Working Paper

An Economic Analysis of Potential Impacts of Climate Change in Egypt

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WP-93-12
March 1993

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Abstract

Projections of climate impacts on crop yields simulated for different GCM scenarios are used, in a recursively dynamic general equilibrium framework, to account for potential economy-wide impacts of climate change in Egypt. Comparing these impact projections to those obtained under a reference, business-as-usual, scenario assuming some moderate changes in the political, economic or technological sphere, indicates that global warming has potentially negative effects. The analysis is based on a global assessment of potential climate change-induced variations in world commodity production and trade. The Egyptian agricultural sector (and the nonagricultural sector to a lesser extent), is projected to be increasingly less self-sufficient. Specific adverse impacts include a general rise in food prices, declines in consumer incomes and a consequent decline in per capita food consumption. A deterioration in terms of trade is also projected, suggesting difficulties in augmenting food and other essential supplies with imports. A surplus agricultural labor force is projected to emerge, leading to possible urban and foreign migration. Lower and Upper Egypt where agricultural activity is concentrated are the regions likely to suffer most from the negative impacts on the agricultural sector. Urban Egypt which has a monopoly on nonagricultural activity is expected to be the general destination of possible future labor migration. Baring possibilities for foreign migration, the labor market can be expected to contend with added pressures from greater unemployment and underemployment. The simulation results show that farm level adaptation measures (e.g., adjustments in planting dates, irrigation practices and choice of cultivars), may mitigate these adverse impacts.

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1 Introduction

1.1 Background

The unique characteristics of the Egyptian agriculture which make it one of the most productive in the world also ensures that sector an important role in the entire economy of the country. In addition to a uniquely fertile soil and a very high use of chemical fertilizers, Egyptian agriculture enjoys multiple harvests with a cropping intensity[1] currently 193% of total arable land; it is an all-year round activity in three seasons (Winter, Summer and Nili)[2], and is entirely irrigated by the Nile waters. Over the years, however, rapid population growth, increasing pressures on the natural resource base, and cost-price distortions arising from extensive state intervention have raised concerns about the future role of agriculture in this agriculture-based economy. More recently, these concerns have been added to by the prospects of a greenhouse gas-induced global warming which has the potential of causing climatic zones to shift, eustatic sea level to rise, and major weather patterns to alter. It is estimated that if present rates[3] of greenhouse gas emissions continue, the atmospheric concentration of these gases will effectively amount to a doubling of carbon dioxide to about 660 parts per million (ppm)[4] by the year 2030, consequently raising

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[1] Cropping intensity measures the intensity of land use; it is the ratio of cropped area and cultivated area. All of the land cultivated in any given year is designated the cultivated area; cropped area on the other hand is total land area cultivated in a year including multiple cropped areas.

[2] The winter season runs from November to May; the summer season, from March/April to September; and the Nili season, from May to November.

[3] At the onset of industrial revolution (1850), the atmospheric concentration of carbon dioxide was about 270 parts per million (ppm). Since then, the carbon dioxide level has been rising at an annual rate of 0.4%.

[4] This 660 ppm equivalent carbon dioxide is made up of 555 ppm carbon dioxide plus other greenhouse gases amounting to an equivalent 105 ppm of carbon dioxide.

global mean temperature by between 4°C and 5.2°C[5]; the resulting climatic change is then assumed to occur, with some delay, around the year 2060. Higher atmospheric concentration of carbon dioxide, the single most important anthropogenic greenhouse gas[6], has also the potential of positively affecting crop growth and yield.

Recent studies of the potential effects of global climate change on agriculture project a decline in agricultural productivity in regions of high present-day vulnerability, and in the Asian region of the former USSR and China (Parry et al., 1988). And although there is a possibility of agricultural productivity increase in the high and mid latitudes because of prolonged growing season, agricultural trade patterns could be altered by decreased cereal production in some of the currently high production areas e.g., Western Europe, Southern USA and Western Australia (IPCC, 1990). All of these outcomes could have serious consequences for the economies of the countries of high present-day vulnerability, and the welfare of people living therein. Based on the extent of land liable to inundation by a global warming-induced sea level rise, the population at risk, and the capability of taking protective measures, many countries have been identified as being particularly vulnerable. Most vulnerable are those countries with low-lying, extensive deltas and large human populations like Egypt[7], and whose natural resource base is increasingly under pressure.

1.2 Egypt: Resource Availability and Societal Vulnerability

Egyptian agriculture is irrigated and irrigation water is supplied entirely by a limited Nile water budget. The annual water budget as laid down by agreement between Egypt and the Sudan is 55.5 billion cubic meters. The Nile Delta receives 35 billion cubic meters of surface Nile water, one third of which is lost due to evapo-transpiration and infiltration to groudwater aquifers; the remaining surface water (67%), channeled across the delta through a system of feeder canals,

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[5] More recent estimates of changes in mean global temperatures project lower increases ranging between 1.5°C to 4.5°C (IPCC, 1992).

[6] Carbon dioxide is responsible for more than half of the warming originating from past (and expected future) emissions. It is estimated that about 55% of current natural greenhouse effect is accounted for by water vapor and that, of the remaining 45%, carbon dioxide is responsible for about 85% of this effect (see Jonas et al., 1992).

[7] On an ascending order of vulnerability (1 to 10) the following most vulnerable countries or regions have been identified: 10, Bangladesh; 9, Egypt, Thailand; 8, China; 7, western Denmark; 6, Louisiana; 4, Indonesia (see Parry, 1990).

is deemed insufficient for the planned agricultural development and land reclamation (El-Raey, 1990). Moreover, the possibility of Egypt increasing its fixed quota of the Nile water through bilateral (with the Sudan) or multilateral (with all countries of the Nile Basin) efforts, is limited (Abou-Mandour, 1991). The per-capita amount of Nile water was 1,700 cubic meters in 1970 and fell to 1,005 cubic meters by 1990; by the year 2060, when current Egyptian population will have doubled, the per-capita share of the Nile water is estimated to further drop to about 452 cubic meters.

With only about 4% of available land area inhabited and cultivable (the remainder of the country is largely uninhabited desert), land is one of the most constraining resources to future economic activity in Egypt. To expand arable land the country has been reclaiming desert land. About 1.04 million acres have been reclaimed over the years while some 0.02 million acres have been lost to housing and other urban constructions yearly. Though total agricultural land in use has slightly increased since the mid eighties, it should be noted that the new lands which require a lot of investments to reclaim, are not as agriculturally productive as the old land. In 1976, cropped area per capita amounted to 0.12 ha.; by 1990, it had fallen by some 17% to 0.1 ha. per-capita. Even when we allow for a 200% cropping intensity by the year 2060, cropped area per-capita is calculated to decline further to a mere 0.05 ha.

Because of this shrinking per-capita share of the resource base among other causes, agriculture's role in the Egyptian economy has been declining. Whereas in the 1970s Egypt was self-sufficient in food and a net exporter of agricultural commodities, by the 1980s, however, its agricultural trade had run into deficit. Agriculture's contribution to GDP declined from about 30% in the mid-70s to 17% in 1990. And, currently, about half of the country's food needs is imported. A climate change scenario which results in decreased precipitation in the Nile basin (implying diminished availability of irrigation water), some arable land loss in the Nile delta (due to a global warming-induced sea level rise), and increased atmospheric temperature, is likely to further aggravate the problems of the Egyptian agriculture. In Egypt, the close linkages between the agricultural and nonagricultural sectors of the economy suggest that any changes in agricultural output or its composition can be expected to reflect throughout the economy, and to have important implications for the livelihood of the population for whom the agricultural sector provides food and fiber. A timely understanding of the potential impacts of a changed global climate on this important sector of the Egyptian economy will provide valuable information to policy makers who need to know, among other things, how food consumption might be affected.

1.3 Study Rationale

Concern over the potential impacts of greenhouse gas-induced global warming in Egypt has focused almost exclusively on the implications of rising sea level for the Nile delta which lies barely above sea level and therefore is vulnerable to a sea level rise (see for example, Broadhus et. al (1986); Sestini (1989); Milliman and Broadhus (1989); El-Raey et. al (1990); El-Raey (1991)). That this perceived vulnerability has become a source of concern is not surprising since most of Egypt's population, agriculture and industrial activity is located in the low-lying delta. Table 4 describes the regional distribution of economic activity. As shown in Figure 1, sea level rise, however, is only one of the potential consequences of a greenhouse gas-induced global warming. To the extent that plant photosynthesis and growth are dependent on ambient levels of carbon dioxide, the very atmospheric concentration of this greenhouse gas in itself is likely to have important direct implications for agriculture in Egypt. There are also likely to be additional impacts arising from similarly induced changes in production in the rest of the world to which the Egyptian economy (like every other economy) is linked by trade. National assessments of the potential effects of climate change have often failed to integrate such global level changes in commodity production and trade. In an earlier study that integrates this global component, Onyeji (1992) does not, however, consider the possible effects in Egypt, of adaptive response measures taken both locally and globally. Fischer et al (1992) provide a first attempt at an integrated *global* assessment of the potential effects of climate change on agriculture; this effort, though based on national and regional models, does not specifically focus on a particular country. As a tool of analysis, the present study (like these earlier ones) proposes a dynamic general equilibrium methodology which allows the economy to adjust consistently to exogenous economic and climatic stimuli while still obeying the rules of economic efficiency. With the benefit of these earlier efforts the present study attempts, as an improvement over them, to analyze the economy-wide implications of global warming-induced changes in agricultural output in Egypt, taking into account the role of adaptive response measures both locally and globally.

The specific objectives are to use estimates of potential changes in commodity production (with and without adaptive response measures) under conditions of greenhouse gas-induced changes in global climate to:

- assess the implications of potential changes in commodity production in Egypt;
- assess the role of potential changes in world commodity output and trade in Egypt;
- and to provide insights on the economy-wide implications of greenhouse gas-induced climate change for Egypt, based on these assessments.

We next present a schematic model of potential effects of global warming in Egypt. This is followed by a section describing the procedures used to simulate the reference and impact scenarios. The simulation results are presented and discussed in a subsequent section. A final section highlights the main findings of the study and concludes by drawing some policy implications of the findings; the limitations of the study are also stated in this concluding section together with suggestions for further research.

1.4 A Schematic Model of Climatic Impacts Distribution

Because this study is concerned with the economy-wide implications of potential effects of increased levels of carbon dioxide, and of moisture and temperature changes on crop growth and yield in Egypt it seems useful to outline, at the outset, the pattern of the general distribution of possible global warming effects in Egypt. This is described in Figure 1 which indicates potential impact sources, and how resources and systems interrelate in the entire process. Because of the uncertainty (at both global and national levels) surrounding the spatial distribution of expected climatic changes, the present schematic diagram is only an indication of how these effects *might* be distributed in Egypt.

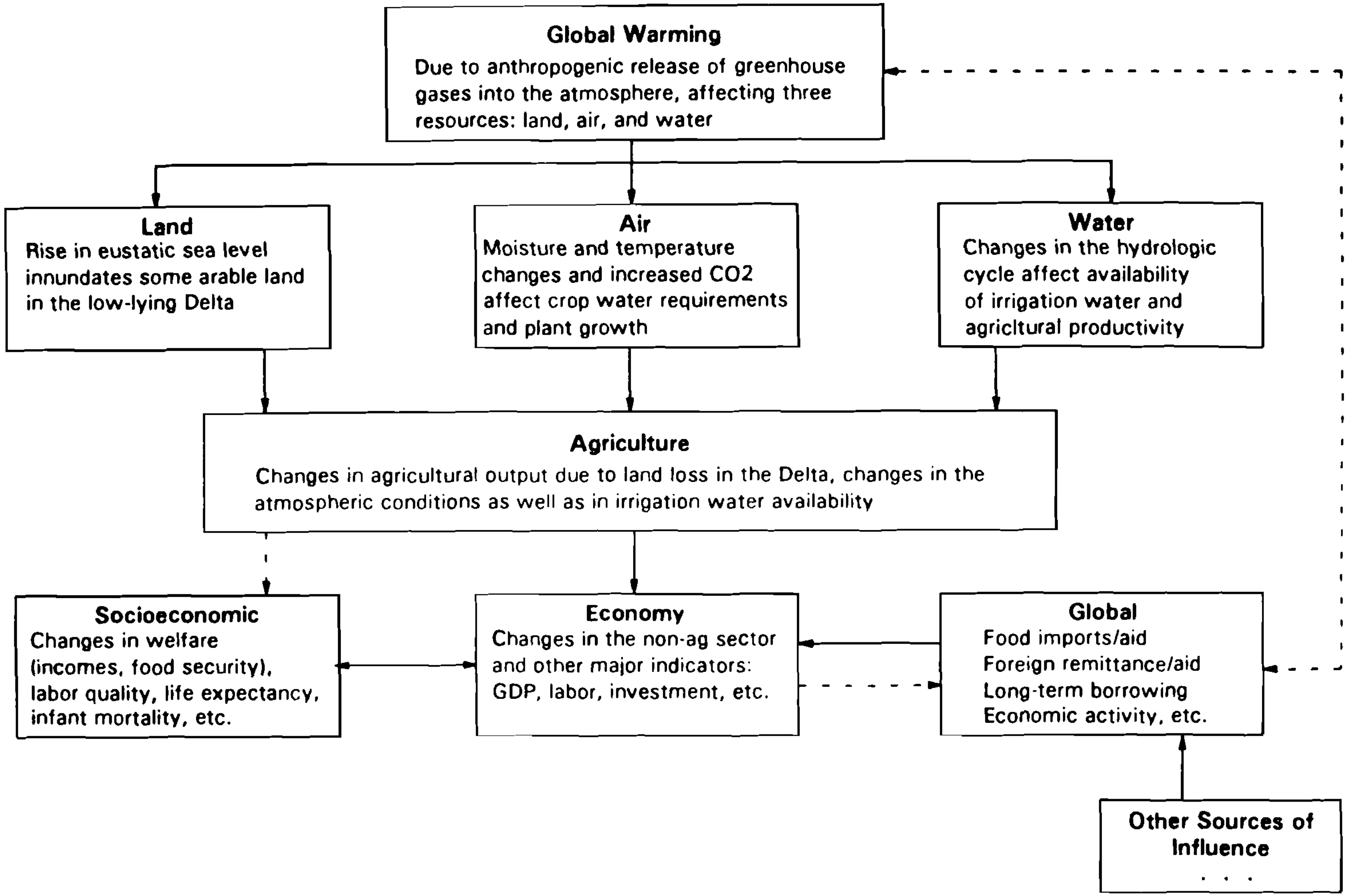

Figure 1. A Schematic Model of Climate Impact Distribution in Egypt.
Source: Onyeji (1992).

In Egypt, three essential resources, *Land*, *Water*, and the *Air* are at risk of perturbation by global climatic changes of the magnitude currently projected. The impact on land is anticipated to result from sea level rise which is projected to inundate some of the arable land in the Delta. The impact on water is anticipated to induce changes in the hydrologic cycle which might adversely affect irrigation water availability. Air or atmospheric impacts are anticipated to occur as moisture and temperature changes and as the ambient levels of carbon dioxide which are expected to affect plant growth, increase. Climate change induced impacts on crop yields are the specific concern of the present paper. Agriculture is modeled as an important primary recipient of shocks from these systems. Impacts on agriculture are measured in terms of changes in yields and agricultural output, aggregated to the level of gross domestic product (GDP). The close link between farm and nonfarm sectors implies that any changes in agricultural output or its composition will affect the level of industrial activity (the economy) and by further extension, the social and cultural conditions of the people. Secondary effects are measured as changes in the aggregate levels of economic indicators like GDP, nonagricultural GDP, labor force, equivalent income, etc. Egypt's interaction with the outside world (via trade, foreign remittances, foreign assistance etc.) will further condition these outcomes. It should be pointed out that the indicated feedback between the **Global Warming** and **Global** boxes (in Figure 1) is not modeled; it only serves to show the possibility of such linkages.

2 Study Approach

The basic approach of this analysis is to drive a general equilibrium model of the world food system, the Basic Linked System (BLS), with climate change impact projections of crop yields simulated with physical crop growth models[8], for different General Circulation Model[9] (GCM) scenarios of climate change.

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[8] The crop models are those developed by the International Benchmark Sites Network for Agrotechnology Transfer (IBSNAT, 1990)—a global network of crop modelers funded by the U.S. Agency for International Development who are collaborating on the Climate Change and International Agriculture Project.

[9] GCMs are complex models that simulate the physical processes of the atmosphere and oceans to estimate global climate; they can be run to estimate current climates and the sensitivity of climate to different conditions such as different compositions of greenhouse gases (Smith and Tirpak, 1990).

A climate change scenario is defined as a physically consistent set of changes in meteorological variables, based on generally accepted projections of carbon dioxide (and other trace gases) levels. Climate change scenarios attempt to replicate, within the associated uncertainties, the range of possible future climatic effects of increasing radiatively active trace gases. Projections of climate sensitivity to a doubling of the present atmospheric concentration of carbon dioxide by the year 2060 are obtained from three GCMs: the Goddard Institute for Space Studies (Hansen et al., 1983) (GISS); the Geophysical Fluid Dynamics Laboratory (Manabe and Wetherald, 1987) (GFDL); and the United Kingdom Meteorological Office (Wilson and Mitchell, 1987) (UKMO). Of the three, the UKMO predicts the largest average global temperature increase of 5.2°C followed by the GISS (4.2°C) and the GFDL (4.0°C). GCMs have been shown to simulate current temperatures reasonably well, but do not reproduce current precipitation as accurately, and their ability to reproduce current climate varies considerably from region to region (Houghton et al., 1990). Furthermore, they cannot reliably simulate such important climate variables as drought frequencies and storms which may have more serious consequencies for agriculture than changes in average climate conditions.

Estimates of climate change impacts on crop yields were obtained from IBSNAT (1989) crop model simulation experiments carried out on two crops (wheat and maize) at two sites each in Egypt. The IBSNAT models simulate crop growth and yield formation as influenced by genetics, climate, soils and management practices. Models used were for wheat (Ritchie and Otter, 1985; Godwin et al., 1989), and for maize (Jones and Kiniry, 1986; Ritchie et al., 1989). The simulations were done for baseline climate (1951-80) and GCM doubled carbon dioxide climate change scenarios. Since most plants growing in experimental environments exhibit increased rates of net photosynthesis and efficient water use corresponding to increased levels of atmospheric carbon dioxide, the experiments also accounted for this beneficial physiological effects of carbon dioxide (Paert et al., 1989). The IBSNAT model results were used in this study because the model is location-neutral having been validated over a wide range of environments that also hold for Egypt. A further advantage of the IBSNAT model is that it permits experiments that simulate adjustments in such management practices as are implied in the farm level adaptations assumed in the models to mitigate adverse climate change impacts on crop yield. It should be noted, however, that the IBSNAT crop models contain some empirically derived relationships which may not hold under the warmer conditions found in the climate change scenarios. This might tend to bias simulated yield results as might also the limiting assumption that weeds, diseases, and insect pests are controlled. This latter assumption may prove to be important for the results obtained for Egypt where, already, the misuse and over-use of pesticides are aggravating insect pests problems and plant diseases, with consequent adverse effects on agricultural productivity.

Crop yield changes expected for different scenarios of climate change were obtained from aggregations of crop model results for wheat and maize. By weighting regional yield changes[10] based on current production, national yield estimates were obtained. Production data were obtained from the crop modelers, from the FAO, the USDA Crop Production Statistical Division, and the USDA International Service. Where crops were not simulated with IBSNAT models, national yield changes for those crops were estimated based on their similarities to the modeled crops. Estimates were made of yield changes for the three GCM scenarios with and without direct effects of carbon dioxide. Estimates for the former case were based on the mean responses to carbon dioxide for the different crops in the crop model simulations.

The next step was to apply the projected changes in yields and crop productivity to the Basic Linked System of National Agricultural Models (BLS) developed by the Food and Agriculture Program (FAP) of the International Institute for Applied Systems Analysis (IIASA), and to simulate impacts for the period 1990-2060. This impact simulation takes into account population growth, technology trends and economic growth. Simulations for the reference scenario were made under the assumptions of no climate change, and for the impact scenarios under the assumption of climate change scenarios outlined above. Production and demand in the BLS are aggregated to ten sectors. Commodities relevant in Egypt have been redefined to match the ten commodity aggregation of the BLS. The list includes wheat; rice; coarse grains; protein feed; bovine and ovine meat; dairy products; pork, poultry and fish; other food products; nonfood

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[10] These regions are the geographical groupings represented in the IIASA/FAP world food model, the Basic Linked System (BLS); the regional yield estimates represent the current mix of rainfed and irrigated production, the current crop varieties, nitrogen management and soils.

agricultural products; and nonagricultural products. The commodity mapping and units are presented in Appendix A.

The BLS is a world level general equilibrium model system comprising at present some thirty-five national and/or regional models: eighteen national models, two models for regions with close economic cooperation (EC and Eastern Europe + former USSR[11]), fourteen aggregate models of country groupings, and a small component that accounts for statistical discrepancies and imbalances during the historical period. The individual models are linked together by means of a world market module. The system is of Walrasian general equilibrium type. There is no money illusion on the part of any economic agent. As a consequence of this, the outcome in terms of 'real' variables is neutral with respect to monetary changes. The system is recursively dynamic, working in annual steps, the outcome of each step being affected by the outcomes of earlier ones. Each model covers the whole economy, for the purpose of international linkage aggregated to nine agricultural sectors and one non-agricultural sector. All accounts are closed and mutually consistent: the production, consumption and financial ones at the national level, and the trade and financial flows at the global level. A detailed description of the entire system of the BLS is provided in Fischer et al. (1988).

3 Simulation Results

In addition to a *reference*, business-as-usual, scenario which assumes that agricultural yields are not affected by global warming conditions, three impacts scenarios were simulated. These impact scenarios are based on the estimated physiological effects of 555 ppm carbon dioxide on crop growth and yield[12]. One impact scenario (scenario I) assumes only that crop growth and yield are physiologically affected by 555 ppm carbon dioxide without any adaptive response measures to counter adverse climate effects. The other two scenarios, in addition to assuming physiological effects on crop growth and yield, assume also that farm-level adaptation measures are taken

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[11] The political changes as well as changes in national boundaries of the very recent past are not captured in the BLS, although the model formulation has been adjusted, away from centrally planned economies to more market oriented behavior.

[12] It is known that under experimental conditions, plant photosynthesis and growth are influenced by ambient levels of carbon dioxide (see for example: U.S. DOE, 1985.)

to mitigate negative yield impacts. These adaptation scenarios are differentiated as low-cost (minor adaptations scenario II) and high-cost (major adaptations scenario III) depending on the extent of the assumed adaptation measures. Low-cost adaptation assumes measures that do not involve major changes in the agricultural system and practices; they include ordinary measures within the reach of the farmer like substituting traditional crops with more tolerant cultivars, additional irrigation gifts etc. High-cost adaptation measures are those that involve major changes in the agricultural system and practices; they are often beyond the reach of the farmer alone and include such options as the introduction of more efficient irrigation systems and their expansion. In the particular case of Egypt, reclamation of desert land and the subsequent expansion of the irrigation system to newly reclaimed land would fall under this heading, as well as the introduction of other technological changes such as replacing manual labor with machines, improved organization of agricultural operations etc. Thus for each of the GCMs, a set of simulation results is obtained for

- Scenario I: with physiological effects of carbon dioxide
- Scenario II: with physiological effects of carbon dioxide and adaptation level I
- Scenario III: with physiological effects of carbon dioxide and adaptation level II.

The reference scenario describes agricultural commodity production and aggregate macroeconomic indicators of development as well as indicators of welfare over the period 1990-2060 as simulated under business-as-usual conditions[13]. The reference scenario provides a benchmark for comparing solutions from the different climatic impact scenarios under which global warming conditions are assumed to register physiological impacts on crop growth and yield. These impact scenarios quantify the implications of alternative assumptions about the impacts of, and responses to global warming conditions. Compared with the reference scenario, these exemplify the consequences of the different assumptions for Egypt.

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[13] The reference run should not be interpreted as a forecast of economic development in Egypt; there are large uncertainties involved in the entire modeling process given the length of simulation period.

3.1 The Reference Scenario

The reference scenario results are presented in Table 1. The projections indicate that in the absence of global warming effects, the performance of the Egyptian economy is assumed to improve remarkably by the year 2060. The capacity of the economy to achieve higher productivity and growth is indicated by substantial increases, over the 1990 levels, in total GDP and total investment. The nonagricultural sector is assumed to grow faster than the agricultural sector. Whereas total GDP increases 5.2 fold and agricultural GDP, by 3.1 fold, nonagricultural GDP has grown 5.6 fold. Similarly, total agricultural labor force increases (1.9 fold) less than total nonagricultural labor force (2.6 fold); demand for agricultural products increases (slightly) more[14] than population growth. Agriculture, as a result, tends toward more capital-intensive techniques. The already noted capacity utilization of cultivable land supports this observation.

Total labor force is projected to grow by an annual average rate of 1.2% over the seventy-year period. This slightly faster growth of labor force than of population (1.1%) indicates that there is an increase in labor force participation, and also that the population is relatively young. The share of agriculture in total output drops from about 17% in 1990 to about 10% in 2060. This is partly because the cultivable area, cropped at maximum intensity, has been expanded to its limits. Overall trade balance while still showing a deficit has improved over the years with smaller relative deficits[15]. This fall in trade deficits indicates that domestic absorption of goods (that is, final domestic demand) is assumed to grow more slowly than GDP. In addition, the relative decline in the terms of trade suggests a tightening of foreign exchange availability.

Nutrition indicators like protein and calorie consumption per capita show some improvement over their levels in 1990—a consequence of higher per capita incomes. The observed increases in the demand for both agricultural and nonagricultural products are a reflection of the increases in consumers' incomes as well as a sizable growth in population.

Table 2 presents a set of relative prices, self-sufficiency ratios and expected net revenues of agricultural commodities in the reference scenario. Commodity retail prices are endogenously

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[14] This greater increase in demand is inferred from the simultaneous increase in both population and equivalent income by 2.3 fold respectively; an increase which is more than the observed increase in agricultural labor force.

[15] As a percentage of GDP.

determined in the model and reflect relative scarcities and the underlying production costs. Thus in the absence of global warming effects and less cost-price distortions[16], prices of wheat, rice, protein feed, and other food products rise relative to the prices of other goods. This rise in the retail prices of food commodities is consistent with a concurrent 2.3 fold increase in consumer incomes, here equated with equivalent income (Table 1). The decline in the crop price index indicates that the observed improvements in expected net revenues may be attributed to increased productivity. The general decline in farm or producer prices suggests a widening of the price spreads which in turn is indicative of increasing processing and marketing costs, and of greater industrial/manufacturing activity. Apart from coarse grains whose relative price in the year 2060 is about equal to the 1990 index, the prices for nonfood agricultural products, bovine and ovine meat, dairy products and other animal products have declined in comparison with the 1990 levels. Except for wheat, coarse grains, dairy products and bovine and ovine meats, Egypt is self sufficient in the rest of the agricultural commodities.

No dramatic changes are recorded in commodity value shares in total agricultural production (Table 3) implying that the structure of agricultural production in the projections of the reference scenario does not change significantly. Thus we infer that the regional distribution of agricultural activities in 1990 as described by the location quotients of Table 4 broadly holds for the year 2060.

At the global level (Table 5), substantial increases in commodity production are recorded for each commodity for the reference scenario. A consequence of this increase in world agricultural commodities is a general decline (or stagnation) in real terms of agricultural prices in international markets (as was the case in the past decades). This also leads to an expansion of agricultural trade at the global level. For Egypt, trade occurs in those commodities in which the country is not self sufficient namely, wheat, coarse grains, and bovine and ovine meats, and in which world production is abundant. Generally, the supply of agricultural commodities from Egyptian domestic sources lags behind demand and the resulting food gap is bridged with imports. Wheat imports increase by three times their 1990 volume, and its per-capita consumption

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[16] It is assumed that the observed price distortions are reduced to half their present levels by the year 2020.

by 1.3 times. The imports of coarse grains and bovine and ovine meat, also increase by twice their 1990 levels. Egypt is self-sufficient in the production of rice, other food products, nonfood agricultural products, and other animal products. The main export items are rice, protein feed, other food and nonfood agricultural products.

3.2 Impacts Scenario Analysis

The impact scenarios were constructed to illustrate the potential consequences for the Egyptian economy of global warming-induced changes in agricultural output and also the economy-wide implications of different adaptation measures aimed at mitigating the negative yield impacts. Simulations were done for the three GCM climate change scenarios. Table 6 presents the impacts simulation results. An examination of the results from alternative scenarios shows that global warming has negative impacts on the overall economy as is revealed by the general decline, relative to the reference scenario, in major economic indicators. By assumption, impacts are stronger on the agricultural sector than on the nonagricultural sector in all scenarios; and there are no direct impacts upon livestock production except indirectly through changes in feed costs.

3.2.1 Scenario I

This scenario assumes that crop growth and yield are affected by global warming; it does not assume any adaptation measures[17] that may mitigate negative climate impacts. In this scenario, decline in agricultural GDP is projected to range from under 2% to about 7% while the projected fall in nonagricultural GDP is between under 1% and about 6%. Decline in total GDP is within similar order of magnitude: from under 1% to about 6%. In all cases, the UKMO predicts the most decline. Crop and food prices rise, reflecting climate change-induced crop failures, higher food import costs etc. The rise in the general level of crop prices, relative to the reference scenario, is sometimes dramatic, ranging between 10% and 90%. On the other hand, the projected rise in the general level of food prices is between 3% and 30%. Global warming effects diminish the ability of the agricultural sector to meet domestic demand for

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[17] It should be noted that normal price-induced and similar other economic measures are, however, assumed to take place.

agricultural products. This is revealed by a decrease in self-sufficiency in agricultural products. Consequently, imports of agricultural commodities are relied upon to augment domestic supply. This seems rather difficult to achieve because of the projected deterioration in the terms of trade, and an equally not self sufficient nonagricultural sector which, otherwise, might have been a source of foreign exchange. There is a general decline in per capita intake of essential food nutrients and important indicators of welfare: calorie and protein. This decline, which ranges between 1% and 3% is consistent with the decline in equivalent income (of between 1% and 8%), and the already noted rise in food prices both of which combine to erode consumers' purchasing power. Expected net commodity revenues (Table 7) have also suffered in this scenario, reflecting declined productivity.

3.2.2 Adaptation Scenarios II and III

The assumptions of scenario I are maintained in scenarios II and III; both these scenarios in addition assume that farmers implement low-cost adaptation measures aimed at mitigating negative climate impacts. Scenario III also assumes additional adaptation measures that may involve large investments.

A visible general effect of adaptation measures is that they moderate global warming-induced changes in yields and consequently in the economic and welfare indicators. Adaptation measures whether low-cost (minimal) or high-cost (comprehensive) do not, however, fully compensate for the decline in agricultural productivity. In fact, the simulated decline in agricultural GDP is stronger when adaptive response measures are taken than when they are not. This happens because the assumed adaptation measures in Egypt are probably less efficient or less effective than those in other regions of the world; in consequence, the comparative advantage of Egyptian agriculture deteriorates.

Whereas the rise (relative to the reference scenario) in the general level of food prices ranges between 3% and 30% in the no-adaptation scenario (Scenario I), low and high cost adaptation measures moderate this range to between -2% and 7%; they also moderate the decline in equivalent income implying a relative enhancement of consumers' purchasing power. Accordingly, we witness a general improvement in per capita food consumption under the scenarios with adaptation measures compared to that without adaptation measures. This relative improvement is reflected in the ranges of observed declines in calorie and protein per capita intake in the no-adaptation and adaptation scenarios (between 1% and 3% in Scenario I and 1% and 2% in the adaptation Scenarios), relative to the reference scenario.

Individual countries benefit from the net positive effects of the mitigating impacts of high-cost adaptation measures on global agricultural supply. In the case of Egypt such benefits are seen, for instance, in the changes in food and crop prices relative to the reference scenario. The general rise in food prices range between 3% and 30% in the no-adaptation scenario; in the low-cost adaptation scenario this range falls to between 1% and 17% and further declines, in the high-cost adaptation scenario, to between -2% and 7% compared to the reference scenario. This pattern of changes is similar to that exhibited by the crop price index and equivalent income.

The behavior of net commodity revenues (see Table 7), as can be expected, follows the general pattern of changes in the crop prices and yields. Under Scenario I changes in crop revenues from climate-induced crop failures are mitigated by higher commodity prices both in Egypt and globally. On the other hand, revenue projections under Scenarios II and III reflect the relative increase in productivity (in relation to Scenario I) rather than changes in commodity prices. The GISS in all scenarios results in a decline in most crop revenues whereas the UKMO predicts a rise in all scenarios (for the most part). The stronger decline in net commodity revenue in the scenarios assuming adaptive response measures (Scenarios II and III) is a reflection of the deteriorating comparative advantage of the Egyptian agriculture already seen in the case of agricultural GDP. This outcome suggests that in the GISS scenarios changes felt in Egypt are dominated by direct local effects whereas in the UKMO scenarios the overall global effects drive changes in domestic crop revenues. To the extent that this worsening comparative advantage erodes net commodity revenues (relative to the reference scenario), farmers may be said to suffer from the adverse effects of climate change.

3.3 Discussion

Compared to the reference scenario, total GDP falls throughout the model scenarios of climate change (except under GISS and GFDL high adaptation scenarios); and so does total investment. The simulation results indicate that under global warming conditions, crop production suffers. Except for rice and to some extent, protein feed and other food products, production of the rest of the commodities is adversely affected by global climatic change. Such climatic conditions may induce a further tightening of the agricultural labor market with the resulting agricultural labor surplus expected to head for possible urban and foreign migration. A concurrent decline in agricultural income is also projected. Assuming that the regional distribution of economic activities in 1990 more or less holds in 2060 (and given the projected doubling of population by this year) the expected migration of labor will tend to occur from Lower and Upper Egypt to Urban Egypt as displaced agricultural labor seeks employment in the nonagricultural sector. Because the present capacity of the urban socioeconomic structure[18]is, in all likelihood, too limited to cope with such migration, economic development of rural areas seems a reasonable, if inevitable, development strategy for the government of today.

Overall, per-capita consumption of most food commodities is projected to decline. Egypt's ability to ensure, through imports, adequate consumption of foodstuffs by low-income consumers is as important as the role of its domestic production; especially, since world market fluctuations in basic grains is one of the uncertainties that determine the nature of food security in the country. Thus, the terms of trade which Egypt faces are crucial to its food security. These, however, are projected to deteriorate under global warming conditions. Naturally, trade imbalance has unfavorable implications for the country's foreign balances and economic development. For a country whose natural resource base is increasingly stressed (indicating limited domestic ability to supply food), closing the food gap will require substantial imports. However, the increased scarcity of foreign exchange under global warming conditions means that the food gap may widen, intensifying food insecurity thereby. As the general level of food prices rises there is a

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[18] Although a seventy-year period is more than sufficient time for substantial improvements in the economy to occur, there is at present little evidence to suggest that dramatic changes in the economy may take place.

decline in per-capita food consumption. All of this amounts to possible limitations on food, health-care and income entitlements etc., especially for low-income classes among others.

The relative declines, under global warming conditions, in domestic production of cereals (wheat, rice, coarse grains) is a cause for concern particularly since these are important food commodity items as revealed by Egyptian family budget surveys and the Food and Agriculture Organization of the United Nations (FAO). Cereals account for about two-thirds of protein and calorie intake in Egypt (FAO, 1991). Deficiencies in these major sources of calorie and protein supply would have unfavorable implications. The nutritional status of individuals, as measured by calorie and protein intake per capita, deteriorates under global warming conditions. This implies a decline in the ability to withstand food deprivation; it also suggests increased vulnerability to diseases and ill health. The decline in equivalent income raises concerns about the adequacy of household resources and, of course, exacerbates this vulnerability especially for consumers from the poorer classes. Limitations on income, food and, by implication, health care entitlements are likely to adversely affect such socioeconomic indicators as life expectancy, infant mortality, quality of labor, etc.

The overall positive effects of adaptation measures indicate the usefulness of specific adaptive responses. Taken in conjunction with planned economic development of rural areas, these responses will probably be more effective—enhancing, thereby, the mitigation of the adverse effects of possible climate change. Egypt may find it difficult to do without food imports as well as the imports of essential raw materials (and machinery); thus, both long-term borrowing and foreign aid may be necessary sources of financing imports.

4 Conclusions

The study demonstrates that if present trends in atmospheric concentration of greenhouse gases persist, and if the consequent warming of global climate occurs as is currently predicted, agriculture in Egypt can be expected to be negatively affected; such negative impacts would have other economy-wide implications. It is apparent that for Egypt welfare conditions under a reference scenario (without climate change) are superior to those under climate impact scenarios. Large uncertainties limit the ability to project future economic conditions over a long time period. However, the simulated directions of changes rather than the exact magnitude of these changes in the economic and welfare indicators relative to the reference scenarios should be of interest. Without implementing adaptation measures, the general levels of crop and food prices are projected to rise globally and in Egypt as a consequence of climate-induced adverse yield changes; incomes also decline, further constraining household resources. Adaptation measures may moderate changes in economic and welfare indicators. Whether low-cost or high-cost, adaptation measures do not fully compensate for the declines in sectoral and total GDP because of the projected deterioration in Egypt's agricultural comparative advantage. Improvements in agricultural productivity may be achieved with increased land reclamation, sustained technological progress, and the adoption of better agro-management techniques.

The present study is limited not only by the model imperfections mentioned earlier, but also by its scope. As indicated in Figure 1, potential climate change impacts are not limited to those considered in this study. Of course, it would be desirable for a study of this nature to be more comprehensive and to simultaneously integrate all the potential impacts of global warming. This is necessary because, in reality, these impacts do not occur in isolation of one another. Because of the possibility that global warming-induced alterations in the hydrologic cycle could cause changes in the Nile river flows, there is concern about the availability of irrigation water under conditions of climate change; this study did not consider this concern for future irrigation water availability in Egypt. Also, costs of adaptation have not been considered. These are issues which should be taken into account by future research.

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Table 1: Changes in Economic and Welfare Indicators in 2060 Relative to 1990.

Indicator	2060 Reference	Average Growth Rates (%) 1990–2020	2020–2060	1990–2060
population	222	1.7	0.8	1.1
agricultural labor	188	1.6	0.4	0.9
nonagricultural labor	259	1.8	1.1	1.4
agricultural capital	341	2.4	1.3	1.8
nonagricultural capital	710	3.5	2.3	2.8
nitrogen fertilizer	727	4.6	1.6	2.9
GDP	523	3.1	1.9	2.4
GDP per caput	235	1.4	1.1	1.2
GDP agriculture	310	2.5	1.0	1.6
GDP nonagriculture	558	3.2	2.0	2.5
calorie per caput	120	0.4	0.2	0.3
protein per caput	118	0.3	0.2	0.2
pa/pna	83	−0.1	−0.4	−0.3
crop price index	86	−0.1	−0.3	−0.2
food price index	103	0.1	0.0	0.1
parity	66	−0.6	−0.7	−0.6
terms of trade	98	−0.7	0.1	0.0
equivalent income	254	1.3	1.0	1.2
total investment	518	3.1	1.8	2.4

2060 Reference scenario values are index numbers (1990=100). See Appendix C for notes.

Table 2: Index of Commodity[a] Relative Prices, Self-Sufficiency Ratios, and Expected Net Revenues in 2060 Reference (1990=100).

Commodity	Producer Price	Retail Price	Self-sufficiency Ratio	Expected Net Revenue[b]
wheat	91	107	93	149
rice	99	112	191	198
coarse grains	81	100	98	143
protein feed	135	135	198	196
other food products	90	112	135	140
nonfood agric.	69	69	120	106
bovine+ovine meat	86	97	91	140
dairy products	90	95	103	140
other animal products	75	82	103	85

[a] See Appendix A for commodity definitions.

[b] The values for bovine+ovine meats, and for dairy products refer to expected revenues per livestock unit; the values for poultry, pork and eggs refer to expected revenues per unit of output. Others refer to expected revenues per hectare.

Table 3: Commodity[a] Value Shares in Total Agricultural Production (%).

Commodity	1980	2060
wheat	4	4
rice	5	7
coarse grains	11	7
protein feed	1	2
other food agric.	27	34
nonfood agric.	14	9
bovine+ovine meat	12	13
dairy products	10	12
poultry,fish,eggs etc.	15	11
Total	100	100

[a] See Appendix A for commodity definitions.

Table 4: Regional location quotients by economic activity in 1990.

	Economic Activities									
Region	1	2	3	4	5	6	7	8	9	0
UBE	0.17	1.36	1.82	1.45	1.51	1.69	1.70	2.16	1.23	1.39
LWE	1.21	0.45	0.89	0.88	0.73	0.74	0.84	0.63	0.97	0.94
UPE	1.29	0.75	0.63	0.85	0.99	0.87	0.74	0.71	0.88	0.83
FTE	0.91	21.10	0.23	1.34	1.44	0.79	1.18	0.52	1.22	0.72

Source: Onyeji (1992).

A location quotient greater (less) than 1.0 indicates that the corresponding region has a higher (lower) concentration of the corresponding activity compared to the concentration at the national level.

1= agriculture; 2= mining/quarrying; 3= manufacturing; 4= electricity, gas and water; 5= construction; 6= commerce, restaurants, hotels; 7= transport, storage, communications; 8= financing, insurance, real estate and business service; 9= community, social and personal services; 0= activities not adequately described.

The regions are constituted of governorates as follows: UBE (Urban Egypt): Cairo, Alexandria, Port-Said, Suez; LWE (Lower Egypt): Damietta, Dakahlia, Sharkia, Kalyubia, Kafr-El-Sheik, Gharbia, Menoufia, Behara, Ismailia; UPE (Uppere Egypt): Giza, Beni-Suef, Fayoum, Menia, Asyut, Suhag, Quena, Aswan; FTE (Frontier Egypt): Red Sea, New Valley, Matruh, North Sinai, South Sainai. Egypt is denominated into twenty-six governorates. Source: CAPMAS, 1990.

Table 5: Index of World Commodity[a] Production and Relative Prices in 2060 Reference (1990=100).

Commodity	Production	Prices
wheat	181	101
rice	214	89
coarse grains	189	90
protein feed	184	151
other food prods.	228	74
nonfood agric.	175	59
bovine+ovine	186	104
dairy products	184	97
other animal prods.	230	91
nonagric. prods.	313	100

[a] See Appendix A for commodity definitions.

Table 6: Percent Changes in Economic and Welfare Indicators in 2060 Relative to Reference Scenario.

	Scenario I			Scenario II			Scenario III		
Indicators	GISS	GFDL	UKMO	GISS	GFDL	UKMO	GISS	GFDL	UKMO
agricultural labor	−0.7	0.7	4.0	−1.0	−0.1	2.0	−1.7	−0.8	0.6
nonagricultural labor	0.4	−0.4	−2.5	0.7	0.1	−1.4	1.1	0.6	−0.5
agricultural capital	−2.1	3.2	20.7	−4.5	0.0	10.7	−6.9	−3.6	3.7
nonagricultural capital	−0.3	−1.4	−7.8	0.3	−0.6	−5.4	1.4	0.7	−2.1
nitrogen fertilizer	14.9	−5.0	−18.6	−16.5	−7.4	−22.7	−13.6	−7.8	−11.6
GDP	−0.6	−1.2	−6.2	−0.3	−0.7	−4.8	0.7	0.3	−1.9
GDP per caput	−0.6	−1.2	−6.2	−0.2	−0.6	−4.0	0.7	0.3	−1.6
GDP agriculture	−6.5	−1.8	−7.3	−7.5	−3.2	−10.2	−6.3	−3.5	−4.9
GDP nonagriculture	−0.1	−1.1	−6.1	0.4	−0.4	−4.2	1.4	0.7	−1.6
calorie per caput	−0.9	−0.6	−3.1	−0.7	−1.1	−2.4	−0.5	−0.8	−1.4
protein per caput	−0.8	−0.7	−3.4	−0.7	−1.2	−2.4	−0.4	−0.8	−1.6
pa/pna	7.2	10.5	63.9	2.1	5.0	36.4	−3.4	−1.9	13.6
crop price index	9.7	14.3	90.9	2.0	6.6	51.6	−5.6	−2.8	19.1
food price index	3.0	5.5	28.5	0.7	2.9	17.3	−1.8	−0.6	6.7
parity	1.5	8.5	51.6	−3.7	2.1	23.5	−7.6	−4.2	8.5
equivalent income	−0.6	−1.3	−7.8	−0.2	−0.8	−6.5	0.9	0.4	−2.4
total investment	−0.6	−1.1	−6.1	−0.3	−0.7	−4.7	0.7	0.3	−1.9

Table 7: Percentage Changes in Expected Net Revenues in 2060 Relative to Reference Scenario.

	Scenario I			Scenario II			Scenario III		
Indicators	GISS	GFDL	UKMO	GISS	GFDL	UKMO	GISS	GFDL	UKMO
wheat	−40.1	−18.4	−0.1	−46.8	−26.8	−25.7	−37.6	−22.5	−8.6
rice	29.5	28.0	117.4	17.7	17.0	84.4	−6.0	−1.2	32.3
coarse grains	4.7	28.1	112.6	−16.2	8.0	51.0	−20.2	−9.4	22.6
protein feed	−6.6	9.0	67.4	−13.1	3.0	36.0	−18.3	−8.2	14.1
other food products	−3.9	5.7	36.8	−6.8	3.0	29.2	−12.5	−5.6	12.0
nonfood agriculture	3.0	18.0	85.5	−7.2	4.6	55.5	−18.1	11.4	18.9
bovine+ovine meats	0.6	−1.8	−8.6	2.2	−0.6	−3.9	3.2	0.9	−2.3
dairy products	−0.5	−2.4	−12.6	1.9	−1.7	−7.8	2.9	0.8	−4.7
poultry,pork,eggs	−0.5	1.4	−12.2	−0.6	−0.2	−6.4	−0.9	−0.8	−1.2

Appendix A: Commodity[19] Mapping

BLS	Egypt
wheat	wheat.
rice	rice.
coarse grains	barley; s+n-maize; s+n-sorghum.
bovine and ovine meat	meats.
dairy products	dairy products.
other animal products	other animal products.
protein feed	cotton(oil/cake); groundnut; sesame; soybeans.
other food products	horse-bean; lentils; other-legumes; w-tomato; s+n-tomato; w-vegetables; sugar; w-onion; s+n-potato; s-vegetable; n-vegetable; citrus; vegetable oil.
non food agriculture	cotton(fiber); flex-fiber.
non agricultural products	non agricultural products.

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[19] Commodity units of measurement are 10^6 t for wheat, rice, coarse grains, bovine and ovine meat, and dairy products, 10^6 t protein equivalent for other animal products and protein feed, and 10^6 US$ 1970 for all other commodities. Commodity prices are in 10^6 US$ per unit of commodity.
s, w, and n respectively stand for the summer, winter and nili season.

Appendix B: Major Crops by Season[20]

Winter Crops	Barley, Beets, Beans, Chickpeas, Fenugreak, Garlic, Lentil, Linen, Lupine, Onion, Strawberry, Vegetables, Wheat.
Summer Crops	Cotton, Maize, Millet, Peanut, Potatoes, Rice, Sesame, Soybeans, Sugarcane, Vegetables.
Nili Crops	Rice, Millet, Maize, Potatoes, Vegetables.

Source: CAPMAS, 1990.

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[20] Winter is from November to May; Summer is from March/April to September; Nili is from May to November.

Appendix C: Notes on Economic and Welfare Indicators

GDP is gross domestic product at 1970 prices; GDP agriculture is GDP of agriculture sector at 1970 prices; GDP nonagriculture is GDP of nonagriculture sector at 1970 prices; agricultural capital is capital stock in agriculture; nonagricultural capital is capital stock in nonagriculture; agricultural labor is total labor force in agriculture; nonagricultural labor is total labor force in non agriculture; GDP per caput is GDP divided by population; calorie per caput is daily energy intake from average diet; protein per caput is protein intake per-capita per day; pa/pna is agricultural price index relative to nonagriculture price index; crop price index is index of crop prices at the farm level; food price index is index of food retail prices; parity is agricultural GDP per person engaged in agriculture divided by nonagricultural GDP per person engaged in nonagriculture; terms of trade is index of unit value of exports over index of unit value of imports; equivalent income is income required to buy a consumption bundle at domestic prices of 1970 that would provide the same utility as provided by current consumption; total investment is total (gross) investment in agriculture and nonagriculture.