the start, duration and end of the rainy season. Therefore, agriculture in the Upper West tends to be mainly affected by rainfall variability, and lower rainfall has serious repercussion on crop yields.

Leyenaar (1976) in conducting three field experiments on maize at the Legon Farm came to the conclusion that good cultural practices increase grain yields and that higher yields are obtained during the major rainy season; that is, planting right after the dry season as soon as the rains start. He argued that little capital is required in this process but more than doubled grain output may be achieved. However, planting in the minor season yields low output of maize unless irrigation and improved cultivars are utilised and stem borers controlled. He further argued that maize production is not practical without the addition of water in the minor rainfall period, but the capital cost of irrigation would be great for the average farmer and might not be economically practical.

A review of optimum planting dates and maize cultivation in Ghana confirms that maize cultivation should only be in the major season since rainfall is fairly stable and reliable during this period (Dom-Anin, 1985). The long-term average rainfall distribution indicates that maximum yield is recorded when tasseling occurs just before the peak of rainfall, since planting early will minimize moisture deficiency during tasseling and grain-filling period.

Fosu et al (1997) in a study of agricultural supply response and structural adjustment in Ghana and Burkina Faso had a result indicating that the supply response to the own-price of a crop is positive only for crops that are grown with non-traditional technologies, example

is maize in Ghana. Also, the supply response of traditional food crops is either insignificant or negative particularly in Ghana.

In Heerink et al (1997) farmer's transport time showed a significant negative effect on production and marketed quantity of cassava and maize. The study concluded that, 25 percent reduction of transport time was needed to increase the output of maize by one percent. Maize had a small positive supply response to price changes: where the price elasticity of maize supply equals 0.04.

Jones and Thornton (2003), in their study on the potential impacts of climate change on maize production in Africa and Latin America in 2055, observed that a 10 percent decrease in maize output by 2055 due to climate change is certainly serious unless the level of decrease as stated by Pardey and Beintema (2001) will be compensated by plant breeding and technological interventions in the intervening period given the history of cereal output increases since 1950. In this study, the output of a global circulation model (GCM) was generated on surfaces that are characteristic of the predicted climate to 2055, which gave an output decrease in maize for Ghana to be 100,800 tons in smallholder rain-fed production systems.

In conclusion, it is evident from the present review of literature that there is a dearth of knowledge on the theme of the present study. The present study therefore contributes to narrowing this gap in knowledge by using cointegration and error correction modelling in analysing the effect of climate change on maize supply in Ghana.

CHAPTER 3

METHODOLOGY

This chapter outlines the present study's methodology. First, the procedures for constructing the time profiles of annual mean temperature and its deviation from the mean, annual mean rainfall and its deviation from the mean and maize supply are described. Second, the theoretical framework for the econometric analysis is also presented in this chapter. Finally, cointegration analysis and error correction modelling are undertaken.

3.1. Time Profiles of Temperature and Rainfall

Climate data are collected from meteorological stations in maize production areas, since they contain more information about the weather characteristics of the maize areas. The mean monthly rainfall and temperatures at these stations are averaged to get the annual mean rainfall and temperatures in the maize belt in Ghana. The major production areas and the selected meteorological stations are representative of Ghana's maize belt. These data, covering 1970-2002, are plotted against time and the time profiles described. The mean of temperature and rainfall are also calculated to derive the deviations from the mean. The time profile of the deviations of temperature and rainfall from the mean are then plotted and described.

3.2. Time Profile of Maize Supply

Data on maize supply, the price of rice and the price of cassava are also plotted against time. Section 3.7 details the sources of these data. The time profile of maize supply is compared with the time profiles of the annual rainfall, the price of rice and the price of cassava. The various comparisons are described.

3.3. Theoretical Framework

The theoretical framework for the analysis of this study is the conventional theory of agricultural supply. This theory is based on the profit-maximising behaviour of a rational farmer (Heerink et al, 1997). Based on this theory, increasing prices of farm inputs would lead to decreases in the demand for these inputs, whereas increases in price of farm products are expected to lead to increases in market supply. For the purposes of this study, climate variables are added to the set of arguments of the well-behaved production function. Economic theory suggests that the supply function of an economic agent, the farmer in this study, starts with a well-behaved production function. In theory, the determinants of agricultural production comprise local conditions like soil type, climate, agricultural resources and the techniques used. Inputs and output are rates of resources used and the rate of production per unit of time respectively. The production function could be written as:

$$q_o = f(Z_i, F_i, W_i) \qquad (1)$$

where q_o is the output in a given time period, Z_i are the variable inputs, F_i are the fixed inputs and W_i are the climate variables. Variable inputs are those which change with the volume of output over the period of time to which the production function applies; for example, fertiliser, seeds and pesticides. The fixed inputs are those which cannot be changed during the period for which the production function is defined. The climate variables for this study are rainfall and temperature. The profit-maximising function consists of output and input prices and production factors, describing the farm's production technology at profit-maximising points in the set of production possibilities. Thus, it is assumed in the present study that maize farmers attempt to maximize profit defined as the return to the variable factors. The restricted profit function (Lau, 1976) is defined as follows:

$$\pi(p,c) = Max_q(p.q \mid q \in V(c), c \in C) \tag{2}$$

where q is a vector of outputs ($q_i > 0$) and inputs ($q_i < 0$), p is a vector of output and input prices, c is a set of fixed or environmental factors (such as fixed land endowment, weather indicators and government policies, captured by C) and V is the state of the technological constraint.

Applying Hotelling's Lemma yields the supply functions for output and demand functions for input variables:

$$q_i = \frac{\partial \pi}{\partial p_i} > 0 \tag{3}$$

$$q_k = \frac{\partial \pi}{\partial p_k} < 0 \tag{4}$$

where i and k represent output and input variables respectively.

From equation (3), the maize supply function is derived with temperature and rainfall, inter alia, as the relevant arguments. Notably, within the range of temperature and rainfall said to be ambient with respect to maize supply, increases in rainfall and temperature are likely to stimulate increases in maize supply and vice versa. From this theoretical framework, a number of hypotheses arise with prices of variable inputs and the product price (of maize) following the respective conventional negative and positive signs. The main focus of the present study is climate variables and the relevant hypotheses validated with respect to the climate variables are stated as follows.

3.4. Statement of Hypotheses

The hypotheses validated with respect to climate variables in this study are as follows (the null and alternative hypotheses are denoted as H_0 and H_1, respectively):

I. H_0: Rainfall exerts no effect on the supply of maize, versus

H_1: Rainfall exerts a positive effect on the supply of maize.

II. H_0: Temperature exerts no effect on the supply of maize, versus

H_1: Temperature exerts a negative effect on the supply of maize.

Here, climate change is captured by changes in temperature and rainfall. When rainfall is yet to reach its maximum, an increase in rainfall is likely to increase the supply of maize especially in Ghana where agriculture is largely rainfed. A higher maize supply is obtained during major rainy seasons; that is, the period of high rainfall (Leyenaar, 1976). According to the EPA (2000), the general decline in crop yields could be attributed to current high temperatures causing water stress through evaporation. Moisture stress during flowering, pollination and grain-filling is harmful to most crops; hence, a decrease in the supply of crops occurs in drought years when temperatures increase (Ofori-Sarpong, 1985; 2001). Also in the tropics where temperatures are already high (near their maximum), increases in temperature are likely to result in decreases in cereal (maize) supply (IPCC, 2001).

3.5. Empirical Model

The empirical model employed in this study is specified as in equation 5:

$$\text{Ln } Q_t = a_o + a_1 \ln P_t^m + a_2 \ln P_t^c + a_3 \ln P_t^r + a_4 \ln P_t^{npk} + a_5 \ln T_t + a_6 \ln R_t + e_t \qquad (5)$$

where $\ln Q_t$ denotes the natural logarithm of the output of maize, a_o is an intercept term, P_t^m is the real producer price of maize, P_t^c is the real producer price of cassava (specifically, the

price of a competitive crop). Cassava competes with maize for land and other agricultural resources in the ecological zone in which maize is cultivated. P_t^r is the real producer price of rice: this is another crop which competes with maize for agricultural resources. P_t^{npk} is the real price of the fertiliser used in the production of maize, T is the mean annual temperature in Ghana's maize belt and R is the mean annual rainfall in Ghana's maize belt. T and R represent climate variables in this study, and e_t is the error term which satisfies the classical normal regression assumptions. The *a priori* signs of the respective arguments of the function in equation (5) are as follows: $a_1 > 0$, $a_2 < 0$, $a_3 < 0$, $a_4 < 0$, $a_5 < 0$, $a_6 > 0$.

Notably, the prices of herbicides, maize seed, fungicides and agricultural wage rate relevant to maize production could be important additional arguments of the maize supply function, but lack of reliable complete time series data on these variables precludes their consideration in the present study.

3.6. Method of Estimation

Descriptive statistics of the variables employed in this study are analysed briefly, viz., mean, variance, skewness, kurtosis, median, inter alia. The coefficient of variation is computed in order to ascertain the level of variation of each variable. Prior to the estimation of the model using annual time series data, the degree of integration of each of the variables is ascertained. Thus, unit root tests are carried out.

The Augmented Dickey – Fuller (ADF) unit root test and the Phillip-Perron test are used in this study to identify the order of integration of each variable (that is, the number of times a variable needs to be differenced to make it stationary). The ADF procedure involves the estimation of the following regression:

$$\Delta X_t = \alpha + \beta t^* + (\rho - 1) X_{t-1} + \Sigma_i \lambda_i \Delta X_{t-i} + e_t \quad (6)$$

where X_t is the variable under consideration and t^* is the trend term. The ADF approach tests the null hypothesis that a series does contain a unit root (that is, it is non-stationary) against the alternative of stationarity. The order of integration is determined by the stage at which the ADF test confirms the stationarity of the variables. If the ADF test shows that the variable is stationary in level, the variable is said to be integrated of order zero [$I(0)$]. If stationarity is confirmed when the variable is in first difference, then the variable is said to be integrated of order one [$I(1)$]; in second difference, the variable is integrated of order two [$I(2)$]; and so on. The Philip-Perron test is used in the event of the existence of structural breaks in the time series data.

Cointegration is said to exist when a linear combination of a set of time series is stationary, given that the individual series are non-stationary (Engle and Granger, 1987). Cointegration of two or more time series suggests that there is a long-run or equilibrium relationship between them. Two conditions must be satisfied for variables to be co-integrated. First, the series for the individual variables must be non-stationary. Second, a linear combination of the non-stationary variables from a static regression involving levels of the variables must be stationary.

It is possible to have a mixture of different order series when there are three or more time series variables in the model. For example, it is possible that cointegration is present when there is a mix of $I(0)$, $I(1)$ and $I(2)$ variables in a model (Harris, 1995). Stationary, viz., $I(0)$ variables, might play a key role in establishing a sensible long-run relationship between non-stationary variables, especially if theory suggests *a priori* that such variables should be included in a model (Ibid). According to Pagan and Wickens (1989), in the case where variables are integrated of different orders, a subset of the higher-order series must

cointegrate to the order of the lower–order series. So, if $y_t \sim I(1)$, $x_t \sim I(2)$ and $z_t \sim I(2)$ then as long as we can find a cointegration relationship between x_t and z_t such that v_t ($v_t = x_t - \lambda z_t$) $\sim I(1)$, then v_t can potentially cointegrate with y_t to obtain w_t ($w_t = y_t - \xi v_t$) $\sim I(0)$. Also, if there are $n > 2$ variables in a model, there can be more than one cointegration vector. It is possible for up to $n - 1$ linearly independent cointegration vectors to exist, and this has implications for testing and estimating cointegration relationships (Harris, 1995). Johanssen (1985) also found some mathematically exact and attractive results for the general case which do not rely on the assumption that all components of x_t are integrated of the same order. He points out that, if x_{1t} is $I(1)$ and x_{2t} is $I(0)$, then x_{1t} and the mean of x_{2t} could be cointegrated; thus, expanding the class of variables that might be tested.

Based on the above literature, the long-run equation of the model in this study can be estimated as in equation (5), since as will be evident in Chapter 4, the climate variables are integrated of order $I(0)$, prices of own and competing commodities integrated at $I(1)$, maize supply integrated at $I(1)$, as well as price of fertiliser integrated as $I(1)$. The parameters are estimated using the Ordinary Least Square (OLS) method. These parameters describe the nature of the long-run relationship between the supply of maize in Ghana and the relevant determinants including the climate variables.

The Error Correction Model (ECM) developed by Engle and Granger is a means of reconciling the short run behaviour of an economic variable with its long-run behaviour (Gujarati, 1995). Granger and Engle (1985) proved that cointegrated series have an ECM representation and conversely, that ECMs generate cointegrated series, thus reconciling the two approaches as well as clarifying when levels information could be legitimately retained in econometric equations. The ECM is closely bound up with the concept of cointegration. Engle and Granger (1987) show that if y_t and x_t are cointegrated CI (1, 1), then there must exist an ECM.

A specification of the ECM involves the first difference of the dependent variable as a function of the distributed lags of the first differences of the independent variables as well as the one period lagged equilibrium error, referred to as the error correction term. In effect, it reinstates the levels, and hence the long-run considerations into the differences specification that describes the short-run relationships between the variables (Gujarati, 1995).

Hallam and Zanoli (1993) have demonstrated the relevance of the ECM to agricultural response, and how it avoids the partial adjustment mechanism's unrealistic assumption of a fixed target supply based on stationary expectations. In the present study, the ECM is formed for maize supply in the form:

$$\Delta Q_t = a_0 + a_1\Delta P^m{}_t + a_2\Delta P^c{}_t + a_3\Delta P^r{}_t + a_4\Delta P^{npk}{}_t + a_5\Delta T_t + a_6\Delta R_t + a_7 e_{t-1} + U_t \qquad (7)$$

where U_t is the error term and the other variables which are in natural logarithms are as already specified.

The Granger-Causality Test (Granger, 1969) is conducted to find out the causal relationships which exist between the relevant variables (the supply of maize, rainfall and temperature) in the study, since cointegration says nothing about the direction of the causal relationship that exist between the variables. The concept of Granger-causality is that there must be causality in at least one direction if two variables are found to be cointegrated. Granger-causality involves regressing a variable say Z on lagged values of itself and another variable say W. The model is:

$$Z_t = \sum_{i=1}^{n} \alpha_i W_{t-i} + \sum_{i=1}^{n} \beta_i Z_{t-i} + U_t \qquad (8)$$

where n represents the number of lags and U_t is the error term. Causality is determined by performing the relevant F-test.

In the present study, a series of experiments are conducted using the cointegration equation as specified in equation 5. Thus, different versions of this equation are experimented with. First, the dependent variable, supply of maize is regressed on the independent variables, namely, prices of maize, rice, cassava, fertiliser, the annual mean temperature and rainfall. The same regression procedure is performed with the squares of annual mean temperature and rainfall. The process is repeated with the annual mean temperature being replaced by annual mean maximum and minimum temperature. The regression is further repeated with the rainfall in the critical (major and minor) periods and non-critical period in place of the annual mean rainfall. The linear and square of annual mean temperature and rainfall could not be regressed together because the results showed a near-singular matrix.

3.7. Description of Variables and Sources of Data

Annual time series data on maize supply in Ghana, the producer prices of maize, rice and cassava, and the price of fertiliser (NPK:15-15-15) are obtained from the Ministry of Food and Agriculture, Ghana. The climate data for the major maize growing areas are obtained from the Ghana Meteorological Services Department. The real producer prices of maize, rice, cassava and fertiliser are obtained by deflating the available wholesale prices, since the relevant farm gate prices are not readily available. The deflator is the Consumer Price Index (CPI) and it is obtained from various issues of the *International Financial Statistics* (IFS), published by the International Monetary Fund (IMF). The base year is 1994. The various annual time series data used in this study cover the period 1970 to 2002.

Eleven weather stations are selected across the country. The selection is based on the weather stations located within the major maize producing areas in each region. Mean

monthly temperature and rainfall data are obtained from the Ghana Meteorological Services Department for these weather stations. Mean monthly maximum and minimum temperatures are also similarly acquired. The mean monthly temperature in each year is computed for each station and then averaged again using the eleven stations to get the annual mean monthly temperature for the country. A similar method is used for rainfall and the maximum and minimum temperatures.

To acquire the relevant data on rainfall during the critical periods (major and minor) and the non-critical period for maize, the rainfall during the months of major and minor rains, as well as the months with no or very few rains are computed for each station and then averaged for the whole country. The months of the major rains are March, April, May and June, which also represent the major planting season for maize. The minor rains are experienced in the months of July, August and September. Cultivation during the minor season is only recommended for the forest and transition zones and not for the coastal savannah. The non-critical periods are therefore the months of October, November, December, January and February.

CHAPTER 4

EMPIRICAL RESULTS

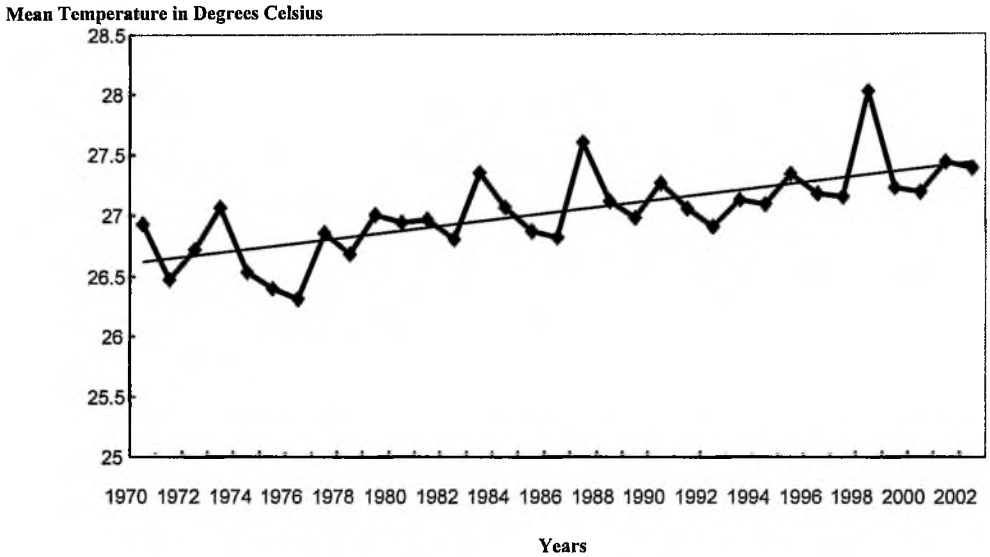
In this chapter, the time profiles of annual mean temperature, the annual mean deviation of temperature, the annual mean rainfall, the annual mean deviation of rainfall, and the output of maize in Ghana over the period of the study are described. The empirical estimates of the effect of climate change on maize supply in Ghana are also presented.

4.1. Time Profile of Annual Temperature

Figure 1 depicts the annual mean temperature in the maize growing areas in Ghana during the period 1970 – 2002. Temperature has been increasing gradually from the beginning of the stipulated time period. It however decreased between 1973 and 1976, but the general rise continued from that period. The highest temperature over the period of the study occurred in 1999 when it reached 28°C. Peak temperatures were also recorded in 1983, 1987, 1990, 1995 and 1998. Global warming due to the greenhouse effect may be part of the causes of the observed general increase in temperature.

Temperature increase may accelerate the rate at which plants release carbon dioxide (CO_2) in the process of respiration, resulting in less than optimal conditions for net growth (Ofori-Sarpong, 2001). Crops including maize often respond negatively with a steep drop in net growth and yield when temperatures exceed the optimal for biological processes (Ofori-Sarpong, 2001). The optimum range of temperature for the growth of maize is 16-32 degrees Celsius (Rouanet, 1992), but the most favourable temperature during germination is 18.3 degrees Celsius (Berger, 1962). Temperature below 10 degrees Celsius would result in lower crop yields (Berger, 1962), and fertilisation is disrupted when temperature exceeds 35 degrees Celsius (Rouanet, 1992).

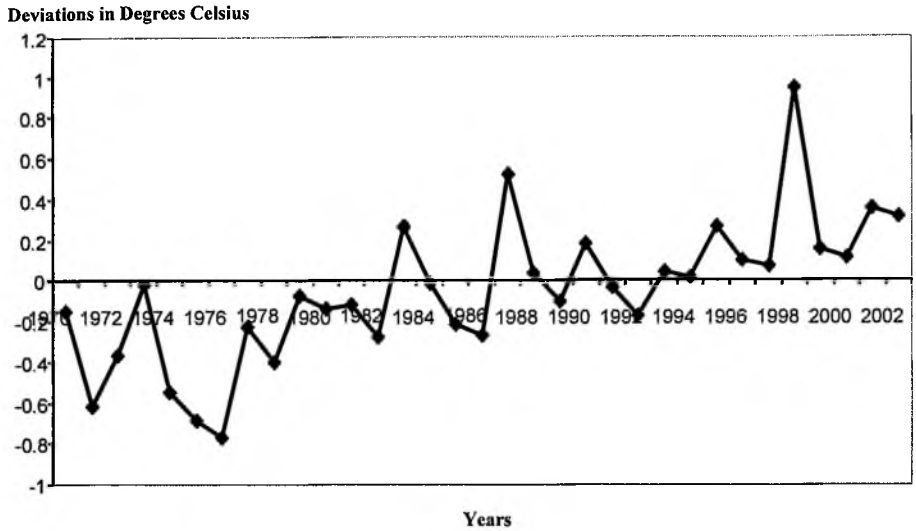
Figure 1. Annual Mean Temperature in Maize Growing Areas in Ghana, 1970-2002



Source: Based on data obtained from the Ghana Meteorological Services Department Accra, Ghana.

The deviations of annual temperatures from the mean temperature are depicted in Figure 2. A continuous increase in annual temperatures around the mean temperature is observed. The deviations of temperature from 1993 to 2002 have tended to move above the mean. This confirms Ontoyin's study on temperature at a number of stations in Ghana (Ontoyin, 1993). Increasing temperature due to global warming would further increase annual temperatures and their deviations from the mean.

Figure 2. Annual Mean Deviations in Temperature in Ghana, 1970-2002



Source: Author's computations based on data obtained from the Ghana Meteorological Services Department, Accra,Ghana.

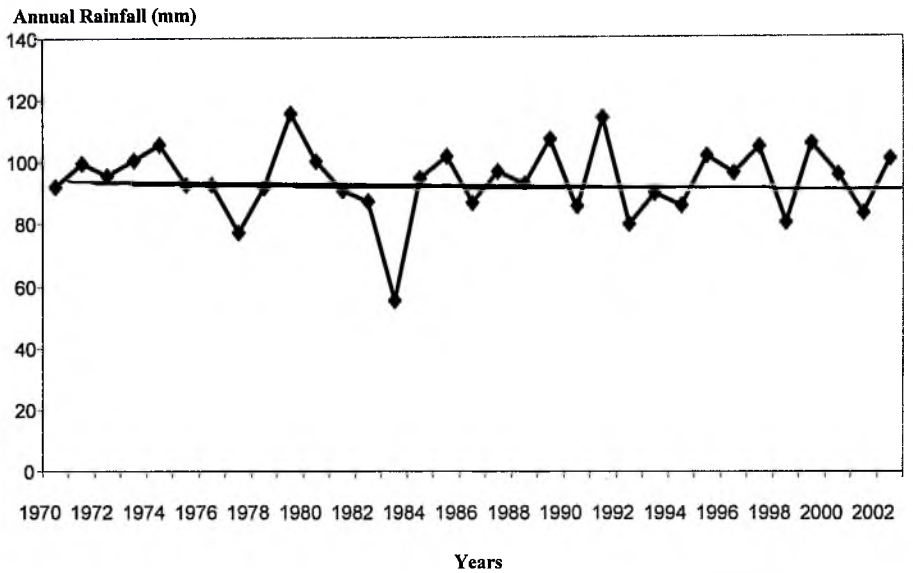
4.2. Time Profile of Annual Rainfall

In Ghana, annual mean rainfall in the maize growing areas has tended to fluctuate around a trend with a zero slope (Figure 3). Peak rainfall amounts were recorded in 1974, 1979, 1985, 1989, 1991, 1995, 1997 and 1999. The lower periods of decline in rainfall amounts occurred during 1977 and 1983.

The lowest amount of rainfall was recorded in 1983, which was a drought year (Figure 3). During times of drought, the length of the growing period for crops (maize inclusive) reduces due to lack or inadequate rains. Farmers are tempted to delay planting with the late onset of rains, since water availability strongly influences agriculture. With the abrupt ending of the rainy period, hence inadequate water, the growing period too becomes short for crops to give good harvest (Ofori-Sarpong, 1985). Moisture stress during flowering, pollination and grain filling is harmful to most crops (Leyenaar, 1976). Increasing evaporation from the soil and accelerated transpiration in the plants themselves cause

moisture stress. The intensified evaporation increases the hazard of salt accumulation in the soil, thus rendering it infertile. Here, inadequate rainfall precipitates lower levels of crop output.

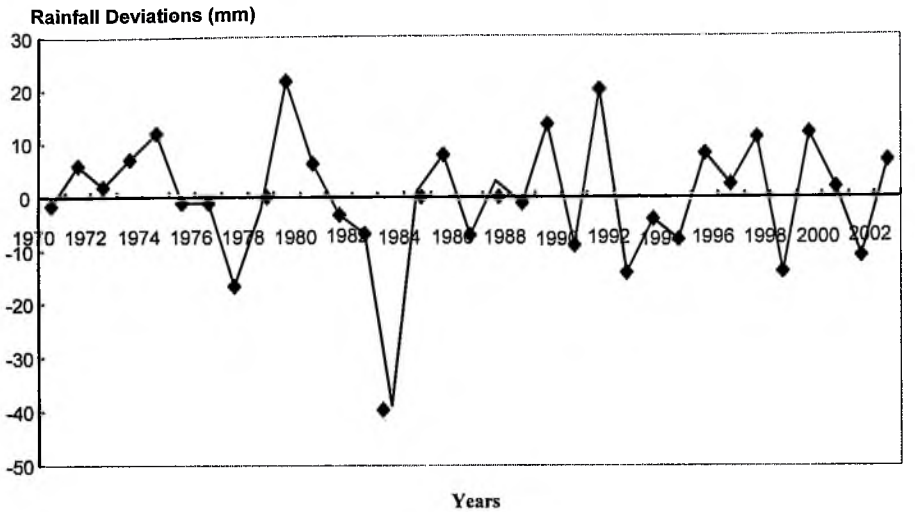
Figure 3. Annual Rainfall in Maize Growing Areas in Ghana, 1970-2002



Source: Based on data obtained from the Ghana Meteorological Services Department, Accra, Ghana.

The deviations of rainfall around the mean show fluctuations around the mean (Figure 4). Rainfall amounts fell below the mean in some years. The lowest deviation was recorded in the drought year (specifically, 1983) and the highest was recorded in 1979. In some years, the amount of rainfall hovered around the mean, and did not deviate much from the mean.

Figure 4. Annual Rainfall Deviations from the Mean. 1970-2002



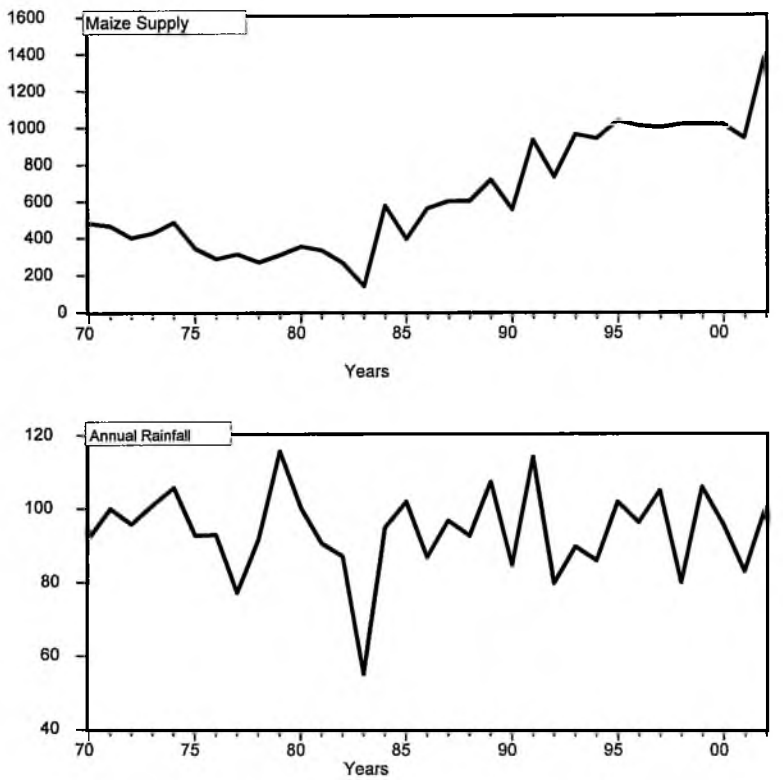
Source: Author's computations based on data obtained from the Ghana Meteorological Services Department, Accra,Ghana.

4.3. Time Profile of Maize Supply

In 1983 when there was drought, maize supply decreased precipitously (Figure 5). This indeed is the lowest supply of maize recorded during the period of the study. In years of decreased rainfall, supply of maize falls whereas increases in rainfall result in increases in the supply of maize. It is observed that from 1985 to the end of the period of the study, though the amount of rainfall recorded was not far from the mean, the supply of maize increased gradually. This could be explained by the use of fertilisers by farmers, improved cultivars of maize and early planting of seeds to mention but a few. Generally, increases in the annual mean temperature tend to be associated with increases in the supply of maize. Maize needs light and solar energy for photosynthesis, which is the food-producing process for plants. This increases plant growth and output of crops. However, it should be noted that other

factors could influence this relationship; for example, the prices of competitive crops like the price of rice and cassava.

Figure 5. Comparison of Maize Supply with Annual Rainfall, 1970-2002

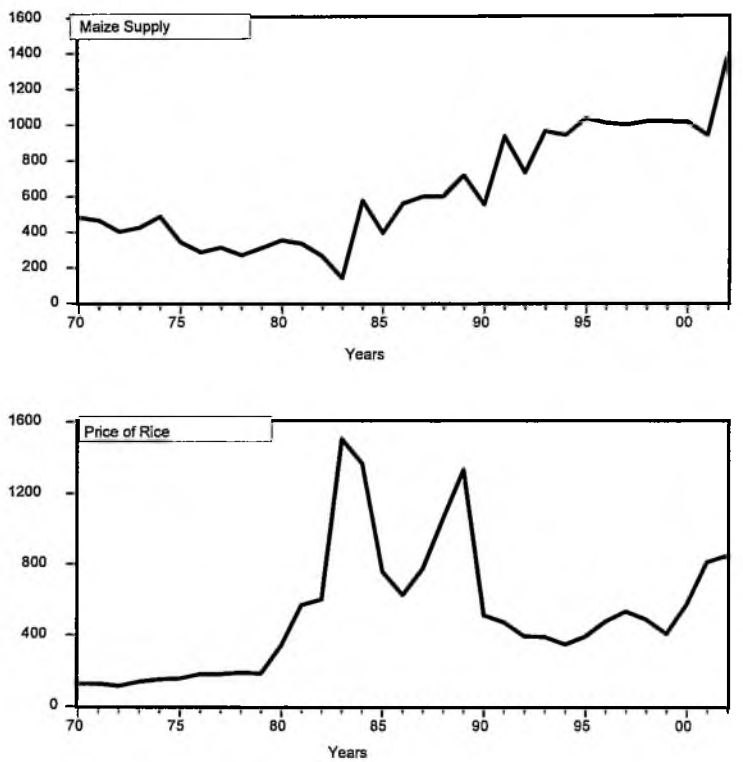


Source: Data on maize supply are obtained from the Ministry of Food and Agriculture, whereas data on rainfall are obtained from the Ghana Meteorological Services Department, Accra, Ghana.

The output of maize and the price of rice are generally indirectly related as can be observed in Figure 6. This suggests that maize and rice are competing crops; they compete for the land and other factor inputs of farmers. Farmers in anticipation of prices, carry out their cultivation accordingly. Hence, when they have a favourable anticipation of future

prices of a crop like maize, they tend to plant more at the expense of say rice and vice versa. Hence, a prediction of a high price of rice could precipitate a decrease the cultivation of maize and the supply of maize grain. An inverse relationship is observed between the price of rice and the output of maize (Figure 6). A notable observation in the time profile of the price of rice is the fluctuation witnessed between 1980 and 1994. A steady rise in the price of rice is observed after 1995.

Figure 6. Comparison of Maize Supply with the Prices of Rice, 1970-2002

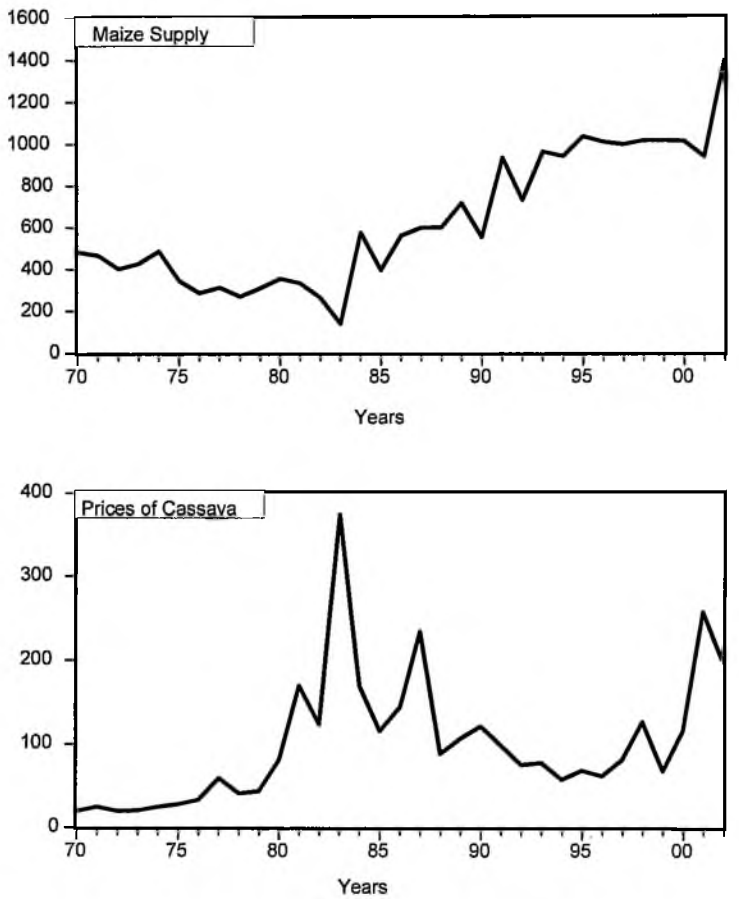


Source: Data on maize supply and price of rice are obtained from the Ministry of Food and Agriculture, Accra, Ghana.

The time profile of the price of cassava is not very different from that of the price of rice. The shock in prices that was witnessed in 1983 is also revealed in the price of cassava

(Figure 7). As with the price of rice, there seem to exist an inverse relationship between the price of cassava and the output of maize. Here again, an indication of cassava being a competing crop in relation to maize, specifically in land use.

Figure 7. Comparison of Maize Supply with Price of Cassava, 1970-2002



Source: Data on maize supply and price of cassava are obtained from the Ministry of Food and Agriculture, Accra, Ghana.

4.4. Descriptive Statistics of the Variables in the Econometric Model

The definitions of variables used are presented in Appendix 1. The descriptive statistics of the raw data concerning the relevant variables are presented in Table 1. The

Jarque-Bera statistic is significant for rain, maximum temperature, prices of cassava, maize, fertiliser (NPK: 15-15-15), the square of maximum temperature and the square of the non-critical rainfall period. This indicates that the null hypothesis of a normal distribution for each of these variables is rejected in favour of the alternative hypothesis that these variables are not normally distributed. This corroborates the fact that the skewness coefficient (which is equal to zero for normal distribution), is not equal to zero for each of these variables. In addition, the estimated kurtosis coefficients for these variables are generally greater than 3.

Supply of maize, mean rainfall, mean rainfall during the non-critical period, price of cassava, the square of the critical major and minor rainfall period, the square of rain and the square of maximum temperature have a kurtosis of less than 3. The data therefore seem not to follow a normal distribution. The estimated coefficient of variation shows low variance in temperature and its square and maximum temperature and its square (Table 1).

The descriptive statistics for the transformed data, viz., the natural logarithm of the price of rice, the natural logarithm of the square of temperature, the natural logarithm of the square of the non-critical rainfall period, the logarithm of the critical major rainfall period, the natural logarithm of temperature, the natural logarithm of the maximum and minimum temperature and the natural logarithm of the price of fertiliser (npk) are statistically significant according to the Jarque-Bera statistic and therefore not normally distributed (Appendix 2).

The correlation matrix shows that the climate variables, namely, temperature and rainfall, and their squares are characterised by high correlation (Appendix 3). There is a high positive correlation (0.776) between mean rainfall and mean critical minor rainfall as well as the square of mean rainfall and the square of mean critical minor rainfall. Similarly, mean temperature is highly correlated with mean minimum temperature (0.934). A high correlation is observed between the price fertiliser and the supply of maize (0.871). The price of maize

and the prices of cassava are also highly correlated (0.966) and the correlation between the prices of rice and cassava is 0.909.

The price of maize and the price of rice have a correlation of 0.939. Similarly, high correlation is observed between the square of minimum temperature and the square mean temperature (0.934). Minimum temperature and mean temperature are also highly correlated (0.934) as well as the square of the mean minimum temperature and mean temperature.

Table 1. Descriptive Statistics of the Relevant Variables: Raw Data, 1970-2002

	Maize	Rain	Temp	Maxt	Mint	NonC	Pxcass	Pxmaize	Pxnpk	Pxrice
MEAN	631.8	93.9	27.03	31.96	20.43	38.11	87.83	204.09	1.219	483.574
MEDIAN	559.1	94.9	27.05	31.93	20.43	39.22	75.38	176.74	0.668	470.074
MAXIMUM	1400.0	115.5	28.03	33.16	21.08	63.44	374.25	964.50	5.148	1503.00
MINIMUM	140.8	55.07	26.31	31.34	19.77	17.09	-108.43	-195.82	0.035	-309.62
STD. DEV.	315.72	11.654	0.350	0.438	0.284	9.240	85.999	209.438	1.450	410.773
SKEWNESS	0.472	-0.898	0.294	0.993	-0.184	0.157	1.123	1.305	1.420	0.746
KURTOSIS	2.184	5.141	3.88	3.99	3.421	3.906	5.773	6.512	4.190	3.364
C. V.	0.500	0.124	0.013	0.014	0.014	2.242	0.979	1.026	1.190	0.849
J. B.	2.142	10.74	1.54	6.772	0.430	1.266	17.510	26.323	13.035	3.242
PROB	0.343	0.005	0.463	0.034	0.806	0.531	0.000	0.000	0.001	0.198
OBS	33	33	33	33	33	33	33	33	33	33

Maize denotes output of maize, **Pxmaize** denotes real price of maize, **Pxcass** denotes real price of cassava, **Pxnpk** denotes real price of fertiliser, **Pxrice** denotes real price of rice, **Rain** denotes annual mean rainfall, **Temp** denotes annual mean temperature, **Maxt** denotes annual maximum mean temperature, **Mint** denotes annual minimum mean temperature, **NonC** denotes annual non-critical rains, **C.V** denotes coefficient of variation, **J.B** denotes Jarque-Bera statistic, **PROB** denotes probability, OBS denotes observation.
Source: Author's computations.

Continuation of Table 1.

	Sqcrmaj	Sqcrmin	Sqrain	Sqtemp	Sqmaxt	Sqmint	SqnonC	Crmaj	Crmin
MEAN	133725.8	245838.6	8951.03	730.64	1021.56	417.288	1535.47	354.91	457.96
MEDIAN	116262.4	207941.5	8999.97	731.68	1019.74	417.188	1538.35	340.97	456.01
MAXIMUM	256582.0	597230.5	13353.81	785.59	1099.68	44.142	4024.92	506.54	772.81
MINIMUM	48866.1	19849.3	3033.50	692.31	982.015	390.794	292.099	221.06	140.89
STD. DEV.	65432.7	178592.6	2083.11	18.93	28.192	11.603	731.648	89.49	192.99
SKEWNESS	0.497	0.477	-0.291	0.348	1.034	-0.135	1.163	0.191	-0.037
KURTOSIS	2.074	2.081	3.770	3.959	4.090	3.415	5.490	1.895	1.841
C. V.	0.489	0.726	0.233	0.026	0.028	0.028	0.476	0.252	0.421
J. B.	2.540	2.414	1.280	1.929	7.512	0.337	15.957	1.879	1.854
PROB.	0.281	0.299	0.527	0.381	0.023	0.845	0.000	0.391	0.396
OBS	33	33	33	33	33	33	33	33	33

Sqcrmaj denotes square of annual critical major rains, **Sqcrmin** denotes annual critical minor rains, **Sqrain** denotes square annual mean rainfall, **Sqtemp** denotes square annual temperature, **Sqmaxt** denotes square annual maximum temperature, **Sqmint** denotes square annual minimum temperature, **SqnonC** denotes square non-critical annual mean rains, **C.V** denotes coefficient of variation, **J.B** denotes Jarque-Bera **PROB** denotes probability, **OBS** denotes observation.
Source: Author's computations.

4.5. Empirical Results of Stationarity Tests

Before undertaking the econometric estimations, unit root tests using the Augmented Dickey-Fuller (ADF) and Phillip-Perron (PP) approaches are conducted to find out whether each variable is characterised by stationarity (or non-stationarity) and the order of integration of the variable. The Philip-Perron test is carried out to deal with some of the weaknesses of the Augmented Dickey-Fuller test, like dealing with the existence of structural breaks.

In conducting the ADF test on the variables under consideration, an attempt is made to determine the appropriate number of lagged difference terms to include in the ADF model. In this study, using the general ADF model with trend and intercept, unit root tests were conducted using lags from 1 to 5. The Akaike Information Criterion (AIC) and Schwartz-Bayes Information Criterion (SBIC) values for each model of a given lag were examined and compared. The number of lags in the model which had the smallest SBIC and AIC values with the DW statistic close to 2 was chosen as the appropriate number of lags to be used for the test (Johnston and DiNardo, 1997). For all the variables, both information criteria suggest that the ADF model should contain only 1 lag of the differenced term. Then the trend and intercept terms are closely examined. Models with insignificant trend and intercept terms were dropped for models with only the intercept. In cases where the intercepts were also not significant, the unit root tests were conducted using models with no intercept and trend terms. Column 2 of Table 2 shows the type of ADF model used for each variable tested for stationarity. It is clear from Column 5 of Table 2 that all the price variables and maize quantity are integrated of order 1 viz., I (1), while the climate variables are integrated of order zero.

To corroborate the results of the ADF unit root tests, the study further conducted stationarity tests using the Phillip-Perron approach (Table 3). The results of the Phillip-Perron test are consistent with the results of the Augmented Dickey-Fuller test.

Table 2. Results of Unit-Root Test (Augmented-Dickey Fuller) for 1970 to 2002

Variables	Model	t-statistic in level	t-statistic in 1st difference	Order of Integration
Maize output	T & I	-2.466458	-5.221123***	I (1)
Real price of maize	None	0.835426	-835426***	I (1)
Real price of rice	None	0.751117	-3.921808***	I (1)
Real price of cassava	None	0.966162	-5.091725***	I (1)
Real price of fertiliser	T & I	-2.433526	-4.838637***	I (1)
Temperature	T & I	-4.826504***		I (0)
Temperature square	T & I	-4.826504***		I (0)
Rain	I	-4.097348***		I (0)
Rain square	I	-4.097348***		I (0)
Max.temp.	T & I	-5.916444***		I (0)
Min.temp	T & I	-4.772944***		I (0)
Max.temp.square	T & I	-5.916444***		I (0)
Min.temp.square	T & I	-4.772944***		I (0)
Critical major rains	I	-4.164124***		I (0)
Critical major rains square	I	-4.164124***		I (0)
Critical minor rains	I	-4.176165***		I (0)
Critical minor rains square	I	-4.176165***		I (0)
Non-critical rains	I	-3.221440***		I (0)
Non-critical rains square	I	-3.221440***		I (0)

McKinnon Tables are used for the rejection Critical Values
T & I represent Trend and Intercept
I represent Intercept
"None" represents no Trend and Intercept
*** denotes significance at the 1 percent level, **denotes significance at the 5 percent level
All variables are in natural logarithms and climate variables are in annual means as well.
E-views econometric software is used in the performance of the tests.
Source: Author's computations.

Table 3. Results of Unit-Root Test (Phillip-Perron) for 1970 to 2002

Variables	Model	t-statistic in level	t-statistic in I[st] difference	Order of Integration
Maize output	T & I	-3.369688	-10.47194***	I (1)
Real price of maize	None	0.885123	-6.688509***	I (1)
Real price of rice	None	0.909598	-4.615568***	I (1)
Real price of cassava	I	-1.832079	-7.409832***	I (1)
Real price of fertiliser	T & I	-2.412061	-5.758878***	I (1)
Temperature	T & I	-6.217564***		I (0)
Temperature square	T & I	-6.217564***		I (0)
Rain	I	-6.037438***		I (0)
Rain square	I	-6.037438***		I (0)
Max.temp.	T & I	-7.159166***		I (0)
Min.temp	T & I	-5.209286***		I (0)
Max.temp.square	T & I	-7.159166***		I (0)
Min.temp.square	T & I	-5.209286***		I (0)
Critical major rains	I	-5.886277***		I (0)
Critical major rains square	I	-5.886277***		I (0)
Critical minor rains	I	-6.099075***		I (0)
Critical minor rains square	I	-6.099075***		I (0)
Non-critical rains	I	-4.694971***		I (0)
Non-critical rains square	I	-4.694971***		I (0)

McKinnon Tables are used for the rejection Critical Values
T & I represent Trend and Intercept
I represents Intercept
"None" represents no Trend and Intercept
*** denotes significance at the 1 percent level, ** denotes significance at the 5 percent level
All variables are in natural logarithm and climate variables are in annual means as well
E-views econometric software is used in the performance of the tests.
Source: Author's computations.

4.6. Empirical Results of Cointegration Analysis

Unit root tests are performed on the residuals of the present study's econometric models as specified in equation 5 on page 28 to find out whether the variables in each of the models are cointegrated. Testing for the stationarity of the error term in order to establish whether the relevant variables are cointegrated provides a way to determine whether there is a long run relationship between these variables (Johnston and DiNardo, 1997). The error terms are significant and therefore integrated of order zero [namely, $I(0)$].

The variables in Model 1 are thus cointegrated; hence, Model 1 shows the relevant long-run equilibrium relationship between maize supply, mean annual rainfall and temperature in the maize belt, the prices of maize, rice, fertiliser (npk: 15-15-15), and cassava (Table 4). The relevant ADF statistic of -3.529888 is significant at the 1 percent level, implying a rejection of the null hypothesis of non-stationary in favour of the alternative hypothesis of stationarity.

The R^2 is approximately 95 percent, meaning that the model explains 95 percent of the variation in maize supply. The F statistic with a probability value of (0.000) shows that the explanatory variables jointly explain maize supply. The estimated Durbin-Watson statistic of 2.23 shows the absence of an autocorrelation problem.

The econometric results for Model 1 further show that annual mean rainfall exerts a significant effect on the output of maize at the 1 percent level in the long-run. The positive coefficient of rainfall indicates that an increase in rainfall during the growth period of maize tends to stimulate an increase in maize supply, whereas a reduction in rainfall decreases maize supply. The significance of rainfall indicates how critical it is for maize to receive adequate rain at the developmental stage and its dependence on rainfall. Maize production in Ghana is largely rainfed. A 1 percent increase (decrease) in mean annual rainfall stimulates a 0.799 percent increase (decrease) in maize supply. A similar result was found by Muchena

(1994) as well as Muchena and Iglesias (1995) who observe that lower rainfall leads to lower maize output.

The significant negative coefficient of the price of rice at the 1 percent level shows that rice competes with maize for agricultural resources. A 1 percentage increase (decrease) in the price of rice tends to precipitate a 0.3058 percent decrease (increase) in the supply of maize.

Mean annual temperature, the prices of maize and cassava are not significant even at the 10 percent level. The coefficient of the price of fertiliser (NPK: 15-15-15), though statistically significant, does not conform to the a priori expectation. It is worth noting that this result is rather intriguing, since farmers are likely to purchase less fertiliser in the event of a rise in the price of fertiliser. Future studies could re-examine this issue.

Table 4. Cointegrating Equation: Model 1

Dependent Variable: lmaize
Sample: 1970 - 2002
Included observations: 33

Variable	Coefficient	Std. Error	t-Statistic	Prob.
C	-5.089971	9.887331	-0.514797	0.6110
Lrain	0.799244	0.211853	3.772631	0.0008
Ltemp	2.334991	3.010569	0.775598	0.4450
Lrpxmaize	-0.026529	0.161078	-0.164694	0.8705
Lrpxrice	-0.305780	0.111928	-2.731938	0.0112
Lrpxcassava	0.021508	0.125097	0.171933	0.8648
Lrpxnpk	0.403369	0.028034	14.38841	0.0000
R-squared	0.947318	Mean dependent var		6.315912
Adjusted R-squared	0.935161	S.D. dependent var		0.542588
S.E. of regression	0.138162	Akaike info criterion		-0.934943
Sum squared resid	0.496310	Schwarz criterion		-0.617502
Log likelihood	22.42657	F-statistic		77.92113
Durbin-Watson stat	2.231349	Prob(F-statistic)		0.000000
Jarque-Bera	3.530558	Prob(Jarque-Bera)		0.171139
Breusch-Godfrey	1.053805	Prob(Breusch-Godfrey)		0.314463
White Heteroscedasticity Test	0.353929	Prob(White Heteroscedasticity Test)		0.965717
Ramsey RESET Test	0.825026	Prob(Ramsey RESET Test)		0.372388
ADF Test Statistic of the Error Term	-3.529888	1% Critical Value*		-2.6395
		5% Critical Value		-1.9521
		10% Critical Value		-1.6214

Lrpxmaize denotes log of the real price of maize. **Lrpxrice** denotes the log of the real price of rice. **Lrpxcassava** denotes the log of the real price of cassava. **Lrpxnpk** denotes the log of the real price of fertiliser (npk). **Ltemp** denotes the log of annual mean temperature. **Lrain** denotes the log of annual mean rainfall. **lmaize** denotes output of maize.
Source: Author's computation.

To analyse the effects of minimum temperature and maximum temperature on the supply of maize, Model 1 is revised by substituting minimum and maximum temperatures for mean temperature to give Model 2. The error term of Model 2 is found to be stationary at the 1 percent level (Table 5). This implies the existence of a long-run relationship between supply of maize and mean annual rainfall, maximum and minimum temperature, prices of maize, rice, cassava and fertiliser. The high value of the R^2 demonstrates a high explanatory power of the independent variables in the model. The F–statistic with a low probability value of (0.000) shows that the explanatory variables jointly influence maize supply. The Durbin-Watson statistic with a value of 2.488 lies in the inconclusive region of the DW statistic table of range 2.224 and 3.184 in this model. The Breusch-Godfrey Test for first order autocorrelation shows no autocorrelation problem. Similarly, the Ramsey RESET Test does not reject the null hypothesis of no model misspecification.

In this model, the coefficient of rainfall is again positive and significant at the 1 percent level (Table 5). A 1 percent increase (decrease) in rainfall tends to stimulate (precipitate) a 0.857 percent increase (decrease) in maize supply in the long-run. An increase in the elasticity of maize with respect to rainfall is observed here. The increase is from 0.799 in the previous model to 0.857 in this model. Thus, maize supply seems to be more sensitive to rainfall when temperature is analysed using its maximum and minimum components. The price of rice still exhibits the significant competitive relationship between rice and maize supply.

Maximum temperature exerts a positive effect whereas minimum temperature exerts a negative effect, but both are not significant even at the 10 percent level. The insignificance of maximum and minimum temperatures cannot be attributed to multicollinearity because their correlation coefficient of 0.6 and those between minimum temperature and the other variables as well as those between maximum temperature and the other variables in the model are not

high. The relevant correlation coefficients hardly exceed 0.75 (Appendix 3) with the exception of mean square temperature and mean temperature (0.934). The coefficient of the price of maize in model 2 is seen to be positive but still not significant (Table 5). The price of cassava is not significant even at the 10 percent level. The price of fertiliser, though significant at the 1 percent level, still shows a positive coefficient, which is contrary to expectation.

Table 5. Cointegrating Equation: Model 2

Dependent Variable: lmaize
Sample: 1970 - 2002
Included observations: 33

Variable	Coefficient	Std. Error	t-Statistic	Prob.
C	-8.167712	8.754656	-0.932956	0.3598
Lrain	0.857075	0.218731	3.918390	0.0006
Lmaxtemp	3.529747	2.378796	1.483838	0.1504
Lmintemp	-0.607273	3.244894	-0.187147	0.8531
Lrpxmaize	0.024804	0.166946	0.148576	0.8831
Lrpxcassava	0.009843	0.123777	0.079524	0.9372
Lrpxrice	-0.334321	0.116685	-2.865149	0.0083
Lrpxnpk	0.405554	0.025282	16.04131	0.0000

R-squared	0.951321	Mean dependent var	6.315912
Adjusted R-squared	0.937691	S.D. dependent var	0.542588
S.E. of regression	0.135439	Akaike info criterion	-0.953368
Sum squared resid	0.458596	Schwarz criterion	-0.590578
Log likelihood	23.73057	F-statistic	69.79576
Durbin-Watson stat	2.487669	Prob(F-statistic)	0.000000
Jarque-Bera	3.093605	Prob(Jarque-Bera)	0.212928
Breusch-Godfrey	3.146688	Prob(Breusch-Godfrey)	0.088771
White Heteroscedasticity Test	0.328683	Prob(White Heteroscedasticity Test)	0.980139
Ramsey RESET Test	0.459465	Prob(Ramsey RESET Test)	0.504357
ADF Test Statistic of the Error Term	-4.078141	1% Critical Value*	-2.6395
		5% Critical Value	-1.9521
		10% Critical Value	-1.6214

Lrpxmaize denotes log of the real price of maize. **Lrpxrice** denotes the log of the real price of rice. **Lrpxcassava** denotes the log of the real price of cassava. **Lrpxnpk** denotes the log of the real price of fertiliser (npk). **Lmaxtemp** denotes the log of annual mean maximum temperature. **Lmintemp** denotes the log of annual mean minimum temperature **Lrain** denotes the log of annual mean rainfall. **Source:** Authors computation.

In order to analyse the effects of three other types of rainfall indicators, Model 1 is revised to include the amount of rainfall during the critical major rainfall periods, amount of rainfall during the critical minor rainfall periods and the amount of rainfall during the non-

critical rainfall periods instead of the mean annual rainfall, giving Model 3 (Table 6). Thus, climate variables included in the model are mean temperature, amount of rain in the critical major rainfall period (March, April, May and June) and minor rainfall period (July, August and September) and the non-critical rainfall period (January, February, October, November and December).

The ADF test statistic on the error term in Model 3 is significant, implying a significant long-run relationship between the variables (Table 6). The adjusted R^2 value is about 0.9366, showing an improvement in explanatory power over those of the previous models. The F statistic is significant at the 1 percent level, indicating that the explanatory variables in the model jointly explain maize supply. The estimated Durbin-Watson statistic with a value of 2.3687 lies in the inconclusive zone in the DW table. The coefficient of critical major rainfall period is positive as expected and it is significant at the 1 percent level.

Higher maize yields are obtained during major rainy seasons (Layenaar, 1976). The maize supply elasticity with respect to the mean critical major season rainfall is 0.614 (Table 6). It is lower than the elasticity with respect to annual mean rainfall. The critical major rainfall is that recorded during the period when plants receive the maximum amount of water which it needs for development. This is in consonance with Endrody-Younga (1968), who observed that maize planted in the major season have higher output since crop growth escapes heavy pest infestation and mature before insects could cause damage. Water availability also makes plant use of fertilisers more effective. The minor critical rainfall period is not significant even at the 10 percent level. This could be due to the fact that it is not always economically viable to plant in the minor critical period since planting during this period has to be done with irrigation, fertilisers, insecticides and improved cultivars of maize. The capital cost of irrigation is too much for the average farmer and the market price of

maize does not warrant such investment (Leyenaar, 1976). The coefficient of the non-critical period of rainfall is not significant even at the 10 percent level.

The price of rice is significant at the 5 percent level and has a negative coefficient. The price of fertiliser is significant but has an unexpected positive coefficient. The prices of cassava and maize are not significant even at the 10 percent level.

Table 6. Cointegrating Model 3

Dependent Variable: lmaize
Sample: 1970 - 2002
Included observations: 33

Variable	Coefficient	Std. Error	t-Statistic	Prob.
C	-10.19682	10.30724	-0.989286	0.3324
Ltemp	3.660503	3.106074	1.178498	0.2502
Lcrmj	0.614095	0.207304	2.962296	0.0068
Lcrminor	0.159845	0.128204	1.246798	0.2245
Lnoncrit	0.175061	0.107150	1.633795	0.1154
Lrpxmaize	-0.150204	0.181168	-0.829086	0.4152
Lrpxrice	-0.266200	0.114138	-2.332260	0.0284
Lrpxcassava	0.121986	0.140520	0.868101	0.3939
Lrpxnpk	0.388703	0.029115	13.35051	0.0000
R-squared	0.952477	Mean dependent var		6.315912
Adjusted R-squared	0.936636	S.D. dependent var		0.542588
S.E. of regression	0.136581	Akaike info criterion		-0.916797
Sum squared resid	0.447705	Schwarz criterion		-0.508659
Log likelihood	24.12715	F-statistic		60.12763
Durbin-Watson stat	2.368713	Prob(F-statistic)		0.000000
Jarque-Bera	3.407320	Prob(Jarque-Bera)		0.182016
Breusch-Godfrey	1.401034	Prob(Breusch-Godfrey)		0.248640
White Heteroscedasticity Test	0.291865	Prob(White Heteroscedasticity Test)		0.990744
Ramsey RESET Test	0.259101	Prob(Ramsey RESET Test)		0.615587
ADF Test Statistic of the Error Term	-4.568020	1% Critical Value*		-2.6395
		5% Critical Value		-1.9521
		10% Critical Value		-1.6214

Lrpxmaize denotes log of the real price of maize. **Lrpxrice** denotes the log of the real price of rice. **Lrpxcassava** denotes the log of the real price of cassava. **Lrpxnpk** denotes the log of the real price of fertiliser (npk). **Ltemp** denotes the log of annual mean temperature. **Lcrmj** denotes log of the amount of rainfall in the critical major rainfall periods. **Lcrminor** denotes log of the amount of rainfall in the critical minor rainfall periods. **Lnoncrit** denotes log of the amount of rainfall during the non-critical rainfall periods.
Source: Author's computation

Results of another variant of Model 1 are presented in Table 7. Here, a different set of climate indicators are included. The ADF statistic on the error term in Model 4 is significant and hence the variables in the model are cointegrated, implying a long-run relationship between the variables (Table 7). The value of the R^2 is 0.95, meaning that the model explains

95 percent of the variation in the supply of maize. The Durbin-Watson statistic of 2.61 lies in the inconclusive region using the DW table. The Breusch-Godfrey test shows the absence of first order autocorrelation. The F statistic is significantly different from zero, implying a significant joint effect of the explanatory variables.

Notably, the new climate variables in Model 4 are the amount of rainfall during the critical major rainfall period (March, April, May and June), minor rainfall period (July, August and September), and non-critical rainfall (January, February, October, November and December) periods, the maximum and minimum temperatures. In this model, both the critical major rainfall and the critical minor rainfall are positive and significant at the 1 percent level and the 10 percent level respectively.

Table 7. Cointegrating Equation: Model 4

Dependent Variable: lmaize
Sample: 1970 - 2002
Included observations: 33

Variable	Coefficient	Std. Error	t-Statistic	Prob.
C	-10.47062	9.115326	-1.148683	0.2625
Lcrmj	0.572933	0.196929	2.909344	0.0079
Lcrminor	0.246431	0.135083	1.824288	0.0811
Lnoncrit	0.151779	0.111460	1.361743	0.1865
Lmaxtemp	3.788078	2.460339	1.539657	0.1373
Lmintemp	-0.350872	3.373874	-0.103997	0.9181
Lrpxmaize	-0.056122	0.189732	-0.295799	0.7700
Lrpxcassava	0.087818	0.140334	0.625776	0.5376
Lrpxrice	-0.319306	0.118631	-2.691583	0.0130
Lrpxnpk	0.397301	0.025947	15.31205	0.0000

R-squared	0.955589	Mean dependent var	6.315912
Adjusted R-squared	0.938210	S.D. dependent var	0.542588
S.E. of regression	0.134874	Akaike info criterion	-0.923904
Sum squared resid	0.418393	Schwarz criterion	-0.470417
Log likelihood	25.24442	F-statistic	54.98727
Durbin-Watson stat	2.610053	Prob(F-statistic)	0.000000
Jarque-Bera	2.940236	Prob(Jarque-Bera)	0.229898
Breusch-Godfrey	3.617221	Prob(Breusch-Godfrey)	0.070359
White Heteroscedasticity Test	0.252774	Prob(White Heteroscedasticity Test)	0.996353
Ramsey RESET Test	0.166679	Prob(Ramsey RESET Test)	0.687026

ADF Test Statistic of the Error Term	-4.942032	1% Critical Value*	-2.6395
		5% Critical Value	-1.9521
		10% Critical Value	-1.6214

Lrpxmaize denotes log of the real price of maize. **Lrpxrice** denotes the log of the real price of rice. **Lrpxcassava** denotes the log of the real price of cassava. **Lrpxnpk** denotes the log of the real price of fertiliser (npk). **Lcrmj** denotes log of the critical major rainfall periods. **Lcrminor** denotes log of the critical minor rainfall periods. **Lnoncrit** denotes log of non-critical rainfall periods. **Lmaxtemp** denotes the log of annual mean maximum temperature. **Lmintemp** denotes the log of annual mean minimum temperature

Source: Author's computations.

The non-critical period is not significant even at the 10 percent level. The price of rice, which is significant at the 5 percent level, has the expected negative coefficient. The maximum and minimum temperatures are not significant. The price of fertiliser is significant but unexpectedly positive. The price of cassava and maize are not significant even at the 10 percent level.

Table 8 reports the results of a model with the square of mean temperature and the square of rainfall as the climate variables. The error term in Table 8 is significant at the 1 percent level and shows a long-run relationship between the variables in the model. The value of the R^2 shows that the explanatory variables in the Model explain 95 percent of the variation in maize supply. The F statistic is significantly different from zero. The Durbin-Watson statistic is 2.23 indicates that there is no autocorrelation problem in this model. The table further shows a similar outcome as with mean temperature and rainfall except that the magnitudes of the coefficients of the square of temperatures and rainfall changed. The coefficient of temperature increased from 2.335 in the case of mean temperature to 1.167 in the case of the square of mean temperature. The coefficient of rainfall however decreased from 0.799 in the mean rainfall to 0.399 in the case of the square of mean rainfall. Similar outcomes are observed for other cointegrating equations estimated, viz., Model 6, Model 7 and Model 8 (Appendix 4 to 6).

Table 8. Cointegrating Equation: Model 5

Dependent Variable: lmaize
Sample: 1970 2002
Included observations: 33

Variable	Coefficient	Std. Error	t-Statistic	Prob.
C	-5.089971	9.887331	-0.514797	0.6110
Lsqrain	0.399622	0.105927	3.772631	0.0008
Lsqtemp	1.167495	1.505284	0.775598	0.4450
Lrpxmaize	-0.026529	0.161078	-0.164694	0.8705
Lrpxrice	-0.305780	0.111928	-2.731938	0.0112
Lrpxcassava	0.021508	0.125097	0.171933	0.8648
Lrpxnpk	0.403369	0.028034	14.38841	0.0000

R-squared	0.947318	Mean dependent var	6.315912
Adjusted R-squared	0.935161	S.D. dependent var	0.542588
S.E. of regression	0.138162	Akaike info criterion	-0.934943
Sum squared resid	0.496310	Schwarz criterion	-0.617502
Log likelihood	22.42657	F-statistic	77.92113
Durbin-Watson stat	2.231349	Prob(F-statistic)	0.000000
Jarque-Bera	3.530558	Prob(Jarque-Bera)	0.171139
Breusch-Godfrey	1.053805	Prob(Breusch-Godfrey)	0.314463
White Heteroscedasticity Test	0.353929	Prob(White Heteroscedasticity Test)	0.965717
Ramsey RESET Test	0.825026	Prob(Ramsey RESET Test)	0.372388
ADF Test Statistic of the Error Term	-3.529888	1% Critical Value*	-2.6395
		5% Critical Value	-1.9521
		10% Critical Value	-1.6214

Lrpxmaize denotes log of the real price of maize. **Lrpxrice** denotes the log of the real price of rice. **Lrpxcassava** denotes the log of the real price of cassava. **Lrpxnpk** denotes the log of the real price of fertiliser (npk). **Lsqtemp** denotes the log of the square of annual mean temperature. **Lsqrain** denotes the log of the square of annual mean rainfall.
Source: Author's computations.

4.7. Results of Error Correction Modelling

The error correction model (ECM) provides a useful link between long-run equilibrium relationships and short-run (disequilibria) dynamics (Gujarati, 1995). The specification of the ECM involves expressing the first difference of the supply of maize as a function of the first difference of the independent variables in the cointegrating equation (specifically, prices of maize, rice, cassava and fertiliser, and the climate variables), as well as the one period lagged equilibrium error term. This error term is called the error correction term (ECT). It re-instates the levels, and hence the long-run considerations into the differences specification that describes the short-run relationships between the variables (Abdulai and Rieder, 1995).

The results of the ECM for the supply of maize with mean annual temperature and mean annual rainfall as climate variables, the prices of maize, rice, cassava and fertiliser (NPK: 15-15-15) which capture the short-run relationships are reported in Table 9. The general performance of the Error Correction Model 1 can be seen, inter alia, from the coefficient of determination (R^2) and the F statistic of 32.2264 which show the joint significance of the explanatory variables in explaining the variation in the change in maize supply in Ghana in the model (Table 9). The R^2 value of 0.9038 means that the model explains about 90 percent of the total variation in the change in maize supply. With respect to the diagnostic tests, the Jarque Bera statistic is not significant at the 5 percent level, implying that the null hypothesis of normally distributed residuals is not rejected. The F-statistic of the Breush-Godfrey serial correlation test is insignificant, suggesting that the residuals of the Error Correction Model 1 are not serially correlated. The White's heteroscedasticity test also shows that the null hypothesis of homoscedastic residuals is not rejected, since the F statistic reported is not significant at the 5 percent level. Furthermore, the null hypothesis of no model misspecification is not rejected, as indicated by the insignificant F statistic of the Ramsey reset test. On the whole the diagnostic tests indicate that there is no misspecification of the Error Correction Model 1.

The change in rainfall is significant with a positive coefficient (Table 9). Thus, a 1 percent change in rainfall tends to stimulate a 0.753 percent change in maize supply. This is similar to the results of Molua (2002), Muchena, (1994) and Muchena and Iglesias (1995), who conclude that a change in climate (for example a decrease in rainfall) may lower maize yield (and supply) due to water stress and a shortening of the favourable growing period. Change in the price of maize is significant at the 5 percent level. Change in the mean annual temperature, the prices of rice and cassava are not significant even at the 10 percent level.

The change in the price of fertiliser is significant but the coefficient is positive, which is not as expected.

Table 9. Error Correction Model 1

Dependent Variable: D(lmaize)
Sample(adjusted): 1971 - 2002
Included observations: 32 after adjusting endpoints

Variable	Coefficient	Std. Error	t-Statistic	Prob.
C	-0.010310	0.022207	-0.464266	0.6466
D(lrain)	0.753548	0.140303	5.370873	0.0000
D(ltemp)	1.314038	2.037076	0.645061	0.5250
D(lrpxmaize)	-0.234494	0.102988	-2.276909	0.0320
D(lrpxrice)	-0.067061	0.091716	-0.731175	0.4718
D(lrpxcassava)	0.114554	0.089077	1.286015	0.2107
D(lrpxnpk)	0.407435	0.057363	7.102745	0.0000
RESID01(-1)	-1.227594	0.192034	-6.392569	0.0000

R-squared	0.903840	Mean dependent var	0.033347
Adjusted R-squared	0.875794	S.D. dependent var	0.340841
S.E. of regression	0.120122	Akaike info criterion	-1.188295
Sum squared resid	0.346305	Schwarz criterion	-0.821861
Log likelihood	27.01272	F-statistic	32.22638
		Prob(F-statistic)	0.000000
Jarque-Bera	0.204760	Prob(Jarque-Bera)	0.902686
Breusch-Godfrey	0.531854	Prob(Breusch-Godfrey)	0.473190
White Heteroscedasticity Test	0.594201	Prob(White Heteroscedasticity Test)	0.834805
Ramsey RESET Test	0.586863	Prob(Ramsey RESET Test)	0.451426

DLrpxmaize denotes difference of the log of the real price of maize. **DLrpxrice** denotes the difference of the log of the real price of rice. **DLrpxcassava** denotes the difference of the log of the real price of cassava. **DLrpxnpk** denotes the difference of the log of the real price of fertiliser (npk). **DLtemp** denotes the difference of the log of annual mean temperature. **DLrain** denotes difference of the log of annual mean rainfall. **RESID01** denotes the error correcting term.
Source: Author's computations.

The adjustment coefficient has a negative sign, suggesting that any previous disequilibrium in the long-run maize supply relationship will be corrected in the current year. However, the magnitude of the adjustment coefficient is greater than 1 suggesting that any previous disequilibrium in the long-run maize supply is corrected more than proportionately in the short-run. In other words, maize supply in Ghana returns to its long-run equilibrium path in an oscillating manner following previous year's deviation from equilibrium. This oscillating equilibrium convergence in the maize supply relationship can be explained by the fact that in Ghana, maize supply experiences a glut in a particular period and a shortage in another period immediately following. Thus, it is not uncommon to experience "excess" supply of maize which dampens its price in one period and in another period shortage which

puts an upward pressure on the price. This glut-shortage movement in maize supply can be attributed partly to the unreliability and unpredictability of the weather variables, notably rain since generally agriculture in Ghana is rain-fed. Also, the glut-shortage movement could partly be due to the high sensitivity of farmers' behaviour to price incentives that makes them shift resources to the production of those farm produce that commanded relatively high price in the previous crop season.

The ECM for Model 2 (Table 10) is estimated by replacing the climate variables with mean annual rainfall and mean annual maximum and minimum temperatures. The Breusch-Godfrey of the Error Correction Model 2 in Table 10 implies the absence of autocorrelation. The value of the R^2 is 0.93 meaning that the model explains 93 percent of variation in the supply of maize. The F statistic is significantly different from zero. The White heteroscedasticity test also shows that the null hypothesis of homoscedastic residuals is not rejected, since the relevant White F statistic reported is not significant at the 5 percent level. The Jarque Bera statistic is not significant at the 5 percent level, implying that the residuals are normally distributed. The null hypothesis of no model misspecification is also not rejected, as indicated by the insignificant F statistic of the Ramsey RESET test.

Change in mean annual rainfall is significant at the 1 percent level with a positive coefficient. A 1 percent increase (decrease) in the first difference in rainfall tends to result in a 0.767 percent increase (decrease) in the change in the supply of maize. This confirms the view that, better rainfall conditions tend to enhance the supply of maize in Ghana (Ofori-Sarpong, 2001). Change in the price of fertiliser is significant but its effect does not have the expected sign. The change in the mean annual maximum and minimum temperatures are not significant even at the 10 percent level. The change in the prices of maize, rice and cassava are not significant even at the 10 percent level.

Table 10. Error Correction Model 2

Dependent Variable: D(lmaize)
Sample(adjusted): 1971 - 2002
Included observations: 32 after adjusting endpoints

Variable	Coefficient	Std. Error	t-Statistic	Prob.
C	-0.009631	0.019433	-0.495589	0.6249
D(lrain)	0.766674	0.123003	6.232976	0.0000
D(lmaxtemp)	1.487902	1.382166	1.076500	0.2929
D(lmintemp)	0.315382	1.965728	0.160440	0.8739
D(lrpxmaize)	-0.221234	0.090242	-2.451574	0.0222
D(lrpxcassava)	0.093772	0.074003	1.267149	0.2178
D(lrpxrice)	-0.061219	0.085275	-0.717898	0.4800
D(lrpxnpk)	0.396277	0.051910	7.633900	0.0000
RESID02(-1)	-1.362613	0.175042	-7.784504	0.0000

R-squared	0.929310	Mean dependent var	0.033347
Adjusted R-squared	0.904723	S.D. dependent var	0.340841
S.E. of regression	0.105207	Akaike info criterion	-1.433506
Sum squared resid	0.254578	Schwarz criterion	-1.021268
Log likelihood	31.93610	F-statistic	37.79571
		Prob(F-statistic)	0.000000
Jarque-Bera	0.296467	Prob(Jarque-Bera)	0.862230
Breusch-Godfrey	0.837136	Prob(Breusch-Godfrey)	0.370137
White Heteroscedasticity Test	0.610326	Prob(White Heteroscedasticity Test)	0.831274
Ramsey RESET Test	1.053579	Prob(Ramsey RESET Test)	0.315838

DLrpxmaize denotes difference of the log of the real price of maize. **DLrpxrice** denotes the difference of the log of the real price of rice. **DLrpxcassava** denotes the difference of the log of the real price of cassava. **DLrpxnpk** denotes the difference of the log of the real price of fertiliser (npk). **DLmaxtemp** denotes the difference of the log of annual mean maximum temperature. **DLmintemp** denotes the difference of the log of annual mean minimum temperature **DLrain** denotes difference of the log of annual mean rainfall. **Resid02** denotes the error correcting term.
Source: Author's computations.

Table 11 depicts the ECM results of a different combination of climate variables. These are the mean annual temperature, the mean annual critical major, critical minor and non-critical periods of rainfall. The Breusch-Godfrey LM test suggests an absence of serial correlation of the residuals. The value of the R^2 shows that 93 percent of the variation in the first difference of supply of maize is explained by the model. The F statistic shows a significant joint effect of the explanatory variables. The White's heteroscedasticity test shows that the null hypothesis of homoscedastic residuals is not rejected since the relevant F statistic reported is not significant at the 5 percent level. The Jarque-Bera statistic is not significant at the 5 percent level, implying that the residuals are normally distributed. The null hypothesis of no model misspecification is not rejected as indicated by the insignificant F statistic of the Ramsey RESET test.

Change in the mean annual critical major rainfall and change in non-critical rainfall are significant at the 1 percent level, with the expected positive sign for the mean annual critical major rainfall (Table 11). Change in the mean annual critical minor rainfall is not significant even at the 10 percent level. The change in the mean annual temperature, the prices of maize, rice and cassava are not significant even at the 10 percent level.

Table 11. Error Correction Model 3

Dependent Variable: D(lmaize)
Sample(adjusted): 1971 2002
Included observations: 32 after adjusting endpoints

Variable	Coefficient	Std. Error	t-Statistic	Prob.
C	-0.020612	0.020710	-0.995267	0.3304
D(ltemp)	2.186738	2.080076	1.051278	0.3045
D(lcrmj)	0.540790	0.145349	3.720632	0.0012
D(lcrminor)	0.148198	0.097870	1.514230	0.1442
D(lnoncrit)	0.293725	0.078300	3.751281	0.0011
D(lrpxmaize)	-0.311273	0.112702	-2.761905	0.0114
D(lrpxrice)	-0.027551	0.085252	-0.323164	0.7496
D(lrpxcassava)	0.235756	0.099459	2.370391	0.0270
D(lrpxnpk)	0.458841	0.059686	7.687619	0.0000
RESID03(-1)	-1.182686	0.181667	-6.510192	0.0000

R-squared	0.928942	Mean dependent var	0.033347
Adjusted R-squared	0.899873	S.D. dependent var	0.340841
S.E. of regression	0.107852	Akaike info criterion	-1.365814
Sum squared resid	0.255903	Schwarz criterion	-0.907772
Log likelihood	31.85303	F-statistic	31.95642
		Prob(F-statistic)	0.000000
Jarque-Bera	0.238257	Prob(Jarque-Bera)	0.887694
Breusch-Godfrey	1.614087	Prob(Breusch-Godfrey)	0.217814
White Heteroscedasticity Test	0.291865	Prob(White Heteroscedasticity Test)	0.990744
Ramsey RESET Test	0.259101	Prob(Ramsey RESET Test)	0.615587

DLrpxmaize denotes difference of the log of the real price of maize. **DLrpxrice** denotes the difference of the log of the real price of rice. **DLrpxcassava** denotes the difference of the log of the real price of cassava. **DLrpxnpk** denotes the difference of the log of the real price of fertiliser (npk). **DLtemp** denotes the difference of the log of annual mean temperature. **DLrain** denotes difference of the log of annual mean rainfall. **DLcrmj** denotes the difference of the log of critical major rainfall periods. **DLcrminor** denotes the difference of the log of critical minor rainfall periods **DLnoncrit** denotes the difference of the log of non-critical periods RESID03 denotes the error correcting term.
Source: Author's computations

In Table 12, the ECM is estimated with climate variables, mean annual critical major, minor and non-critical rainfall periods, and mean annual maximum and minimum temperatures for the short-run equilibrium analysis. The Breusch-Godfrey LM test suggests the absence of serial correlation of the residuals. The model explains 95 percent of the variation in the supply of maize. The F statistic is significantly different from zero. The

White's heteroscedasticity test shows that the null hypothesis of homoscedastic residuals is not rejected since the F statistic reported is not significant at the 5 percent level. The Jarque-Bera statistic is not significant at the 5 percent, implying that the residuals are normally distributed. The null hypothesis of no model misspecification is not rejected, as indicated by the insignificant F statistic of the Ramsey reset test even at the 10 percent level.

Table 12. Error Correction Model 4

Dependent Variable: D(lmaize)
Sample(adjusted): 1971 2002
Included observations: 32 after adjusting endpoints

Variable	Coefficient	Std. Error	t-Statistic	Prob.
C	-0.017894	0.018005	-0.993831	0.3316
D(lcrmj)	0.482369	0.116187	4.151675	0.0005
D(lcrminor)	0.210012	0.085336	2.461005	0.0226
D(lnoncrit)	0.270991	0.070165	3.862188	0.0009
D(lmaxtemp)	1.510380	1.266399	1.192657	0.2463
D(lmintemp)	-0.090760	1.882117	-0.048222	0.9620
D(lrpxmaize)	-0.259115	0.099585	-2.601953	0.0166
D(lrpxcassava)	0.195317	0.086782	2.250651	0.0352
D(lrpxrice)	-0.037815	0.078418	-0.482224	0.6346
D(lrpxnpk)	0.435717	0.053141	8.199305	0.0000
RESID04(-1)	-1.322840	0.163193	-8.105963	0.0000

R-squared	0.948897	Mean dependent var	0.033347
Adjusted R-squared	0.924563	S.D. dependent var	0.340841
S.E. of regression	0.093615	Akaike info criterion	-1.632970
Sum squared resid	0.184038	Schwarz criterion	-1.129123
Log likelihood	37.12752	F-statistic	38.99379
		Prob(F-statistic)	0.000000
Jarque-Bera	0.109725	Prob(Jarque-Bera)	0.946615
Breusch-Godfrey	2.887945	Prob(Breusch-Godfrey)	0.104747
White Heteroscedasticity Test	0.651497	Prob(White Heteroscedasticity Test)	0.804923
Ramsey RESET Test	0.030338	Prob(Ramsey RESET Test)	0.863475

DLrpxmaize denotes difference of the log of the real price of maize. **DLrpxrice** denotes the difference of the log of the real price of rice. **DLrpxcassava** denotes the difference of the log of the real price of cassava. **DLrpxnpk** denotes the difference of the log of the real price of fertiliser (npk). **DLmaxtemp** denotes the difference of the log of annual mean maximum temperature. **DLmintemp** denotes the difference of the log of annual mean minimum temperature. **DLcrmj** denotes the difference of the log of critical major rainfall periods. **DLcrminor** denotes the difference of the log of critical minor rainfall periods **DLnoncrit** denotes the difference of the log of non-critical periods RESID04 denotes the error correcting term.
Source: Author's computations.

The change in the mean annual critical major rainfall is significant at the 1 percent level with a coefficient of 0.482. This implies that a 1 percent increase in the first difference of rainfall tends to increase the supply of maize by about 0.482 percent. The change in the prices of maize, rice, cassava and the mean annual maximum and minimum temperatures are

not significant even at the 10 percent level. The insignificance of the mean annual maximum and minimum temperatures could be due to the small variation in these two variables.

The ECM with the squares of the mean annual rainfall and temperature as climate variables is presented in Table 13. With the exception of the square annual mean rainfall, which is significant at the 1 percent level, all the independent variables are insignificant even at the 10 percent level. The value of the R^2 is 0.90. The F statistic is significantly different from zero. There are no heteroscedastic and autocorrelation problems. Other Error Correction Models are presented in Appendix 7 through Appendix 9; these show similar results.

Table 13. Error Correction Model 5

Dependent Variable: D(lmaize)
Sample(adjusted): 1971 - 2002
Included observations: 32 after adjusting endpoints

Variable	Coefficient	Std. Error	t-Statistic	Prob.
C	-0.010310	0.022207	-0.464266	0.6466
D(lsqrain)	0.376774	0.070151	5.370873	0.0000
D(lsqtemp)	0.657019	1.018538	0.645061	0.5250
D(lrpxmaize)	-0.234494	0.102988	-2.276909	0.0320
D(lrpxrice)	-0.067061	0.091716	-0.731175	0.4718
D(lrpxcassava)	0.114554	0.089077	1.286015	0.2107
D(lrpxnpk)	0.407435	0.057363	7.102745	0.0000
RESID05(-1)	-1.227594	0.192034	-6.392569	0.0000

R-squared	0.903840	Mean dependent var	0.033347
Adjusted R-squared	0.875794	S.D. dependent var	0.340841
S.E. of regression	0.120122	Akaike info criterion	-1.188295
Sum squared resid	0.346305	Schwarz criterion	-0.821861
Log likelihood	27.01272	F-statistic	32.22638
		Prob(F-statistic)	0.000000
Jarque-Bera	0.204760	Prob(Jarque-Bera)	0.902686
Breusch-Godfrey	0.531854	Prob(Breusch-Godfrey)	0.473190
White Heteroscedasticity Test	0.594201	Prob(White Heteroscedasticity Test)	0.834805
Ramsey RESET Test	0.586863	Prob(Ramsey RESET Test)	0.451426

DLrpxmaize denotes difference of the log of the real price of maize. **DLrpxrice** denotes the difference of the log of the real price of rice. **DLrpxcassava** denotes the difference of the log of the real price of cassava. **DLrpxnpk** denotes the difference of the log of the real price of fertiliser (npk). **DSqLtemp** denotes the difference of the log of the square of annual mean temperature. **DSqLrain** denotes difference of the log of the square of annual mean rainfall. **RESID05** denotes the error correcting term.
Source : Author's computations

4.8. Results of Granger-Causality Tests

In this study, Granger Causality Tests are performed to determine whether the level of maize supply is caused by temperature and whether rainfall causes maize supply. The results in Table 14 show there is a uni-directional causal relationship between maize supply and temperature and between maize supply and rainfall at lag two. This is in consonance with theory and the relevant existing empirical literature (see for instance, Muchena, 1994, Muchena and Iglesias, 1995; Molua, 2002).

Table 14. Results of the Granger Causality Tests between the Supply of Maize, Rainfall and Temperature.

Null Hypothesis:	Obs	F-Statistic	Probability
LRAIN does not Granger Cause LQMAIZE	31	5.37978***	0.01109
LQMAIZE does not Granger Cause LRAIN	31	0.45611	0.63872
LTEMP does not Granger Cause LQMAIZE	31	4.45421***	0.02171
LQMAIZE does not Granger Cause LTEMP	31	1.26923	0.29789

*** represents significance at the 1 percent level. **LRAIN** denotes annual mean rainfall; **LQMAIZE** denotes maize supply.
Source : Author's computations.

CHAPTER 5

SUMMARY AND RECOMMENDATIONS

5.1. Summary and Policy Recommendations

This study has analysed the effects of climate change on maize supply in Ghana during 1970-2002. The climate variables used are temperature and rainfall. The study employs econometric modelling to quantify the effects of climate change (specifically, changes in rainfall and temperature) on the supply of maize and provides a theoretical foundation for the modelling based on the theory of the firm. It uses the techniques of cointegration and error correction modelling. Cointegration is applied to validate the long-run equilibrium relationships between the time series data employed.

The present study observes that rainfall and change in rainfall have consistently been found to be significant in all the models with coefficients having the expected positive signs. This is consistent with the relevant existing literature (see for instance, Hamid, 1984; Schulze et al, 1996; Muchena, 1994 and Ofori-Sarpong 2001). These clearly suggest a large dependence of maize supply on rainfall in Ghana. In the present study, it is observed that inadequate rainfall in Ghana adversely affects the supply of maize, and income of maize farmers and food security in the country, ceteris paribus. The economic welfare of inhabitants in general would decrease, ceteris paribus. Some of the strategies adopted by farmers in the case of decreased rainfall as a result of climate change are the use of drought resistant crops, shifting the planting season, relying on more legumes than cereals and selling their labour for cash and food (Ofori-Sarpong, 2001).

Critical major periods of rains were significant in the present study's models because these are the periods when crop growth escapes heavy infestation and mature before insects could cause severe damage. Maize planted during this period are said to be planted early and

this activity minimizes moisture stress during flowering and grain-filling period and insect population are also at low levels at the beginning of this period. Temperature, however, has not been significant in determining the supply of maize. This could be due to the small variation in the annual mean temperature. This in turn, may be because the period covered in the present study, viz., 1970 – 2002, may be too short for an observation of significant variation in temperature.

The empirical results of the present study suggest that policy makers should take the issue of climate change (Global Warming) seriously. The effect of climate change on maize farmers who have the ability to adapt and with the availability of technology is likely to be less serious. Improvement in technology such as establishment of irrigation facilities and the rehabilitation of old ones, as well as teaching adaptive measures and making it part of national policies even before the onset of adverse effect of climate change would help maize farmers in particular and the nation in general.

The present study's observation that rainfall is significant in all the estimated models shows how important water is to the production of maize. Hence, maize farmers should be encouraged to plant their maize early during the major rainy season during which time the rains are fairly stable and reliable. Due to the significant influence of rainfall on maize supply, the Meteorological Stations and the Ministry of Food and Agriculture should have regular consultations and effectively monitor current climate and environmental conditions in the country to establish an early warning system.

5.2. Limitations of the Study and Suggestions for Future Research

Due to lack of data, the study could not incorporate information like the effect of actual agricultural wage rate on maize supply. The fees charged by the Ghana Meteorological Service Department on the delivery of meteorological data was a constraint to the acquisition

of a longer-term time series data set for rainfall and temperature from the various weather stations selected. A larger time series data on climate variables as well as the inclusion of data on relative humidity, evaporation rates may improve the understanding of the effect of climate change on maize supply. The inclusion of annual time series data on agricultural wages, land rent, and soils may improve the outcome of the study; this was not possible due to lack of data. Most farmers in Ghana are small-scale and do not normally keep records of their assets. In addition, annual time series data on the quantities and prices of insecticides used in maize production are not available.

Increases in rainfall normally increase the output of crops (maize inclusive), but this increase in output is only to a point, which is referred to as its maximum. Continuous increase in rainfall from this maximum rather leads to decreases in output. This theory may be captured by climate variables (rainfall and temperature) and their squares in the relevant models. The estimation of this model was however impossible due to the existence of a near linear correlation relationship in the climate variables and their squares, hence a singular matrix.

APPENDICES

Appendix 1. Definition of Variables

Variable	Definition
Lmaize	Output of maize
Lpxmaize	Real price of maize
Lpxrice	Real price of rice
Lpxcassava	Real price of cassava
Lpxnpk	Real price of fertiliser (npk)
Lrain	Rainfall
Ltemp	Temperature
Lcrmaj	Critical major rainfall
Lcrmin	Critical minor rainfall
LnonC	Non-critical rainfall
Lmaxt.	Maximum temperature
lmint.	Minimum temperature
Lsqrain	Square rainfall
Lsqtemp	Square temperature
Lsqmaxt	Square maximum temperature
Lsqmint	Square minimum temperature
Lsqcrmaj	Square of critical major rainfall
Lsqcrmin	Square of critical minor rainfall
LsqnonC	Square of non-critical rainfall
ecm_I	The error correction term

*Climate variables are in annual means and all real prices are in natural logarithms.

Appendix 2 Descriptive Statistics of the Relevant Variables: Transformed data (The natural log of data)

	Maize	Rain	Temp	Maxt	Mint	NonC	Pxcass	Pxmaize	Pxnpk	Pxrice
MEAN	6.316	5.840	1.505	3.609	4.534	3.297	6.021	1.310	4.198	5.029
MEDIAN	6.326	5.832	1.504	3.669	4.552	3.298	6.123	1.310	4.352	5.232
MAXIMUM	7.244	6.228	1.521	4.150	4.750	3.333	6.650	1.324	5.925	6.872
MINIMUM	4.947	5.398	1.496	2.839	4.009	3.270	4.948	1.296	0.950	1.822
STD. DEV.	0.543	0.258	0.006	0.264	0.136	0.013	0.497	0.006	0.964	0.994
SKEWNESS	-0.330	-0.141	0.953	-0.927	-1.655	0.242	-0.661	-0.233	-1.063	-0.949
KURTOSIS	2.437	1.909	3.891	4.679	7.831	3.806	2.364	3.432	5.161	4.548
C. V.	0.385	0.136	0.044	0.004	0.083	0.005	0.073	0.030	0.004	0.086
J. B.	1.035	1.746	6.090	8.600	47.147	1.215	2.958	0.556	12.638	8.255
PROB.	0.596	0.148	0.048	0.014	0.000	0.545	0.228	0.757	0.002	0.016
OBS	33	33	33	33	33	33	33	33	33	33

Maize denotes output of maize, **Pxmaize** denotes real price of maize, **Pxcass** denotes real price of cassava, **Pxnpk** denotes real price of fertiliser, **Pxrice** denotes real price of rice, **Rain** denotes annual mean rainfall, **Temp** denotes annual mean temperature, **Maxt** denotes annual maximum mean temperature, **Mint** denotes annual minimum mean temperature, **NonC** denotes annual non-critical rains, **C.V** denotes coefficient of variation, **J.B** denotes Jarque-Bera, **PROB** denotes probability, OBS denotes observation.

Source: Author's computations

pendix 2. Continued

	Sqcrmaj	Sqcrmin	Sqrain	Sqtemp	Sqmaxt	Sqmint	SqnonC	Crmaj	Crmin
EAN	3.768	5.940	11.680	6.929	12.042	6.033	7.218	9.068	6.594
EDIAN	4.269	6.153	11.664	6.927	12.245	6.034	7.338	9.105	6.595
AXIMUM	5.856	7.315	12.455	7.003	13.300	6.096	8.300	9.500	6.666
INIMUM	1.386	4.363	10.797	6.890	9.896	5.968	5.677	8.017	6.540
STD. DEV.	1.450	0.807	0.516	0.027	0.993	0.028	0.527	0.273	0.026
SKEWNESS	-0.201	-0.167	-0.141	0.953	-0.661	-0.233	-0.927	-1.655	0.242
KURTOSIS	1.425	1.997	1.909	3.891	2.364	3.432	4.679	7.831	3.806
C. V.	0.044	0.004	0.073	0.030	0.004	0.083	0.005	0.230	0.198
J. B.	3.634	1.536	1.746	6.090	2.958	0.556	8.600	47.147	1.215
PROB.	0.162	0.464	0.418	0.048	0.008	0.757	0.014	0.000	0.545
OBS	33	33	33	33	33	33	33	33	33

Sqcrmaj denotes square of annual critical major rains, **Sqcrmin** denotes annual critical minor rains, **Sqrain** denotes square annual mean rainfall, **Sqtemp** denotes square annual temperature, **Sqmaxt** denotes square annual maximum temperature, **Sqmint** denotes square annual minimum temperature, **SqnonC** denotes square non-critical annual mean rains, **C.V** denotes coefficient of variation, **J.B** denotes Jarque-Bera **PROB** denotes probability, **OBS** denotes observation.

Source: Author's computations

Appendix 3. Correlation Matrix of Variables

	lcrmin	lcrmj	lmaxt	lmint	lnonC	lmaize	lrain	lpxcas	lpxmaize	lpxnpk
lcrmin	1.000	0.304	-0.23	-0.03	0.066	0.279	0.776	-0.12	-0.14	0.130
lcrmj	0.304	1.000	-0.20	-0.16	0.169	0.351	0.739	-0.34	-0.23	0.106
lmaxt	-0.232	-0.21	1.000	0.608	-0.05	0.341	-0.22	0.377	0.342	0.406
lmint	-0.030	-0.16	0.608	1.000	-0.13	0.439	-0.13	0.669	0.660	0.603
lnonC	0.067	0.169	-0.05	-0.13	1.000	0.067	0.460	-0.48	-0.50	-0.21
lmaize	0.279	0.351	0.341	0.439	0.067	1.000	0.361	0.162	0.165	0.871
lrain	0.776	0.739	-0.22	-0.13	0.460	0.361	1.000	-0.38	-0.35	0.061
lpxcas	-0.117	-0.34	0.377	0.669	-0.48	0.163	-0.38	1.000	0.966	0.543
lpxmaize	-0.142	-0.23	0.342	0.660	-0.51	0.165	-0.35	0.966	1.000	0.554
lpxnpk	0.131	0.106	0.407	0.603	-0.21	0.871	0.061	0.543	0.554	1.000
lpxrice	-0.025	-0.16	0.335	0.575	-0.48	0.254	-0.24	0.909	0.939	0.640
lsqcrmj	0.304	1.000	-0.20	-0.16	0.169	0.351	0.739	-0.34	-0.23	0.106
lsqcrmin	1.000	0.304	-0.23	-0.03	0.067	0.279	0.775	-0.11	-0.14	0.130
lsqmaxt	-0.232	-0.20	1.000	0.608	-0.05	0.341	-0.22	0.377	0.342	0.406
lsqmint	-0.030	-0.16	0.608	1.000	-0.13	0.439	-0.13	0.669	0.660	0.603
lsqnonC	0.067	0.169	-0.05	-0.13	1.000	0.067	0.460	-0.48	-0.51	-0.210
lsqrain	0.776	0.739	-0.22	-0.13	0.460	0.361	1.000	-0.38	-0.35	0.061
lsqtemp	0.008	-0.23	0.617	0.934	-0.28	0.511	-0.02	0.62	0.611	0.672
ltemp	0.008	-0.23	0.618	0.934	-0.28	0.511	-0.20	0.62	0.611	0.672

lcrmin denotes critical minor rainfall; **lcrmj** denotes critical major; **lmaxt** denotes maximum temperature; **lmint** denotes minimum temperature; **lnonC** denotes non-critical rainfall; **lmaize** denotes maize output; **lrain** denotes rainfall; **lpxcas** denotes prices of cassava; **lpxmaize** denotes prices of maize; **lpxnpk** denotes prices of fertilizer.

Source: Author;s computations

Appendix 3. Continued

	lpxrice	lsqcrmj	lsqcrmin	lsqmaxt	lsqmint	lsqnonC	lsqrain	lsqtemp	ltemp
lcrmin	-0.024	0.304	1.000	-0.232	-0.030	0.066	0.775	0.008	0.008
lcrmj	-0.160	1.000	0.304	-0.205	-0.165	0.169	0.739	-0.230	-0.23
lmaxt	0.335	-0.205	-0.232	1.000	0.608	-0.055	-0.220	0.617	0.617
lmint	0.575	-0.165	-0.030	0.608	1.000	-0.129	-0.128	0.934	0.934
lnonC	-0.482	0.169	0.066	-0.055	-0.129	1.000	0.460	-0.284	-0.28
lmaize	0.253	0.351	0.279	0.341	0.439	0.067	0.361	0.511	0.511
lrain	-0.243	0.739	0.775	-0.220	-0.128	0.460	1.000	-0.202	-0.20
lpxcas	0.909	-0.340	-0.116	0.377	0.669	-0.486	-0.386	0.625	0.625
lpxmaize	0.939	-0.234	-0.141	0.342	0.660	-0.506	-0.356	0.611	0.611
lpxnpk	0.640	0.106	0.130	0.406	0.603	-0.210	0.061	0.672	0.672
lpxrice	1.000	-0.160	-0.024	0.335	0.575	-0.482	-0.243	0.561	0.561
lsqcrmj	-0.160	1.000	0.304	-0.205	-0.165	0.169	0.739	-0.230	-0.23
lsqcrmin	-0.024	0.304	1.000	-0.232	-0.030	0.066	0.775	0.008	0.008
lsqmaxt	0.335	-0.205	-0.232	1.000	0.608	-0.055	-0.220	0.617	0.617
lsqmint	0.575	-0.165	-0.030	0.608	1.000	-0.129	-0.128	0.934	0.934
lsqnonC	-0.482	0.169	0.066	-0.055	-0.129	1.000	0.460	-0.284	-0.28
lsqrain	-0.243	0.739	0.775	-0.220	-0.128	0.460	1.000	-0.202	-0.20
lsqtemp	0.561	-0.230	0.008	0.617	0.934	-0.284	-0.202	1.000	1.000
ltemp	0.561	-0.230	0.008	0.617	0.934	-0.284	-0.202	1.000	1.000

lpxrice denotes prices of rice; **lsqcrmj** denotes square of critical major rainfall; **lsqcrmin** denotes square of the critical minor rainfall; **lsqmaxt** denotes square of maximum temperature; **lsqmint** denotes square minimum temperature; **lsqnonC** denotes square of non-critical period of rainfall; **lsqrain** denotes square of rainfall; **lsqtemp** denotes square of temperature; **ltemp** denotes temperature.

Source: Author's computations

Appendix 4. Cointegrating Equation: Model 6

Dependent Variable: lmaize

Sample: 1970 - 2002

Included observations: 33

Variable	Coefficient	Std. Error	t-Statistic	Prob.
c	-8.167712	8.754656	-0.932956	0.3598
lsqrain	0.428537	0.109366	3.918390	0.0006
lsqmaxtemp	1.764873	1.189398	1.483838	0.1504
lsqmintemp	-0.303636	1.622447	-0.187147	0.8531
lrpxmaize	0.024804	0.166946	0.148576	0.8831
lrpxrice	-0.334321	0.116685	-2.865149	0.0083
lrpxcassava	0.009843	0.123777	0.079524	0.9372
lrpxnpk	0.405554	0.025282	16.04131	0.0000

R-squared	0.951321	Mean dependent var	
Adjusted R-squared	0.937691	S.D. dependent var	
S.E. of regression	0.135439	Akaike info criterion	
Sum squared resid	0.458596	Schwarz criterion	
Log likelihood	23.73057	F-statistic	
Durbin-Watson stat	2.487669	Prob(F-statistic)	

ADF Test Statistic	-4.078141	1% Critical Value*	-2.6395
		5% Critical Value	-1.9521
		10% Critical Value	-1.6214

Lrpxmaize denotes log of the real price of maize. **Lrpxrice** denotes the log of the real price of rice. **Lrpxcassava** denotes the log of the real price of cassava. **Lrpxnpk** denotes the log of the real price of fertiliser (npk). **Lsqmaxtemp** denotes the log of annual mean maximum temperature. **Lsqmintemp** denotes the log of annual mean minimum temperature **Lsqrain** denotes the log of annual mean rainfall.

Source: Author's computation.

Appendix 5. Cointegrating Equation: Model 7

Dependent Variable: lmaize

Sample: 1970 - 2002

Included observations: 33

Variable	Coefficient	Std. Error	t-Statistic	Prob.
c	-10.19682	10.30724	-0.989286	0.3324
lsqcrmj	0.307048	0.103652	2.962296	0.0068
lsqcrminor	0.079923	0.064102	1.246798	0.2245
lsqnoncrit	0.087531	0.053575	1.633795	0.1154
lsqtemp	1.830251	1.553037	1.178498	0.2502
lrpxmaize	-0.150204	0.181168	-0.829086	0.4152
lrpxcassava	0.121986	0.140520	0.868101	0.3939
lrpxrice	-0.266200	0.114138	-2.332260	0.0284
lrpxnpk	0.388703	0.029115	13.35051	0.0000

R-squared	0.952477	Mean dependent var	6.315912
Adjusted R-squared	0.936636	S.D. dependent var	0.542588
S.E. of regression	0.136581	Akaike info criterion	-0.916797
Sum squared resid	0.447705	Schwarz criterion	-0.508659
Log likelihood	24.12715	F-statistic	60.12763
Durbin-Watson stat	2.368713	Prob(F-statistic)	0.000000

ADF Test Statistic	-4.568020	1% Critical Value*	-2.6395
		5% Critical Value	-1.9521
		10% Critical Value	-1.6214

DLrpxmaize denotes difference of the log of the real price of maize. **DLrpxrice** denotes the difference of the log of the real price of rice. **DLrpxcassava** denotes the difference of the log of the real price of cassava. **DLrpxnpk** denotes the difference of the log of the real price of fertiliser (npk). **DsqLtemp** denotes the difference of the log of annual mean temperature. **DsqLrain** denotes difference of the log of annual mean rainfall. **DsqLcrmj** denotes the difference of the log of critical major rainfall periods. **DsqLcrminor** denotes the difference of the log of critical minor rainfall periods **DsqLnoncrit** denotes the difference of the log of non-critical periods RESID03 denotes the error correcting term.

Source : Author's computation

Appendix 6. Cointegrating Equation: Model 8

Dependent Variable: lmaize

Sample: 1970 - 2002

Included observations: 33

Variable	Coefficient	Std. Error	t-Statistic	Prob.
c	-10.47062	9.115326	-1.148683	0.2625
lsqcrmj	0.286467	0.098464	2.909344	0.0079
lsqcrminor	0.123215	0.067542	1.824288	0.0811
lsqnoncrit	0.075890	0.055730	1.361743	0.1865
lsqmaxtemp	1.894039	1.230170	1.539657	0.1373
lsqmintemp	-0.175436	1.686937	-0.103997	0.9181
lrpxmaize	-0.056122	0.189732	-0.295799	0.7700
lrpxrice	-0.319306	0.118631	-2.691583	0.0130
lrpxcassava	0.087818	0.140334	0.625776	0.5376
lrpxnpk	0.397301	0.025947	15.31205	0.0000

R-squared	0.955589	Mean dependent var	6.315912
Adjusted R-squared	0.938210	S.D. dependent var	0.542588
S.E. of regression	0.134874	Akaike info criterion	-0.923904
Sum squared resid	0.418393	Schwarz criterion	-0.470417
Log likelihood	25.24442	F-statistic	54.98727
Durbin-Watson stat	2.610053	Prob(F-statistic)	0.000000

ADF Test Statistic of the Error Term	-4.942032	1% Critical Value*	-2.6395
		5% Critical Value	-1.9521
		10% Critical Value	-1.6214

Lrpxmaize denotes log of the real price of maize. **Lrpxrice** denotes the log of the real price of rice. **Lrpxcassava** denotes the log of the real price of cassava. **Lrpxnpk** denotes the log of the real price of fertiliser (npk). **Lsqcrmj** denotes log of the critical major rainfall periods. **Lsqcrminor** denotes log of the critical minor rainfall periods. **Lsqnoncrit** denotes log of non-critical rainfall periods. **Lsqmaxtemp** denotes the log of annual mean maximum temperature. **Lsqmintemp** denotes the log of annual mean minimum temperature

Source: Author's computations.

Appendix 7. Error Correction Model 6

Dependent Variable: D(lmaize)

Sample(adjusted): 1971 - 2002

Included observations: 32 after adjusting endpoints

Variable	Coefficient	Std. Error	t-Statistic	Prob.
C	-0.009631	0.019433	-0.495589	0.6249
D(lsqrain)	0.383337	0.061501	6.232976	0.0000
D(lsqmaxtemp)	0.743951	0.691083	1.076500	0.2929
D(lsqmintemp)	0.157691	0.982864	0.160440	0.8739
D(lrpxmaize)	-0.221234	0.090242	-2.451574	0.0222
D(lrpxrice)	-0.061219	0.085275	-0.717898	0.4800
D(lrpxcassava)	0.093772	0.074003	1.267149	0.2178
D(lrpxnpk)	0.396277	0.051910	7.633900	0.0000
RESID10(-1)	-1.362613	0.175042	-7.784504	0.0000

R-squared	0.929310	Mean dependent var	0.033347
Adjusted R-squared	0.904723	S.D. dependent var	0.340841
S.E. of regression	0.105207	Akaike info criterion	-1.433506
Sum squared resid	0.254578	Schwarz criterion	-1.021268
Log likelihood	31.93610	F-statistic	37.79571
		Prob(F-statistic)	0.000000
Jarque-Bera	0.296467	Prob(Jarque-Bera)	0.862230
Breusch-Godfrey	0.837136	Prob(Breusch-Godfrey)	0.370137
White Heteroscedasticity Test	0.610326	Prob(White Heteroscedasticity Test)	0.831274
Ramsey RESET Test	1.053579	Prob(Ramsey RESET Test)	0.315838

DLrpxmaize denotes difference of the log of the real price of maize. **DLrpxrice** denotes the difference of the log of the real price of rice. **DLrpxcassava** denotes the difference of the log of the real price of cassava. **DLrpxnpk** denotes the difference of the log of the real price of fertiliser (npk). **DsqLmaxtemp** denotes the difference of the log of annual mean maximum temperature. **DsqLmintemp** denotes the difference of the log of annual mean minimum temperature **DsqLrain** denotes difference of the log of annual mean rainfall. **Resid02** denotes the error correcting term.

Source: Author's computation

Appendix 8 Error Correction Model 7

Dependent Variable: D(lmaize)

Sample(adjusted): 1971 - 2002

Included observations: 32 after adjusting endpoints

Variable	Coefficient	Std. Error	t-Statistic	Prob.
C	-0.020612	0.020710	-0.995267	0.3304
D(lsqcrmj)	0.270395	0.072674	3.720632	0.0012
D(lsqcrminor)	0.074099	0.048935	1.514230	0.1442
D(lsqnoncrit)	0.146863	0.039150	3.751281	0.0011
D(lsqtemp)	1.093369	1.040038	1.051278	0.3045
D(lrpxmaize)	-0.311273	0.112702	-2.761905	0.0114
D(lrpxcassava)	0.235756	0.099459	2.370391	0.0270
D(lrpxrice)	-0.027551	0.085252	-0.323164	0.7496
D(lrpxnpk)	0.458841	0.059686	7.687619	0.0000
RESID07(-1)	-1.182686	0.181667	-6.510192	0.0000

R-squared	0.928942	Mean dependent var	0.033347
Adjusted R-squared	0.899873	S.D. dependent var	0.340841
S.E. of regression	0.107852	Akaike info criterion	-1.365814
Sum squared resid	0.255903	Schwarz criterion	-0.907772
Log likelihood	31.85303	F-statistic	31.95642
		Prob(F-statistic)	0.000000
Jarque-Bera	0.238257	Prob(Jarque-Bera)	0.887694
Breusch-Godfrey	1.614087	Prob(Breusch-Godfrey)	0.217814
White Heteroscedasticity Test	0.291865	Prob(White Heteroscedasticity Test)	0.990744
Ramsey RESET Test	0.259101	Prob(Ramsey RESET Test)	0.615587

DLrpxmaize denotes difference of the log of the real price of maize. **DLrpxrice** denotes the difference of the log of the real price of rice. **DLrpxcassava** denotes the difference of the log of the real price of cassava. **DLrpxnpk** denotes the difference of the log of the real price of fertiliser (npk). **DsqLtemp** denotes the difference of the log of annual mean temperature. **DsqLcrmj** denotes the difference of the log of critical major rainfall periods. **DsqLcrminor** denotes the difference of the log of critical minor rainfall periods **DsqLnoncrit** denotes the difference of the log of non-critical periods RESID03 denotes the error correcting term. Source : Author's computation

Source: Author's computation

Appendix 9 Error Correction Model 8

Dependent Variable: D(lmaize)

Sample(adjusted): 1971 - 2002

Included observations: 32 after adjusting endpoints

Variable	Coefficient	Std. Error	t-Statistic	Prob.
C	-0.017894	0.018005	-0.993831	0.3316
D(lsqcrmj)	0.241185	0.058093	4.151675	0.0005
D(lsqcrminor)	0.105006	0.042668	2.461005	0.0226
D(lsqnoncrit)	0.135496	0.035083	3.862188	0.0009
D(lsqmaxtemp)	0.755190	0.633200	1.192657	0.2463
D(lsqmintemp)	-0.045380	0.941058	-0.048222	0.9620
D(lrpxmaize)	-0.259115	0.099585	-2.601953	0.0166
D(lrpxrice)	-0.037815	0.078418	-0.482224	0.6346
D(lrpxcassava)	0.195317	0.086782	2.250651	0.0352
D(lrpxnpk)	0.435717	0.053141	8.199305	0.0000
RESID08(-1)	-1.322840	0.163193	-8.105963	0.0000

R-squared	0.948897	Mean dependent var	0.033347
Adjusted R-squared	0.924563	S.D. dependent var	0.340841
S.E. of regression	0.093615	Akaike info criterion	-1.632970
Sum squared resid	0.184038	Schwarz criterion	-1.129123
Log likelihood	37.12752	F-statistic	38.99379
		Prob(F-statistic)	0.000000
Jarque-Bera	0.109725	Prob(Jarque-Bera)	0.946615
Breusch-Godfrey	2.887945	Prob(Breusch-Godfrey)	0.104747
White Heteroscedasticity Test	0.651497	Prob(White Heteroscedasticity Test)	0.804923
Ramsey RESET Test	0.030338	Prob(Ramsey RESET Test)	0.863475

DLrpxmaize denotes log of the real price of maize. **DLrpxrice** denotes the log of the real price of rice. **DLrpxcassava** denotes the log of the real price of cassava. **DLrpxnpk** denotes the log of the real price of fertiliser (npk). **DsqLcrmj** denotes log of the critical major rainfall periods. **DsqLcrminor** denotes log of the critical minor rainfall periods. **DsqLnoncrit** denotes log of non-critical rainfall periods. **DsqLmaxtemp** denotes the log of annual mean maximum temperature. **DsqLmintemp** denotes the log of annual mean minimum temperature

Source: Authors computation

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