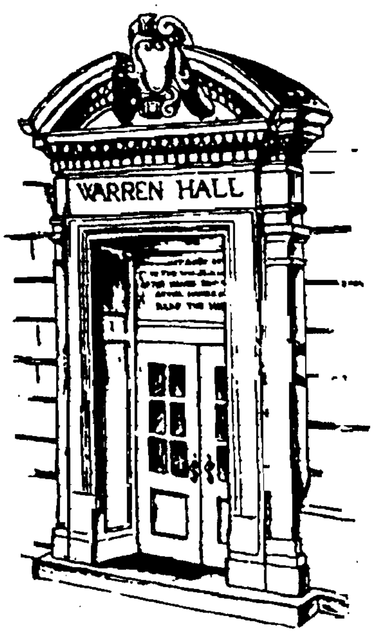

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Department of Agricultural, Resource, and Managerial Economics
Cornell University, Ithaca, New York 14853-7801 USA

CLIMATE CHANGE EFFECTS IN A MACROECONOMIC CONTEXT FOR LOW INCOME COUNTRIES:

by

Steven C. Kyle
and
Radha Sampath

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Introduction

Scientists predict a global climate change on a scale unprecedented in human history-with the potential for great impacts, both beneficial and harmful to food security. One issue receiving increased attention recently is the possible impact on agricultural production of a global climate change caused by increasing 'greenhouse gas' emissions (Rosensweig, Adams). Climate change will have far reaching impacts on low income economies, especially since agriculture accounts for a much larger share of income and employment than in richer countries. In light of the fact that developing countries face a number of other problems such as rapidly growing population, decreasing per capita income, increasing government debt, unemployment etc., the question of how they can cope with the added problems stemming from climate change in the context of pre-existing issues need to be addressed.

The main objective of this paper is to look at climate change effects in low income countries from a macroeconomic perspective. Typically, governments intervene in many ways in the agricultural sector in developing economies in the form of subsidies, taxes, and government price policies. The crux of the problem is to determine how important the effects of climate change are in relation to the effects of other problems faced by these countries. Or, put another way, how big a change in government policy does it take to offset the effect of climate change? We have developed a multimarket simulation model, where on the one hand gradual climate change effects are introduced on the production side, while at the same time trends in population are incorporated. This system is run to determine exports and imports and balance of payments. In this paper we have presented results from a study of Kenya but the model developed can be applied to any developing country. The paper first gives an overview of climate change and its impact on plant growth, subsequently describing how low income economies will be affected by the problem. Further, the model is described and the climate change effects in Kenya are analyzed.

Climate Change

1. An Overview

The phenomenon of global warming has numerous implications but is difficult to predict, especially for specific locations. There is an increasing scientific consensus that the continuing build up of heat absorbing gases such as carbon dioxide and methane will cause a global climate change-- often called the greenhouse effect. A 1985 meteorological organization (WMO UNEP)/International Council of Scientific Unions (ICSU) study predicted that the world will likely experience a warming trend by 1.5-4.5^{0}C by early in the next century. On average the global surface air temperature is predicted to go up by 3.9^{0}C with a 10% increase in precipitation (IPCC, 1992). Scientists have developed general circulation models (summarized by Rosenwieg and Adams) to predict warming trends. These models synthesize our knowledge of the physical and dynamic processes of the overall climate systems, allowing for complex interactions between the various components (atmosphere-ocean-land) (Kane et. al.). Broad scientific agreement exists on the underlying theory of climate change, although the nature and magnitude of future effects from greenhouse warming as predicted by computer models remain in debate.

2. Impact on Agriculture

Reports of IPCC (1990) and NAS (1991) indicate that there is potential for major impact on agriculture, especially if there is significant mid continental drying and warming in the US. While modern technology, improved plant varieties, increased fertilizer use and other factor inputs have mitigated some aspects of weather variability, climate remains the key factor determining agricultural productivity. Although less is known about variability than about most other aspects of climate change, it may have greater impacts on some systems than changes in average climate conditions. Climate variability is a principal source of fluctuations in the production and price of agricultural commodities and will continue to be a major problem whether or not the current warming trend leads to an increase in the frequency or intensity of short term fluctuations around the mean.

Temperature is one of the most important factors in plant growth since it determines the length of the growing season and has a strong effect on the development process and on the rate of expansion of the leaves. Temperature increase shortens the reproductive phase of determinate crops, decreasing the time during which the canopy exists and the period in which the plant intercepts light and produces biomass. Higher temperatures also tend to increase the rate of evapotranspiration, and reduce moisture availability for the crop. Crop growth depends on the amount of growing degree days it can accumulate daily, which in turn is a function of temperature and radiation. (For a detailed discussion see Parry). For example, in the case of wheat yields in India, an increase in 0.5^0C will reduce yield by 0.45 t/Ha. (Kaiser and Drennen). Temperature also affects the growing seasons of plants. In cold regions like Canada and USA, the increase in temperature will increase the growing season, and consequently the crops may avoid winter kill by frost, but on the other hand this will also reduce the time between flowering and maturity, and thus the net effect of these will determine the final yield.

If warming occurs and causes more evaporation, soil moisture may decrease. The yield is limited by the amount of water stored by the soil. With higher temperatures microbial decomposition could increase and this would lower soil fertility.

The higher levels of CO_2 are expected to enhance the growth rate of some staple cereal crops, e.g. wheat, rice, soybean (c3 plants), but not to have much effect on maize, sorghum, sugarcane, or millet (c4 plants). However the interaction of increased CO_2 and plant response is not clearly understood, and thus it may have positive as well as negative effects on productivity.

Thus an anthropogenically induced climate change potentially affects strategic world grain supplies and food security in all countries. In order to develop an integrated model for low income countries to examine climate change effects, one has to consider several macroeconomic problems and constraints which often are not as significant in developed economies. Among these differences are:

1. A far larger proportion of the population is directly dependent on agriculture for subsistence in low income countries. This proportion ranges as high as 90% in very low income countries, compared to less than 5% in the U.S. and other developed countries.
2. Absolute levels of income are much lower in many countries, with annual per capita income well below $100 in many areas. This reduces the ability of farmers to take the risks inherent in changing technologies and/or crop mixes in order to adapt to climate change. Also the farmers are much more poorly informed and cannot access recent weather reports to anticipate any drastic effects.
3. Application of purchased inputs (fertilizers, pesticides, etc.) are much lower by any measure in most agricultural systems in low income countries. These inputs are typically those which can be most readily changed to adapt to new situations. Deficiencies in the input supply systems can result in damped or no adaptation.
4. Chronic shortages of foreign exchange experienced by many developing countries make considerations of export crops vs. food crops an issue of paramount importance, something

that is not as pressing a concern when analyzing countries such as the U.S. This also leads governments to intervene with their own price policies, since most developing countries cannot dictate prices in the world markets and are essentially price takers.

5. More obviously, crop mixes in tropical areas differ from temperate zones. In some areas, crops are grown under more extreme temperature and humidity regimes and are consequently nearer to the limits of tolerance even without climate change. These factors constrain crop mix choices as does the rudimentary nature of marketing systems in many areas.

Food security implications of climate change are complicated by economic and political considerations. If climate change reduces output in major food exporting countries, fluctuations in price could hurt low income food importing countries. Thus low income countries, even though they may have a positive impact of climate change, will still be losers. Incorporating these considerations into an analysis of adaptation to climate change requires an integrated modeling approach, such that climate change is considered in conjunction with other macroeconomic problems. This paper presents a first step toward looking at climate change effects in the context of other important macroeconomic issues affecting a single country.

The Structure of the Computer Simulation Model

We have developed a simulation model to look at the effects of climate change from a macroeconomic perspective. The main objective is to examine how the effects of global warming on yields of major crops is reflected in prices of crops, agricultural policies, consumption, foreign exchange earnings and income of various groups within the population. The model traces out implications of changes in production given the assumption of how markets work and the results provide some insight into the paths of future variables relative to what they would be in absence of the change. After an extensive literature review some estimates of the effect of global warming on the yields of different crops have been obtained. These estimates are entered in the model as gradual yield changes year by year. The analysis conducted here focuses on quantifying the effects of supply shifts caused by climate change and demand shift caused by population growth on price volatility and on the net trade balance, upon government costs and revenues associated with subsidy support prices and taxes.

The model structure is given in the attached Figure 1. It is a simulation model which starts with modeling farm supply and retail demand with simple supply and demand functions for key agricultural commodities. On the producer side, supply is a function of farm level prices and fertilizer input. Farm prices in turn are functions of wholesale and world prices. On the consumer side, per capita retail demand is modeled as a function of retail prices and income. As with farm prices, retail prices are linked to the wholesale and world prices. Most developing countries are price takers and cannot influence world market prices through either their consumption or production changes and hence this assumption is reasonable. Given world prices, the value of taxes or subsidies and the wholesale to world price markups the wholesale price can be calculated. From the wholesale price, retail prices can be calculated. Modeling prices in this manner gives us the flexibility to examine the effect of a change in the world price or tax structure. For a given world price changes in internal supply and demand result in changes in net trade of the commodity in question.

The impact of the export-import tax on the wholesale price is different depending on whether the commodity in question is an export or import. For example a tax on an export will be negative and the a tax on an import will be positive. It is assumed that any imbalance in supply and demand will result in trade.

The own elasticities for the commodities and the cross price elasticities for complementary crops are provided as input by the user from econometric estimation or from literature review. Thus, using elasticity matrices, base year prices and quantities, import export tax values, world prices, incomes, population and appropriate price markups, the entire model for all the commodities can be generated for a number of years. After introducing yield changes due to climate change, the entire system for all commodities can be run again. A comparison of the two runs can throw some light on potential government policy changes to offset the climate change effects.

An African Case -- Kenya

Africa still relies heavily on agriculture to feed its growing population. African agriculture is very sensitive to climate, which is marked by its fluctuations and variability. Frequent and prolonged drought and desiccation are already a threat to agricultural production. At present the projections of global warming produced by various general circulation models suggest that much of tropical Africa will remain warm and may be up to 1 degree warmer, but the subtropical parts of the country could experience a more significant warming of up to 1.5^{o}C (Rosensweig et. al.). Global warming in Africa may be accompanied by a northward shift in the rain belts bringing more rainfall to the hitherto parched desert lands of Sahara in the north and Kalahari in the south, making it possible to carry on some form of agriculture in these regions. It is expected that certain crops like wheat and corn associated with the subtropical latitudes may suffer a drop in yield due to increased temperature. Elsewhere, agriculture is expected to survive and even become stronger especially where mixed cropping is currently practiced and where tree crops are predominant.

The Kenyan economy faces a tremendous growth and employment challenge. Growth has been insufficient to significantly raise the per capita income and create sufficient jobs for Kenya's young and rapidly growing population. Living standards remain vulnerable to external shocks.

Kenya's agriculture has three main food crops and two main export crops. 90% of smallholder farms plant maize and it accounts for 70% of national production. Wheat is next in importance to maize in production and can compete in transitional areas depending on relative producer prices. Wheat is often grown on land that is not suitable for maize and the level of domestic wheat production depends mainly on the structure of incentives, primarily the relationship between maize and wheat prices and prices of other competing activities (like milk production). The export crops coffee and tea are critical to the balance of payments of the country. Expansion of production is limited by the international coffee agreement, domestic restrictions on coffee and tea, the low income elasticity of demand for these commodities, and low projected world market prices.

Apart from adverse weather conditions which culminated in a drought in 1984, Kenya's agricultural sector has been constrained by factors such as the inadequate availability and application of key inputs, as well as inadequate production incentives. Support services in extension, research, credit and marketing were also unsatisfactory because of institutional weaknesses in the parastatal and government bodies which provide them. Government price controls have had the greatest impact on foodstuffs; major problems are low official prices, inadequate producer incentives, and parastatal losses. The government sets official producer prices for a range of domestically consumed agricultural commodities, including maize, wheat, sugar, beef, milk and cotton. Producers receive world prices for export crops adjusted for quality of deliveries less marketing costs and in some cases, taxes. See Lele and Myers for a detailed discussion of agricultural policy in Kenya.

Expected Climate Change in Kenya

The climatic elements of greatest significance to agricultural production in Kenya are rainfall, temperature and evapotranspiration. Average annual rainfall ranges from 500 mm to 2300 mm; the average potential evaporation, less than 1200 mm to 2500 mm; and average annual temperatures, from 10^0C to 30^0C. The observed mean temperature increase in Kenya during the last 15 years is 0.45^0C while observed global increase during the last 100 years is $0.3\text{-}0.7^0$C (Ottichilo et al). Indications are that in humid areas (highlands), rainfall and temperature have increased for the last 25 years, while in the arid, semi-arid and sub-humid areas the rainfall decreased as the temperature increased over the same period.

Kinuthia et al. studied the historical data and trends for rainfall and temperature from year 1930 to 1986 for seven stations in Kenya. The results of the study are summarized as follows:

Temperature

1. Mean Temperature (Maximum and Minimum) were above normal for late 1940-mid 1950.
2. Temperatures decreased from 1950-early 1960 and were below normal in mid 1960's.
3. All seven stations had an upward trend from mid 1960's and temperatures were above normal from 1970's.
4. The magnitude of increase is not known with precision. The temperature increase for the 1970-85 period was 0.45^0C.

Rainfall

1. Rainfall increased with a decrease of both minimum and maximum temperature and vice versa.
2. The minimum temperature influenced the pattern of rainfall more than the maximum temperature in all stations.
3. As temperature showed an upward trend in arid, semi-arid and sub-humid and coastal stations, the rainfall showed a downward trend. Therefore, it is speculated that the rainfall will decrease as the temperature increases in the coming years.
4. Increase in temperature will inevitably increase evapotranspiration which in turn will markedly lower the available soil moisture.
5. The humid areas will benefit from the increased convection due to increase in temperature and moisture.

Maize requires average temperatures of 14-30^0C. It doesn't do well at higher temperatures and cannot withstand frost. Maize does well at altitudes of up to 2,200 meters. Rainfall of 600-1200 mm per year is needed and it should be distributed over the growing season and is particularly important during the flowering stages. Given the physiology of maize, increases in CO_2 are not likely to enhance yield significantly. Therefore with an expected increase in temperature, maize yields may decrease.

Wheat in Kenya is becoming an increasingly important food crop and is grown mainly in high altitudes, humid and sub-humid areas from 1200-2500 meters. It needs rainfall of 800-1200 mm, and temperature of 14-30^0C. Some dry blend during ripening and early stages is essential for maximum yield. Increase in temperature and rainfall may reduce the yields.

There are two varieties of coffee in Kenya-- Arabica and Robusta. Arabica needs an average temperature of 20-22 and grows well in the highlands of altitudes 1400-2000 m. It requires high rainfall of around 1800 mm/year, but also grows where the rainfall is as low as 900 mm/year. On the other hand, the Robusta variety requires 1500-2000 mm of rainfall per year and an average temperature of about 25-28^{0}C It grows well within the Lake Victoria basin between at altitudes between 6000 and 1200 mm.

The anticipated slight decrease in rainfall and increase in temperature around the lake region are expected to have a marginal effect on Robusta production while Arabica production is expected to improve due to temperature increase in the highlands. The anticipated increase in Arabica coffee production may be negated, however, by the increased problem of weeds, diseases and pests.

Tea requires an annual rainfall of 2000-2500 mm and grows well at altitudes of 1500-2200 mt. It requires temperature of 14-30^{0}C. The increase in temperature and rainfall within the humid areas where tea is grown is expected to enhance its production.

The three food crops: maize, wheat, and sugarcane, and two export crops: coffee and tea, have been modeled with a simple Cobb-Douglas functional form. Wheat and maize compete for land while sugarcane is modeled separately as it does not compete with either maize or wheat. Two tree crops, coffee and tea, are modeled separately and a simple CES functional form is assumed. In all the supply equations fertilizer input is included, and in the demand equations per capita income is considered as variable. For example, the supply equation for maize is:

*Supply of maize = constant * (price of maize)* α ** (price of wheat)* β ** (price of fertilizer)* γ

where α = own elasticity of maize supply

β = *cross price elasticity of maize supply with respect to wheat*

γ = *elasticity of maize supply with respect to fertilizer price*

The constant term can be calculated from the base year supply quantities, prices and elasticities. The demand equation is similar and the equations for tea coffee and sugarcane are functions of price expressed in a linear functional form. Thus, using these equations the entire model for five commodities can be generated from elasticity matrices, base year prices and quantities, import export tax values, world prices, incomes, population and appropriate price markups.

The model is run for 80 years (1980-2060) and changes in production under no climate change (Base Case Scenario) verses a milder Scenario 1 and a more severe Scenario 2 are examined. The milder climate change Scenario 1 is an exponential curve which corresponds in temperature to the relatively mild 'Scenario B' of Hansen et al. (1988), where average global temperature increases by 2.5°C by the year 2060 (time of equivalent doubling of CO_2), with half of the warming occurring between 2030 and 2060. The production function shifts are calculated as percentage differences of the exponential curve for different crops. The more severe climate change Scenario 2 is based on Scenario A of Hansen et al. (1988), and includes an increase in average temperature of 4.2°C by 2060, again with half the warming occurring between 2030 and 2060. Thus gradual climate change effects are introduced year by year to shift the production function such that the shift is more severe as time progresses. Based on the simulated changes in production, the model calculates farm, retail, wholesale prices, and the corresponding changes in consumption, and net trade balance.

Based on the literature review it has been assumed that by year 2060, maize and wheat yields and hence production will decrease by 6 percent and 3 percent in Scenario 1 and 20 percent and 10 percent in Scenario 2 respectively. Similarly, coffee and tea production will increase by 2 percent and 4 percent in Scenario 1 and 8 percent and 15 percent in Scenario 2 respectively. The results are analyzed as the relative changes between the base case scenario and the two climate change scenarios. Further different cases of the model are analyzed to examine the effect a 1 percent change in some of the assumptions of the model on other variables of the model. The different cases are:

CASE 1 ---- Increase in the base case fertilizer price by 1 percent per year.
CASE 2 ---- Increase in the population growth rate by 1 percent per year
CASE 3 ---- Increase in the Gross National Income by 1 percent per year.
CASE 4 ---- Increase in the world price of each of the four crops by 1 percent per year.

The inputs for running the model are the elasticity matrices, base year prices and quantities, import and export tax values, incomes, population and appropriate price markups. Price and income elasticities of demand and supply, for all the crops are derived from references to earlier works (See Askari and Cummings). Once all the parameters of the model were determined, extensive sensitivity analysis was performed to check the assumptions of the elasticity values. As mentioned above, farm retail and wholesale prices are determined as a function of world prices which have been assumed to remain constant at 1980 average values. Data on the approximate price markups on farm and retail price in Kenya were very limited. Hence the price markups are derived from past production, consumption and world price data and are assumed to remain constant at 1980 value for the base case. Since oil prices are expected to increase over the next few decades and the fertilizer price is affected by oil prices, it is reasonable to assume the that fertilizer price will grow at the rate of 1 percent for the 80 year period. Since data on taxes and subsidies are not available , we have assumed them to be zero for maize and wheat, in the base case. A 4 percent retail tax and a 10 percent export tax is imposed in the case of coffee and tea. Gross National Income at constant 1980 prices is forecast using the following regression equation:

$$GNI = 1740156 + .794755*I\text{-}1 + .084082*I\text{-}2 - .16762*I\text{-}3 - .00769*I\text{-}4 - .06063*I\text{-}5 + 109671*t \quad (R^2 = .9565).$$

where GNI is the Gross National Income at constant 1980 prices, and I-1, I-2, I-3, I-4, I-5 are the respective lagged gross national Income. t-- is a time trend where in 1980 t=1. 1982, t=2 and so on till 2060, t=60. This regression resulted in a moderate rate of growth at trends similar to those experienced over the past 15 years.

After an extensive literature review on the population growth estimates in Africa, Kenya and the world, we have assumed a conservative growth rate of 3.5 percent for 1990s, 3 percent for 2000, 2.5 percent 2010, 2 percent for 2020, 1.5 percent for 2030, 1 percent for 2040, 0.5 percent for 2050.

Results And Analysis

Based on the structure of the model described above and the initial assumptions, this section presents the results of the effect of climate change on production, consumption and trade of different commodities.

Table 1 shows the percent difference between average 1980 and the average 2050 production values for the base case and the two climate change scenarios. Production over 60 years for all the crops under the base case increases by about 15%. Under the mild Scenario 1, maize and wheat production goes down a little, but the magnitude is nevertheless higher than the 1980 level, unlike in the severe scenario where production drops below the 1980 level. In the case of coffee and tea, it has been assumed that climate change will be beneficial, and hence will enhance production by more than 25 percent of the 1980 value.

Table 1. Percent Difference between average 2050 and average 1980 production values

	Base case	Mild	Severe
Maize	15	9	-6
Wheat	16	13	5
Coffee	17	19	26
Tea	16	20	31

Figures 2 and 3 show the percent change in consumption and production respectively between the base case and the two climate change scenarios. It is evident from Figure 2 that as the production of the food crops go down due to climate change, consumption goes down as the farm and retail price goes up. Similarly, coffee and tea consumption increase as their prices drop due to climate change. It is interesting to note that the percent decrease in consumption is not as high as the percent decrease in production. In the case of maize, production decreases by about 20 percent and consumption by 6 percent in the severe climate change scenario, but the magnitude of the decrease in consumption is greater than the magnitude of decrease in production in absolute terms and this marginally decreases the imports of maize. Figure 4 shows that the retail price of maize increases by 22 percent under severe climate change, which will have adverse effect on consumers, especially the poor, who are living on the primary food crop. Thus the decrease in imports of the food crops is not due to an increase in production, but is due to the substantial increase in the retail price. Similarly, coffee and tea retail prices have decreased by 12.8 percent and 21 percent respectively.

We have assumed that climate change is likely to increase the production of coffee and tea. The increase in production causes the farm and retail prices to fall, and this increases domestic consumption as well. The percent increase in tea production in decade 2050 is about 13.5 percent in the severe climate change scenario, and this decreases the retail price by 23 percent and increases consumption only by

1.7%. Therefore, due to the increase in production, coffee and tea exports go up by 13 percent and 32 percent respectively under the mild and severe climate change scenario. The retail price of tea under the base case scenario is higher than the world price, but under Scenario 1 the retail price decreases by 7.4 percent. Under Scenario 2 the retail price has dropped by 23.8 percent, with the result that the price is lower than the world price. Increasing trends for exports are evident from Figure 5. Thus climate change will have a positive effect on the export crop trade. In this analysis we have not considered any restrictions on exports. In this case, the excess production will have to be sold at a lower prices, and producers will not make as much profit.

Sensitivity Analysis

Table 2 presents the result of a 1 percent increase in some of the policy assumptions on production consumption and trade for the decade 2050, under the base case, and the mild and severe climate change scenarios. The changes examined are an increase in the fertilizer price by 1 percent, increase in the assumed population by 1 percent, increase in the gross national income by 1 percent, and the increase of 1 percent in the price of each of the four crops under consideration. Entries are percentage changes in the indicated variable and since the policy is a 1 percent change, these figures can be considered as elasticities. In the first case, where the fertilizer price is increased by 1 percent, under the no climate change, the supply for all crops increases by 0.2 percent and Demand decreases by 0.2 percent , but there is a clear distinction between food crop imports which decrease and exports of coffee and tea which increase. A 1 percent increase in the fertilizer input is not enough to offset the decrease in production and the consequent increase in the farm and retail prices due to climate change under the two climate change scenarios. The next Case 2 shows the percent changes in variables when the gross national income increases by 1%. With an increase in income, consumption under the base case increases. With this increase in consumption maize imports in the base case and the mild scenario increase, but the increase is not enough to offset by the rising retail price of maize under the severe climate change scenario. It is interesting to note that coffee and tea exports are lower by 0.2 and .0.3 percent respectively under the base case. In Case 3, it is clear that with an increase of one percent in population, consumption increases by zero percent. In the case of maize this consumption causes a rise in imports by 1.1 percent in base case, 1.0 percent in the mild scenario, and .0.4 percent in the severe scenario. Exports are also lower in all three scenarios .Case 4 presents the change in the variables if the crop price increases by 1%. The results are as expected, imports of maize and wheat reduce and exports of coffee and tea rise.

Climate Effects and Policy Interventions

Tables 3, 4 and 5 show the relative magnitude of the effects of policy instruments on the crops in question over the years since the early 1970s in Kenya. It is clear that the magnitudes of the effects presented here are comparable, and the many cases greater than, those estimated to result from climate change. In particular, Table 3 shows that direct and indirect taxation of producers in the cases of tea and coffee has ranged as high as 44 percent in some years swung into subsidization. These magnitudes and variabilities are greater than those to be expected from climate change.

In the case of maize the results of government policy are even greater. It can be seen in Table 4 that the ratio of maize prices to coffee prices has varied widely and has in some years seen changes of as much as 50 percent. Again these magnitudes and variations are far in excess of any predictions of the effects of global climate change.

Table 5 shows ratios of fertilizer prices to maize prices for Kenya and two other East African countries. It is apparent here too, that the effects of government interventions are in many cases far greater than those resulting from climate change.

In summary, global climate change in Kenya is but one of the myriad of factors affecting agricultural production. Our analysis, though it can be further refined in various ways, is accurate enough to provide estimates which allow comparison of the relative orders of magnitude of the issues involved. It is clear that the magnitude of the effects of climate change are smaller than those currently experienced from government interventions. The sensitivity analysis demonstrates that this conclusion is unlikely to be altered by alternative estimates for parameters or functional forms involved, since such changes constitute a second order effect compared to the results shown here. One implication of this result is that, barring catastrophic effects of climate change, it is within the power of policy makers to offset these effects by manipulating policies already in use. Put another way, global climate change will not necessarily be the most important or determining factor affecting the welfare of Kenyan farmers.

References

Askari, Hossein and Cummings, John, T. Agricultural Supply Response - A Survey of Econometric Evidence. Preager Publishers, 1976.

Baijou, Ahmad. "A Stochastic Agricultural Price Analysis Model of the Moroccan Agricultural Sector," Ph.D. Thesis, Oklahoma State University, 1990.

Beattle, Bruce R. and Robert C. Taylor, The Economics of Production, John Wiley and Sons, Inc., 1985.

Braverman, A., J.S. Hammer, and A. Gron, "Multimarker Analysis of Agricultural Price Policies in an Operational Context: The Case of Cyprus," The World Bank Economic Review. vol. 1, No. 21, 337-356.

Braverman, A., and J.S. Hammer, "Evaluating Agricultural Price and Tax Reforms for Policy Lending," The World Bank Staff Paper, 1989.

Ghattak, S., and K. Ingersent, Agriculture and Economic Development, The Johns Hopkins Studies in Development, Johns Hopkins University Press, Baltimore, Maryland, 1984.

Kaiser, Harry and Tom Drennen. Agricultural Dimensions of Global Climate Change. St. Lucie Press, Del Ray Beach, FL 1993.

Lau, Lawrence J., and Pan A. Yotopoulos. "Profit, Supply, and Factor Demand Functions," American Journal of Agricultural Economics, Feb. 1972

Lele, Uma and L. Richard Meyers. "Growth and Structural Change in East Africa: Domestic Policies, Agricultural Performance and World Bank Assistance, 1983-86," MADIA Discussion Paper No. 2, Washington, D.C.: World Bank, 1989.

Lopez, R. E., "Applications of Quality Theory to Agriculture," Western Journal of Agricultural Economics. December 1982.

Marquez, J. and Caryl McNeilly, "Income and Price Elasticities for Export of Developing Countries," The Review of Economics and Statistics, vol. 70, May 1988, 306-309.

Mundlak, Y., and Rene Hellinghausen. "The Intercountry Agricultural Production Function: Another View," American Journal of Agricultural Economics, November 1982.

Parry, M. L., and T. R. Carter. "An Assessment of the Effects of Climatic Change on Agriculture." Climate Change. 15(October 1989):95-116.

Rosenweig, C., M. L. Parry, G., Fischer, and K. Frohberg. "Climate Change and World Food Supply." Research Report No. 3. Environmental Change Unit, University of Oxford, 1993.

Rosenweig, C. and M. L. Parry. "Potential Impacts of Climate Change on World Food Supply: A Summary of a Recent International Study." in Agricultural Dimensions of Global Climate Change. eds., H. M. Kaiser and T. E. Drennen, Chapter 5. St. Lucie Press: Florida, 1993.

Tweeten L., Agricultural Policy Analysis Tools For Economic Development. Westview Press, Inc., 1989.

Tweeten, L. G., and C.L. Quance. "Positive Measures of Aggregate Supply Elasticities: Some New Approaches," Proceeding Papers, winter meeting of the AAEA, Dec. 1968.

Table 2. Percent change in production, consumption and trade given a 1 percent increase in the decade 2050.

Case 1 World Fertilizer price increases by 1%

Maize	Demand	Supply	Imports
scenario 0	-0.2	0.2	-0.3
scenario 1	-1.7	-5.3	-0.4
scenario 2	-5.5	-18.2	-1.0
Wheat	Demand	Supply	Imports
scenario 0	-0.2	0.2	-0.3
scenario 1	-1.9	-2.5	-1.1
scenario 2	-5.8	-8.9	-5.0
Coffee	Demand	Supply	Exports
scenario 0	-0.2	0.2	0.6
scenario 1	0.2	2.0	3.7
scenario 2	1.2	7.4	13.0
Tea	Demand	Supply	Exports
scenario 0	-0.2	0.2	0.8
scenario 1	0.3	3.8	9.4
scenario 2	1.5	13.7	33.1

Case 2 Gross national Income increases by 1%

Maize	Demand	Supply	Imports
scenario 0	0.17	0.00	0.23
scenario 1	-1.35	-5.47	0.13
scenario 2	-5.19	-18.33	-0.48
Wheat	Demand	Supply	Imports
scenario 0	0.3	0	0.4
scenario 1	-1.4	-2.7	-1.1
scenario 2	-5.3	-9.2	-4.4
Coffee	Demand	Supply	Exports
scenario 0	0.20	0.00	-0.2
scenario 1	0.55	1.8	3.0
scenario 2	1.58	7.2	12.2
Tea	Demand	Supply	Exports
scenario 0	0.2	0.0	-0.3
scenario 1	0.6	3.6	4.5
scenario 2	1.9	13.5	31.8

Case 3 Population increases by 1%

Maize	Demand	Supply	Imports
scenario 0	0.8	0.00	1.1
scenario 1	-0.7		1.0
scenario 2	-4.6	-18.33	0.4
Wheat	Demand	Supply	Imports
scenario 0	0.7	0	0.9
scenario 1	-0.9		-0.5
scenario 2	-4.9	-9.16	-3.9
Coffee	Demand	Supply	Exports
scenario 0	0.8	0.0	-0.72
scenario 1	1.2		2.4
scenario 2	2.2	7.2	11.7
Tea	Demand	Supply	Exports
scenario 0	0.8	0.0	-1.3
scenario 1	1.3		7.2
scenario 2	2.5	13.5	30.9

Case 4 World crop price increases by 1%

Maize	Demand	Supply	Imports
scenario 0	-0.4	1.5	-1.08
scenario 1	-1.92	-4.05	-1.15
scenario 2	-5.73	-17.16	-1.65
Wheat	Demand	Supply	Imports
scenario 0	-0.3	0.5	-0.5
scenario 1	-1.95	-2.25	-1.9
scenario 2	-5.89	-8.71	-5.2
Coffee	Demand	Supply	Exports
scenario 0	-0.1	0.6	1.2
scenario 1	0.3	2.4	4.3
scenario 2	1.3	7.8	13.7
Tea	Demand	Supply	Exports
scenario 0	-0.1	0.5	1.4
scenario 1	0.4	4.10	9.9
scenario 2	1.6	14.0	

Table 3. Ratios of Producer to International Prices, 1970-86.

Year	Kenya Smallholder	
	Coffee	Tea
1970	0.85	0.56
1971	0.88	0.66
1972	0.98	0.63
1973	1.02	0.64
1974	1.01	0.57
1975	1.02	0.64
1976	0.89	0.59
1977	0.94	0.71
1978	0.90	0.61
1979	0.92	0.65
1980	0.98	0.75
1981	0.86	0.64
1982	0.82	0.56
1983	0.94	1.02
1984	0.77	0.64
1985	0.87	0.74
1986	0.96	0.85

Note: Exchange rates estimated at purchasing-power parity.

Source: Lele, U. “”Agricultural Growth, Domestic Policies, the External Environment and Assistance in Africa’s Economic Development Experience: Lessons from a Quarter Century.” In Colleen Roberts, ed., Trade, Aid, and Policy Reform: Proceedings of the Eighth Agricultural Sector Symposium. Washington, D.C. World Bank.

Table 4. Ratios of Official Export Producer Prices to Maize, Producer Prices, 1970-85

Year	Coffee Kenya
1970	27.2
1971	19.1
1972	20.0
1973	23.7
1974	21.7
1975	15.3
1976	32.9
1977	44.7
1978	31.7
1979	36.8
1980	27.6
1981	22.6
1982	25.8
1983	22.7
1984	22.0
1985	21.2

---- Not available.

Source: Lele U., and R. L. Meyers. 1986. "Agricultural Development and Foreign Assistance: A Review of the World Bank's Experience in Kenya, 1963-1986." World Bank Special Studies Division, Country Economics Department, Washington, D.C.

Table 5. Ratios of Fertilizer Nutrient Price to Maize Price and Rates of Explicit Fertilizer Subsidy in Kenya, Malawi, and Tanzania.

Year	Kenya		Malawi		Tanzania	
	Price Ratio	Subsidy Rate percent	Price Ratio	Subsidy Rate percent	Price Ratio	Subsidy Rate percent
1972	4.6	0	8.7	----	----	----
1973	6.2	0	8.7	----	----	----
1974	5.9	0	15.6	----	----	75
1975	7.3	0	10.5	----	7.0	66
1976	6.5	0	10.5	----	6.6	----
1977	4.2	0	10.5	----	6.6	----
1978	4.5	0	10.5	----	5.6	50
1979	5.6	0	7.5	----	8.1	----
1980	7.0	0	8.8	----	6.0	----
1981	7.2	0	7.8	----	5.1	60
1982	6.9	0	9.1	----	4.1	60
1983	6.1	0	9.0	25	5.6	60
1984	5.6	0	9.9	29	6.0	60
1985	----	0	12.2.	23	5.5	0
1986	3.7	0	12.5	23	5.0	0
1987	3.4	0	10.0	17	5.0	0

---- Not available.

Note: The fertilizer prices are transformed to reflect their nutrient contents, and the ratios are computed as: price of one kilogram of nutrient per the price one kilogram of maize.

Source: Lele, U., R. E. Christiansen, and Kundhavi Kadiresan. 1988. "Issues in Fertilizer Policy in Africa: Lessons from Development Policy and Adjustment Lending Experience in MADIA Countries, 1970-87." World Bank Special Studies Division, Country Economics Department, Washington, D.C.

Figure 1. Model Structure of a Single Commodity

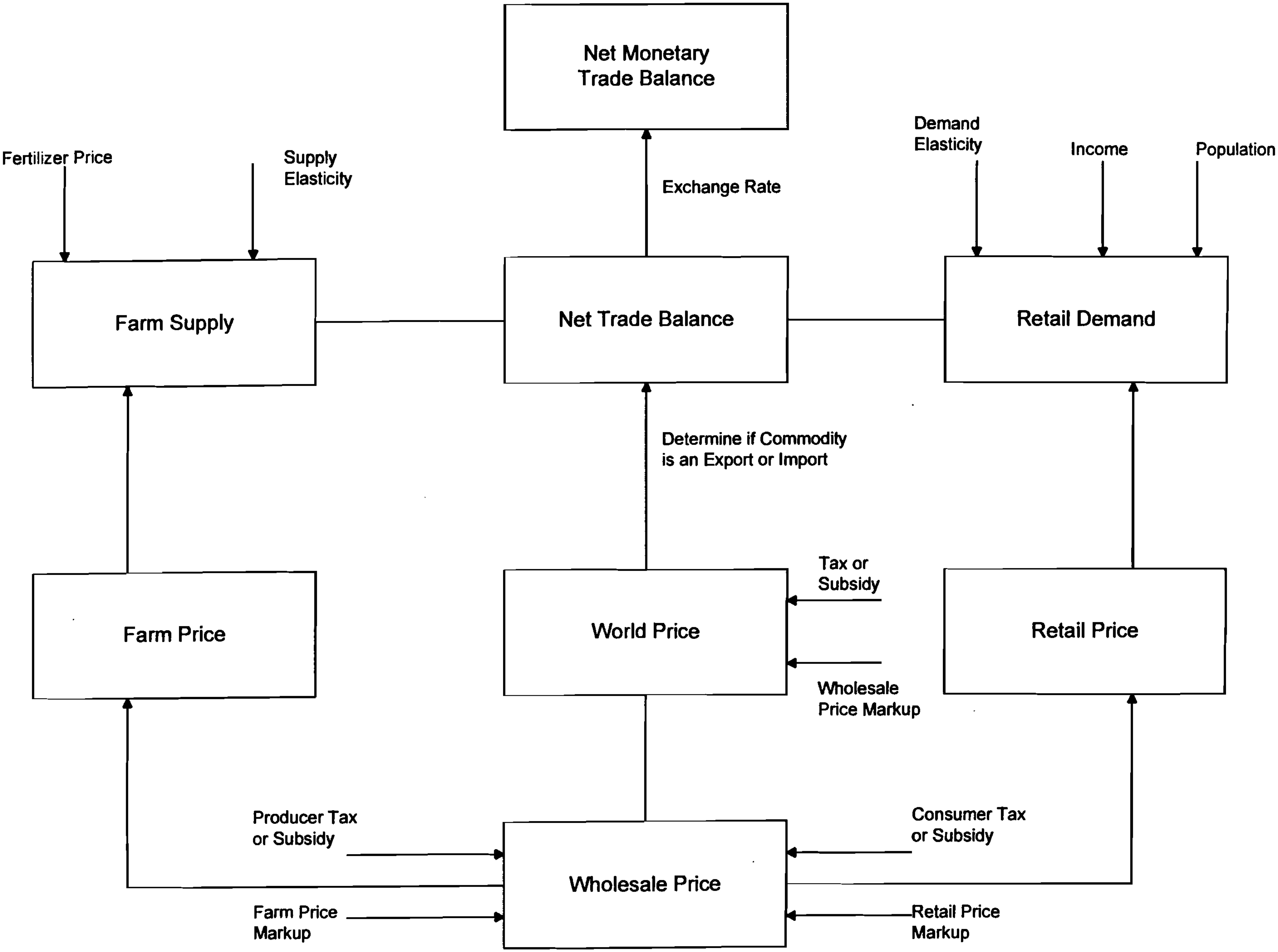
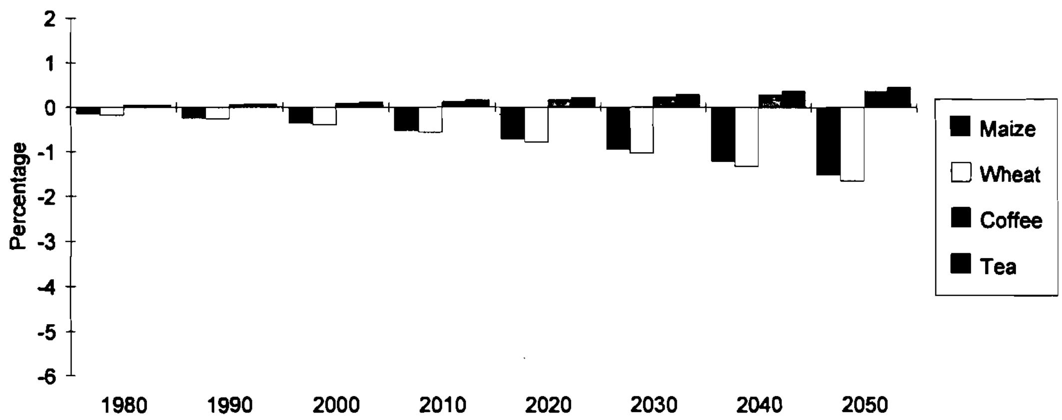


Figure 2. Percent change in consumption between the base case and climate change scenarios

Scenario 1



Scenario 2

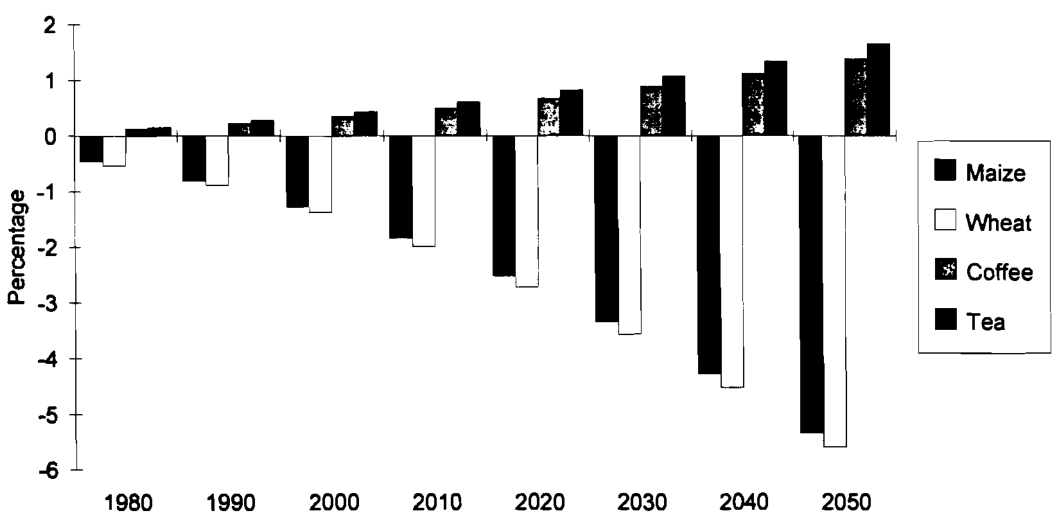
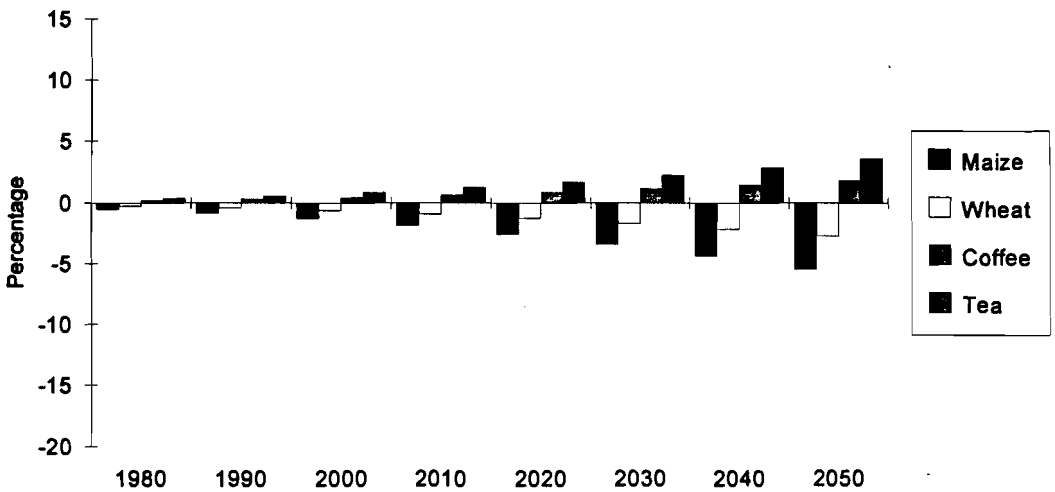


Figure 3. Percent change in production between the base case and climate change scenarios

Scenario 1



Scenario 2

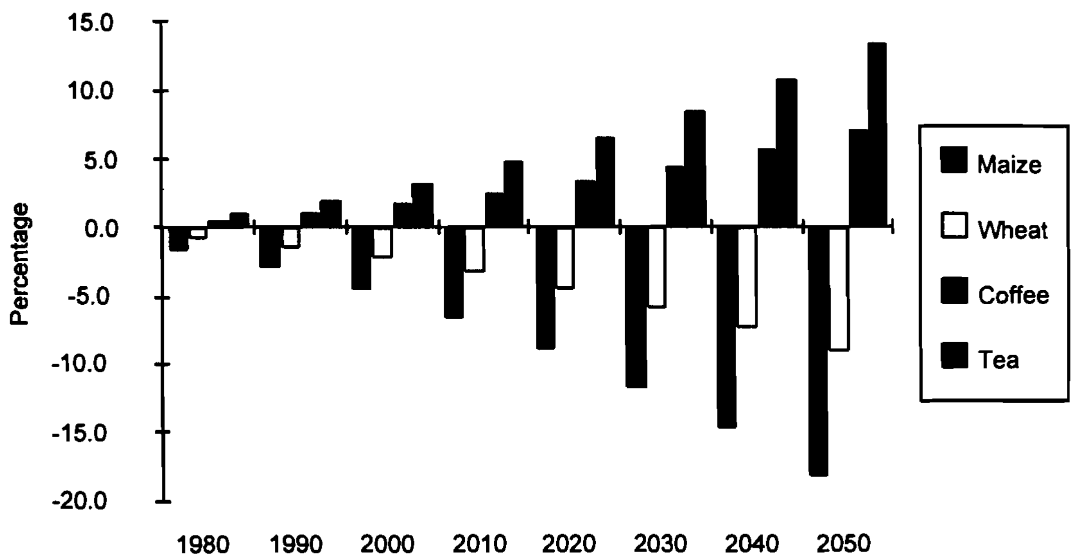
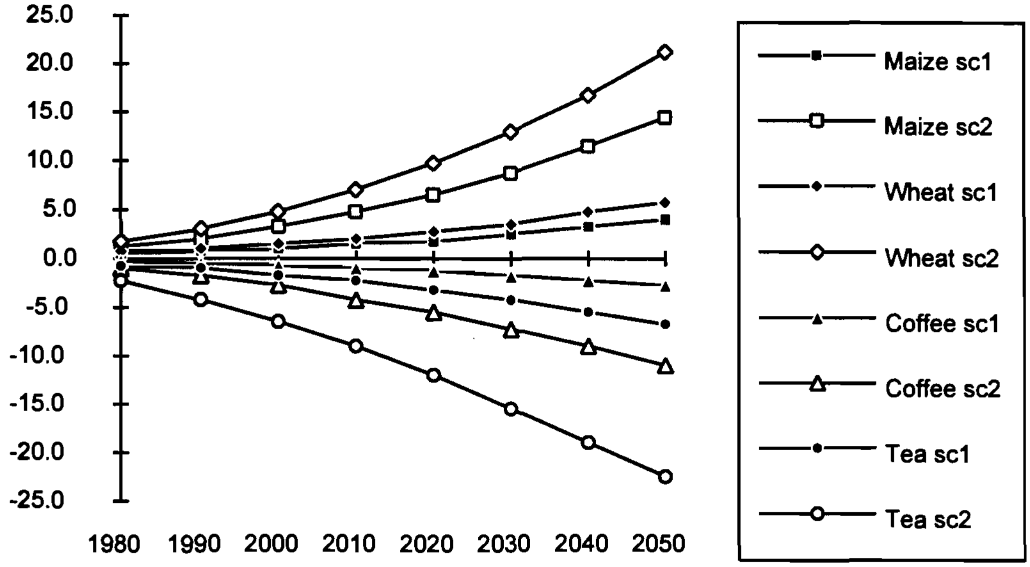


Figure 4 Percent change in farm and retail price under the two climate change scenarios.

Farm Price



Retail Price

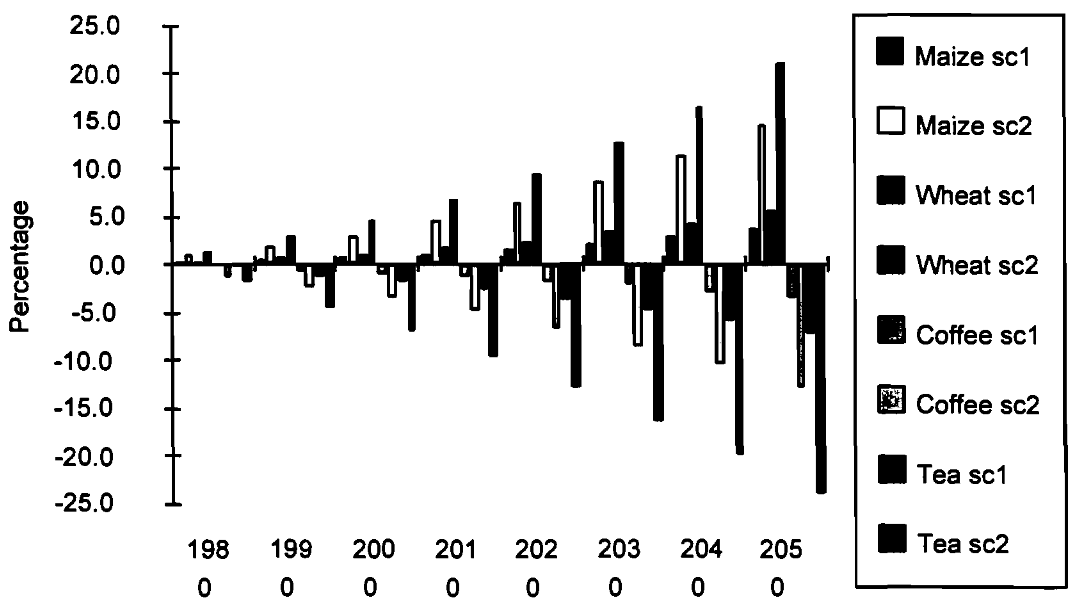
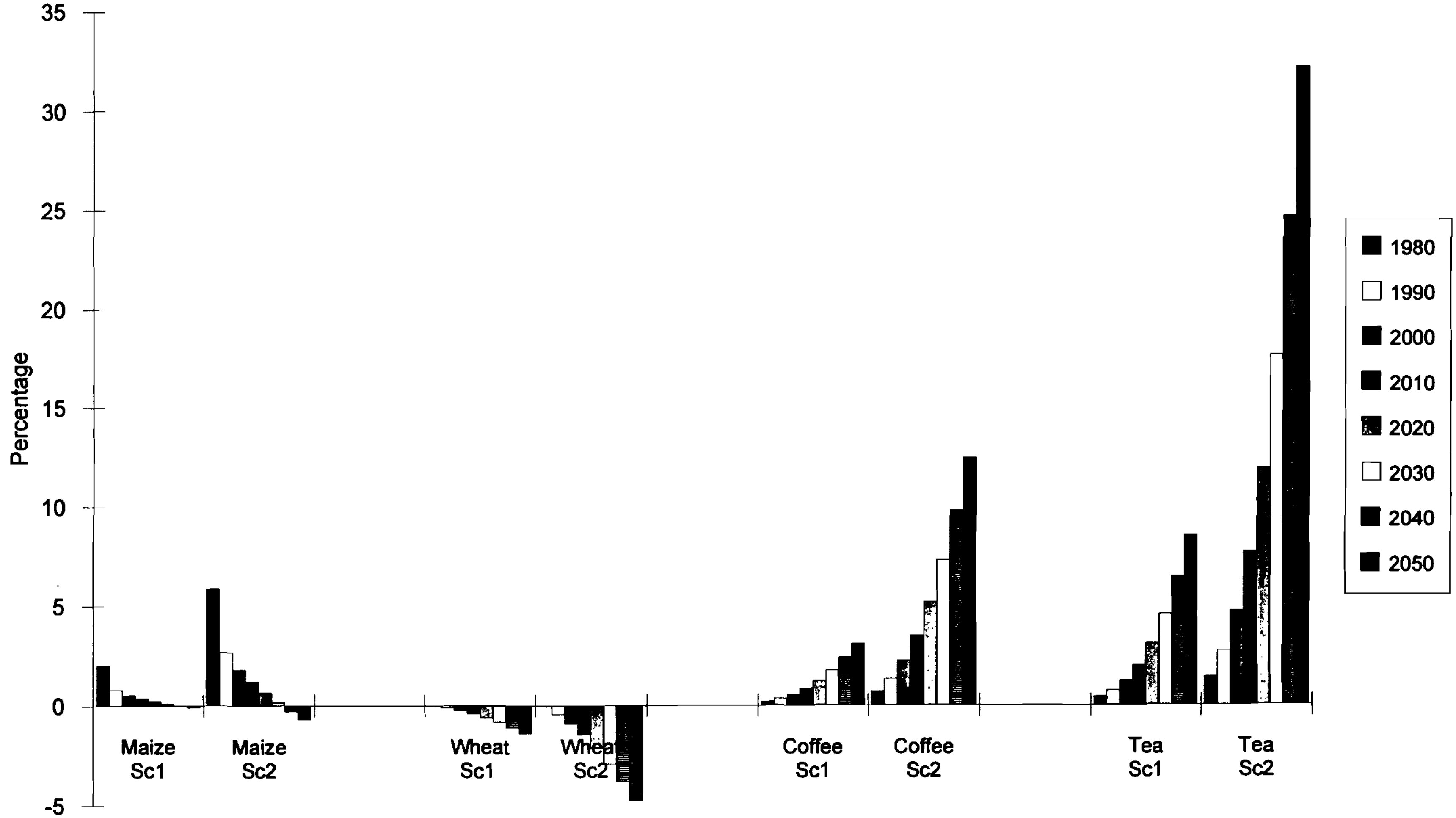


Figure 5 Imports and Exports



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