AN ASSESSMENT OF INTEGRATED CLIMATE CHANGE IMPACTS ON THE AGRICULTURAL ECONOMY OF EGYPT

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Abstract. This study used a quadratic programming sector model to assess the integrated impacts of climate change on the agricultural economy of Egypt. Results from a dynamic global food trade model were used to update the Egyptian sector model and included socio-economic trends and world market prices of agricultural goods. In addition, the impacts of climate change from three bio-physical sectors – water resources, crop yields, and land resources – were used as inputs to the economic model. The climate change scenarios generally had minor impacts on aggregated economic welfare (sum of Consumer and Producer Surplus or CPS), with the largest reduction of approximately 6 percent. In some climate change scenarios, CPS slightly improved or remained unchanged. These scenarios generally benefited consumers more than producers, as world market conditions reduced the revenue generating capacity of Egyptian agricultural exporters but decreased the costs of imports. Despite increased water availability and only moderate yield declines, several climate change scenarios showed producers being negatively affected by climate change. The analysis supported the hypothesis that smaller food importing countries are at a greater risk to climate change, and impacts could have as much to do with changes in world markets as with changes in local and regional biophysical systems and shifts in the national agricultural economy.

> . . . God has shown Pharaoh what he is about to do. Seven years of great abundance are coming throughout the land of Egypt, but seven years of famine will follow.
> . . . The seven years of abundance in Egypt came to an end and the seven years of famine began, just as Joseph had said.
>
> (Genesis 41: 29–30; 53–54)
> (Holy Bible, New International Version, 1984)

1. Introduction

Egypt has been facing climate variability and its influence on agricultural production for at least four thousand years, since Joseph averted a disaster through a series of resource management decisions. Joseph was able to develop an optimal agricultural management plan because he had a ‘perfect’ hydroclimatic forecast. Today, however, Egyptian planners do not have the luxury of perfect forecasts and must rely on the scientific understanding and analysis of physical and socio-economic systems. The understanding of these complex systems allows for improved planning in light of local and regional climatic variability, untimely and/or limited

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resource availability, and socio-economic uncertainty. The potential for anthropogenic climate change due to green house gas emissions heightens the need for sound development plans. Strategies to deal with the potential problems and impacts of climate change on the agricultural system of Egypt requires qualitative and quantitative analysis.

Egypt's historic vulnerability to climatic fluctuation changed greatly with the completion of the High Aswan dam. The reservoir can hold more than two times the average annual flow, which allows for the storage of surpluses in wet years to be saved for dry years. The entire Egyptian Agricultural system is based upon Egypt's treaty with The Sudan, which annually allocates 55.5 billion cubic meters from the Nile to Egypt. Increased greenhouse gases and potential global and regional climate change could affect River Nile flows and Egypt's water resource availability. How climate induced changes in water resource availability, crop yields, crop water use, land resources and global agricultural markets affect Egyptian agriculture are the focus of this paper.

A mathematical sector model of Egyptian agriculture was used in conjunction with a previous study of the macro-economy, agronomy, water resources and land resources of Egypt to study the integrated impacts of climate change on the agricultural economy of Egypt. This work is an extension of Strzepek et al. (1995) that included economy-wide effects of water resources, the results from a more detailed hydrologic model of the River Nile and additional socio-economic scenarios (Yates and Strzepek, 1996; Strzepek and Yates, 1996).

Examples of other integrated studies of climate change impacts on agricultural systems include: the MINK study on Minnesota, Iowa, Nebraska, and Kansas (Bowes and Crosson, 1993; Crosson and Rosenburg, 1993); the St. Lawrence River Basin (Mortsch et al., 1993); Southeast Asia (Parry et al., 1992); U.S. agriculture (Adams et al., 1990, 1995) and world food trade (Fischer et al., 1994; Rosenzweig and Parry, 1993; Darwin et al., 1995).

2. Egypt: A Background Sketch

2.1. GEOGRAPHY AND CLIMATE

Egypt occupies the northeastern corner of Africa (Figure 1) from 22° to 31° North latitude and 24° to 36° East Longitude. It is bounded in the east by the Red Sea, in the west by Libya, in the north by the Mediterranean Sea and in the south by Sudan. The total land area is 997,688 square kilometers and is made up of five major geographical regions: the Nile Valley (upper Egypt, lower Egypt, the Nile Delta), the Eastern Desert, Sinai, and the Western Desert. These geographical areas are divided into 26 administrative units or governorates that are grouped into four aggregate regions: Urban Egypt, Lower Egypt, Upper Egypt, and Frontier Egypt.

Most economic activity is located in the narrow, 1000 kilometer Nile Valley corridor from the High Aswan Dam in the South to the Nile Delta in the North.

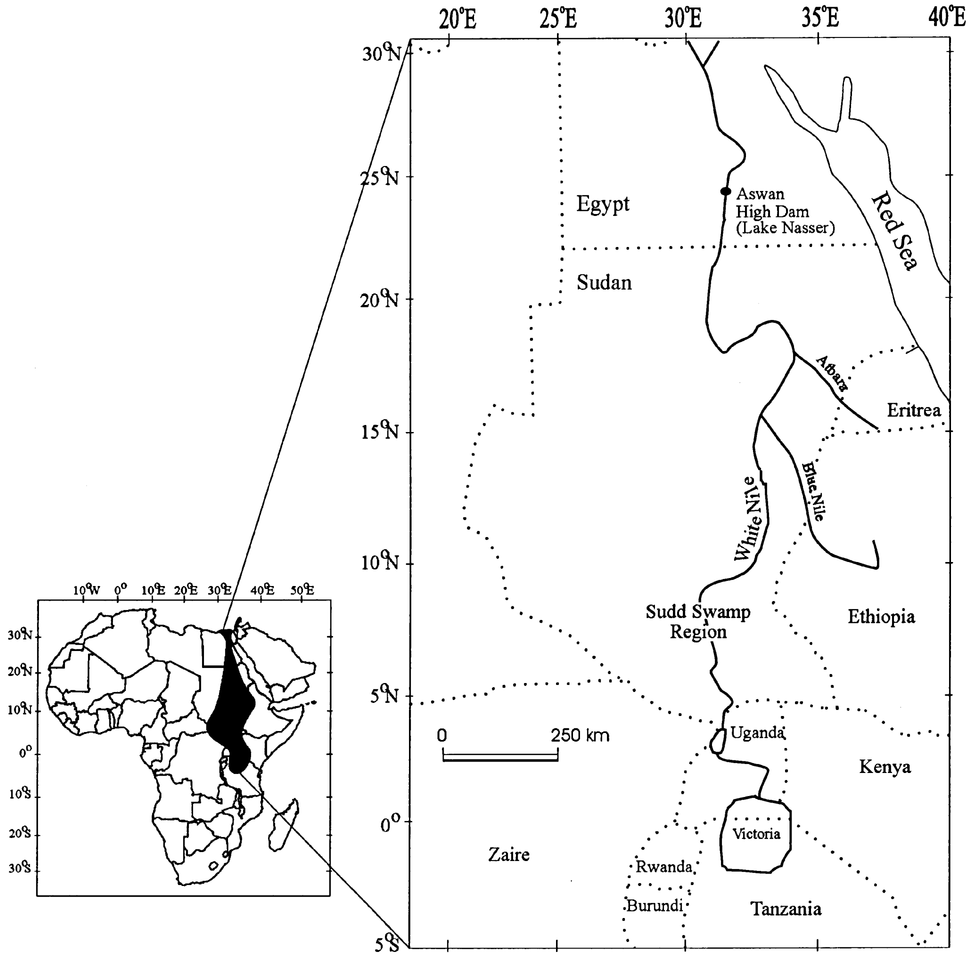

Figure 1. The Nile Basin in relation to Africa and Egypt (note, political boundaries are not exact).

The Nile Delta region is particularly important as it accounts for 60 percent of the agricultural land and over 60 percent of the population. Egypt's northern coastline is currently subsiding at a rate of 1 cm per decade, largely attributable to reduced sediment load to the Nile delta due to the High Aswan Dam. This has led to the loss of agricultural lands and reduced productivity in coastal lands due to waterlogging and salinity. In addition, 15 percent of the Nile Delta is below the 1 meter contour, which poses a threat to a significant portion of Egypt's agricultural lands due to subsidence and salinization (Nicholls and Leatherman, 1995). Egypt is an arid country with only trace rainfall from the southern border to just south of Cairo, limited rainfall in the Delta, and up to 200 mm in a narrow strip along the Mediterranean Coast. Egypt is effectively desert land except for a very narrow strip along the coast and the Nile Valley 'oasis'.

Table I
Agricultural land in Egypt, 1990

Agro-climatic zone	Area (10^3 feddans)	Percentage
Upper Egypt	1076	18
Middle Egypt	1192	20
Delta	3624	62
Total	5892	100

2.2. A SNAP SHOT OF THE EGYPTIAN AGRICULTURAL SECTOR

Egypt, with its very arid climate, has a unique agricultural system. Virtually all the agricultural land is irrigated with Nile River water which is stored in Lake Nasser behind the High Aswan Dam. Currently agriculture is practiced on 3 million hectares (5.892 million feddans*) or only 3 percent of the area of Egypt. New, less fertile land on the fringe of the Delta and in the Sinai are being reclaimed, while more productive land (old land) is being lost to urbanization (Humphries, 1991). Table I shows the aggregate distribution of agricultural land within Egypt.

The agricultural year has three crop seasons. The winter season starts from October to December and ends between April and June. Its main crops are wheat, barley, berseem,** lentils, winter onions and vegetables. The summer crops – cotton, rice, maize, sorghum, sesame, groundnuts, summer onions and vegetables – are sown from March to June and harvested from August to November. A third growing season known as ‘nili’ is a delayed summer season where rice, sorghum, berseem and some vegetables are grown. A piece of land cannot be planted in both summer and nili crops in any one year because nili and summer cropping seasons overlap. There are significant perennial crops such as sugarcane in Upper and Middle Egypt and citrus, grapes, bananas, mangoes, olives and dates (Humphries, 1991). An elaborate crop rotation is practiced to prevent soil degradation and crop loss due to pests.

In 1990, agriculture (including livestock) accounted for nearly 20 percent of Gross Domestic Product and employed 37 percent of the labor force. These figures do not include Agro-industries such as textiles or food processing (Onyeji, 1992). Agricultural exports accounted for approximately 20 percent of export earnings. Egypt is currently importing over two-thirds of its wheat and vegetable oils and one-third of its corn, despite some of the most productive agricultural land in the world. Agricultural imports have increased three-fold since 1975, resulting in an annual agricultural import bill of over $3 billion. This is due to a combination of governmental policies, international commodity prices, foreign food aid and pop-

* A feddan is the Egyptian unit of land measurement. It is equal to 1.1 acres or 0.48 hectares.
** Berseem is an Egyptian clover used for fodder.

ulation growth (FAO, 1991; Hansen, 1991). Agricultural production has increased by 46 percent over the period 1978 to 1990, while the population has grown 28 percent resulting in a per capita increase in agricultural production of 14 percent over this period.

2.3. EGYPT'S FUTURE

Egypt's 2060 population is estimated to more than double (2.2 times) 1990 population estimates. This represents a 1 percent average annual growth rate over a 70 year period (based on World Bank estimates; Fischer et al., 1994). The growing Egyptian population puts stress on efforts to increase agricultural production through land reclamation and technological improvement. Future socio-economic conditions in the country will depend on the sign and magnitude of the difference in the economic and population growth rates.

There are two quite opposite views about Egypt's long-range economic development (O'Mara and Hawary, 1992). The pessimists see Egypt having dug itself into a deep economic hole. Very low overall economic growth and the prospect of unchecked population growth and slow changes in government policies will lead to short-term consumption rather than long term investment. Egypt will continue to be a 'major' consumer through inexpensive imports of food commodities. Foreign debt will increase, as public policy will continue to hinder economic growth. Significant investments in new technologies will remain small. Economic reform will be difficult because of the short term pain associated with structural reform, as policy makers will be unwilling to take agonizing short run risks without knowing the long-run benefits. The economic 'hole' will only grow deeper. Resource and environmental conditions will constrain growth.

The optimists believe that in spite current debt and low technology industries, Egypt will invest in new, innovative technologies in the mid and long term and will actually surpass some countries with aging, less productive technologies (Lofgren, 1994). This group sees Egypt as the South Korea of the 21st century. Trade liberalization, an advantageous location on the Mediterranean, control over the Suez Canal and a fairly well-educated yet inexpensive labor force will allow Egypt to become a major center for manufactured goods using imported factor inputs. Higher agricultural prices will accelerate economic growth and generate employment for the poor in the non-agricultural sector in the long-run. The possible short term effect is higher prices, which will reduce the purchasing power of the poor, incurring high short-run costs on this group. Decreased government intervention will increase the flexibility of the agriculture and non-agriculture sectors to changing national and global markets. Both will benefit from liberalized policies. Resource and environmental conditions will not be a major constraint to growth.

The description of the Egyptian economy in 1990 suggests a sensitivity to the types of impacts postulated for Egypt as a consequence of climatic changes. With 20 percent of GDP and 38 percent of the labor force involved directly in agriculture, any impact is likely to have economy wide effects. In addition, major investments to mitigate impacts will take away from more productive investments. Future assumptions are crucial to analyzing the effect of climate change on the future economy of Egypt. However, these scenarios are not forecasts and only represent two plausible future scenarios. Given the structure of the economy, impacts may greatly vary. We look at Egypt's vulnerability to climate change in the next section.

2.4. EGYPT'S VULNERABILITY TO CLIMATE CHANGE

Egypt is very dependent on natural resources that are vulnerable to climate change. A large portion of the arable land is in the Nile Delta and is particularly vulnerable to sea-level rise. Agriculture needs water from the Nile for irrigation which is vulnerable to precipitation and temperature changes within the entire Nile basin. Crop yields and crop water use could be affected by climate change.

Previous studies of climate change impacts on Egypt suggest that this country could be particularly sensitive to climate variability. Broadus et al. (1986) and El-Raey et al. (1995) both suggest land losses of 12 to 15 percent of Egypt's current arable land for a one meter sea-level rise. A study of the Nile Basin by Gleick (1991) suggested that it is extremely sensitive to changes in temperature and precipitation. Aside from the low elevation of the Nile Delta, Egypt's vulnerability to sea-level rise is further heightened by the damming of the Nile by the High Aswan Dam which has reduced the sediment flux to the delta and increased land subsidence and soil salinization. Nicholls and Leatherman (1995) estimated that a mean, 1 meter global sea-level rise by 2100 would give rise to a 0.37 meter sea-level rise at the Nile delta. This, combined with a non-climate induced subsidence of the Nile Delta of 0.38 meters would result in the movement of the shoreline to the current 0.75 meter contour and a 5 percent loss of Egyptian agricultural land by 2060. Agriculture below an elevation of one meter is very difficult due to salinization and sea-water intrusion and requires careful water management (Rosenzweig and Hillel, 1994).

Egypt must rely solely on the Nile, as there are few water supply options which are economically feasible. Climate change could affect flow in the Nile and the availability of water for Egypt. Also, Nile flows are likely to be influenced by upstream development in countries like Sudan and Ethiopia. Increased temperatures would increase evapotranspiration, which is likely to increase crop water requirements and lower crop yields (Eid and Saleh, 1992).

3. Sectoral Impacts of Climate Change Based on Select GCM Scenarios

Climate change scenarios were based on a GCM approach and included: the Geophysical Fluid Dynamics Laboratory (GFDL), the United Kingdom Meteorological Office (UKMO), and the Goddard Institute for Space Studies (GISSA) models. Two

Table II
Summary of GCM climate change scenarios. GISSA transient values are taken from the 2050 decade (Rosenzweig et al., 1995)

GCM	Resolution (lat. × long.)	CO_2 (ppm) in 2060	Change in average global: Temp. (°C)	Precip. (%)
GFDL	4.4 × 7.5	600	4.0	8
UKMO	5.0 × 7.5	640	5.2	15
GISSA	7.8 × 10	630	2.5	6

See Phillips (1994) for model summaries.

of the scenarios are steady state GCMs (GFDL and UKMO) and the third is a transient GCM (GISSA). Table II is a summary of select globally averaged climate variables for each GCM.

Table III contains the climate variables (temperature and precipitation) for four regions within the Nile Basin. This includes the upper lakes region in the southern portion of the Nile, the Sudd Swamp region including the Bahr El Gazal and the Sobat basins, the Blue Nile including Tana and the upper and lower portions of the Blue and the Atbara basin. The UKMO model is the warmest, with temperature increases as high as 4.8 °C. The GISSA scenario is the wettest, with regional precipitation increases of over 150 percent.

A linked monthly water balance model of 13 Nile sub-basins was combined with models of the Equatorial Lakes, Sudd Swamps and Lake Nasser to determine annual available water to Egypt – Table IV (see Yates and Strzepek, 1997; Yates, 1996). Two of the three GCMs predicted increased average annual water availability to Egypt (UKMO and GISSA), while GFDL gave an approximate 9 percent decline. Model results indicated that the Nile Basin, on the whole, is quite sensitive to changes in precipitation. Nemec and Schaake (1982) support this finding and point to the strong non-linearities between precipitation and runoff. They modeled a tributary of Lake Victoria and found that a 20 percent increase in precipitation, combined with 6 percent decrease in potential evapotranspiration, can lead to a greater than 80 percent increase in runoff! A 5 percent land loss due to sea-level rise and land subsidence was assumed under all climate change scenarios.

Two agricultural scenarios were used for each of the three GCMs. The first took into account the positive physiological impacts of a CO_2 doubling on yield while the second accounted for CO_2 fertilization as well as extensive adaptation measures, including: (1) significant shifts in planting dates, increased fertilizer application, and the development of new crop varieties (see Rosenzweig et al., 1995). Table V shows the percent change in crop yields between 1990 and 2060 for the three GCM scenarios. Yield changes were not dependent upon the pessimistic or optimistic socio-economic scenario. The UKMO model showed the most negative impacts, primarily due to larger temperature changes, while the GISSA scenario produced moderate yield declines.

Table III
Annual changes in temperature and precipitation for the main regions of the Nile Basin

	GFDL		UKMO		GISSA	
	ΔT °C	Ratio P	ΔT °C	Ratio P	ΔT °C	Ratio P
Lake region	2.7	1.14	4.8	1.20	2.1	1.22
Swamps	3.3	1.02	4.7	1.17	2.1	1.28
Blue Nile	3.5	0.95	4.8	1.29	2.2	1.30
Atbara	3.6	0.95	4.8	1.42	2.2	1.29

ΔT °C is the absolute change in temperature: $T(2 \times CO_2) - T(1 \times CO_2)$. Ratio P is the precipitation ratio: $P(2 \times CO_2)/P(1 \times CO_2)$. The GISSA scenario is taken for the decade of 2050.

Table IV
Runoff from the Nile Basin and annual water availability to Egypt for the baseline and 3 GCM scenarios (in billions of m^3)

	BASE	GFDL	UKMO	GISSA
Natural inflow	84	74	132	130
Sudan abstraction	18.5	13.6	42.5	41.0
Evaporation loss at Aswan	10.0	10.6	11.9	11.6
Total available for Egypt	55.5	49.8	77.6	77.4

Crop water use is a difficult metric because it is heavily dependent upon management and agricultural practices. Irrigation efficiencies for Egypt are low due to inefficient flood irrigation practices, as evaporation tends to be a larger share than plant transpiration in flood irrigation (Rosenzweig and Hillel, 1994). Water efficiencies could increase if Egypt were to adopt high technology irrigation. Table VI gives the changes in crop water use under the climate change scenarios relative to the 1990 base. In some cases, crop water use declined due to reduced plant transpiration as a consequence of CO_2 fertilization affects. The protein feed, other food and non-food crops showed the most significant increases in water use, while the crop water demand for wheat and coarse grain crops declined.

4. A Forward-Linkage, Sector Approach to Impact Assessment

The forward-linkage method applied two statically coupled economic models (Figure 2). First, an Egypt specific Computable General Equilibrium (CGE) sub-model (the Standard National Model-SNM) of the Basic Linked System (BLS) was used (Fischer et al., 1988; Yates, 1996). Impacts of climate change on crop yields, crop water use, water supply and land resources were applied linearly over the 70 year time horizon within the Egyptian SNM. National socio-economic trends (both optimistic and pessimistic) were also applied, as were world market prices taken from

Table V
Percent change in crop yields relative to 1990 for the three GCMs

	GFDL		UKMO		GISSA	
	w/CO_2	ADPT II	w/CO_2	ADPT II	w/CO_2	ADPT II
Wheat	–26.0	–13.0	–51.0	–25.0	–5.0	–2.5
Rice	–7.0	–3.0	–27.0	–13.0	–5.0	–2.5
Grains	–17.0	–8.0	–30.0	–15.0	–20.0	–10.0
Protein feed	–1.0	0.0	–21.0	–10.0	–3.0	–1.5
Other food	–1.0	0.0	–21.0	–10.0	–3.0	–1.5
Non-food	–1.0	0.0	–21.0	–10.0	–3.0	–1.5
Fruit	–6.0	–3.0	–21.0	–10.0	–3.0	–1.5

W/CO_2 is the impact of climate change on crop yield with CO_2 fertilization considered. ADPT II are farmer adaptation as defined by Rosenzweig and Parry (1993), which includes the physiological effects of carbon dioxide and climatic variables (temperature and precipitation) as well as high cost adaptation measures.

Table VI
Percent change in water use for the three GCM scenarios relative to the 1990 base scenario

	GFDL		UKMO		GISSA	
	CO_2	ADPT II	CO_2	ADPT II	CO_2	ADPT II
Wheat	–10.0	–10.0	–8.0	–8.0	–15.0	–15.0
Rice	6.0	6.0	13.0	13.0	0.0	0.0
Grains	–10.0	–10.0	0.0	0.0	–10.0	–10.0
Protein feed	20.0	20.0	25.0	25.0	0.0	0.0
Other food	20.0	20.0	25.0	25.0	0.0	0.0
Non-food	20.0	20.0	25.0	25.0	0.0	0.0

Four crop simulations were performed in Egypt using detailed physiological crop models (Rosenzweig and Parry, 1993) and included wheat, rice, maize and soybeans. Wheat, rice and grains were considered as maize. Protein feed, other food and non-food agriculture were mapped to soybean. A negative value indicates a decrease in crop water use.

previous simulations of the BLS. Output from the Egyptian SNM served as input to the Egyptian Agricultural Sector Model (EASM).

Briefly, the BLS is a recursively dynamic CGE model and incorporates several national models linked together through international markets which globally balance commodities and adjust international prices to generate a balanced global economic state of prices and demands. There are 16 linked SNMs and 4 unique national models (U.S.A., India, China and the former planned economies of the Eastern Block) which together comprise almost 80 percent of the agricultural activity of the globe (i.e., production, demand and land usage). Additionally, 14 regional models comprise the remaining 20 percent and are generally grouped according to

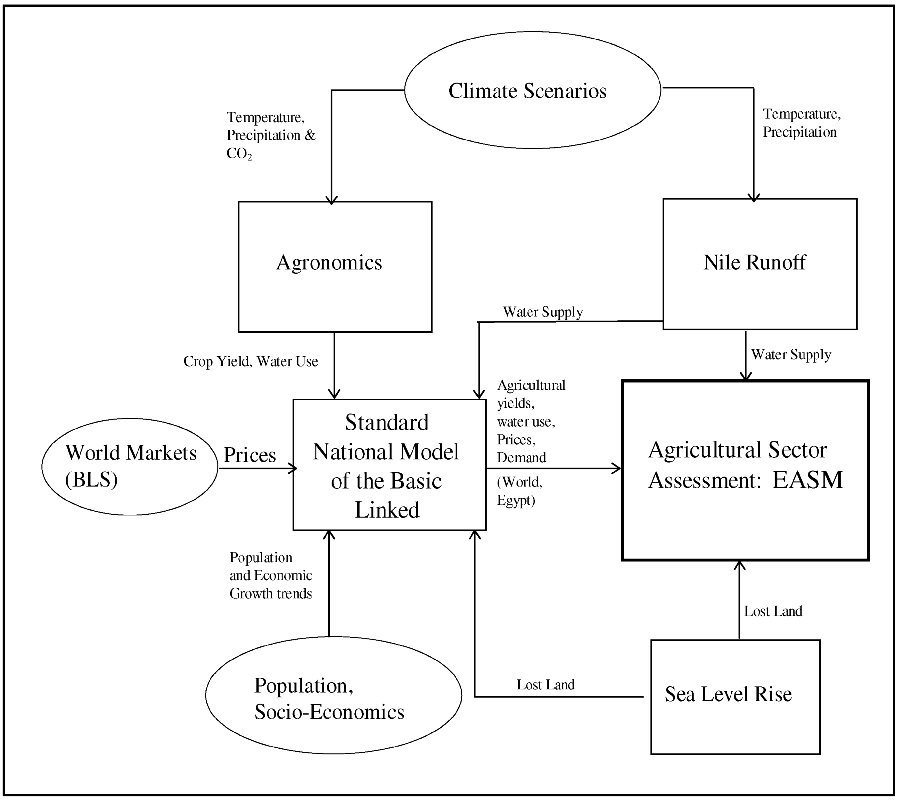

Figure 2. Schematic of the forward-linkage approach to an integrated assessment of climate change impacts on Egypt using an agricultural sector model.

socio-economic conditions (i.e., African oil exporters, African low-income calorie importers, Asia low income, etc.). Egypt is one of the sixteen Standard National Models.

The SNM includes 10 agricultural and 1 non-agricultural commodities at the international level. Non-agriculture supply is determined through a Cobb-Douglas production function dependent upon labor and capital, while supply within the 10 agricultural commodities is based on revenue-maximization and feed-mix cost minimization given availability of factor inputs (fertilizer, land, labor and water) at current domestic prices. Processing of agricultural products, intermediate inputs and non-agricultural inputs are also part of agricultural production.

The BLS is a world trade model, but this work focuses on a single country. Fortunately, the SNM is able to run in a stand-alone-mode, where world market prices are taken as exogenous from a previous global simulation of the entire BLS system. It was assumed that Egypt's influence on international markets was not great enough to significantly impact the global market – a small country assumption.

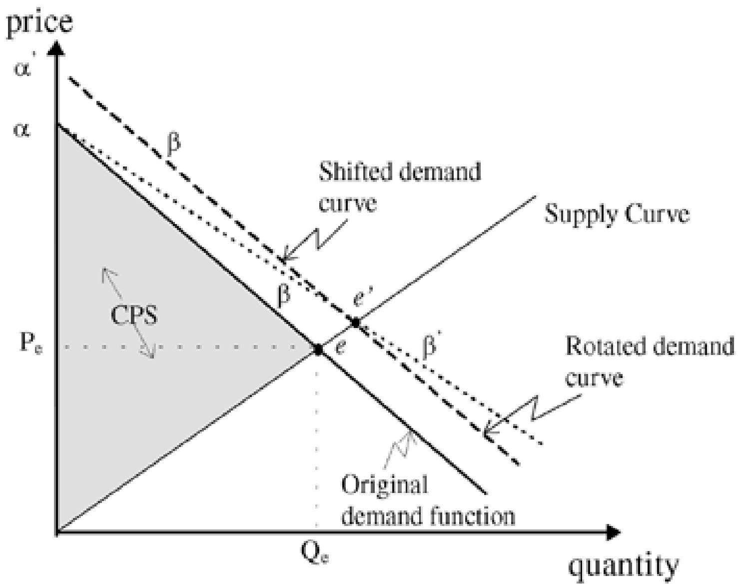

Figure 3. Representation of consumer and producer surplus. Rotation and/or shift of the commodity demand curve can be used to reflect demand changes.

Crop yields, crop water use, annual available Nile water and land changes due to sea-level rise were inputs to the Egyptian SNM to the year 2060 (Figure 2) (Fischer et al., 1988, 1994; Yates and Strzepek, 1996). Egyptian domestic commodity demands and domestic consumer and producer prices in 2060 were taken from the Egyptian SNM. 2060 scenario specific water availability, land availability, crop yield and crop water use were entered into a modified Egyptian Agricultural Sector Model (EASM-CC – Egyptian Agricultural Sector Model for assessing Climatic Change).

The EASM is a partial equilibrium, quadratic programming model which simulates a single agricultural year and captures water, land, crop, livestock, labor and other components at a sub-national scale. The EASM was first developed by Kutcher (1981) in the context of a UNDP funded, World Bank managed water resource master planning study aimed at rationalizing a proposed sequence of water resource investments. It has since been updated by Humphries (1991) to perform a drought policy study, a study of new land development (Farag et al., 1993), and a climate change study (Strzepek et al., 1995). The model maximizes the sum of all commodities consumer-producer surplus (CPS) according to the specification of supply and demand curves derived from domestic prices and demand elasticities (see Hazell and Norton, 1986). Samuelson (1952) showed that under a competitive market, maximizing the area between the supply and demand curves (CPS) drives the solution to a competitive equilibrium position in terms of price and quantity, P_e and Q_e. The grayed area in Figure 3 represents CPS.

Two approaches were possible for assessing the impacts of climate change with the single year EASM-CC model. The first was to apply bio-physical projections on present day socio-economic conditions – a *present-day* approach. Second was to apply biophysical and socio-economic changes on a future projection – a *forward-linkage* approach. The likelihood that future conditions in Egypt will be significantly different than today's motivated the use of the *forward linkage* approach for this study. Future socio-economic conditions can lead to changes in demand for certain commodities due to price changes and income effects, but the EASM can not account for these because income is not modeled in this partial equilibrium model. Instead, results from the SNM were used to update demands and commodity prices, as demand elasticities were held constant. Demand curves could be shifted and/or rotated, with a shift maintaining the current slope of the demand curve and requiring an update of the intercept, α to α' (Figure 3). A rotation maintains the intercept but changes the slope, β to β' (and would require some estimate of income changes), while shifting and rotating the demand curve would require updating both α and β.

Commodity-specific demand curves were updated through an upward shift and with no rotation. The new intercept, α', was estimated from demands and prices taken from the BLS, with prices assumed to be demand inelastic (i.e., fixed prices with given demand). 2060 demand estimates for the EASM were specified by multiplying the observed 1990 levels by the results from the baseline and climate change scenarios from the BLS.

5. Generation of Baseline Scenarios

Two 2060 base scenarios were generated based on an optimistic and pessimistic scenario for Egypt (2060-OPT and 2060-PES). A 1990 baseline using 1990 observed population, land and water resources, technology and agricultural policy constraints was generated and referenced to the 2060 baseline scenarios. Several constraints and assumptions applied in 1990 were removed or adapted for 2060, while important agronomic constraints remained. Changes include:

- Removing the upper limit on sugar processing, the upper bound on citrus, cotton and vegetables;
- The removal of the exogenous herd of camels, donkeys and goats;
- Crop by-product fodder utilization of only 50 percent of 1990 (assumption of specialization);
- Labor availability as a linear increase of total population;
- The addition of equally distributed new lands in the Upper Valley and the Nile Delta comprising 2 million feddans;
- Land subsidence in the Nile Delta which removed 124,000 feddans of agricultural area;
- Removal of the navigational requirement;

- Removal of bounds on imports and exports, with exports limited to a fixed percentage of the global total.

Changes in crop yields were taken from BLS based on exogenous technological growth rates and crop production functions. Crops in 2060 (baseline scenarios) were assumed to require more water as yields increased and more inputs were applied. Crop water requirements were assumed to be 25 percent of the yield change based on experimental data from the Southwestern U.S.A. (Rosenzweig, 1994). Inputs such as mechanization, fertilizer, etc. were taken from the BLS as percent increases or decreases from 1990 data. Restrictive taxes and subsidies were removed from the marketing costs for the 2060 base scenarios. Marketing costs were assumed to be true mark ups between domestic prices and farm gate prices. Export marketing prices were assumed to be 20 percent greater than the domestic marketing costs. International commodity prices were taken from previous BLS simulations (Fischer et al., 1994) and were used to update the EASM-CC prices.

5.1. OPTIMISTIC BASELINE SCENARIO-2060 (2060-OPT)

2060-OPT was based on a consistent scenario for 2060 with population, commodity demands and yield changes taken from the BLS. Land and water resources were based on current climate, and crop water use was based on agronomic and technological assumptions in 2060 (Strzepek et al., 1995).

Characteristics of the optimistic scenario were:

- High investment rate (12 percent above depreciation rate for non-agricultural sector);
- High non-agricultural productivity rate increase (2%/year);
- High labor transformation rate: The movement of labor from agricultural to non-agricultural activity;
- High-quality, competitively-priced non-agricultural good was reflected through a competitively priced non-agricultural good available on the world market;
- Increased labor rate relative to population growth. The labor force was rapidly assimilated into the economy;
- Non-agricultural sector became more dominant into the 21st century;
- Non-agricultural sector became less dependent on the agricultural sector.

5.2. PESSIMISTIC BASELINE SCENARIO-2060 (2060-PES)

The 2060-PES scenario for Egypt focused on recent trends and future predictions of population growth, limited natural resources, and waning foreign investment.

Characteristics of the pessimistic scenario are:

- Low investment rate (8 percent above depreciation rate of non-agricultural sector);
- Low non-agricultural productivity rate increase (1%/year);

- Low labor transformation rate;
- No non-agricultural advantage to Egypt, reflected in higher relative prices on the world market;
- Decreasing or constant labor rate relative to population growth, slow mobility from the agricultural to non-agricultural sector;
- Non-agricultural sector remained labor intensive: i.e., limited foreign capital investment;
- Agricultural sector remained a large portion of the economy into the 21st century;
- Non-agricultural sector remained highly dependent upon the agricultural sector.

5.3. OPTIMISTIC AND PESSIMISTIC BASELINE SCENARIOS – ECONOMY-WIDE RESULTS

Table VII is a compilation of socio-economic indicators for the baseline scenarios taken from the SNM of Egypt. Generally, the pessimistic case maintained higher levels of agricultural output (reflected in higher agricultural GDP) as compared with the optimistic scenario, as fewer resources were diverted to the non-agricultural sector. Non-agricultural growth was approximately three times greater for the optimistic scenario, driven by higher investment rates and agricultural-non-agricultural transformation rates with respect to capital and labor.

For the optimistic scenario, a larger portion of labor was occupied in the non-agricultural sector and labor participation outpaced population growth. The population in 2060 was 2.22 times greater than in 1990 and employment in 2060 was 2.26 times the 1990 value. In the pessimistic scenario, a larger share of economic activity remained in the agricultural sector, hence labor assimilation (2.23 times 1990) barely outpaced population growth (2.22 times 1990).

Incomes in the optimistic scenario rose considerably, yet falling domestic crop prices (measured by the crop price index) negatively affected the agricultural sector as parity (a relative metric comparing agricultural and non-agricultural wage earnings) declined by 42 percent. In the pessimistic scenario, the agricultural sector maintained a larger share of total GDP; and per-capita GDP increased by a modest 38 percent from 1990. The gap between the agricultural and non-agricultural wage earner (parity) increased by a more modest 7 percent.

5.3.1. *The Agricultural Sector in 2060-EASM*

Economic Indicators of the Agricultural Sector. Table VIII is a summary of agricultural economic indictors for 1990 and the two 2060 baselines from the EASM-CC model. Not surprising, there was considerable growth in consumer and producer surplus – the principle welfare indicator. Consumer surplus was much greater than producer surplus, driven by increased food demands from the growing population and higher domestic agricultural prices. Producer surplus, on the other

Table VII

Economic and resource indicators for 1990 (absolute) and the two 2060 reference scenarios (percent change from 1990) from BLS solutions

Indicator	BLS		
	1990	2060 OPT	2060 PES
Population	54156	122	122
GDP Ag	1143	96	135
GDP non-Ag	4878	617	224
GDP/cap.	256	178	38
Parity	0.30	–42	–7
Trade balance	247	–19.3	–45.2
Cal./day	2587	24.5	8.9
Crop price index	1.19	–22	–22
Food price index	1.16	6.9	–3.4

For the 1990 Base, the above indicators are as follows:
GDP – millions of 1970 dollars.
Trade balance – Net import (positive) or export (negative) in millions of 1970 dollars, agriculture and non-agriculture.
Cal./day – Daily calorie intake per capita.
Parity – Agricultural GDP per capita of one agricultural wage earner divided by non-agricultural GDP per capita of one non-agricultural wage earner; an equity indicator.
Crop price index – Index of crop prices
Food price index – Index of food prices.
OPT – Optimistic scenario; PES – Pessimistic scenario.

hand, did not keep pace with population under the pessimistic scenario and is slightly higher under the optimistic scenario.

The baseline scenarios implied significant structural adjustment of the agricultural sector, with Egypt becoming increasingly dependent on international markets to meet domestic demand. This was reflected in decreased food self-sufficiency. Per capita food consumption (calories per capita per day) increased by 8.8 percent under the optimistic baseline and decreased by 2.6 percent under the pessimistic baseline. The volume of imports and exports both rose, but the agricultural trade deficit continued to increase under both 2060 baseline scenarios. The import to export ratio in 1990 was 1.6:1.0. By 2060 this had become 3.7:1.0 and 2.5:1.0 for the optimistic and pessimistic scenarios, respectively.

Agricultural Commodity and Factor Input Changes for Baseline Scenarios. A large portion of the increased demand for *bovine and ovine meat* and *dairy* (meat and milk) were met through imports, while demand increases for *other animal* products (poultry meat and eggs) were met through increased national production (Figure 4). Domestic production of basic foodstuffs – *wheat, rice* and *coarse grains* – did not keep pace with population growth, as larger shares were met through imports.

Table VIII

Economic indicators for the agricultural sector for 1990 (absolute) and the *2060 OPT* and *2060 PES* reference scenario (percent change from 1990)

Indicator	EASM-CC		
	1990 base	2060 OPT	2060 PES
Cons./prod. surplus	36995	518	369
Consumer surplus	28112	639	451
Producer surplus	8883	136	108
Trade balance	–1631	1437	914
Cal./day	3000	8.8	–2.6
Self sufficiency	0.51	–39	–31
Imports	4447	720	559
Exports	2816	305	353
Water use	35.2	28	28
Harvested area	4530	30	30

The above indicators are as follows:
Cons./prod. Surplus – Consumer-producer surplus (1990 Egyptian Pounds).
Consumer and producer surplus – 1990 Egyptian Pounds.
Trade balance – Net import (positive) or export (negative) in 1990 Egyptian Pounds. The positive percent change for 2060 OPT and 2060 PES represent increases in the trade defecit.
Cal./day – Per capita calorie intake.
Self sufficiency – Commodity weighted ratio of total calories domestically produced to total consumed.
Imports and exports – 1990 Egyptian Pounds.
Water use – Consumptive use for agricultural production, including fodder production (km^3).
Harvested area – Total cropped area in hectares.

The pessimistic scenario maintained a higher production of staple commodities (*wheat* and *rice*), reduced *non-food agriculture* and increased *livestock* agriculture (except for *other animals*) when compared with the optimistic scenario. The food self sufficiency ratios of the pessimistic scenario were higher than the optimistic (Table VIII) pointing to an agricultural sector meeting a larger share of domestic food demand.

Despite decreased world market prices for *other food* and *non-food agriculture* products, production remained high to meet domestic demand and to leverage the differences between domestic and international prices. The optimistic scenario increased *other-food* imports relative to exports because domestic prices were generally higher than world market prices, while the pessimistic scenario reduced *other-food* imports due to lower domestic prices (Figure 5). *Non-food agriculture* imports and exports were practically the same for both the optimistic and pessimistic baselines scenarios.

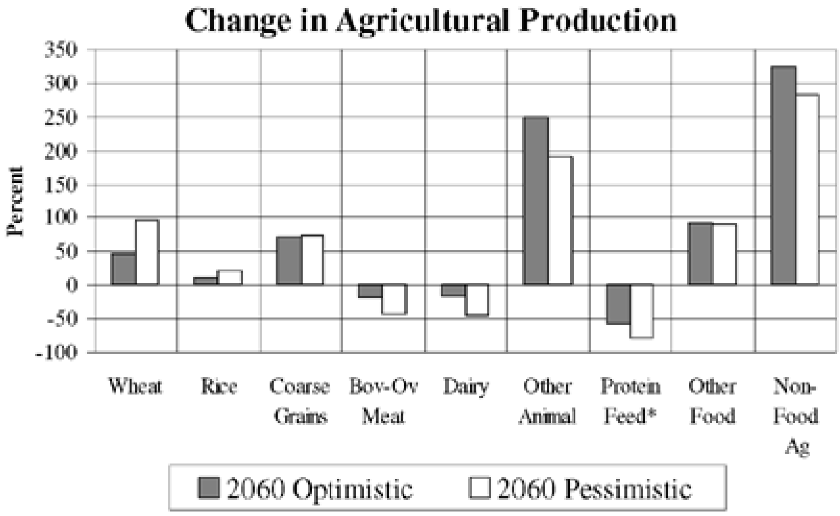

Figure 4. Change in domestic production for the optimistic and pessimistic scenarios in 2060 as a percent of 1990.
* Protein feed for EASM is green fodder (berseem) used for animal feed.

Spatial and temporal disaggregation in the EASM-CC model allowed for the redistribution of factor inputs. Winter water use increased relative to summer months in response to cropping pattern changes which conserved water (Figure 6). The shadow price or marginal value* on water in 1990 was zero, reflecting a surplus relative to the more scarce resource, land (with a positive shadow price in 1990). Overall water use by 2060 had increased by almost 30 percent, reflected in a positive shadow price for water. Commodity disaggregation and spatial and temporal disaggregation allowed for adjustments in national agricultural production. Cheaper imports were used to make-up for deficits in domestic food demand (*wheat* and *coarse* grains) and select commodities were produced for export revenue generation (such as *cotton*).

6. Integrated Assessment of Climate Change Impacts on the Agricultural Sector of Egypt

Relative values of select model output from the climate change scenarios were compared to the baselines and across scenarios. Analyzing the large number of scenarios in detail (2 baselines and 12 climate change scenarios) can be over-

* Shadow price or marginal value is the change of the model objective function at the margin to the addition or subtraction of an additional unit of a resource. If a resource is in surplus at the optimal value, then the shadow price is zero. A positive shadow price means that the resource is limiting and the objective will increase by the marginal value if an additional unit of the resource can be supplied or decrease if a unit is removed.

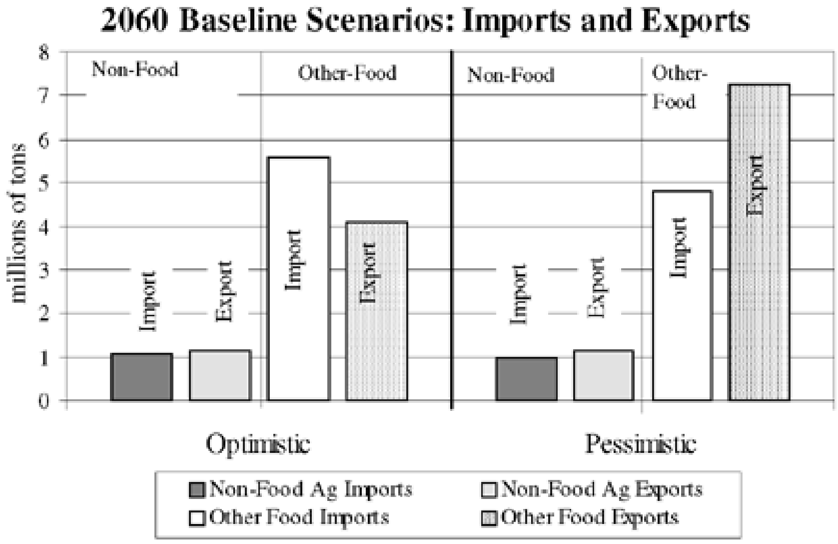

Figure 5. Net import and export of *other-food* and *non-food agricultural*.

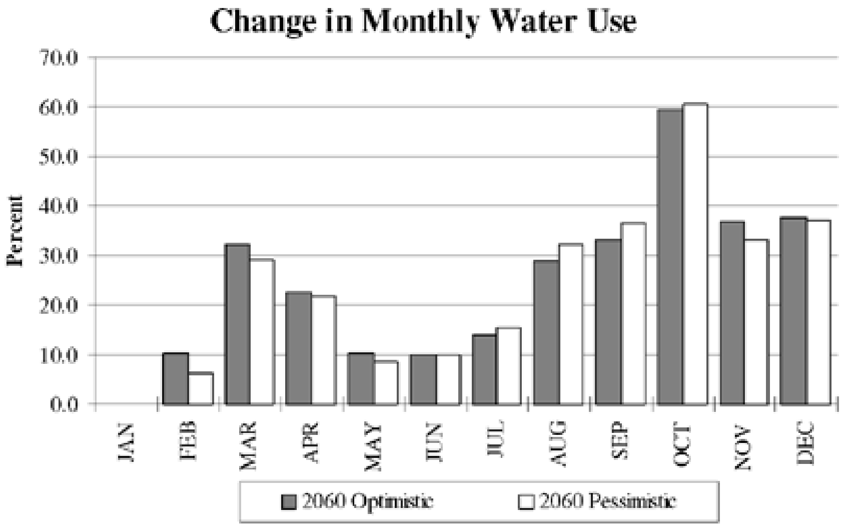

Figure 6. Percentage change relative to 1990 of agricultural water use for the optimistic and pessimistic scenarios (with annual water availability of 55.5 milliards for Egypt).

whelming and not greatly instructive, so a only a select number were chosen to highlight broad lessons for Egypt.

6.1. EXOGENOUS GLOBAL CONDITIONS FROM THE BLS

The three GCMs gave a mixed picture of world market prices (Table IX). UKMO results showed the largest price increases for most commodities due to decreased

Table IX
Relative index of international commodity prices. 1990 values (1990 = 100.0)

	2060 BASE	GFDL w/CO_2	GFDL ADPT II	UKMO w/CO_2	UKMO ADPT II	GISSA w/CO_2	GISSA ADPT II
Wheat	102	105	86	226	129	70	58
Rice	89	126	97	216	126	80	61
Coarse grains	91	115	84	249	126	69	50
Bov. and ov. meat	104	107	105	117	106	104	102
Dairy	97	100	97	121	101	94	91
Other animal	91	93	88	107	96	85	80
Protein feed	152	152	124	365	193	92	76
Other food	74	73	65	115	87	55	49
Non-food ag.	59	63	54	106	70	44	38
Non-ag.	100	100	100	100	100	100	100

global production. The GISSA scenario gave slight increases to large decreases in relative prices, as moderate temperature changes in the low latitudes and favorable changes at higher latitudes led to greater global production of agricultural goods. In all cases (with the exception of *UKMO w/CO_2 fertilization)* both *non-food agriculture* (for Egypt this would be cotton and flax fiber) and *other food* (fruits and vegetables and other cash crops) decreased in price due to global increases in production and other market forces.

The integrated assessment results are presented below for each of the scenarios. Summarizing the sectoral climate change impacts:

- Under all scenarios crop yields declined and crop water requirements increased – albeit some greater than others;
- Agricultural land was lost to sea-level rise (5 percent);
- Domestic commodity demand showed moderate declines, with a slight increase under the GISSA scenario;
- Nile water resources declined under GFDL and increased for the GISSA and UKMO scenarios.

6.2. CLIMATE CHANGE IMPACTS ON THE AGRICULTURAL SECTOR OF EGYPT

The analysis showed there are likely winners and losers within the agricultural economy of a food importing, developing country such as Egypt. This outcome is in large part due to the inelastic demand for most agricultural commodities. All of the scenarios pointed to the strong role of domestic and world market prices on the agricultural sector of Egypt. Generally, when world market prices were high, producers benefited (UKMO); and when world market prices were low, consumers benefited (GISSA). When resources were reduced and there was a mix of impacts on the international markets due to global climate change, then both consumer

Table X

Percent change in economic indicators for the climate change scenarios referenced from the pessimistic baseline scenario

	Pessimistic (percent change from 2060-PES baseline)					
	GFDL w/CO_2	GFDL ADPT II	UKMO w/CO_2	UKMO ADPT II	GISSA w/CO_2	GISSA ADPT II
Cons./prod. surplus	–5.6	–3.1	–6.1	–0.6	0.6	6.2
Consumer surplus	–4.5	0.0	–15	–1.6	6.5	12
Producer surplus	–15	–29	69	8.2	–49	–45
Trade balance[a]	47	36	48	24	19	3.7
Cal./day	–2.2	0.0	–7.1	–1.0	2.7	5.2
Self sufficiency	–23	–11	–29	–5.7	–8.6	0.0
Imports	18	–3.2	72	12	–20	–34
Exports	–19	–55	102	–2.6	–72	–84
Marginal land	–43	–52	186	71	–19	–48
Marginal water	64	21	–57	–64	–100	–100

See Table VIII for a description of indicators.
[a] A positive percent change in trade balance is an increase in the trade deficit, since the 2060 trade balance is negative for Egypt.

and producer surplus declined (GFDL). These results could only be found via an integrated (and global) analysis. Sector results (water resources, agronomics, land resources) pointed to a range of variability, but different conclusions were drawn when linked to global conditions via the BLS.

Producer surplus (PS) was dependent upon international prices and producers capacity for revenue generation on international markets. 8 of 12 climate change scenarios gave a drop in PS, with declines in PS occurring even for scenarios where the national climate change impacts were marginal. Export prices (other-food and non-food agriculture in particular) were often low, hurting Egyptian producers (reflected in lower producer surplus). Only in the UKMO w/CO_2 scenario did the relative price of other-food and non-food agricultural increase, resulting in increased export earnings and higher producer surplus. Consumers generally benefited from lower international world market prices of both food and non-food agricultural commodities. Tables X and XI are the changes for each scenario relative to their respective 2060-OPT or 2060-PES baseline.

The integrated climate change assessment of the Egyptian agricultural economy gave changes in consumer-producer surplus (CPS) ranging from a decrease of 6.1 percent (UKMO PES *w/CO*$_2$) to an increase of 6.2 percent (GISSA PES *ADPT II*) relative to their 2060 Baseline. PS showed a wide range of variability – dropping by almost 50 percent under the GISSA PES *w/CO*$_2$ scenario and increasing almost 70 percent under the UKMO PES *w/CO*$_2$ scenario. Consumer surplus (CS) also showed a range of variability (from a 12.3 percent increase to a 15 percent decrease), although more moderate than producer surplus due to its relative larger magnitude.

Table XI

Percent change in economic indicators for the climate change scenarios references from the pessimistic baseline scenario

	Optimistic (percent change from 2060-OPT baseline)					
	GFDL *w*/CO_2	GFDL ADPT II	UKMO *w*/CO_2	UKMO ADPT II	GISSA *w*/CO_2	GISSA ADPT II
Cons./prod. surplus	–2.9	–2.6	–3.1	–0.8	0.4	2.8
Consumer surplus	–1.6	0.0	–9.0	–1.5	4.9	6.9
Producer surplus	–15	–28	55	6.8	–44	–38
Trade balance[a]	41	25	49	14	3.8	–15
Cal./day	–1.0	0.0	–4.5	–0.9	2.0	3.1
Self sufficiency	–29	–16	–29	–6.5	0.0	9.7
Imports	25	–1.4	73	14	–22	–36
Exports	–11	–60	127	14	–77	–81
Shadow price land	–60	–68	140	24	–36	–68
Shadow price water	89	56	–44	–44	–100	–100

The agricultural trade deficit increased under all scenarios (except GISSA OPT *ADPT II*), indicating increased dependency on imports to meet domestic demand. The scenario which gave the largest negative impact on CPS (UKMO) was the only one which showed increased surplus to producers, despite the fact that it had the largest negative impact on commodity yields. The brunt of the negative effects of climate change were felt by consumers under the UKMO scenarios – primarily driven by increased domestic and international agricultural prices. The climate change scenarios with marginal impacts or improvements in CPS tended to benefit consumers more than producers, except the GFDL scenarios where both consumers and producers were negatively affected. The GFDL scenarios had reduced water resources, diminished yields, higher international food prices and lower international prices on key exports (*non-food* and *other food* agriculture). These factors combined to reduce both national production and export earnings, increase dependence on food imports and increase domestic food prices. The GFDL scenarios could be considered a ‘worst case’ for Egypt, as even significant farmer adaptation (*ADPT II*) did not greatly reduce the negative effects of climate change. Farmer adaptation tended to benefit consumers and not producers, through the reduction in domestic and international food prices.

Four of six adaptation scenarios produced a counter-intuitive (but explainable) result, due in large part to the assumption of uniform global adaptation. Nationally, adaptation benefited consumers more than producers due to improved global production, which lowered international prices and reduced Egyptian export earnings. Imports of low cost flood staples from the international market increased, improving CS but reducing Egypt’s food self sufficiency. The GISSA scenario showed the only improvement in PS under adaptation, as local production was used to meet a larger share of national consumption given marginal yield declines and ample water. It should be noted, however, that the GISSA scenario also gave the largest reduction in total agricultural output relative to the 2060 baseline. This is largely due to falling national and world market prices and highlighted the importance of analyzing both relative and absolute changes, as a single metric can be misleading. Adaptation did improve producer surplus; but the improvement was within a much smaller agricultural sector (see Tables X and XI), as adaptation largely benefited consumers.

Significant shifts in agricultural production patterns were observed (allowed though the removal of restrictive constraints), but it was assumed that theses changes were made gradually over the 70 year period. The socio-economic scenario did not produce a significant difference in CPS but it did play a role in the structural make-up of the agricultural sector. Adaptation also impacted the structure of the agricultural markets. Figure 7 is an example of the structural shifts within the agricultural sector for the GFDL scenarios. The *GFDL OPT* and PES *w/*CO_2 scenarios reduced the national production of livestock, as a greater share of demands were met through imports. Adaptation increased rice, coarse grain and livestock production which reduced dependence on imports to meet domestic demand. The pessimistic scenario produced less wheat and more coarse grains and kept a larger livestock sector fed by local fodder. Despite lower water availability, rice was still a major component of cropped agriculture due to the high world market price which tended to favor national production for domestic consumption. Smaller amounts of available irrigation water increased its marginal value relative to land and forced a shift in cropping activity. The monthly re-distribution of agricultural water diminished the negative effects of reduced water and depressed yields, particularly for the GFDL scenarios.

Farmer adaptation and the socio-economic projection (either optimistic or pessimistic) played a role in determining climate change impacts, with the relative importance of each being scenario dependent. Figure 8 includes the change in CPS for the three scenarios relative to their 2060 baselines. UKMO with farmer adaptation (*UKMO ADPT II)* greatly reduced the overall impact of climate change on CPS regardless of the socio-economic scenario, as adaptation largely benefited consumers due to greater national and global production which led to lowered prices. For GFDL, benefits from adaptation were moderate, especially under optimistic socio-economic assumptions where the negative impacts on consumers were small. GISSA was considered a ‘best case’ scenario.

The results of this analysis not only provide lessons for Egypt but provide for more general lessons that may be applicable to a number of nations or regions of the world. These are as follows:

1. When performing an integrated analysis it is essential that all scenarios and assumptions be consistent across each sector or integrated results can be misleading.

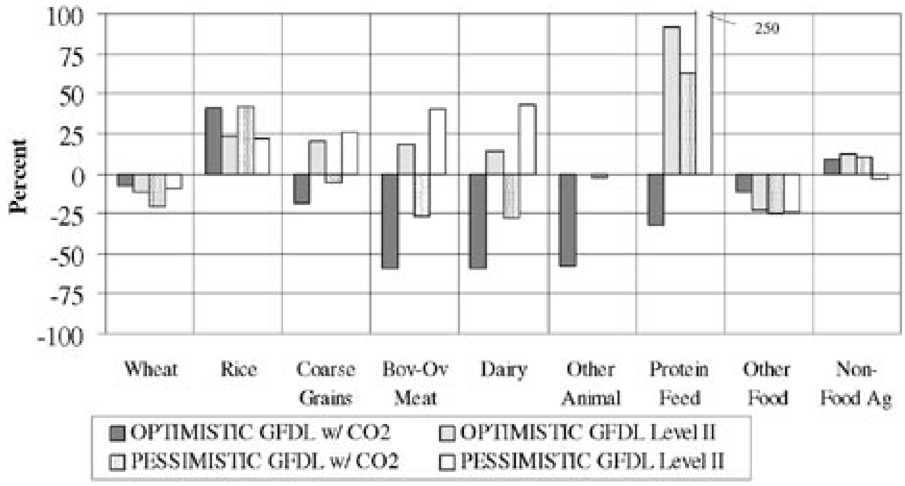

Figure 7. Percent change in agricultural production for the GFDL scenario relative to their 2060 baseline.

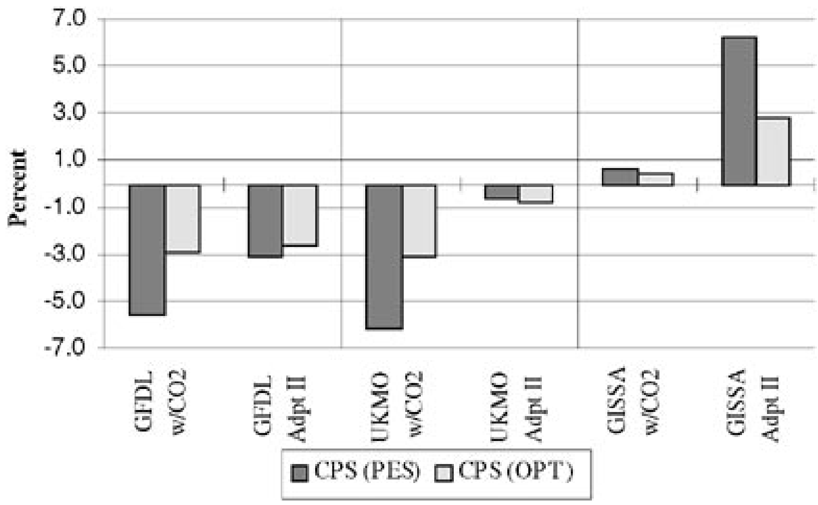

Figure 8. Percent change in consumer-producer surplus for the UKMO and GFDL climate change scenarios.

2. A single economic measure (such as consumer-producer surplus) may not adequately reflect the true social consequences of climate change. Social inequities could continue to intensify, as already struggling portions of the population, such as agricultural producers, continue to suffer.
3. The amount of food available to the population at large may not be greatly reduced by climate change. Changes in world markets, however, could reduce producer revenues in spite of moderate or even beneficial regional climate change. Consumers could benefit from climate change if there are increas-

es in global output and national markets are free to respond to changes in international prices.

4. Socio-economic and population growth scenarios should be included, with a feedback of resources and economic impacts due to climate change over a dynamic time horizon. Government, social and economic policies can result in a system that is relatively flexible and more easily adaptable to climatic change or produce a rigid system which is more vulnerable to climate change.
5. A sectoral, mathematical modeling approach to integrated climate change impact assessment, which uses consumer and producer surplus as its economic metric, showed that economically driven autonomous adjustments will be necessary to minimize (maximize) the negative (positive) effects of climate change. Without these structural adjustments, the negative (positive) effects of climate change impacts would be greater (lesser).

This analysis has identified a number of insights or lessons about Egypt's vulnerability to climate change. A list of the more important lessons are listed below.

1. Population and the path of development are significant factors in all future scenarios with or without climate change. How the country adapts to climate changes will be important.
2. Water resources availability and crop water use are important factors in assessing the vulnerability of Egyptian Agriculture and should be included in any analysis; however market forces could minimize the negative effects of limited resources through shifts in their patterns of use and increased efficiency. Structural adjustments within the agricultural sector, such as new cultivars, adaptable livestock agricultural markets, the shifting of planting dates and changing water use patterns will be necessary for Egypt to adapt to the consequences of both regional and global climate change.
3. Land lost due to sea-level rise in 2060 is not a major factor since water is the more limiting resource. In addition, most of the land loss occurs on the lands that are or will be reclaimed over the next 70 years which are not as productive as existing lands.
4. Loss of existing, highly productive agricultural lands to urbanization is a crucial problem which will become more acute should sea-level rise dramatically.
5. High food consumption, even in the base scenario, is based on incomes generated from significant growth in the non-agriculture sector of the economy which is very uncertain.
6. The most efficient agro-economic strategy for feeding the future population is to develop high valued export crops and import low-cost staples. This policy, however, reduces food self-sufficiency and could compromise food security.
7. Economic, trade and social policies greatly affect the potential integrated impacts of climatic change. Egypt is vulnerable not only to its own direct impacts but to the fate and response of the rest of the world to the consequences

of climate change. Global commodity production and prices and how they are influenced by climate change could be one of the most significant determinants of climate change effects on Egypt.

7. Summary and Recommendations

Egypt is vulnerable to the warming and potential changes in agriculture, water and land resources and the local and global agricultural markets that are forecast to accompany greenhouse-gas-induced climate change. This study has shown that a single sector can not provide sufficient information regarding broader impacts of climate change on the agro-economy. Indeed, a collection of sector impacts, placed within an integrated assessment, can provide keen insight into the potential consequences of climate change on a major food importing country such as Egypt. This insight would not have been possible without the integrated approach. Climate change would likely affect many socio-economic groups, influencing people's food entitlement based on prices and incomes, the agricultural sector's productivity and the economy's ability to import and export agricultural commodities to maintain some reasonable level of trade deficit. Sectors which are directly affected by climate should be analyzed in concert with other sectors in sufficient detail so that feedbacks are part of the analysis.

Future research needs include the development and application of more crop models that include CO_2 effects and cover a broader range of important crops. There is a need for improved understanding of potential agricultural/water adaptations to climate change, an improved understanding of sea-level rise impacts on deltaic agricultural lands, development of better macro and sectoral economic models and improved understanding of the bio-geophysical resources of the Nile Basin. Future socio-economic development of Nile Basin countries should be considered, as this could play a critical role in the future policy and development of Egypt. Finally, global scenarios which include non-uniform adaptation between developed and developing nations should be created. These kinds of scenarios are highly plausible given the technological advantage of developed countries. These new scenarios could have a large influence on global markets, as global markets were shown to greatly affect the climate change impact assessment on a food importing country such as Egypt.

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