THREE ESSAYS ON ECONOMIC DEVELOPMENT IN AFRICA

A Dissertation

by

MARK MUSUMBA

Submitted to the Office of Graduate Studies of
Texas A&M University
in partial fulfillment of the requirements for the degree of

DOCTOR OF PHILOSOPHY

August 2012

Major Subject: Agricultural Economics

Three Essays on Economic Development in Africa

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Approved by:

Chair of Committee,	Bruce A. McCarl
Committee Members,	James Mjelde
	Ximing Wu
	Gerald R. North
Head of Department,	John P. Nichols

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ABSTRACT

Three Essays on Economic Development in Africa.
(August 2012)
Mark Musumba, B.S., Texas A&M University;
M.S., Texas A&M University
Chair of Advisory Committee: Dr. Bruce A. McCarl

To achieve economic development, regional authorities have to address issues that relate to climate change, efficient information flow in the market place, and health care. This dissertation presents three essays on current issues of concern to economic development in Africa. Climate change is examined in terms of its effects on the Egyptian agricultural sector; transmission of world price to small scale growers is examined in Uganda; and the benefits of insecticide-treated bed nets use is examined in Africa.

In essay I, to address the impact of climate change on the Egyptian agricultural sector under alternative population growth rates, water use and crop yield assumption; the Egyptian Agricultural Sector Model (EASM) is updated and expanded to improve hydrological modeling and used to portray agricultural activity and hydrological flow. The results indicate that climate change will cause damages (costs) to the Egyptian agricultural sector and these will increase over time. Egypt may reduce these future damages by controlling its population growth rate and using water conservation strategies.

In essay II, I use vector autoregressive analysis to examine the transmissions of price information to Uganda coffee growers; using monthly coffee price data on retail, futures, farmgate and world prices from 1994 to 2010. Improved transmission of world prices to farmers may increase their decision making to obtain a better market price. Directed acyclic graphs reveal that there is a causal flow of information from the indicator price to the London futures price to the Uganda grower's price in contemporaneous time. Forecast error variance decomposition indicates that at moving ahead 12 months, the uncertainty in Uganda grower price is attributable to the indicator price (world spot price), own price (farmgate), London future and Spain retail price in rank order.

In essay III, the cost of malaria in children under five years and the use of insecticide treated bed nets is examined in the context of 18 countries in Africa. I examine the direct and indirect cost of malaria in children under five years and the benefit of investing in insecticide treated mosquito nets as a preventative strategy in 18 African countries. The results indicate that the use of mosquito treated nets reduces the number of malaria cases in children; and this can induce 0.5% reduction in outpatient treatment costs, 11% reduction in inpatient treatment costs, 11% reduction in productivity loss, and 15% reduction in disability adjusted life years (DALY) annually.

DEDICATION

I dedicate this dissertation to my father, Robert N.K. Lutamu, whom I wish could have lived to see the completion of this work.

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CHAPTER I

INTRODUCTION

This dissertation presents three essays on current issues that are of concern in economic development in Africa. Economic development is a multidimensional process or phenomenon with a broad definition but for this dissertation economic development will refer to economic growth that leads to a better standard of living. This growth can be measure in terms of social welfare to evaluate economic wellbeing. The welfare for this study is assessed as improvements in agricultural productivity, health and life expectancy, and access to the market place for producers. The essays are: (1) climate change and water use in agricultural productivity in Egypt; (2) flow of price information to small scale growers in developing economies for Ugandan coffee; and (3) the impact of diseases (malaria) on economic development in Africa. This section introduces the essays and objectives.

Essay I focuses on Egypt and assesses the implication of climate change on the agricultural sector. Climate change is an important issue of concern today. Changes in climate including variability in temperature and precipitation are likely to have a major impact on the agriculture sector. A major issue of concern in Egypt, apart from the potential impacts of climate change, is that Egypt's population has increased from 28 million in 1960 to an estimated 82 million in 2011 yet its water allocation from the Nile has remained the same at 55.5 BCM (CIA 2011; Knott and Hewitt 1994).

This dissertation follows the style of the *American Journal of Agricultural Economics.*

The Nile's natural flow contributes 95% of Egypt's total water budget with the remaining 5% coming from groundwater and rainfall (EEAE 2010). Egypt's population is projected to increase to 95 million by 2025 yet the country's water allocation is threatened by increased water use up stream and climate change's impact on Nile flow. In terms of water supply, climate change and increased demand by upstream countries may decrease the amount of fresh water available in Egypt. Climate change is expected to reduce the amount of rainfall and increase the temperature in Egypt by 3 to 4 degrees Fahrenheit by 2030 and by 8 to 11 degrees by the 2090s (IPCC 2007a). Increase in temperature and decrease in rainfall contributes to increased evaporation and decreased groundwater recharge. This implies that there will be an increase in water demand for irrigation at the same time as a decrease in water supply (Loutfy 2010). On the other hand, an increase in temperatures and projected sea level rise in Egypt will result in salt water intrusion in Nile River Deltas and coastal groundwater aquifers which will reduce fresh water supply and water quality (Loutfy 2010; Iglesias et al. 2007). Also climate models tend to show a reduction in the flow of the River Nile from the upstream countries by 2060 (Beyene et al. 2010). Increased demand for water by upstream countries and development along the Nile River is also likely to affect the amount of water flowing into Egypt and holds potential for international conflict (Wu and Whittington 2006).

The objective in essay I is to analyze the implications of climate change on the Egyptian agricultural sector under population growth projections, water use/water supply and crop yield assumptions for the years 2030 and 2060. To do this, the Egyptian

Agricultural Sector Model (EASM) is updated and expanded to improve hydrologic modeling and is used to portray agricultural activity and hydrological flow. The model is used under climate change scenarios that alter water flows in the Nile, irrigation water requirement, crop yields, land lost to sea level rise, livestock performance, and municipal and industrial water use. It simulates what would happen in the Egyptian agricultural sector in the future under these conditions. This essay explores water conserving alternatives that ensure efficient water supply systems like irrigation conveyance efficiency, irrigation field efficiency and distribution efficiency of public water system (PWS) networks for municipal and industrial water (M&I) use. This essay concentrates on the economic impacts to the agricultural sector. Water quality and water reuse implications are assessed.

Essay II assesses the transmission of world coffee prices to small scale growers. In developing economies one issue is access of market information by small scale growers and how this has affected the price that they can receive at the farm-gate. In this study, I focus on Robusta coffee growers in Uganda. Coffee is the second most important export product for developing countries after crude oil (ECF 2006). Uganda depends on agriculture for most of its export earnings and coffee is Uganda's primary export crop. In 2008, coffee accounted for 26% of the total value of exports with the main destination being the European Union (EU) (Keane et al. 2010). In 1990/1991, a structural change in the coffee market meant new and emerging paradigms that are likely to dictate coffee prices. This may have permanent effects on the livelihoods of millions who depend on it (Lewin et al. 2004). Increased competition in the buyer market meant that farmers would command a higher price in proportion to the world price (Sayer 2002). This new market structural change to more efficient markets has left the less informed and poorly capitalized market actors at a disadvantage. In Uganda, the majority of farmers are small holders and it has been shown that even with a rise in export price, the farm gate price does not rise proportionally (Fafchamps and Hill 2008).

The market oriented liberalization movement that lead to the structural adjustment in 1990/91 was to resolve market failure and 'get prices right'. The Uganda Coffee Development Authority (UCDA) was established in 1991 to promote and manage development of the coffee industry through research and improved marketing (UCDA 2007). Even though UCDA has no authority to set prices, it does provide price information to market players and the indicator coffee price. The indicator coffee price is an overall benchmark for the price of green coffee of all major origins and types. It is considered to be the best available measure of the price of green coffee transactions on a global basis (International Coffee Organization (ICO) 2011). Due to the reduction in radio programs on coffee that informed farmers about prevailing prices, farmers are unaware of the going coffee price and may sell their coffee at the farm gate for half the price (Sayer 2002). A common complaint for farmers has been the lack of information about the markets. Liberalization led to concentration of few export firms and this limited the flow of information from the market to the producers. Even though UCDA offers annual market information in reports, there has been limited information available to farmers and small traders on how markets work, day to day price fluctuations and relationship between prices and quantities (Complete Project 2001). Coffee farmers principally rely on the indicator price to bargain for a fair price (Krinovos 2004).

The focus of essay II is the process through which prices are transmitted to Ugandan growers and the markets that play an important role in these dynamics. Per the first theorem of welfare, competitive market equilibrium ensures an efficient allocation of resources. If farmers are able to obtain better information about the market place, this will improve market efficiency. Using monthly prices received by growers, retail prices in Europe (Belgium and Spain), futures prices and the composite indicator price, I examine how prices are transmitted to the Robusta coffee growers. This study contributes to literature on coffee price transmissions in that no study has studied price transmission to Uganda coffee grower while incorporating both retail prices to the destination countries and futures prices over the post liberalization period. With access to this information, farmers can improve on their price forecast and bargaining power in the market place.

Essay III explores the costs of malaria in children and the benefits of using insecticide-treated bed nets. Malaria has had a huge impact on the health and economic wellbeing of people on the African continent. The World Health Organization (WHO) estimated that there are at least 300 million acute cases of malaria each year resulting in nearly a million deaths (RMB 2010). Approximately 90% of these deaths occur in sub-Saharan Africa with the largest affected group (80%) being children under five (UNICEF 2009). Malaria infections also cause child mortality during pregnancy and cause reductions in birth weight of about 20% with approximately 50 million pregnant women exposed each year (UNICEF 2009; RBM 2010; and UNICEF 2007). Various studies have demonstrated a significant relationship between gross domestic product (GDP) per capita and the burden of malaria (Gallup and Sachs 2001; McCarthy et al. 2000). Gallup and Sachs (2001) estimated that countries with a high malaria burden grew at 1.3% per year less than countries without a large burden. A number of strategies have been proposed to address reduction in malaria burden but insecticide treated nets (ITNs) are considered the most cost effective available strategy to control malaria (Breman, Alilio and Mills 2004). ITN usage has been shown to reduce mortality rates in children under five by 20% in malaria endemic areas (Lengeler 2004). Even though international funding has increased only an estimated 35% of African at risk children are sleeping under a mosquito net as of 2010 (WHO 2010). Furthermore, the global economic slowdown has led to stagnation in international funding.

The objective in essay III is to estimate the cost of malaria in children under five years and further examines the benefits of use of ITNs as a preventative strategy in 18 African economies. The cost estimates focuses on: (1) loss in productivity by an informal caregiver[1]; (2) cost of inpatient and outpatient treatment; and (3) the burden of malaria utilizing the disability adjusted life years (DALY) measure (Murray and Lopez 1996). The benefits of ITN use are calculated using the results from the econometric estimation. This study extends on earlier work by Egbendewe-Mondzozo et al. (2011) focusing on malaria in children under 5 years since they are the most affected and

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[1] A parent (worker) staying home or at the hospital to take care of sick child that is not a health worker

vulnerable population. It also explores the use of nets from a government program policy perspective unlike studies that have explored provision of nets as a subsidized good or through a micro loan program.

CHAPTER II

ASSESSING THE ECONOMIC IMPLICATIONS OF CLIMATE CHANGE ON THE EGYPTIAN AGRICULTURAL SECTOR

Introduction

Egypt is the second most populous country in Africa with an estimated population of 82 million in 2011 (CIA 2011). Egypt is located between 22^o to 32^o North and 24^o to 37^o East. To the West of Egypt is Libya, to the South is Sudan, to the East is the Garza Strip and the Dead Sea, and to the North is the Mediterranean Sea. The coastline in the North is more than 3,500 kilometer (KM) along the Mediterranean sea with highly populated cities: Alexandria, Port-Said, Rosetta and Damietta (Agrawala et al. 2004). The Nile River is the main source of fresh water in Egypt. About 97% of the people live in the Nile Valley and Nile Delta. Agriculture is dependent on the Nile waters and employs 32% of the Egyptian workforce and produces 14% of the GDP (CIA 2011). The Nile's natural flow contributes 95% of Egypt's total water budget with the remaining 5% from groundwater and rainfall. Egypt's share of Nile water has been fixed at 55.5 billion cubic meters (BCM) per year as part of a 1959 agreement with Sudan (Knott and Hewitt 1994; Abdel-Gawad 2008).

The annual water budget of Egypt from the Nile has remained the same (55.5 BCM) yet the demand for water has continued to grow. That water budget served a population of 28 million in 1960, double that in 1980 and with a further rise to an estimated 82 million inhabitants in 2011 (Khouzam 2002; CIA 2011). This increasing population implies an increase in urban demand for water and food. Even though Egypt has raised its productivity/yield per acre, reclamation of desert land has increased demand for irrigated agriculture. There is significant future concern about the allocation of water resources in the face of increasing population.

Food production in Egypt is constrained by the availability of water and fertile soils. The Ministry of Water Resources and Irrigation (MWRI) developed a national water plan designed to improve water productivity that recommended efforts to increase the efficiency of current agricultural water use, minimize irrigation water losses, waste water reuse, shift from resource based and low technology industries to high technology industries, as a central mechanism to cope with the water shortages (Abdel-Gawad 2008). Climate change is an important factor with Egypt being vulnerable to climate change because of its dependence on Nile River water, the long coastline, potential increase in demand for water in the Upper Nile Basin countries, and increase in agricultural demand causing a possible increase in irrigated acres (reclaimed dessert land) (IPCC 2007; Loutfy 2010). Climate models estimate and increase in temperature for Egypt from 2030 to 2100 with little intermodal variance and given that it highly depends on irrigated agriculture, changes in precipitation matter very little. This means that the projections of climate changes effect on source waters of the White Nile, Ethiopian Highlands and equatorial lake regions are important in assessing the future of the Egyptian Agricultural sector (Agrawala et al. 2004).

Objective

The objective is to analyze the implications of climate change on the Egyptian agricultural sector under population growth projections, water use/water supply and crop yield assumptions for the years 2030 and 2060. To do this, the Egyptian Agricultural Sector Model (EASM) is updated, and expanded to improve hydrologic modeling and used to portray agricultural activity and hydrological flow. The model is used under climate change scenarios that alter water flows in the Nile, irrigation water requirement, crop yields, land loss to sea level rise, livestock performance, and municipal and industrial water use. It simulates what would happen in the Egyptian agricultural sector in the future under these conditions. This essay explores water conserving alternatives that ensure efficient water supply systems like irrigation conveyance efficiency, irrigation field efficiency and distribution efficiency of public water system (PWS) networks for municipal and industrial water (M&I) use. This essay concentrates on the economic impacts to the agricultural sector. Water quality, water reuse, and potential for changes in water allocation due to conflict are assessed.

Overview on Water Use in Egypt

The Egyptian economy currently uses or reuses 77 BCM of water per year with 62 BCM of that used by the agricultural sector, 8 BCM for drinking water (municipal use), and 7.5 BCM for industrial use (EEAE 2010). This budget of 58 BCM is supplied by 55 BCM of Nile water plus 1.0 BCM of deep aquifers and 1.2 BCM of rain water. The use in excess of this water budget is accommodated by recycling agricultural drainage water and reuse of treated municipal waste water (EEAA 2010). An important concern is the increased water need for the Egyptian economy in the face of potential reduction in water supply and increase in water demand.

On the demand side, with the increasing rate of population growth, the per capita share is expected to decrease from $850m^3$ per year to $600m^3$ by 2025 making the country's water consumption well below the water poverty line of $1000m^3$ per capita (Abdel-Gawad 2008; EEAA 2010; USAID 2006). The population in Egypt is projected to grow to 88.8 million by 2017 and 95 million by 2025. With this population increase, urban water demand is estimated to increase by 47% from the 2000 levels while industrial growth is projected to increase to 40% (Abdel-Gawad 2008). Increased population also implies increased demand for food production and land for housing.

The Egyptian agricultural sector has continued to increase agricultural production by technological progress and extensification (increasing its total production acreage). The MWRI plans to increase irrigated lands by 3.7 million acres (1.4 million hectares) by 2017 through reclaiming desert land (Salem 2005; EEAA 2010). New land reclaimed represents 20% of total cultivated land (EEAE 2010). This implies that there is going to be added stress to the current water supply to provide water to irrigate this land. To cope with the increasing demand, Egypt needs to develop more efficient irrigation and conveyance techniques, improve and increase waste water treatment, and increase access to an efficient sewage system (or explore water markets since Egypt does not charge a water price to farmers).

In terms of water supply, climate change and increased demand by upstream countries may decrease the amount of fresh water available in Egypt. Climate change is expected to reduce the amount of rainfall and increase the temperature in Egypt by 3 to 4 degrees Fahrenheit by 2030 and 8 to 11 degrees by the 2090s (IPCC 2007a), while climate models tend to show a reduction in the flow of the River Nile from the upstream countries by 2060 (Beyene et al. 2010). Increase in temperature and decrease in rainfall contributes to increased evaporation and decreased groundwater recharge. This implies that there will be an increase in water demand for irrigation at the same time also a decrease in water supply (Loutfy 2010). On the other hand, an increase in temperatures and projected sea level rise in Egypt will result in salt water intrusion in Nile River deltas and coastal groundwater aquifers which will reduce fresh water supply and water quality (Loutfy 2010; Iglesias et al. 2007). Increased demand for water by upstream countries and development along the Nile River is also likely to affect the amount of water flowing into Egypt and holds potential for international conflict (Wu and Whittington 2006).

Nile Basin

The Nile River basin encompasses 10% of the area in Africa and serves 11 countries: Egypt, Sudan, South Sudan, Ethiopia, Uganda, Kenya, Tanzania, Burundi, Rwanda, Democratic Republic of Congo (DRC) and Eritrea (figure 1). Egypt does not contribute to the Nile River flow yet it depends on the Nile for 95% of its water supply and consumes 80% of the Nile's water. The Blue Nile that originates in Ethiopia highlands contributes 85% of the Nile flow and the White Nile contributes 15% (Whittington 2004). Even though the White Nile contributes only 15% of the total amount of water into the Nile River, it ensures that the Nile has a constant flow during the dry months of April and May (Postel 2011).

The Nile Basin Initiative (NBI) was established in 1999 as an inter-governmental organization dedicated to management and development of the shared water in the Nile Basin. Some of the objectives of the NBI are: a) to ensure efficient water management and optimal use of the resource; and b) ensure cooperation and joint action between the riparian countries.[2]

An escalating concern is that water needs and planned developments along the Nile by riparian countries will affect the future flow and the amount of water received annually in Egypt. Egypt is planning an increase of about 3.7 million acres of irrigated land by 2017; Sudan plans an additional demand of 12 BCM of water and Ethiopia is planning an ambitious irrigation expansion plan to meet its growing population. If all these plans are enacted, estimates are that there will be a deficit of 50 BCM (Wu and Whittington 2006; Knott and Hewitt 1994; Loutfy 2010). In addition, equatorial lakes and the Blue Nile are very sensitive to changes in climate. Therefore, the amount of water flowing from the Ethiopian Highlands and equatorial lakes into Lake Nasser are likely to be affected by climate change (Kim and Kaluarachchi 2009).

Another point of contention is the risk associated with the seasonal and annual variations and the declining trend in Nile River flow. Nile River flow is affected by variability of flow in the Blue and White Nile. Varying contributions of the White and Blue Nile are reflected in the flow of the Nile where the low flows in the Blue Nile in the

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[2] NBI member countries are Burundi, Democratic Republic of Congo, Egypt, Ethiopia, Kenya, Rwanda, Sudan, Tanzania and Uganda. Eritrea is the observer.

1960s were partially offset by a higher White Nile flow in the 1960s (Conway 2002). The two explanations are: a) the "Hurst Phenomenon" of high and low flow in Nile River history; and b) south ward migration of the precipitation zone (Khouzan 2002). The migration has been attributed to El Niño events, climate change, depletion of land cover and change in the earth's orbit (Khouzan 2002). These fluctuations should be considered in planning for the future of fresh water availability in Egypt even without considering projected climate change.

Water Conflict

The potential for water conflict in Nile basin has been discussed in literature by Wu and Whittington (2006) and Woodward et al. (2007). In 1929, the Nile water agreement was signed by Britain which was representing Kenya, Sudan, Tanzania and Uganda. The treaty barred countries upstream from development along the Nile that would negatively affect the flow of water to Egypt (Agrawala et al. 2004). In a section of the 1929 agreement it states,

> 'No works or other measures likely to reduce the amount of water reaching Egypt was to be constructed without prior Egypt consent' (Agrawala et al. 2004).

Building of the High Aswan dam (HAD) lead to a bilateral agreement between Egypt and Sudan that allocated 75% (55.5 BCM/year) of the Nile water resources to Egypt and 25% (18.5 BCM/year) to Sudan (Allan 2009). This has been a point of contention since no other upstream riparian countries were included. In March 2011[3] the upstream riparian countries, Democratic Republic of Congo (DRC), Burundi, Kenya, Uganda,

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[3] See http://www.ssudan-nrmg.org/nrmg/index.php/nrnewssouthsudan/1-latest-news/263-watersudan-shrugs-off-burundis-signing-of-new-nile-water-deal

Ethiopia and Rwanda, ratified the Cooperation Framework Agreement (CFA) that repealed the old treaty which Egypt signed with Great Britain in 1929 (NRMG 2011). The CFA was not signed by DRC, Egypt and Sudan who wish to maintain the old agreement. The CFA would alter water allocation. The challenge in water allocation is reaching an agreement that allows for efficient water allocation. Therefore management and allocation have remained in the status quo and no assessment has been made on whether the current allocation can sustain current and future needs. As for the Nile River, water usage is based on political dominance, military strength and financial superiority with little or no regard to efficient allocation of water and impacts of negative externalities on the resource base (Nigatu and Dinar 2011; Elhance 1999; Waterbury 2002; Allan 2009).

Nigatu and Dinar (2011) propose a principle of "Allocate and Trade" for Nile Basin water management. Under "Allocate and Trade" an institution would assign water rights for riparian countries through a treaty and then allow them to trade within the basin. In their study, they assess water allocations that include: 1) baseline scenario of 55.5 BCM as per the 1959 agreement; 2) a proposed alternative allocation of 51.7 BCM based on recommendations by Nile experts, Dale Whittington, John Waterbury and Elizabeth McClelland; and 3) the unilateral allocation (23.2 BCM for Egypt) that assumes that countries pursue projects along the Nile River according to the natural flow of the river without consideration to it immediate or distant neighbors.

Water Reuse

Water is reused in many areas of the world typically as a water management strategy to cope with shortage in water supply. When Egypt indicated a deficit of 8 BCM, the shortage was covered by drainage water reuse and use of underground water (Abdel-Gawad 2008). In Egypt, reused water is in two major categories: 1) agricultural drainage water that is reused for agriculture after mixing with freshwater; and 2) treated sewage and industrial effluent. These two sources contribute 15 BCM of recycled agricultural drainage water and 4 BCM of treated sewage water which contributes to the 77 BCM of available water for use per year (EEAA 2010).

Sewage water reuse is mainly from municipal use. Of the 13.88 million cubic meters (MCM) per day of municipal waste water discharged in Egypt, more than 3 million remains untreated (Osman 2007). The untreated water constitutes 45% of the treated domestic waste water with the remaining 55% remaining either untreated or treated in onsite facilities like septic tanks (EEAA 2010). There is a need to emphasize the need to increase waste water treatment which contributes to an increase in water supply for agricultural production but also to water quality as a return flow to the Nile.

In Egypt, water reuse supplies a significant portion of the annual water budget, but there is a potential to increase this water supply portion and improve water quality. In Egypt, rural sanitation is at a low 4% which results in serious problems of water pollution and degradation of health conditions because raw waste water is directly discharged into the water ways (Abdel-Gawad 2008). Although no guidelines govern the reuse of waste water in Egypt, Martial Law of 1994 prohibits the use of effluent to irrigate crops unless treated to the required drainage water standards. Even though there are governmental restrictions on reuse of treated waste water to only non-food crops, farmers use waste water to irrigate all types of crops when there is no alternative irrigation water (Shaalan 2001). Some of the major concerns of use of irrigated sewage water in Egypt include: a) a lack of enough treatment plants to treat all water produced; b) a large proportion of the population is not connected to these sewage system; c) a significant amount water enters the water bodies without treatment; d) the quality of treated waste water differs from one treatment plant to another; and f) the health and environmental impact of the above problems (Bazza 2002).

More than 2 BCM/year of treated sewage is discharged into agricultural drainage canals. Drainage water flow and final destination depends on the region in Egypt. In Upper and Middle Egypt, all drainage water is discharged into the Nile River, where as drainage water in the Delta area is recycled for irrigation by mixing part of the flow with the water in the main irrigation canal. Industrial effluent reuse is minimal because of the negative impact on machinery (MWRI/USAID 2000). The Egyptian National Committee on Irrigation and Drainage (ENCID) proposed strategies for drainage water reuse and these include:

- draining 50% of drainage water from the Delta into the sea to avoid seawater intrusion and to maintain a salt balance;
- improving the quality of drainage water in the main drains;
- imposing a limit on the use of treated waste water to non-food crops such as cotton, flax and trees;

- increasing the reuse of drainage water from 4.5 BCM/year to 9.0 BCM/year by 2017 and
- minimizing cost by separation of industrial waste water from domestic sewage (ENCID 2001).

A major example of drainage water reuse is the El-Salaam canal project where drainage water is mixed with Nile water at ratio of 1:1 and then used to irrigate reclaimed lands. This canal project has been used to create new communities and supply irrigation water to North Sinai Peninsula and land west of Suez Canal. It is estimated that 4 BCM/year will be delivered in this canal at completion (Hafez et al. 2008). Waste water used to irrigate forests encourages desert reclamation, helps urban areas reduce the burden of increased sewage water and helps sequester carbon (climate change mitigation).

Agricultural Supply and Demand

Egyptian agriculture depends on irrigation with a total of 7.8 million feddans[4] of which 6.2 million feddans are ‘old land’ and 1.6 million feddans are new reclaimed lands (desert land that is turned into agricultural or residential land). There are 12 important crops; maize, cotton, rice, wheat, tomatoes, broad beans, onion, potato, soybeans, sugarcane, long and short season berseem, and sugar beets. Summer (April – November),Winter (November- May) and Nili[5] (July – October) are the main cropping seasons. These three seasons allow for multiple cropping, where land is cropped an average 1.8 times a year (USAID 2006). In the late 1990’s, Egypt made plans to

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[4] Feddan =0.42 hectares = 1.04 acres

[5] Early fall

increase land productivity and expand the irrigated area to cope with increased food demands (Khouzam 2002).

Efforts to increase productivity, reclaimed land, and expand irrigation, led to increased yields between 1961 to 2001; with rice increasing from 2 to 3.7 metric tons (mt)/acre, maize from less that 1 to 3.55 mt/acre and cereal from 1.18 to 3 mt/acre (FAO 2001). Egypt also increased efforts to reclaim desert soil with 0.1 million acres reclaimed between 1901 and 1950, and 2.5 million reclaimed from 1951 to 2001 (Khouzam 2002). Land reclamation projects are still increasing the arable land in Egypt. Land reclamation projects such as Toshka, El Salaam Canal, and Dwaynat East are expected to increase the arable land by 3.4 million feddans in 2017 (USAID 2006). Another path to expansion is increasing irrigated acres to allow for intensive agriculture. Irrigated acreage increased from 6.3 million acres in 1961 to 8.2 million acres in 1997 (FAO 2001).

The production of agricultural commodities is determined by four factors:1) the agricultural resource base that includes land, water, capital, human resources, and institutional setting; 2) agricultural technology advance rate which is important because of limited land and water resources; 3) environmental/climatic conditions and associated water pollution, salinity loads, soil deterioration and soil erosion' and 4) agricultural policy and its weightings on food security, agricultural exports and providing raw materials for local agro-industries (figure 2) (USAID 2006). Land area is relatively small and the average per capita cultivated land is 0.12 feddans which is the lowest in the world. Egyptian labor has been stated at 7 million laborers with the majority being unskilled labor (USAID 2006). Even though Egypt increased its local food production to cope with the food demand increase associated with the population growth, net imports of agriculture grew from $160 million to $3 billion while net food imports and animal products increased from $74 million to more than $2 billion by 1997 (Khouzam 2002; USAID 2006).

Domestic production is affected by a number of factors as shown in the figure 3. Three main factors affect demand for commodities in Egypt: 1) consumer prices which in turn are affected by market structures, consumer price policy; world prices and trade policy; 2) population and population characteristics plus population growth; and 3) income and income distribution with the size of population below the poverty line estimated between 23% to 45% by the World Bank (USAID 2006).

Economics of Water Use

In an efficient water market, equilibrium is achieved when the marginal value of water use across all users is equal (Figure 4). The price (P*) that equates these values is the efficient water price. Given a total water supply Q, agricultural water users will consume QQ* while the municipal and industrial users (M&I) will consume OQ*. The horizontal axis represents the total water supply. The efficient allocation of scarce water is determined by the intersection between the marginal net benefit curves for municipal and industrial water demand curve ($G_{M\&I}$) and agricultural water demand (G_A). At this equilibrium point where the marginal net benefits are equalized among all users, water allocation maximizes welfare.

Few world systems have efficient water pricing because of the lack of competitive water markets. To have a competitive market, there should be well defined water rights[6] . Buyers and sellers must have the right to purchase water and sellers the right to sell to buyers. Government intervention and policies prevent the pricing of water at marginal cost, creating an inefficient market. In the case where the total supply reduces to OQ^1, the high end users $G_{M\&I}$ are able to afford all the water leaving G_A without enough water. In these cases, government has intervened to prevent such occurrences in order to allocate water to all users since water is a necessity. This case illustrates that markets may not be the best mechanisms of distributing an essential good like water. In areas of scarce water like Egypt, the shadow price of water should be the indicator of scarcity. Shadow price is the maximum price a player is willing to pay for an extra unit of limited resource. If the shadow price is zero, then the resource is not scarce. In the case of ground water extraction, the rate of extraction should be equal to the rate of recharge to ensure sustainability of the resource and intergenerational equity. Once the rate of extraction exceeds recharge, the resource becomes a non-renewable/exploitable resource. For a non-renewable resource in a perfectly competitive market, the efficient price rises at the discount rate/interest rate[7]. For illustration, assume that ground water can be left in situ or extracted without cost at time, t, and sold for price, P_t. The opportunity cost of leaving the water in the ground is the rate of return

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[6] Coarse Theorem state that if property right are well defined and free trade exist, bargaining will lead to an efficient outcome regardless of the initial allocation of property rights (assumes zero transaction costs)
[7] Hotteling's rule that in a competitive market, the price of a depletable resource must increase at the same rate as the discount rate

to P_t. In period 1 (P_{t+1}), assuming that the water left in the ground has rent zero the price of water is given as

$$(1) \qquad \frac{P_{t+1}}{P_t} = (1 + r) \rightarrow P_{t+1} = P(1 + r)$$

This equation implies that a non-renewable resource owner will only leave water in the ground if the price of water rises at the discount rate, r. Therefore if $P_{t+1} < P_t(1 + r)$ firms will supply water in the current period and put proceeds in the bank to earn a higher rate of return than leaving the water in the ground. This increase in water supply reduced the price of water to reestablish the equilibrium. As shown in figure 5, the price path and quantity path of a nonrenewable resource, like ground water, over time. P_t will continue to rise at the rate of interest unless there is a back stop technology like desalinating water that will act as a substitute at a given price.

Conjunctive Water Use

The water use in Egypt involves water reuse through canal return flows and drainage use. There is also interdependence between surface and ground water in some regions. In cases where groundwater and surface water are used jointly, the efficient condition maximizes the discounted marginal products of surface water and ground water across time and space. To specify this model, we draw from work by Pongkijvorasin and Roumasset (2007). Consider an irrigation region where water is supplied from a point source into a canal. Every farmer can divert water from the canal and use it on his/her farm. Let y_i denote the distance from the point source to each farm and y_0 denote the farm at the point source; x_i water received by farmer i where $i = 1$ is the nearest farm and nth farm is the farthest farm. If ws_i is the percentage of water sent that is actually received by the ith farm then conveyance loss depends on distance from the point source at each farm, $ws_i = ws(y_i)$ where $0 \leq ws(y) \leq 1$, $ws(0) = 1$, and $ws'(0) = 1$, and $ws'(y) < 0$. To receive x_i units of water requires a release of $Q_{ws_i} = \frac{x_i}{ws(y_i)}$ from the point source. μ is assumed as the percentage loss that percolates to the groundwater aquifer, and the other losses are due to evaporation during conveyance that cannot be reused. Farms can use groundwater in conjunction with surface water. Let g_i be the amount of groundwater used by farm i. The marginal cost of extracting groundwater depends on the head level, $C_{g(h)} \geq 0$, where $C_g'(h) < 0$ and $C_g''(h) \geq 0$. Natural leakage from groundwater aquifers is assumed to be a positive increasing, and convex function in head level, $(h) \geq 0, l'(h) > 0$ and $l''(h) > 0$. The state of the aquifer can be explained by

(2) $\dot{h} = a\left[R - l(h) - \sum_{i=1}^{n} g_i + \beta \sum_{i=1}^{n} (x_i + g_i) + \mu \sum_{i=1}^{n} \frac{1 - ws(y_i)}{ws(y_i)} x_i\right]$ where R is natural recharge and a is a conversion parameter that converts aquifer volume to height. For a unit of water used, we assume that k proportion is used for farm production. To account for seepage, β percent of on-farm water use recharges to underground aquifer and therefore the rest, $1 - k - \beta$ is canal return flow and is available for downstream users. Given that return flow to the canal will be available for use by the downstream farmer, the total amount of water sent from the point source, Z, is not simply equal to the sum of sent water over all farms. The total amount of water sent to farm i, Q_{ws_i}, is equal to: $Q_{ws_i} = \frac{x_i}{s(y_i)} - (1 - k - \beta)\frac{(x_{i-1} + g_{i-1})}{s(y_{i-1})}$. The right-hand side is the canal return flow

coming from the closer farm is given by the second term on the right hand side. Total water sent from the point source can be expressed as:

(3) $$Z = \sum_{i=1}^{m} Q_{ws_i} = \sum_{i=1}^{n} \frac{x_i}{s(y_i)} - (1 - k - \beta) \sum_{i=1}^{m-1} \frac{(x_i - g_i)}{ws(y_i)}$$

where m is the last farm using the surface water. Therefore the social planner chooses the amounts of surface water and groundwater used to maximize social welfare, i.e:

(4) $$\max_{x_i, g_i} \int_{t=0}^{\infty} \left[\sum_{i=1}^{n} \int_{o}^{kx_i + kg_i} p_i' \, (q_i) dq - cZ - \sum_{i=1}^{n} c_g(h) g_i \right] e^{-rt} dt$$

s.t $Z = \sum_{i=1}^{m} Q_{ws_i} = \sum_{i=1}^{n} \frac{x_i}{ws(y_i)} - (1 - k - \beta) \sum_{i=1}^{m-1} \frac{(x_i + g_i)}{ws(y_i)}$

and $\dot{h} = a \left[R - l(h) - \sum_{i=1}^{n} g_i + \beta \sum_{i=1}^{n} (x_i + g_i) + \mu \sum_{i=1}^{n} \frac{1 - ws(y_i)}{ws(y_i)} x_i \right]$

where p is the price of the farm product, $f(\cdot)$ is the production function, and q_i is the total consumptive use, which is equal to $k(x_i + g_i)$. The production function is assumed to have traditional properties, i.e., $f'(q) > 0$, $f''(q) < 0$. Conveyance cost of surface water is given by the constant per unit cost, c with a discount rate is given by r. The efficient price of surface water received at each location is derived from the first order conditions of equation 4.[8]

(5) $$P_x(y_i) = \frac{c}{ws(y_i)} - \frac{c(1 - k - \beta)}{ws(y_i)} - \lambda a \beta - \lambda a \mu \frac{(1 - ws(y_i))}{ws(y_i)} = kpf_i'(kx_i + kg_i)$$

The optimal unit price of received water for a farmer at distance y is shown in equation (5). A water institution may implement efficient water allocation by charging P_x per unit of received water or P_x/k per unit of consumptive use. The cost of sending water for consumptive use is optimal if there is no groundwater recharge. Efficient pricing in may

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[8] See Pongkijvorasin and Roumasset (2007) for detailed derivation of the price.

be assessed by charging the full cost for received water (($c/ws(y_i)$ per unit) and giving differential credits for canal return flow (($c/s(yi)$ per unit) and percolation to the aquifer (λa per unit) For farms using surface water, the last farm can be charged for received water and credit back parts flowing to the aquifer. The last farm is not credited for canal flow since the water will not be used by other farms. For the condition where the cost of sending surface water is higher than the value of its conveyance loss, i.e., $c \geq \lambda a\mu$, the optimal price for surface water use increases with distance, $p_x'(y) > 0$. The efficient price for ground water use within surface water boundary, is given by

(6) $$p_g(y_i) = c_g(h) + \lambda a - \frac{(1-k-\beta)c}{ws(y_i)} - \lambda a\beta$$

Therefore the optimal policy for groundwater is to charge the user and extraction costs while giving credit for canal return flow and groundwater recharge from on-farm water use. Groundwater users outside the surface water boundary will not receive the credit for canal return flow i.e.,

(7) $$p_g(y_i) = c_g\ (h) + \lambda a - \lambda a\beta$$

In contrast to surface water within the surface irrigation area, the efficient price for groundwater decreases with distance. Marginal costs of groundwater are equal outside the surface water area (Pongkijvorasin and Roumasset 2007).

Literature Review

The Nile is potentially sensitive to climate change and various model and studies have examined the impact on crop yields, CO2 concentration, water resources and sea level rise (Strzepek et al. 1995; Yates and Strzepek 1996; Onyeji and Fischer 1993; Conway and Hulme 1993; Yates and Strzepek 1998). Strzepek and Yates (2000) used a recursively dynamic general equilibrium model to address the impact of climate change on water resources of the Nile. They showed that under declining water resources (< 55.5 BCM), the total share of agriculture to GDP decreased and this led to an increase in imported agricultural products. The climate scenario with abundant water supply (> 76 BCM) saw a decrease in the marginal value of water to zero.

Beyene et al. (2010) used a macro hydrology model to assess the impact of climate change on hydrology and water resources in the Nile River. They observed that the Nile River will experience an increase in stream flow from 2010 - 2039 because of increased precipitation but will experience a decline in flow for periods 2040 - 2069 and 2070 – 2090 due to decline in precipitation and an increase in evaporation. For the global scenarios A2 (B1) as a percentage of historical,[9] the average stream flow at the High Aswan Dam (HAD) is expected at an annual average of 111(114), 92 (93) and 84 (87). The HAD releases for irrigation increase to 106 (109)% of historical then decrease to 87 (89) and 86 (84)% for the later three periods.

A Ricardian approach is used by Eid et al. (2001). They regressed farm net revenue against climate, socio-economic and hydrologic variables to determine which factors influence variability in farm net revenues in Egypt. Their results indicated that high temperature will constrain agricultural production. The recommended adaptation options are irrigation and technological advancement. Irrigation was the favored option to increased temperature. They suggested policies to cope with the effects of climate change, and these include crop management, water management and land management.

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[9] 1950-1999

Farmers are advised to use crop varieties with high water use efficiency, adjust crop sowing dates and use early maturing varieties.

Strzepek et al. (2008) used a computable general equilibrium model of the Egyptian economy to estimate the economic impact (value) of the HAD. They used a comparison between the 1997 economy without the HAD and the actual situation with the dam. The dam's ability to control the uncertainty in the flow of the Nile River with water stored in Lake Nasser and increased investment in transportation and agriculture shows a total gain of 7.1 billion Egyptian Pounds (LE) to 10.3 billion (LE) which equates to 2.7% to 4.7% of annual GDP in 1997.

Egypt has a large population to land ratio. Adrianson (2009) explored land reclamation in Egypt and life in the new lands using the Mubarak project initiated in 1987. The study found that although land reclamation provides new opportunities for graduates and horizontal expansion, it may not be ecologically and economically sustainable given the resource availability situation. Luiz et al. (2011) studied water policy networks in Egypt and Ethiopia using a social network analysis. The results showed that international donor agencies do play an important role in connecting different actors. The lack of connectedness to non-state actors usually prevents policy makers from tapping all available expertise and implementing policies.

Block and Strzepek (2010) used the Investment Model for Planning Ethiopian Nile Development (IMPEND) to assess the influence of the transients and long term periods of proposed development under varying economic, flow policy, construction and climate change. For the climate change effect on the system, policy implications call for significant economic planning that requires securing energy trade contracts with neighboring countries prior to extensive expansion. In addition, the success of hydro power and irrigation development will rely on water resource planning and strategizing with downstream riparian countries. The model indicated that any increase in flow due to climate change should be applied to irrigation and hydropower generation.

Using a water balance model, Tarekegn and Tadege (2006) studied the effect of climate change on the Lake Tana sub basin in Ethiopia. Their results indicated that a temperature increase of 2^{o}C with no change in rainfall will decrease the mean annual flow by 11.3%. A rainfall decrease by 10% and 20% decreased the run off by 29.3% and 44.6%. Their conclusion was that the basin is more sensitive to changes in rainfall than temperature.

A potential for water conflict exists in the Nile River Basin because downstream riparian countries are highly dependent on the river compared to upstream riparian countries. Wu and Whittington (2006) used the Nile Economic Optimization Model (NEOM) as a non-linear constrained model to determine the annual pattern of water use that would maximize the sum of economic benefits from irrigated agriculture and hydroelectric power generation in the Nile Basin. They applied cooperative game theory concepts such as core, nucleolus and Shapley's value, to Nile water conflicts to examine the incentive structure of both cooperation and non-cooperative strategies for different riparian countries. They concluded that the value of cooperation will be highest if all countries came together under the Nile Basin Initiative (NBI).

Attaher, Medany, and Abou-Hadid (2009) used a preset questionnaire to conduct a community based multi-criteria adaptation assessment in the Nile Delta. Their results indicate that farmers in the Nile Delta are willing to act positively to reduce the impact of climate change through adaptation efforts proposed with clear support from government. 'Changing cultivars' were considered the most important adaptation measure for the agriculture systems followed by 'increasing irrigation requirements' and 'changing sowing dates'.

Kim and Kaluarachchi (2009) assessed the impact of both climate change and dam operation on water resources on the Upper Blue Nile river basin using six GCMs for the 2050's. The results of the weighted scenarios suggested mild increases in hydrologic variables over the study area. This study provided policy makers a recommendation for water resource planning and management which included reuse of return flow from irrigation fields, increase in water use efficiency and conjunctive use of underground water.

Theoretical Framework

The model to be used is a partial equilibrium model that maximizes social welfare, that is, producer and consumer surplus. Drawing from previous work by Takayama and Judge (1973) and McCarl and Spreen (2003), if we have region i demanding products Q_{di} at price P_{di} given as $P_{di} = f_{di}(Q_{di})$ and the supply function of region i is $P_{si} = S_i(Q_{si})$ where P_{si} is the supply price and Q_{si} the quantity supplied. The welfare function is the area underneath the demand curve minus the integral of the area underneath the supply curve expressed mathematically as

(8) $$W_i\left(Q_{si,}^*, Q_{di}^*\right) = \int_0^{Q_{di}^*} P_{di}\, dQ_{di} - \int_0^{Q_{si}^*} P_{si}\, dQ_{si}$$

Partial equilibrium (PE) analysis is used to analyze the impact at a local, regional and national level. These PE analyses can provide information on the ripple effects of change in an economic variable (water) throughout the economy. These PE provide both direct and secondary effects. PE analyses usually incorporate supply and demand relationships to recognize interdependencies that cover both vertical and horizontal relationship within sectors. This implies that several aspects of the variable (water) can be considered in a single modeling framework while applying underlying assumptions that reflect actual market relationships (Hagerman 2009; Paarlberg et al. 2002; Mangen and Burrell 2003; Rich and Winter-Nelson 2007; Schoenbaum and Disney 2003; Paarlberg et al. 2008). The model to be used in this study is the Agricultural Sector Model of Egypt, a partial equilibrium model, which was updated from an earlier version of the EASM.

Model

The EASM was developed in the early 1980's and revisions have been made to the model by numerous modelers including McCarl, Binder, Shawky, and the MWRI (McCarl 1989; Kieth et al. 1999; Shawky 2001). The latest revision of the model, which updates the MWRI Agricultural Sector Model of Egypt (ASME), arises through the effort of the MWRI working together with the UNDP to assess the implications of climate change on the Agricultural sector in Egypt. The ASME is a static partial equilibrium model that maximizes welfare as consumers' surplus plus producers' surplus[10] subject to land, labor, water, commodity balance, policy and livestock feed constraints as illustrated in the figure 6.

Land is divided into the following regions/governorates regions; Upper Egypt, West Delta, Fayoum, South Middle Egypt, North Middle Delta, South East Delta, North East Delta, Toshka Valley, Sinai, Sandy Soil ground water, Sandy Soil Canal, and Calcar Canal. An upper bound is set to the land for each region. Expansion is left to potential reclamation in Newlands (Sinai, Toshka Valley, Sandy_SW Land). Future new land area is the sum of total planted area plus the potential land to be reclaimed. The land reclamation is constrained by the cost and resource availability. Land availability varies by region so does the number of farmers. Family labor in the old land is assumed at 1.5 people per farm household with 30 working days a month, while in the new lands, labor is at 2 people per household. Water is obtained from the HAD at an annual allocation of 55.5 BCM plus water ground water, water reuse and rainfall. Water reuse involves water from agricultural drainage and treated Municipal and Industrial (M&I) waste water. For the commodity balance, consumption and production must be balanced nationally, and regional production of commodities must be consistent with cropping and livestock activities.

The drainage balance, which is the main focus of this study looks at the drainage balance of agricultural and M&I water by region. Figure 7 is adapted from Alnaggar (2003). Net municipal and industrial water consumption depends on amount diverted, conveyance efficiency, and the public water system. Return from M&I use goes to the

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[10] For both livestock and crops. Social welfare is in terms of consumer and producer surplus.

drains. Only treated M&I waste water is reused with the exception of Upper and Middle Egypt where their waste goes directly into the Nile and is mixed with fresh water for reuse downstream. The model constrains the cropping options based on land, labor and water. Although the land requirements of normal growing season are set in the model, earlier and later planting is allowed. Seasonal cropping occurs but is limited by land availability. Labor requirements are dependent on the labor needs per feddan and the crop and livestock mix. Labor supply depends on region, number of working days per month, and family size. Irrigation water application rates per acre and crop for each region are given by the crop requirements. For example, rice requires 0.0025 (MCM) of extra water for percolation.

The livestock types in this model include buffalo, local and exotic cattle and sheep/goats. There are several types of categories of livestock commodities which include beef and milk as well as marketable animals which include veal and fattened animals. Draft animals are also included in the livestock commodities and are only distributed to old lands Draft animals include such animals as camels, horses mules and donkeys.

The production of livestock and poultry meat in the model differs in nutrient allocation and source of feed. The livestock have an annual nutrient requirement that is set at a seasonal basis. In the production of poultry meat and eggs, the feed used is imported soybean meal and maize. The commodities of interest are livestock animals, meat, milk, eggs and poultry meat. Production constraints ensure that the amount produced does not exceed optimal total output. The commodity balance constraint limits consumption plus exported to be less than or equal to crop production plus net imports. Resource constraints limit resource use to region or national availability.

The objective function is the net consumers' and producers' surplus (CSPS). The commodities are given in table 1 in Appendix B. The objective function contains demand and supply functions. Demand price is endogenously determined for agricultural consumer commodities. Parameters for a linear (inverse) demand function for each commodity are calculated based on prior price and quantity plus elasticity estimates.[11] The demand function is then integrated and included in the objective function yielding a quadratic term. The cost or supply functions are calculated by multiplying the inputs used for production by their prices or costs. The model calculates equilibrium prices shadow values and quantities from the optimal solution. The models mathematical formulation and constraints for hydrology are described further in Appendix C.

Data

Various sources of data are used in this model and here I will focus on the main data that is used in the scenarios.[12] The population data for the scenarios was obtained from the Stratus report and it includes the pessimistic and optimistic population growth projections for the years 2030 and 2060. A rate of yield progress was used to portray a linear rate of progress in Egypt, for the major crops such as barley, cotton, maize, rice, sorghum, and wheat. A slower yield progress scenario was included and is discussed in

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[11] slope=base year price – slope times base year consumption divided by elasticity; intercept = base year price – slope times base year consumption

[12] Sources can be obtained from the author on request. Data was provided by the Ministry of Water Resources and Irrigation in Egypt

the model specification. No yield increases were assumed for other crops. Data on the changes in crop yield and irrigation were taken from the Egypt Second National Communication (natcom) (EEAA 2010); scenarios from sea level rise were obtained from the Egyptian Coastal Research Institute (CORI) (Elshinnawy 2008); Nile River flow Data were obtained from Krishen analysis based on the work by Elshawmy et al. (2009); livestock yield were based on data from the US National assessment in the Southwest region and; also the municipal and water demand was expanded under climate change using data from the southwest part of the US from the US National assessment.

Procedure and Model Specification

The ASME was run with a number of projected conditions against a baseline for the years 2010, 2030 and 2060.[13] These projections include future population growth levels (pessimistic and optimistic), yield technological progress, degree of climate change as it affects crop yield, crop water use, irrigation water supply, HAD water releases/outflows, land lost to sea level rise, livestock performance and M&I water use. The base scenarios for the years 2010, 2030 and 2060 involve only population growth projections and yield technological progress.

Population Projection – Pessimistic and Optimistic Case

Population projections use two case scenarios: 1) the optimistic scenario where the population growth rate is assumed to decrease; and 2) the pessimistic projection shows continued rapid growth in population. The population projections for 2030 and 2060 are

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[13] See appendix A for detailed description.

in Table 2. This report uses the 2010 population of Egypt of 80 million for the base. The agricultural commodities and municipal water demand quantities are assumed to be constant per capita in the baseline scenario. Therefore an increase in population leads to an upward shift of the total country demand curve reflecting an increase in the demand for food and water.

Yield Technological Progress

Two scenarios for the yields are developed; a ‘slower’ scenario based on communication with the Ministry of Agriculture in Egypt, and a ‘faster’ one, based on estimation from US National Agricultural Research, Extension, Education, and Economic Advisory Board, the Agricultural productivity and Agricultural Research. The scenarios are shown in table 3. Adams et al. (1999) assumed that a one percent increase in simulated yield led to a 0.4 % increase in purchased input use (fertilizer, seeds, pesticides, but not in water, land, and labor). Therefore a yield increase of 2% per year by 2030 created a 40 % larger crop yield and required use of 16 % more inputs.

Projections of Climate Change Effects on Crop Yields and Water Use

The projected effects of climate change on crop yields are obtained from the Egypt Second National Communication (EEAA 2010) with interpolations made to match up the years. Scenario A1 is used for both the 2030 and 2060 projections as shown in table 4. Data were not available for climate change sensitivity on all crops therefore the sensitivity for select proxy crops were used for crops for which data were not available. Table 5 provides the proxy crop mapping. In addition, table 6 shows the assumed climate change induced percentage change in crop yields increase in irrigation water use by crop.

Nile Delta Inundation Due to Climate Change

Climate change effects on sea level rise would have effects on land inundation. In the model, projections from CoRI and Stratus Consulting are used that indicate the percentage of arable agricultural land that would be lost by region with and without protection efforts. The data are presented in table 7. The areas of concern for sea level rise are the northern parts of the Delta regions (NorthEast, NorthMiddle and West Delta). The scenarios indicate that with protection in 2030, there will be an agricultural land loss of 0.2% and 0.1% in the East and West Delta. The rest of the table is interpreted the same way.

Livestock Yield due to Climate Change

Livestock productivity is affected by temperature, but given that no data is available for Egypt, I use data for the Southwestern US drawn from Riley et al. (1999) and Adams et al. (1999). This study uses the average effect of climate change on livestock productivity which are presented in Table 8.

Climate Change and Municipal and Industrial (M&I) Water Use

Higher temperatures increase municipal and industrial water use. Again data were not available for Egypt so data from the US were used. Specifically data from Chen, Gillig and McCarl (2001) in the San Antonio Texas area were used. The average increase in water demand from that study of 0.025 percent was used and is given in Table 9.

Water Resources/Supply Changes due to Climate Change

The Nile inflows due to climate change are adapted from Beyene et al. (2010). The study assesses climate change's impact on the White and Blue Nile and projects the flow at the HAD. Emissions scenarios (greenhouse gas emissions) ranked from highest to lowest are A1F1, A2, AIB, B2, A1, and B1. For the inflows, both the A2 and B1 scenarios are used because they are the most widely simulated global emissions scenarios by all models. Scenario A2 projects that the global average CO^2 concentration will reach 850 parts per million (ppm) by 2100 while B1 assumes increasing dependence on clean and resource efficient technologies and the CO^2 concentrations leveling off at 550ppm in 2100. There are 11 global circulation models used to compute the multimodel average projection of outflow from the HAD that will be used in this study. These models are listed in table 10. Given that there is no data specific to the years 2030 and 2060, I used the projection of flow for the period 2010-2039 for 2030 and 2040-2069 for 2060. The average percentage changes in flow for global emissions scenarios A2 and B1 are then transformed to HAD flow in BCM as shown in table 11.

Water Releases Changes due to Seasonal Variation and Potential Conflict

Water release scenarios are used to reflect both seasonal and annual variations in Nile flow and the potential changes in Nile flow due to conflict from Nile basin countries as mentioned by Nigatu and Dinar (2011). These scenarios are used to examine the sensitivity of Egyptian economy to changes in water supply without climate change due to seasonal variation and changes in allocation due to conflict or changes in the 1959 agreement. The changes in water supply or HAD releases under the two scenarios are shown in table 12. The proposed alternative, unilateral and social planner allocation of water in the Nile basin, are discussed in the water conflict section of this paper. The water release scenarios are also used to study the sensitivity to water supply changes in table 13.

Water Reuse Scenarios

Water reuse is important to the water budget in Egypt. In Egypt water reuse is defined in two forms; agricultural drainage water that is reused in agriculture after mixing with freshwater, mainly from middle and upper Egypt and treated sewerage and industrial effluent in the Delta regions. In the Upper and Middle Egypt, all drainage water returns to the Nile to be reused whereas in Delta regions water has to be treated in order to be reused as drainage water. In this model, I look at the changes in water allocation and climate changes effect on reuse.

Results

The scenarios and results presented in the next section are as follows. The first section assesses the implications of population growth without climate change in Egypt for the years 2030 and 2060. The second section looks at the implication of climate change on Egypt for the year 2030 and 2060 mainly focusing on changes in water supply at the HAD. Adaptation measures in the sector to variability in water supply are analyzed. The last section evaluates the scenario where conflict within the Nile River affects water supply in Egypt before 2030 and how this water conflict together with climate change may affect water allocation and agricultural productivity.

Scenario without Climate Change

In the scenarios without climate change, the results are presented as percentage change from the 2010 baseline scenario. For the baseline scenarios 2030 and 2060 I held other factors constant and vary the population growth depending on the optimistic or pessimistic population projection.[14] The Nile flow or releases at the HAD is set at 55.5 BCM for the baseline scenarios except for sensitivity analysis to Nile inflow. The technological yield progress is set to the "slower rate" for the baseline scenarios. Figure 8 is a summary of the scenarios. Tabulated results are presented in appendix A. The basic definitions for the terms and units are presented in the tables 15 and table 16.

The results from table 17 are compared to the 2010 baseline scenario indicate an increase in welfare, value of total production, increase in import, decrease in export and increase in consumer prices for 2030 and 2060. The increase in these variables is higher

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[14] The pessimistic and optimistic scenarios from this point will refer to pessimistic and optimistic population projections.

for the pessimistic population growth scenario because there is increased demand for food and water due to a higher population (increased demand). The main reason for the welfare gains is the outward shift of the demand curve due to the population increases. As municipal water demand competes with agricultural demand, there is an increase in groundwater use to account for the increase in water demand. This implies an increase in water supply to accommodate increased demand. The population increase creates a demand for new land for agriculture and settlement, therefore water reuse becomes critical (increases) with the increase in the value of scarce water. The total agricultural land decreases in 2060 compared to 2030 and employment (labor hours) also reduces. This implies that in an agricultural sector that employs over 32% of the population, a reduction in employment with increased population may not be very popular politically ceteris paribus.

Climate Change Scenarios

Climate change implications to be addressed include; changes in water supply/release from HAD, land inundation from sea level rise, crop yields, crop water demands, livestock productivity and municipal water consumption. I present the results for 2030 and 2060, also population projections are accounted for. The results with climate change are compared to the baseline scenarios for that given year to obtain the percentage change.

Climate Change 2030

For the baseline scenario for 2030, the main focus is on the projected changes in water releases at the HAD using the A2 and B1 scenarios and the sea level rise. The eight scenarios are presented as percentage changes of the 2030 baseline scenarios (pessimistic and optimistic), and then these changes are compared to the baseline scenarios of the respective years without climate change. These eight scenarios are described in table 18 and the "sloweryield" for technological progress is used. The A2 and B1 scenarios are used to depict the future water supply. These two scenarios are then used to project the changes in water supply and releases at the HAD. These two scenarios for the water release/supply scenarios at HAD. The land inundation scenarios assume either no protection or protection against sea level rise to observe the sensitivity to sea level rise. Protection from sea level rise or land inundation shows that the agricultural land lost is less than that where there is no protection against land inundation. Protection implies that land that is currently available for either agricultural production or settlement potential losses to sea level rise is close to zero. These sea level scenarios are used for both the pessimistic and optimistic scenarios. For the other variables, I assume average M&I water consumption, average livestock production and, crop yields are from the A1 scenario of the ENCID. The water supply is from the two scenarios (A2 and B1) (table 18 and figure 8).

The climate change results for 2030 while focusing on the pessimistic scenarios indicate a reduction in welfare compared to the 2030 scenario without climate change (table 19). The reduction in agricultural production leads to an increase in prices, therefore, a reduction in welfare. The increase in population shifts the demand curve upwards while the projected decrease in yields because of climate change is not offset by the increase in water supply. For the 2030 water supply scenarios A2 and B1, the projection is increase water supply above the 55.5 BCM and this plays a role in increase in agricultural production although the climate change projection indicates decrease in yields. The increased water supply shows a reduction in extraction of ground water. Agricultural land use increases and as does employment or labor hours. There is a decrease in water reuse and increase in water value because of the increase population. I observe an increase in the flow of water to the sea which is good environmentally to reduce sea water intrusion into the delta and estuaries (maintain salt balance), and also for in stream activities like fishing. The climate change impacts for 2030 are higher for the pessimistic scenarios in magnitude compared to the optimistic scenarios and the protection for land inundation plays a role in mitigating the effects of climate change.

Focusing on the 2030 pessimistic scenario without protection from sea level rise and A2 water supply scenario compared to 2030 pessimistic scenarios without climate change; there is a 6% and 4% reduction in crop production and livestock respectively. The consumer price increases by 14% and coupled with an increase in demand due to population rise leads to a reduction in welfare of 1.5%. Imports increase by 21% and exports decrease by 7% to account for the increases in demand and decrease in supply of agricultural commodities. Agricultural land use increases by 3%, agricultural water use by 10%, and agricultural employment increase by 4%. Water value increase by 6% and water reuse decreases.

Climate Change 2060 Baseline Scenario

As in the last section, for the 2060 climate change scenarios, eight scenarios are presented as illustrated in table 18. The water releases at the HAD follow the A2 and B1 scenarios as discussed in the 2030 climate change scenarios. Sea level rise is analyzed for both the optimistic and pessimistic scenarios. The results are percentage change to the baseline 2060 scenarios without climate change.

Looking at the pessimistic scenarios for 2060 with climate change in comparison to the baseline 2060 pessimistic scenario without climate change; results indicate a loss in welfare and this is because of the increase in consumer prices for agricultural produce and increased demand due to population growth (table 20). Although there is a reduction in productivity, imports increase to offset this decrease in supply. The model has a constraint on the import and export amount to be less than five times that of 2007. There is also a reduction in the land used for agriculture, unemployment also increases (agricultural labor hours decrease), and so does water use in agriculture. This can be explained as a reaction to increased demand for land by population increase and projected reduction in water supply in 2060 below the 55.5 BCM baseline. This decrease in unemployment is a concern for the year 2060 given the population increases at that time. Also the decrease in water releases at the HAD leads to an increase in water value, water reuse and exploitation of groundwater. The increase in groundwater is to account for the decrease in supply of surface water due to climate change. There is a reduction in water flow to the sea which may have environmental repercussions given that the reduced water flow reduces water quality[15] and affects ecology at the point where Nile River enters the Mediterranean Sea. Focusing on the 2060 pessimistic

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[15] Reduction in water flow in the Nile to mix with agricultural and municipal and industrial drainage water.

scenario without protection from land inundation with A2 water supply projection, and compare it to 2060 scenarios without climate change; there is a 28% and 23% reduction in crop yields and livestock; consumer prices increase by 39%. This leads to a decrease in welfare of 6%, agricultural water use decreases by 15%, agricultural land use decreases by 11%, unemployment by 13%, and water reuse also increase by 9%.

Water Conservation/Adaptation Strategies to Climate Change

In this section, I focus on the ability of Egypt to adapt to climate change projected effects by improving on water supply efficiency. I explore adaptation strategies of improving irrigation water conveyance, field irrigation efficiency, distribution efficiency of public water system (PWS) network, and technological yield progress.

Distribution Efficiency of Public Water System (PWS) Network

This scenario is used to study the implications of an improvement in the distribution efficiency of PWS network (municipal and industrial) would have on the economy. Distribution efficiency (D_e) for municipal and industrial water is given $D_e = {}^{V_C}/_{V_D}$

where V_c is total water volume paid for by a consumer (M&I) and V_D is the total volume of water distributed in BCM/year (water demanded for M&I use). The current distribution efficiency for the regions was at 50% implying that a 50% of the water distributed to municipal and industrial sector is lost through network leakage or economic inefficiency. There is a predicted 60% and 75% increase for the rational pessimistic and optimistic case in distributional efficiency respectively, for the year 2017. I used the optimistic scenario of 75% for the years 2030 and 2060 and compare this to the baseline scenario for 2030 and 2060 at 50% distribution efficiency in the PWS network.

The results of these scenarios are compared to the climate change scenario without improvement in PWS (table 21). The results indicate that there is an increase in welfare and decrease in agricultural GDP. This is because of a relative decrease in prices of agricultural commodities compared to scenarios without increased PWS efficiency. Because of this improvement, there is a decrease in ground water use and surface water use and increased allocation to agricultural water use. The value of water decreases for 2030 scenarios because increased efficiency in PWS increases the supply to M&I and also increases supply to agricultural sector. Agricultural land use increases and so does the employment in the agricultural sector compared to climate change scenario without PWS improvement. As in tables 21 and 22, the impact of improvement in PWS is similar for 2030 and 2060 but the order of magnitude is higher for 2060 because in 2060 there is a projected decline in water releases at the HAD below the 55.5 BCM compared to a projected increase in 2030. Therefore, an improvement in water supply for 2060 has a higher impact on the agricultural sector because of scarce water supply and increase in demand for agricultural produce with population growth. Protection from sea level rise is beneficial to the agricultural sector than scenarios without protection. Looking at implications on welfare, an improvement of PWS to 75% will increase welfare in 2030 by 0.3% and by 1.4% for 2060 for the pessimistic scenarios compared to the scenario without this implementation.

Field Irrigation Efficiency

Field irrigation efficiency (I_e) plays a major role in efficient crop water consumptive use and water use management. Field irrigation efficiency is the ratio of irrigation water consumed by the crop (C_I) to the water delivered from surface of groundwater sources for the farm (W_D); $I_e \; {}^{C_I}\!/_{W_D}$. Field irrigation efficiency represents efficiency in agricultural water application which depends on irrigation method and farmer ability and willingness to adopt the technology or method. Drip irrigation has been shown to have high irrigation efficiency. In this scenario, I assume that by 2030 and 2060, the irrigation efficiency for all regions had increased to 90%.

The results for the improvement in field irrigation efficiency are compared to the climate change scenario without this improvement. The results in tables 23 for 2030 indicate that: welfare increases because amount of water used for agriculture increases and production of agricultural commodities increase so prices decrease. There is an increase in ground water use for this scenario. Because of increase in irrigation efficiency, there is a reduction in ground water recharge which may decrease groundwater availability. Also there is a reduction in the flow of water to the sea which may affect the environment in terms of in stream activities and salt water intrusion. Using 2030 as the pessimistic scenario, there is an increase in welfare of 0.6% because of improvement in irrigation efficiency as an adaptation strategy. The 2060 results are similar to 2030 but because of decrease in water supply due to climate change and population growth, water use differs. Agricultural water use for both the optimistic and pessimistic scenarios for 2030 increase, flow to sea decreases while employment increases in the agricultural sector with improvement in irrigation efficiency. Considering the pessimistic scenario with protection from land inundation, there is an increase in welfare of 0.7% due to the improvement in irrigation efficiency for 2060 compared to the scenario without this improvement.

Conveyance Efficiency

The amount of water diverted from the Nile that reaches the farm depends on conveyance efficiency. In Egypt, conveyance losses between main canals and outlets were estimated to be 25% and 11% between outlets and fields (Tiwar and Dinar 2002). The MWRI in Egypt estimates that the conveyance efficiency was 70% and 80% for old and new lands respectively with an estimated loss of 10 BCM in network loss (CEDARE 2011). The conveyance efficiency accounts for the efficiency of water transportation in the canals. The conveyance efficiency may depend on the condition of the canals, length, and the soil type. In this case, I assume that by 2030 and 2060, the conveyance efficiency in each region is improved to 95% or the current level of Toshka Valley region in 2010. This is to assess how the improvement in conveyance efficiency will have on the climate change impacts. I then compare that with the baseline scenario for 2030 and 2060 with climate change to see the changes (tables 25 and 26). In this scenario, one need to know that conveyance efficiency reduces loss of water to drainage systems and groundwater recharge which may reduce groundwater withdrawals and agricultural water reuse or drainage into the Nile.

The results of this scenario for both 2030 and 2060 scenarios indicate an increase in welfare which is due to an increase in agricultural production and reduction in prices.

Also, agricultural water use as well as employment increase in the agricultural sector. There is a decrease in the flow of water to the sea which has an impact on in stream water use and reduction in water to the sea may lead to salt water intrusion to the mainland. The welfare effect of improvement in conveyance efficiency compared to climate change pessimistic scenario with A2 water release projection indicates a 0.7% and 0.8% increase in welfare in 2030 and 2060. The magnitude is higher in 2060 because of projected water scarcity due to climate change and this improvement in management increase supply of water which is essential to the agricultural sector.

Technological Yield Progress Scenarios (slower and faster)

In this scenario, I compare the impact of change in technological yield progress from the "slower" to the "faster" yield progress. As the scenario is presented in table 3, I present the results of the faster yield progress under climate change in comparison to the climate change scenario with a slower yield progress. Keep in mind that not all crops are included (table 3). The results presented focuses on the pessimistic scenarios with no protection against sea level rise and the water supply is B2 scenario. The results for the 2030 and 2060 pessimistic scenarios show an increase in welfare of 0.15% and 0.14%. This is due to the increase in productivity in agricultural products. There is also a decrease in imports for both cases and increase in labor hours. Agricultural water use increase for the 2030 scenarios but decreases for the 2060 scenario. This can be explained by the water supply between the two climate change projections where 2030 is projected to have more water than 2060 compared to the baseline of 55.5BCM. This result indicates that an increase in yield progress has a positive impact to reduce the impact of climate change.

Water Allocation Scenarios due to Conflict/Water Wars

Water conflict/wars in the Nile basin have the potential to reduce the current annual allocation to Egypt of 55.5 BCM. Increasing population in the upstream countries and potential developments along the White and Blue Nile have a potential to decrease he flow that reaches Lake Nasser. In this section, I look at the impact of changes in water allocation and assess the sensitivity of Egyptian Agricultural water sector to changes on water supply. I look at plausible water changes and allocations that have been proposed in economic literature. In this section I assess three scenarios; an allocation of 51.7 BCM of water that is the allocation that was agreed upon by Nile experts for Egypt, Dale Whittington, John Waterbury, and Elizabeth McClelland; a 50.3 BCM water allocation that is optimal for a social planner (Nigatu and Dinar 2011). I also assess an allocation of 45 BCM and 60 BCM to assess changes in water supply sensitivity without climate change. The results are reported in table 27.

The results indicate that under the allocation that is proposed by experts (51.5 BCM), there will be at least a 0.5% and 0.8% reduction in welfare for 2030 and 2060 (Table 27). The increase in demand for agricultural products and reduced water supply increase prices and reduces the welfare of the population. An increase in water supply by 8% (60 BCM) increases welfare by 0.4 and 0.8% for the pessimistic scenarios of 2030 and 2060 respectively. These results are compared to the baseline scenarios with 55.5BCM. Also a decrease in water supply by 9% reduces welfare for the pessimistic scenarios by 0.7% and 0.6% for 2030 and 2060. These results indicate that a reduction in water supply has a big impact on the agricultural. Reduction in water supply with projected increase in population makes Egypt agricultural sector to be vulnerable to climate change projections. Therefore the Egyptian government should strive to maintain the status quo water allocation 55.5 BCM.

Discussion and Conclusions

In this paper, I assess the impact of climate change on the Egyptian agricultural sector under alternative population, water use and crop yield assumptions. The results without climate change are used to assess the impact that climate change will have on the sector. Comparing the results without climate change to the baseline scenarios with climate change for 2030 and 2060 indicate that agricultural production decreases. For the pessimistic scenarios, the increase in population shifts the demand curve upwards and this leads to increase in price and reduction in welfare. Prices are shown to rise mainly in the pessimistic scenarios relative to the optimistic scenarios. The projected increase in water supply due to climate change in 2030 increase agricultural land use and reduces the price of water but does not make up for the projected decrease in yields due to climate change. The effect of climate change is higher on agricultural yields than livestock and the impact is higher for 2060 than 2030. Water reuse is observed to increase in 2060 relative to 2030. The agricultural water use increases while groundwater reuse decreases in 2030 (vice versa for 2060). This is due to the projected increase in water supply in 2030 and a decrease in water supply in 2060 due to climate change.

The climate change results indicate that negative impact of climate change grows over time being higher in 2060 relative to 2030. Water flow to the sea decreases in 2060 (increases in 2030) and this has environmental implications. Ecologist have indicates that reduced water flow to the sea leads to sea water intrusion; affects the ecosystem at the point where the Nile enters the Mediterranean Sea. This reduced water flow in the Nile affects water quality along the River to the sea. The water conflict scenario that assess projected water change due to different water allocations to Egypt in the Nile basin, indicate that Egypt is very sensitive to changes in water supply. Reduction in water supply due to conflict without considering climate change has a higher impact than increase in water supply of the same proportion. A reduction in water supply by 9% for the pessimistic scenario indicates a decrease in welfare of 0.7% and 1.2% for 2030 and 2060 in comparison to the baseline water allocation of 55.5BCM. Protection from land inundation minimizes the impact of climate change compared to scenario without protection from land inundation.

Using water conservation and adaptation strategies under climate change; improving conveyance and irrigation efficiency, more efficient water conveyance, technological yield progress; lead to an increase in welfare, reduction in water value and water reuse and decrease ground water use. This implies that if Egypt were to invest in water management strategies and improve on yield progress, the impacts of climate change on Egypt may be reduced.

Egypt is sensitive to changes in water releases. Even without climate change, Egypt would benefit from controlling its population growth because of the limited water resources. Egypt also has an unfavorable population to land ratio and this affects production and supply of agricultural commodities. Also, if Egyptian population growth was closer to the optimistic projection, the impact of climate change in 2030 will be lowered. Egypt would be less sensitive if it could develop a more efficient irrigation and conveyance techniques, improve and increase waste water treatment and access to sewage systems to cope with increasing water demand. Population increase and consumer prices affect demand for products and water use. The 2060 climate change projection of water releases at HAD need to look at ways to increase water supply. These strategies may include desalination and exploration of ground water in deep aquifers to increase supply. On the other hand, there is a need for an efficient water market in Egypt. The MWRI might consider modifying the water rights and implementing pricing of municipal and agricultural water or educate farmers about the need to implement and apply better strategies.

The results imply that climate change will have an impact on Egypt. Farmers have been observed to be willing to change irrigation system and other strategies to cope with climate change. Therefore, Egypt might explore expanded reuse of return flow from irrigation fields, increase in water use efficiency and added conjunctive use of ground water. On the water conflict within the Nile Basin, Egypt would loses substantially under a reduction in water share. If Egypt were to divert from this allocation then it would imply that is would mainly depend on imports or exporting virtual water[16] . Water reuse is a strategy that may help to cope with water scarcity and supply in that situation as might tech progress and improvement in PWS and drainage water management. Population growth rate reduction also has major implications.

Further research is warranted both theoretical and modeling of the implication of climate change in Egypt. There is need to improve on the model to assess distributional aspects of climate change to rural populations, incorporating improved data sets more reflective of the effect of climate change on the full set of crop yields, crop water use, livestock performance and M&I water demand. Research could also look into the role of an Egyptian or multi country water market.

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[16] Virtual water is the amount of water embedded in food and other products needed for its production. Production of one kilogram of wheat needs about 1000 liters of water while meant needs five to ten times more.

CHAPTER III

TRANSMISSION OF WORLD COFFEE PRICES TO SMALL SCALE GROWERS: THE CASE OF UGANDA ROBUSTA COFFEE

Introduction

Uganda is a land locked country with a population of approximately 36 million people in 2012. The GDP decomposition by sector is estimated at 22% agriculture, 26% for industry, and 52% for the service sector (CIA 2012). The agricultural sector accounts for about 82% of the total labor force (CIA 2012). Uganda depends on agriculture for most of its export earnings; coffee is Uganda's main export crop. In 2008, coffee accounted for 26% of the total value of exports with the main destination being the European Union (EU) (Keane et al. 2010). In the same year (2008), Ugandaiexported 4.4% of the 46 million coffee bags, making it the seventh largest exporter to the EU[17] (ECF 2008). Uganda is the second biggest coffee producer by volume and the largest producer of Robusta coffee in Africa. These Robusta coffee trees are indigenous to Uganda in the Great Lakes region and small holder farmers grow coffee as a cash crop intercropped mainly with bananas (USDA 2010).

Coffee is very important to the Ugandan economy. In 2000, it was estimated that there were 500,000 small holdings of coffee with a quarter of the population depending on coffee earnings (Sayer 2002). The number of Ugandans living in poverty has declined from 56.4% in 1992/1993 to 31.1% which is part of achieving the Millennium

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[17] In 2011, European Union countries were the main destination of Uganda's coffee accounting for 73 % of total exports followed by Sudan at 19 percent (USDA 2011).

Development Goal 1 (Eradicate extreme poverty and hunger) (Keane et al. 2010). Coffee production and prices have played an important role in this poverty reduction. After liberalization of the coffee market in 1991, the period of 1993 to 1997 saw a strong decline in the gini coefficient in Uganda and was linked to the performance of the coffee sector (Keane et al. 2010). To maintain this strong performance after the emergence of the coffee wilt disease in 2000, the government donated 9.6 billion Uganda Shillings to the Poverty Action Unit to support coffee development (Sayer 2002).

Price volatility on the world market has also affected the livelihood of the Ugandan coffee farmers. This price volatility has been mainly caused by supply side fluctuations (structural change, climatic conditions and frost and drought) while the demand side has been relatively stable with global annual increases of 1 to 2% in recent decades (ECF 2006).

The coffee market in Uganda had a structural change in 1990/1 in that it was liberalized from a dual local marketing system comprising of both private and cooperative marketing channel. Structural changes in the coffee market meant new and emerging paradigms were likely to dictate coffee prices, which may have permanent effects on the livelihoods of millions who depend on coffee for their income (Lewin et al. 2004). The cooperative channel has since disappeared and the vast majority of coffee is now marketed through private traders. Before trade liberalization, cooperatives and local traders used to purchase coffee from the growers at a fixed priceThus, local players were shielded from international price fluctuations. Post trade liberalization, however, farmers' face more of the risk associated with price volatility in the world market as there is a greater transmission of coffee prices in the international market to the local prices in Uganda (Newman 2009). The Uganda Coffee Development Authority (UCDA) was established in 1991 to promote and manage development of the coffee industry through research and improved marketing (UCDA 2007). Even though UCDA has no authority to set prices, it does provide price information about the indicator coffee price (world coffee Spot price). The indicator coffee price is an overall benchmark for the price of green coffee of all major origins and types. It is considered to be the best available measure of price of green coffee transactions on a global basis (International Coffee Organization (ICO) 2011). Due to the reduction in radio programs on coffee that informed farmers about prevailing prices, farmers that live 10 kilometers away from the mill are unaware of the going coffee price and may sell their coffee at the farm gate for half the current price (Sayer 2002). The UCDA states that before liberalization, the World Bank paid for radio programs about coffee but now the World Bank cannot afford such programs (Sayer 2002).

The market oriented liberalization movement in the 1980s was to resolve market failure and ‘get prices right’. Increased competition in the buyer market meant that farmers would command a higher price in proportion to the world price (Sayer 2002). However, this new market structural change has left the less informed and poorly capitalized market actors at a disadvantage (Complete Project 2001). The majority of Ugandan farmers are small holders. Research been shown that the even with a rise in export price, the farm gate price does not rise proportionally (Fafchamps and Hill 2008). Also Fafchamps and Hill (2005) indicate that farmers who are able to transport their coffee to the market where they can obtain information about the prevailing price got a higher price than farmers that sold at the farm gate. This price volatility and fall in prices affect the Uganda economy where farmers rely on income to pay child school fees and employment of labor. These fall in prices lead to low employment levels, low school enrollment and increased rural to urban migration (Sayer 2002). A common complaint for farmers has been the lack of information about the markets (Complete Project 2001; Sayer 2002). Liberalization led to concentration of few export firms and this has limited the flow of information from the market to the producers. Even though UCDA offers annual market information in reports, there has been limited information available to farmers and small traders on how markets work, day to day price fluctuations, and relationship between prices and quantities (Complete Project 2001).

Objective

The objective of this essay is to study the how price information is transmitted to the Ugandan coffee growers and the markets that play an important role in these dynamics. Coffee farmers principally rely on the indicator price to bargain for a fair price (Krivonos 2004). Per the first theorem of welfare, competitive market equilibrium ensures an efficient allocation of resources. If farmers are able to obtain better information about the market place, this will improve market efficiency. Using monthly price series on price received by growers (farm gate price), retail prices in Europe (Belgium and Spain), futures prices, and composite indicator price, this study will examine how prices are transmitted to the Robusta coffee growers. This analysis contributes to literature on coffee price transmissions in that the study price transmission to Uganda coffee grower while incorporating both retail prices to the destination countries and futures prices over the post liberalization period. The focus of this study is mainly on the process through which prices are transmitted to Ugandan growers and the markets that play an important role in these dynamics.

Overview of Uganda Coffee

The majority of Uganda producers sell their coffee as Kiboko (dry green cherries beans) (Fafchamps 2003). After the coffee has been milled and transported to Kampala, it is sorted by exporters. Broken beans, withered beans, stones and husks are discarded and the coffee beans are graded for export to coffee houses in Europe. Kiboko coffee is typically sold by farmers to small traders who tour the countryside on bicycles or motorcycles. The “ddebe” boys act as aggregators either for bigger independent traders or for exporters and their agents. The top destination of Uganda’s coffee is the European Union along with Switzerland which account for 80% of its coffee exports, followed by Sudan with 15% (Fafchamps and Hill 2005; Baffes 2006).

Reforms in the industry began in 1990 and in January 1991, the Coffee Marketing Board was split into two parts (1) the Coffee Marketing Board Ltd. which does the trading and processing, and (2) the Uganda Coffee Development Authority (UCDA) responsible with monitoring and regulating the industry (Akiyama 2001; Baffes 2006). Before the split up, farmers missed the benefits of high coffee prices in 1970s and early 1980s. This was due to the fact that grower prices were determined by cooperatives. The growers received about 15 percent of the export price (Bibangambah 1995). The purchase price of coffee was set annually in June and would remain in place for the rest of the season. Several studies have indicated that the reform has been successful because the share of the export price that producers received increased from less than 30% before the reform to 70 % but have not investigated the price transmissions to Ugandan growers (Akiyama 2001; Krinovos 2004; Bibangambah 1995). The sale of coffee has always been a practice of selling f.o.t. (free on truck) Kampala therefore requiring international sellers to undertake the risk of transporting coffee to Mombasa or Kampala.

The UCDA is currently in charge of all the regulatory aspects of the industry including monitoring quality, enforcing regulations, collecting and disseminating statistics and undertaking promotional efforts. One of the responsibilities of UDCA is to provide farmers with market information on coffee prices and sales. The indicator price is easily observable as they are published daily and can be used as a basis for negotiating local prices. The International Coffee Organization (ICO) provides indicator price indices and by construction, it forms a representative benchmark for the major varieties of green coffee. The indicator price is computed based on four spot indices for coffee: Columbian Mild Arabicas ("Columbian"); Brazilian and other Natural Arabicas ("Brazilian"); Other Mild Arabicas ("Mild"); and Robusta (ICO 2011; Krinovos 2004). The indicator composite price is an aggregate average of the four spot price indices (ICO 2011). An issue has been transmission of these indicator prices to the producers/growers.

Limitations to price transmissions in the agricultural commodities include: arbitrage conditions, market efficiency, and transaction costs (Sexton et al. 1991). The arbitrage condition implies that traders will, if markets are efficient, seek arbitrage opportunities until prices are equalized between markets. The market condition moving this process can also be referred to as the law of one price. This implies that prices might differ from equilibrium levels in the short run while producers seek higher price opportunities. A market is inefficient if there exists arbitrage opportunities that are not being exploited. Also, it could imply the existence of infrastructural obstacles to trade. It does not mean that equilibrium levels are not achieved, but that it might take longer to get there. Arbitrage conditions can therefore be used to achieve market efficiency. Finally, transaction costs cover transport costs from one market to the other, costs related to obtaining information about markets, search costs related to finding suitable buyers or sellers, and other costs due to, say, credit market imperfection. These costs hinder arbitrage opportunities and prohibit full price transmission (Sexton et al. 1991;Kaspersen and Foyn 2010)

Brief Literature Review

Vector autoregression analysis has been used in the literature to investigate price dynamics and transmission (Sims 1980, Johansen 1995). Kaspersen and Foyn (2010) use a dynamic vector autoregression (VAR) to investigate price transmission for agricultural commodities between the world markets and the Ugandan market in an attempt to determine the impact of the world market prices on prices in Uganda. They find that price of Robusta coffee in Uganda during the 1990s was strongly connected to world prices. Price transmissions from the world market were only evident in the case of booming prices of an export commodity, but otherwise agricultural commodity markets were poorly linked. Fafchamps et al. (2003) examined the transmission of international coffee prices through the domestic value chain, with coffee growers, traders, and exporters as the main market participants. They found that fluctuations in international prices were not fully reflected in the prices received by the coffee farmers. In a later paper, Fafchamps and Hill (2005) attribute the lack of transmission (of international price fluctuations to the prices paid to the coffee growers) to the fact that growers generally sell at the farm gate rather than at the nearest market where they could have obtained better information on the prevailing market prices. Selling at the farm gate is attributed to high transaction costs (transportation and search costs) and quantity produced by the farmer. Large scale producers tended to sell their coffee at the market (Fafchamps and Hill 2005). Krivonos (2004) evaluates the impact of the coffee sector reforms during the late 1980s and early 1990s on the coffee growers in 20 coffee exporting countries including Uganda. Using an error correction model, the study reveals that short run transmissions of price signals from world market to producers has improved such that domestic prices adjust faster today to the world price fluctuations than they did prior to the reforms. Also, in Uganda, after the reform the degree of adjustment after six months increased significantly. They also confirmed the hypothesis that the share of producer price in world coffee price had increased after the liberalization. Their paper neglects markets in destination/importing countries.

An issue in literature has been the extent to which futures markets especially for coffee are efficient. Tests on efficiency of futures markets for coffee earlier concluded that coffee markets in New York were efficient but rejected the hypothesis for the

London futures market (Rajaraman 1986). Tests for cointergration and for the Law of One Price for coffee futures traded in New York and London were conducted by Karbuz and Jumah (1995). Evidence for cointegration is found between New York and London but the hypothesis of the Law of One Price is rejected. Milas et al. (2004) estimate linear and non-linear error correction models for spot prices of four coffee types: unwashed Arabica, Columbia Milds, Other Milds and Robusta. Their results indicate that when prices are too high, they move to the equilibrium more slowly than when they are too low. This may be due to the fact that in the short run, it is easier for countries to restrict the supply of coffee in order to raise prices, rather than increase supply and reduce the prices. Evidence indicates that adjustment is faster when deviations from the equilibrium level are greater. Their results also suggest that non-linear error correction models offer very weak evidence of improved forecasting performance relative to the random walk model.

Fry et al. (2010) examine the interdependence of coffee spot and futures markets. Results indicate that spot and futures markets are interdependent; futures markets for coffee appear to be increasingly driven by risk associated with underlying spot markets. They examine how speculative behavior in futures markets affects the associated spot markets. They find a statistically significant negative effect of future markets on the volatility of spot prices, with the exception of the Robusta spot market that was influenced by the futures market to a large extent. Mohan and Love (2004) test London and New York coffee futures markets for efficiency and find that coffee futures markets are inefficient in terms of predicting subsequent spot prices. Their results indicate that futures prices appear to adapt to prevailing spot prices. Fafchamps and Hill (2005) examine the transmission of international coffee prices through the domestic value chain in Uganda using survey data on producers, traders, and exporters. They find that producer price fluctuations are inconsistent with constant transaction costs. The findings suggest that small itinerant traders initiate coffee trading in response to an export price increase, probably taking advantage of farmers' ignorance of price movements. Almost 85% of the coffee growers sell coffee directly at the farm gate, therefore, the fluctuations in international prices are not fully reflected in the prices received by the coffee farmer. Thus the farmers often get a price lower than they could have received had they gone to the market (Fafchamps et al. 2003). In Uganda, over half the farmers interviewed (55%) reported that they did not receive price information from anyone other than the buyers of their coffee. Only a minority of farmers travel to the market to sell their coffee and acquire up-to-date information about the coffee prices. Studies have found that fluctuations in the international coffee prices are reflected relatively rapidly in domestic prices paid by exporters and large traders. However fluctuations in the international prices are not fully reflected in the farm gate prices (Fafchamps and Hill 2005).

The data used in this study reflects the post liberalization period and focuses on the process through which prices are transmitted to Uganda coffee growers.

Model

Time series of commodity prices is generally characterized by time dependence and non stationary behavior. In economic data analysis, there is a belief that price data is non stationary over time implying that they do not return to the mean (Samuel 1971). It is expected that different prices within a single market will move together in that one market will not be independent of price movements in other markets. These price series are expected to be cointegrated. Since I expect existence of cointegration, the data generating process of P_t can be modeled as an error correction model (ECM) with k-1 lags.

(9) $\Delta P_t = \Pi P_{t-1} + \sum_{i=1}^{k-1} \Gamma_i \Delta P_{t-i} + \mu + e_t \; where \; e_t \sim Niid(0, \Sigma)$

and Δ is the difference operator $(\Delta P_t = P_t - P_{t-i})$, P_t is a $n \times 1$ vector of price series at time $t = 1, \ldots \ldots, T$, Γ_i is a $(n \times n)$ matrix of coefficients relating price changes lagged i periods to current change in prices, Π is a $(n \times n)$ matrix of coefficients relating the relationship between levels of different prices which may be reduced in rank $(r < n)$ such that $\Pi = \alpha\beta'$. The lag of the series (P_{t-1}) is the so called error correction term. Π may be a $(n \times n + 1)$ matrix depending on whether the constant is inside or outside the cointegrating space. Therefore, the matrix $\beta'$is a $(r \times n)$ matrix showing the long run relationship between level price series and α is a $(n \times r)$ matrix of adjustment parameters showing how each price series adjusts to perturbations in each of the long run relationships.

The number of cointegrating vectors is obtained from the rank of Π and the trace test on the eigen values of Π is used to determine r (Juselius 2006). Contemporaneous information flows are studied using the estimated innovations $\hat{e}$ through the covariance matrix $\hat{\Sigma}$ in the greedy equivalent search (GES) algorithm (Juselius 2006; Sprites et al. 2000). Exclusion test and weak exogeneity tests are preformed within the cointegration space. To provide a competitive dynamic relationship analysis among prices in the coffee market, innovation accounting techniques of forecast error variance decomposition and impulse response functions are presented.

To examine the long run structure of alternative price series, one needs to determine the rank Π of the cointegrating vector. There are a number of procedures that can be used to determine the lag order and cointegration rank. One procedure is the two step method where the appropriate lag length is determined first, then the cointegrating rank. The optimal lag length (k) is obtained from loss criteria matrix of the VAR representation. The two loss methods used are the Hannan and Quinn (HQ) and Schwarz loss criterion (SIC) (Hannan and Quinn 1979). The second step is to determine the number of cointegrating vectors using the trace test (Johansen 1988). The hypothesis tested for the rank of the cointegrating vector is that $H(r){:}\,\Pi = \alpha\beta'$. The trace test tests the null hypothesis using the test statistics of eigen values. Rejecting the null hypothesis indicates that the rank of the cointegraing vector is greater than r. Once the rank is determined then the Π, matrix can be given as a product of α and β matrices, $\Pi = \alpha\beta'$ (Johansen 1991; Park 2005). The second procedure would be to simultaneously determine the lag length and rank of the cointegration vector (Phillips 1996; Wang and

Bessler 2005). The two step method is used in this study[18]. To determine whether some markets can be excluded in the long run relations, the exclusion test is performed. The null hypothesis is that the markets are not in the cointegrating space and this likelihood ratio test is distributed chi squared with degrees of freedom equal to the rank of the cointegrating vector (Hansen and Juselius 1995). The weak exogeneity test on α is used to determine whether a price series are responsive in the short run to deviations from long run relationships (Johansen 1991). The null hypothesis is that the markets do not respond to perturbations in the cointegration space.

Parameters from the ECM can be used to provide information on the short and long run relationships between prices. Innovation accounting can be used to identify short run and interdependencies among prices (Swanson and Granger 1997; Sims 1980). There is a problem of orthogonalization of residuals from the ECM and the impact of innovation accounting that has not been fully addressed in studies employing VECM and VARs. But, innovation accounting requires a causal assumption on contemporaneous correlations (Haigh et al. 2004; Vitale and Bessler 2006; Costa et al. 2011). Most of the earlier research employing VARs used the Choleski factorization, but recent applications have applied structural factorization suggested by Bernanke (1986). This is mainly because the Choleski factorization is recursive and may not reflect the true patterns in real world. The 'Bernanke ordering' requires writing of the innovation vector (e_t) from the estimated VAR model a $e_t = A^{-1}V_t$ where for this study where six price series will

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[18] From previous studies, two step or one step, have yielded similar results (Costa et al. 2011; Yang and Bessler 2008)

be examined, A is a (6×6) matrix and V_t is a (6×1) vector of orthogonal shocks[19]. Swanson and Granger (1997) and Bessler and Kergan (2002) suggest the use of directed acyclic graphs (DAGs) that uses the covariance matrix of the error term to obtain the contemporaneous ordering. I use the GES algorithm in this study to obtain the ordering following earlier studies (Haigh et al. 2004; Vitale and Bessler 2006; Mjelde and Bessler 2009).

DAGs are used to obtain data based evidence on ordering in contemporaneous time t, under the assumption that the information set on $\sum_t$ is causally sufficient. DAGs are extensively used in fields of artificial intelligence and computer science (Pearl, 2000). A directed graph is a picture representing causal flows among variables that has been suggested by prior study or related theory (Pearl 1986; Pearl 1995). The analysis is based on causal chains $(A \to C \to B)$, causal forks $(A \leftarrow C \to B)$, and causal inverted fork $(A \to C \leftarrow B)$ that imply particular correlation and partial correlation structures between and among measures A, B, and C (Geiger et al. 1990). Sprite et al. (2000) and Pearl (2000) present two algorithms with similar structure and output for inference on DAGs from observational data; the PC algorithm which exploits the fundamental difference between inverted forks and IC algorithm that exploits differences between chains or forks with observational data. The GES algorithm is a two phase algorithm that searches over equivalent classes of DAGs starting from a DAG representation with no edges. A DAG with no edges implies that all variables are independent of all other variables. The algorithm proceeds stepwise examining more complicated

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[19] Also the Bernanke ordering enables one to move away from imposed constraints of recursive causal ordering embedded in the Choleski factorization.

representations, scoring each one using a Bayesian Scoring criterion. Edges are added/or edge direction reversed one at a time in a systematic search across classes of equivalent DAGs if the Bayesian posterior score is imposed. The first stage ends when a local maximum of the Bayesian score is discovered such that no further edge additions or reversal improve the score. From this final first stage DAG, the second stage commences to delete edges and reverse directions, again moving in that direction which increases the score the most, if such action result in an improvement in the Bayesian posterior score. The algorithm, terminates if no further deletions or reversals improve the score (Sprite et al. 2000; Pearl 2002; Chickering 2003). The GES is implemented in Tetrad IV to obtain the DAGs (Tetrad IV 2004).

Data and Descriptive Statistics

The data used in this study are monthly price series in United States cents per pound for coffee from 1994 to 2010. The price series include: retail prices of Spain and Belgium (principal destinations of Ugandan coffee); New York and London futures prices; indicator price (world spot price); and price paid to Ugandan growers. The Uganda growers' price is the average price paid to growers at farm gate level. This data was obtained from the International Coffee Organization.

Time plots are constructed for the natural logarithms of price series (figure 10) and table 28 contains descriptive statistics. The data in the figure 10 indicates an increase in growers' price from 1994 to 1998. The high prices in 1995 and 1998 were caused by a frost in Brazil and an El Niño event; which lead to a reduction in supply on the world market. This decline in supply caused a competitive increase in investment in coffee producing countries leading to oversupply in later years.[20] Vietnam's increase in production and the lowering of coffee standards at the London market were given as reasons for this over supply (Abell 2004). In 2002-2003, there was an oversupply of coffee that led to a 73% decline in the price of coffee compared to the 1995 peak price. The stock of coffee[21] in the 2002/2003 was 160 million bags (one bag =60 kilo grams), but the world coffee consumption was 107 million bags.

As shown in table 28, the means and variances in the prices over the period 1991 to 2010. The mean is higher for the retail prices but also the variation is lower in these markets. The gap between retail and grower prices represents cost such as transportation, marketing and distribution, retail margin and taxes. The variation is larger in the growers' price series, followed by the London futures price and the indicator price.

Results

Both the Augmented Dickey-Fuller (Dickey and Fuller 1981) and Phillips-Perron (Phillips and Perron 1988) test are used to test for non stationarity of coffee price series. The null hypothesis for both tests is that the series are non stationary. Results in table 29 indicates that I fail to reject the null hypothesis at 5% in levels[22] but are stationary in first difference making each series integrated of order (1) one (denoted as I(1)).

Metric considered are Schwarz-loss (SL) and Hannan and Quinn (Φ) measure on lag length (k) of a levels VAR (Table 30):

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[20] Coffee plantations take about 4 years to reach full production

[21] Total availability in a given year = opening stock + production

[22] Since the t-statistics are smaller than the critical value of 2.88 for all prices in levels, there exists a unit root and the cointegration analysis maybe appropriate

(10) $SL = log(|\Sigma|) + (6k + 2n + 1) + (logT)/T$

(11) $\Phi = log(|\Sigma|) + (2.00)(6k + 2n + 1) \times \big(log(logT)\big)/T$

where Σ is the error covariance matrix estimated with $(6k + 11 + 1)$ (the "11" represents 11 seasonal dummy variables, the "1" represents the constant) regressors in each equation, T is the total number of observations on each series, the symbol "||" denotes the determinant operator, and the log is the natural logarithm. I select the model that minimizes the loss matrix. The asterisk (*) indicated the minimum score in each column. Table 30 summarizes the fit on 12 different models. Half the models incorporate 11 seasonal variables with the others having no seasonal variables. Both groups incorporate a constant with zero through six lags. The model with the lower Schwarz and Hannan and Quinn metric is chosen. The optimal lag length chosen is one (1) with no seasonal dummy variables.

The model considered a VAR of logarithms of six coffee prices with lags of 0 through 6; each equation in the panel has either no or 11 seasonal variables. Table 31 shows the trace test results of the number of cointegrating vectors. The number of cointegrating vectors is tested using the trace test with the constant inside and outside the cointegrating space. The results in the column with asterisk (*) indicate the test with a constant within the cointegrating space. The critical value (C (5%)) are taken from Table B.2 (inside) and Table B.3 (outside) in Hansen and Juselius (1995). Column labeled "D" gives the decision to reject (R) or fail to reject (F) at a 5% level of significance, the null hypothesis of the number of cointegration vectors$(r = 0, r \leq 1, \dots . r \leq 5)$. In accordance with Johansen 1992, we stop testing at the first F (Failure to reject) starting at the top and moving left to right. We fail to reject the hypothesis that we have one or fewer cointegrating vectors with constant in the cointegrating space. Cointegrating vectors might also arise not because of a linear combination of two or more series, but because one or more series are stationary. Results presented in table 32 suggest that none of the six coffee price series are stationary. This indicates that I have one cointegrating vector with a constant in the cointegrating space. The Ljung-Box Q test on innovations with 49 degrees of freedom is rejected at P-value of >0.01 indicating that there is no serous autocorrelation problem with the residuals. Given one cointegrating vector tests on whether a given price series is within the cointegration space are given in table 33. The null hypothesis that the price series is not in the cointegration space is rejected for Uganda grower price, Belgium retail price and London Futures Price. This indicates that the Uganda growers' price, Belgium retail price and London futures price are in the longrun (cointegrating) relations. An additional chi squared test is used to determine whether the price series are weakly exogenous. The null hypothesis is that the series in the left column (table 34) does not respond to perturbations in the cointegration space. I reject the null hypothesis for Uganda growers' price ("Decision" column) but fail to reject the hypothesis on other price series. The results suggest that the long run relationships captured in the data are of interest to price discovery in the coffee growers' prices in subsequent periods but not for price discovery in subsequent periods for Belgium and Spain retail prices, New York and London futures, and the indicator price. This also indicates that there is strong evidence that Uganda growers' price respond to perturbations embedded in the data.

The causal structure of GES is applied to the contemporaneous innovations and the results are presented in figure 11. A causal chain from IDP→LFR→UGR is determined as shown in figure 11. The contemporaneous flow of information is from the indicator price to the London futures to the Ugandan growers. There is also a flow of information from Belgium Spain retail market.

The dynamic response of each price to a one time shock in each price series is presented in figure 12. The column heading indicate the onetime series shock and the row heading the response of that series. The results are indicative of the response of the relative markets to a onetime shock rather than absolute metrics. These responses are normalized in that each response is divided by standard error of the innovation of that series which allows the series responses to be compared. They show the log of Uganda growers' prices respond positively to positive shocks in log of indicator price and Belgium retail price. There is a negative response of the log of Uganda growers' price to a onetime shock in London and New York futures price and the Spain retail price.

A more precise measure of the price dynamics among series is given by the Forecast Error Variance Decomposition (FEVD). The FEVD is used to show what proportion of the variance of the forecast error in predicting a given price series is due to a structural shock. The decomposition sections give the percentage of uncertainty in each price series that is accounted for by previous price information of that series and the other five price series. The uncertainty in current Uganda growers price are from information discovered in own price (67%), indicator price (22%) and London futures price (11%). Moving six months ahead, the variance in the growers price is accounted for by indicator price, own price and London futures price in rank order. At 12 months, the variance in price is accounted for by indicator price (48%) own price (21%), London future price (12%), Spanish retail price (8%) and New York futures (8%) (Table 35).

Discussion and Conclusions

In the study, I examine the process through which price information is transmitted to Uganda growers. It examines the influence of the composite indicator price, the futures markets and retail markets for Uganda's Robusta coffee. This study contributes to literature on coffee price transmissions in that it examines the price transmission to Uganda coffee grower while incorporating both retail prices to the destination countries and futures prices over the post liberalization period. The vector error correction model is used to investigate the relationships and innovation accounting to present the results. The test for weak exogeneity is significant for Uganda grower's price indicating that long run relationships captured in the data are of interest to price discovery in the coffee growers' price for subsequent periods. The directed acyclic graphs show a causal flow of information from the indicator price to the London future and then to the Uganda growers. This result is consistent with earlier studies in literature that indicate that futures coffee prices for Robusta tend to follow the spot (indicator) prices.

The DAGs also indicate a flow of information from the Belgium to Spain price. One explanation is that Belgium is a larger importer of coffee than Spain and also a second largest re-exporter of coffee in Europe to Germany. This share in the market may make it influential in price discovery. The impulse response functions indicate that a one-time only shock in the indicator price has a positive impact on the Uganda growers' price; while it has a one-time only shock in the futures prices has a negative effect on the Uganda growers' price. A better measure of dynamic interactions in coffee prices is the forecast error variance decomposition. At a time horizon of zero (0), the uncertainty in the Uganda growers price is explained by own price (67%), indicator price (22%) and London Futures price (11%). Moving ahead to 12 month time horizon, the variance in Uganda growers' price can be explained by indicator price (48%), own price (21%), London futures (12%), Spain retail price (8%) and New York future price (8%) in rank order. This result shows that moving ahead the variance in price of Uganda is also affected by the retail price in destination country. This result indicates that one may have to explore the final destination of the coffee to critically study price transmissions. The results indicate that the indicator price is at the center of price information flow for the Uganda growers' price and futures price. As for the retail markets, they tend to influence each other.

The results show that although indicator price plays a major role in flow of information to Uganda coffee growers, the London futures prices and retail prices also account for the variation in growers' prices. Economic literature indicates that access to market information about prices to farmer's and small traders may improve their decision making in obtaining a better price for the coffee (Fafchamps and Hill 2005). With better information, farmers may have a choice to either sell at the prevailing market price or hold on to their produce in anticipation for a future price. In addition, knowledge of both the London futures market and the prices at the destination market are important for a complete analysis of the variations in the price that Ugandan growers will receive. Policy makers may also consider improving accessibility to the market place by developing infrastructure such as roads that enable farmers to transport produce to the market or mills. Uganda Coffee Development Authority could aid in this effort by providing programs on radio, television or phone that disseminate market information and can educate farmers about the market place. Knowledge of the market may lead to increase in quality of coffee production and participation in futures markets. Also government might encourage creation of cooperatives by farmers so as to improve marketing and price negotiation ability plus be able to participate in futures market and increase access to export market so at to increase the share they receive of the market price.

This study contributes to literature on price transmissions of coffee to Robusta growers but there are some limitations. On the other hand, this study was limited on the data of the price at which the exporters sell green coffee in Uganda and the freight costs of Uganda coffee to the destination countries in the EU. Incorporating this data and the other Robusta markets like Vietnam may produce more comprehensive results.

CHAPTER IV

ANALYSIS OF THE COST OF MALARIA IN CHILDREN AND USE OF INSECTICIDE-TREATED BEDNETS IN AFRICA

Introduction

Malaria has had a huge impact on the health and economic wellbeing of people on the African continent. For children under the age of five this disease accounts for almost one death in ten worldwide and nearly one death in five in sub-Saharan Africa (UNICEF, 2009). The World Health Organization (WHO) estimated that there are at least 300 million acute cases of malaria each year resulting in nearly a million deaths. Approximately 90% of these deaths occur in sub-Saharan Africa with the largest percentage affected group (80%) being children under five. Malaria infections also cause child mortality during pregnancy and cause about 20% reductions in birth weight with about 50 million pregnant women exposed each year (UNICEF 2009; RBM 2010; UNICEF 2007).

Various studies have demonstrated a significant relationship between gross domestic product (GDP) per capita and the burden of malaria (Gallup and Sachs 2001; McCarthy et al. 2000). Gallup and Sachs (2001) estimated that countries with a high malaria burden grew at 1.3% per year less than countries without a large burden. They also estimated that the annual GDP cost of malaria in Africa is more than US$12 billion, and asserted that malaria can be controlled for a fraction of this cost. A combination of factors such as poverty, low government expenditures on health, and limited access to medical care facilities have increased malaria incidence and death rates for children under five years of age. Furthermore, UNICEF (2009) estimates that only 59% of African children would receive treatment at health facilities, while 41% would receive treatment at home (UNICEF 2009). High malaria burdens seriously slow down the accumulation of human capital and poverty reduction efforts. That situation has motivated one of the Millennium Development Goals (MDG). In particular, MDG 6 and 4 are to "Combat HIV/AIDS, Malaria and other diseases" and "Reduce Child Mortality" respectively (UNDP 2010).

A number of strategies have been proposed to address reduction in malaria burden, but insecticide treated nets (ITNs) are considered the most cost effective available strategy to control malaria (Breman, Alilio, and Mills 2004). ITN usage has been shown to reduce mortality rates in children under five by 20% in malaria endemic areas (Lengeler 2004). There are also external benefits to society that ITNs use provides. One of the positive externalities of nets is that with high ITNs usage, many mosquitoes that transmit this disease are killed and infection rates decline even among those not using nets (Hawley et al. 2003). However, even though international funding has increased, only an estimated 35% of African at risk children are sleeping under a mosquito net as of 2010 (WHO 2010). Furthermore, the global economic slowdown has led to stagnation in international funding.

Objective

I estimate the cost of malaria in children under five years and further examines the benefits of use of ITNs as a preventative strategy in 18 African economies. The cost estimates focuses on: loss in productivity by an informal caregiver;[23] cost of inpatient; and outpatient treatment, and the burden of malaria utilizing the disability adjusted life years (DALY) measure (Murray and Lopez 1996). The benefits of ITN use are calculated using the results from the econometric estimation. This study contributes to an earlier work by Egbendewe-Mondzozo et al. (2011) in that the later focuses on the total malaria cases while this study focuses on malaria in children under 5 years since they are the most affected and vulnerable population. It also explores the use of nets from a government program policy perspective unlike studies that have explored provision of nets as a subsidized good or through a micro loan program.

Background on Malaria Control and Strategies in Africa

Available Malaria Control Strategies and Treatment

There is an increase in advocacy for control and preventative strategies for malaria. The most common advocated control and treatment strategies in Africa are the use of ITN and anti-malarial drugs. There has been a substantial increase in the use of ITNs with 19 sub-Saharan African countries experiencing a threefold increase in ITN use since 2000 (WHO 2010). Some areas are experiencing a reduction in the number of cases and deaths and are expecting a higher decline in the future (UNICEF 2009). Manufacturers estimated that more than 150 million ITNs were delivered to African countries during 2004-2008. This implies that malaria endemic African countries have received enough nets to cover 40% of their at risk population. In mid-2010, it was estimated that at least 40% of all households in sub-Saharan Africa owned at least one ITN and at least 35% of

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[23] A person staying home or at the hospital to take care of sick child that is not a health worker

all children slept under ITNs. Although international funding had increased over the decade to its highest level of US$1.8 billion in 2010, it has stagnated. Even though this increase in amount was substantial, it falls short of the estimated US$6 billion that was needed and required for malaria control. This creates a concern about future progress in distribution of ITNs estimated at 289 million distributed by 2010 (WHO 2010). Net obsolescence may also be a concern. Economists have been opposed to provision of free goods in a competitive market with the fear that the poor may resale the good for cash (Hoffman et al. 2009). However, Hoffman et al. (2009) using incentive compatible experimental design found that despite the inability to pay market price for the long lasting insecticide treated mosquito nets (LLIN[24]s), very few households were willing to sell nets they have received for free. Williams et al. (2009) studied the impact of malaria in a small rural village in Uganda and the implementation of subsidized ITNs. They argue that nets must be provided with effective education to be successful.

Studies have indicated that there are high malaria treatment costs incurred by households (Chima et al. 2003; Russell 2003). Williams et al. (2009) in a study in Uganda found high costs from the disease with households spending an average of US$6.22 per month on treatment amounts to 34% of average family income. In sub Saharan Africa, households could spend between US$2 to US$25 on anti-malaria treatment and between US$0.20 to US$15 on prevention each month (Chima et al. 2003; Goodman et al. 2000; Mills 1998; Russell 2003). The development of resistance to

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[24] A long-lasting insecticide-treated net (LLIN) is an ITN designed to remain effective for multiple years without retreatment.

commonly used anti-malaria drugs has led to the adoption of arthemisinin-based combination treatment, which is highly effective, but more costly (Bosman and Mends 2007). A committee on the economics of anti-malaria drugs argued that without heavy subsidies treatment coverage would remain unacceptably low (Arrow et al. 2004; Enserink 2007). There is also an increase in advocacy for control and preventative strategies. Goodman et al. (2009) and Shillcutt et al. (2009) analyzed the consumer market for malaria treatment in Tanzania finding that the high prices of antimalarial drugs were a factor in poor quality treatment. They argued that policy makers might try to lower retail prices by decreasing concentration among antimalarial providers and recommending retail price levels.

Impact of Malaria on African Economies

A number of studies have examined the cost of malaria burden (Gallup and Sachs 2001; McCarthy et al. 2000; World Bank 2007). Since malaria strikes during the rainy/harvest season when farmer productivity should to be at its highest, the disease can harm agricultural production, food security, and household income (Egar 2001). Alaba and Olumuyiwa (2006) studied days lost to Malaria in Nigeria finding 16 days of work was the average number lost per episode. Giraldin et al. (2004) found in Cote D'Ivore that comparing infected to uninfected farmers that the infected ones produced about half the yield and received half the income because loosing between 0 to 26 days of work in 10 months (World Bank 2007). Recent studies (Alaba and Olumuyiwa 2006; Asenso-Okyere et al. 2011) have reported an increase in days of absence which may be due to treatments loosing effectiveness due to increasing drug resistance. It is anticipated that repeated bouts of malaria in agrarian households would cause a decline in farm output, farm income, cause food insecurity and increase in poverty (ESPD 2006).

When children get sick, they need an informal care giver to stay home and take care of them which leads lost wages and productivity. Women play a critical role in African agricultural production; therefore, taking time off to take care of sick adults and especially children constitutes a threat to food production on the African continent in terms of lost labor to for agricultural production (Todaro 2000). For instance, Leightin and Foster (1993) observed that the total value of production loss in Kenya due to malaria morbidity was higher in the agricultural sector than the industrial and service sectors. A high malaria burden is also likely to increase labor turnover resulting in increased training costs, hiring less experienced workers and lower profitability. Also, a high malaria incidence on a particular area may undermine tourism opportunities, deter otherwise profitable foreign and domestic investment and prevent the use of land and other natural resources (WHO 2011).

Data

The observations units: number of cases and deaths for children under five, bednet usage and socioeconomic variables; in this case are for 18 African countries (denoted as i), across 9 years (denoted as t) (2001 to 2009) or 162 total observations. The eighteen African countries are: Benin, Burkina Faso, Burundi, Central African Republic, Eritrea, Gabon, Ghana, Guinea Bissau, Mali, Madagascar, Rwanda, Sao Tome and Principle, Senegal, Sierra Leone, Tanzania, Togo, Zambia. The variables and source are listed in the Table 36.

The map in figure 13 presents the countries under study and the U5MD and GDP per capita. The summary statistics for these variables are also in table 37. Average GDP per capita for the countries is highest in Gabon (US$6262) and lowest in Burundi (US$114). The highest annual average mortality rates (U5MD) occur in Sao Tome and Principe at 62.7 followed by Burkina Faso at 36 deaths per 100,000 of population. Eritrea has the lowest reported mortality rate at 0.35 deaths per 100,000 of population. The average reported malaria cases for children under five per 1,000 of population is highest in Zambia at 184 cases followed by Gambia at 150 cases and Burundi with 99 malaria cases.

Cost Estimation

The total cost of malaria includes the lost productivity by an informal caregiver for monitoring a sick child, the cost of treatment, and the burden of the malaria disease calculated as the disability adjusted life year (DALY) that represents indirect long term costs (Murray and Lopez 1996). Roll Back Malaria (RBM) (2010) estimates that on average each child in Africa has between 1.6 to 5.6 episodes of malaria fever each year. Malaria has an impact on human resources beyond the loss in earnings. It also alters social development, school absenteeism, permanent neurological damage, lost income due to malaria treatment, lower household agricultural production and associated income, plus reduced food security (Egar 2001). In this section, we focus on direct and indirect costs of malaria disease due to child sickness and propose country level investment in ITNs per live birth as an option to mitigate the impact of malaria.

Cost of Lost Productivity by Caregiver

Morbidity is a highly studied topic in the economic cost of illness (Tarricone 2006). The economic valuation of morbidity includes the opportunity cost of lost wages and the cost of treatment. For children under five, the forgone wages are applied instead to a caregiver (parents or relatives) that spend days without work to care for the sick child. This cost has been estimated by multiplying the work time lost by the care giver by the wage rate (Attanayeke et al. 2000). Studies have suggested that the time lost by the caregiver for a malaria case ranges from one to seven days (Tren 2001; Ettling et al. 1994; Shepard et al. 1991; Kumar et al. 2007). The cost of lost productivity (CLP) per country can be calculated as $CLP_{it} = 4 * U5MC_{it} * DGDP_{it}$ where (DGDP) is the calculated GDP per capita per day which represents an average wage rate and U5MC is the number of malaria case for children under five. The four days of lost time due to case of illness is used because it is a median estimate (Trent 2001). In this estimation, I use four as the median and seven days as the maximum loss days per episode. Using the average GDP per capita, I calculate the loss in GDP per capita per day by dividing it by 365 days in a year. The average annual lost productivity by a caregiver due to morbidity is given Table 38. The results indicate that the annual loss in GDP by caregivers staying at home or in the hospital to take care of sick children is highest in Zambia at US$16 million and US$ 28 million for four days and seven days. The average annual loss in GDP across the 18 countries ranges from US$2.5 to US$4.3 million.

Cost of Treatment

The cost of treating malaria in Africa fall into two main categories: inpatient cost and outpatient costs (Ayieko et al. 2009; Ettling et al. 1994; Kirigia et al. 1998). Studies have shown that many children still receive treatment for malaria at home. In this estimation to obtain the cost of treatment, we assume that all the average annual cases are either outpatient treatment or inpatient treatment cases and we estimate the cost accordingly. The outpatient cost, therefore, refers to treatment of mild cases using available drugs without hospitalization for more than one day while in patient treatment requires hospitalization for several days. We use the mean outpatient treatment of US$2.08 and inpatient treatment cost of US$67 in 2004 US dollars which is a combination of reported drug prices by WHO and the transportation cost to reach the demand point (Egbendewe-Mondzozo et al. 2011). The average treatment costs are presented in table 39. Zambia has the highest average treatment cost and Eritrea has the lowest. This is because Zambia has the highest cases and Eritrea the lowest malaria cases.

Lost Productive Life Years due to Malaria

Malaria has an indirect cost in terms of productivity loss that is estimated in this section. The estimate used for productivity loss follows the Global Burden of Disease (GBD) comprehensive estimate of the mortality and morbidity of Murray and Lopez, (1996). GBD quantifies the burden of premature mortality and disability for a disease using a summary measure of population health which is the DALY. One DALY means that 1 year lost of health life on account of a disease is a common currency of disease morbidity and mortality expressed in time (Murray and Lopez 1997; WHO 2004). To estimate the years of productive life lost, the DALY is used as specified below. To place an economic value on the DALYs, one can use the GDP per capita (Spadling-Fecher and Moodley 2002). The equation used for DALY is

(12) $DALY = YLL + YLD$

where: YLL= years of life lost due to premature mortality
YLD= years lived with disability.

YLL corresponds to the number of deaths multiplied by the standard remaining life expectancy at the time the death occurs. $YLL = NxL$ where N is the number of mortality and L is the standard life expectancy minus the age of death in years (Murray and Lopez 1996). To estimate the YLD, the number of disability cases is multiplied by the average duration of the disease and a weighting factor that reflects the severity of the disease on a scale from 0 (perfect health) to 1 (dead). The formula is as follows; $YLD = IxDWxL$ where YLD is the years lived with disability, I is the number of incident cases, DW is the disability weight, and L is the average duration of disability (years).

The DALY was estimated using the GBD template with the age weight and discounting. The disability weight used for malaria is 0.2 and the length of episodes was 4 days (Murray and Lopez 1996; Tren 2001). A discount rate of 3%[25] is used for the DALY calculations. Discounting enables the reflection of social preference of a health year now rather than in the future. These results indicate that the average annual

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[25] Weitzman (2001) conducted a survey of 2160 top economists on the appropriate social discount rate to be used. He found that 3% would be an appropriate discount rate to be used for the near future. See Weitzman,M. 2001. Gamma Discounting. *American Economic Review* 90(1):260-271

DALYs lost across these 18 countries is 29976 life years (table 40). Burkina Faso and Zambia have the largest losses while Eritrea and Sao Tome and Principe have the lowest.

To quantify the lost DALY in monetary terms, I draw from a recent study by Brent (2011). A number of studies (Mueller et al. 2008; Becker-Dreps et al. 2009; Rushby and Hanson 2001) have estimated the value of a DALY saved using the cost effectiveness approach, but Brent (2011) uses the Cost Benefit Analysis (CBA) approach to determine whether intervention was socially worthwhile. Brent (2011) estimates that the price of a DALY saved from any disease is US $6300 in 2005 purchasing power parity (ppp) dollars while that for the three disease covered by the Global Fund to Fight AIDS, TB and malaria (GFATM) was US$ 10,800. We use these prices to estimate the total loss due to malaria from our DALY calculation in dollar terms (table 40). The annual average discounted loss for these 18 countries over the 9 year period is in the range of US$0.2 to 0.3 billion per year. Zambia and Burkina Faso experience the highest losses while Eritrea and Sao Tome and Principle have the lowest losses in terms of DALYs.

Exploring Investing in Bednets as a Control Strategy

In the estimation, I assess the average per capita expenditure in ITNs as a control strategy if the government were to purchase a net for each live birth. I use the crude birth rates as the demand for mosquito nets to protect these infants in a given year implying full coverage for infants less than five years. To make sure that only the at-risk population (AR) is accounted for, I use the percentage of population at risk of malaria (PAR), multiply it by the crude birth rates (CBR) to determine our at risk population

(AR=PAR*CBR). The cost of the mosquito nets used is \$1.7 for an ITN to a high retail price of \$5 for a LLIN (RMB 2010; Teklehaimanot et al. 2007; Curtis et al. 2003). I report the results in the table 41 as average per capita expenditure on ITN and LLIN, by dividing the total cost of ITN by the total population. The annual costs of nets that would be spent in total are presented in Table 41 and are reflective of the country's crude birth rate when multiplied by population. The range of per capita cost of purchasing an insecticidal treated mosquito net is from \$0.05 to \$0.08 for ITNs and \$0.14 to \$0.23 for LLIN.

Econometric Analysis of the Impact of Mosquito Nets

To analyze the relationship between malaria mortality, malaria cases, GDP, income inequality, health expenditure, adult literacy, and the use of ITNs, a panel data econometric technique is used. This procedure estimates the disease effects using the data for each country over multiple time periods. The combination of these two dimensions, time series and cross section, enhances the quality of the resultant estimation in ways that would be impossible using only one dimension (Gujarati 2003). The general panel data analysis specification is as follows;

(13) $Y_{it} = \alpha + X_{it}'\beta + C_{it} + \mu_{it}$

where Y_{it} is the dependent variable for country i in time period t, $X^{'}_{it}$ is a K-dimensional row vector of explanatory variables excluding the constant, α is the intercept, β is a K dimensional column vector of parameters, C_{it} is a country specific effect and μ_{it} is an idiosyncratic error term. In this estimation Y_{it} will be malaria mortality for children under 5 in a country (i) at time t and the X'_{it} are vectors of associated socioeconomic variables.

Model Specification

To show the impact of ITNs on malaria mortality, one has to first assess the relationship between ITNs and malaria cases then analyze how mortality is affected by changes in cases. The impact of use of bednets on malaria mortality is through malaria cases. If malaria cases are reduced, there is high likelihood of decreasing the number of deaths from malaria ceteris paribus.

The first model is an extension of work by Egbendewe-Mondzozo et al. (2011). Earlier work by Egbendewe-Mondzozo et al. (2011) focused on total malaria cases, but in this work I specifically look at children under five years. The relationship between malaria cases in children under five years and use of ITNs is examined using the equation 14 below.

$$U5MC_{it} = \alpha_i + \beta_1 GDP_{it} + \beta_2 ITN_{it} + \beta_3 hexp_{it} + \beta_4 GINI_{it} + \beta_5 Ill_{it} + \beta_6 POP_{it} + C_{it} + \mu_{it} \quad (14)$$

where for country *i* at time period *t*:

U5MD = Malaria Mortality rate for Children Under five
POP = Population
ILL = Adult literacy rate
GDP = GDP per capita in US$
ITN = Proportion of Households in the country owning at least one ITN
HEXP = Health Expenditure per Capita in US $
GINI = income inequality index
C= Country specific effect
μ= idiosyncratic error term

The second model is derived from the 'health production function' approach (Filmer and Pritchett 1999) that assumes that health outcomes depend on a countries income and social capabilities. The model is specified in equation 15 below.

(15) $U5MD_{it} = \alpha_i + \beta_1 GDP_{it} + \beta_2 U5MC_{it} + C_{it} + \mu_{it}$

where for country i at time period t:
U5MD = Malaria Mortality rate for Children Under five
U5MC = Number of Under 5 Malaria Cases
GDP = GDP per capita in US$
C= Country specific effect
μ= idiosyncratic error term

When using a panel data analysis, both fixed and random effects specifications can be used. To ascertain which model is the more consistent and efficient, the Hausman specification test is used (Hausman 1978; Hausman and Taylor 1981). A random effects model was the first one tested. Given that the independence between individual unobserved effects cannot be determined a priori, the Hausman specification test was used to test whether to retain that model. The random effects approach to estimating β exploits the correlation in the composite error in equation (13), $V_{it} = C_{it} + \mu_{it}$. The approach puts C_{it} in the error term assuming that C_{it} is orthogonal to X_{it} and uses a Generalized Least Squares (GLS) estimator to take into account serial correlation in the composite error V_{it}.

In instances where C_{it} can be correlated with X_{it} as in equation (7), the assumption is violated and the fixed effects estimator is more appropriate to use and more robust than the random effects model (Wooldridge 2011). The Hausman specification test could not reject the null hypothesis, suggesting that the random effects assumption is not violated. Thus this model is used. The results of the estimations are transformed into elasticities[26] for easier comparisons following earlier studies (Filmer and Prichett 1999; Egbendewe-Mondzozo et al. 2011; Bell, 2005; Naude 2004;Tol 2008).

In estimating the relationship between malaria cases and ITN use in the first model, the random effects model is used. The failure to reject the null hypothesis for the Hausman specification test indicates that this is the appropriate model. Table 42 indicates that there is a significant relationship between malaria case in children under five, ITN use, income inequality, GDP, health expenditure per capita, and population. The results indicate that the average effect of ITN use over U5MC across time and between countries by one unit is a reduction in cases by 0.3. The remaining significant results are interpreted the same way. The elasticity results indicate that a 1% increase in the proportion of household with a net may reduce the number of malaria cases for children under five by 0.17%. A 1% increase in health expenditure per capita (HEXP) and income inequality (GINI) may lead to an increase in U5MC by 0.34% and 1.48% respectively.

In the second model that estimates the relationship between U5MD and U5MC, a fixed effects model is used. The Hausman specification test indicate that the null hypothesis is rejected and the fixed effects model is more efficient model. The results in table 43 indicate that there is a significant relationship between malaria mortality in children under five, malaria cases for children under 5, and GDP per capita. The elasticities indicate that a 1% increase in U5MC leads to a 1.4% increase in malaria

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[26] An elasticity $(\varepsilon)$is the percentage change in the exogenous variable that would lead to a given percentage change in the dependent variable. $\varepsilon_i = \bar{\beta}_i \frac{\bar{X}_i}{\bar{Y}}$.

mortality for children under five. From the estimations above for the data from 2001-2009, WHO data indicates that at least 35% of children slept under a mosquito net. This implied that 65% of the children need a net per live birth for full coverage. In this estimation, we assume that if an entity like a government was to provide a net per live birth at a price of US$ 1.7 for ITN and US$5 for LLINs. The total cost of malaria is the sum of treatment cost, caregiver cost, and DALY.

Using the econometric estimation, I ascertain the number of cases that can be reduced if every child slept under a mosquito net. The WHO indicates that 35% of the children were sleeping under a mosquito net implying that for total coverage, government needs to provide nets for 65% of the remaining children. An investment in a net per live birth for 65% of the children, it would prevent 11.1% of the cases that would have occurred during this period. This also implies that an 11.1% reduction in cases would lead to a 15.84% reduction in deaths. This reduction in cases and deaths by using mosquito net equates to 5.98 cases per 1000 of population and 2.31 deaths per 100,000 of population. From these results, I calculate the cost that would have been prevented (benefits) by investing in ITNs per live birth compared to the cost of government program to provide the nets. The results are in annual averages for the 18 African economies. The reduction in cost of malaria in children under five by using nets as a preventative strategy per 1,000 population was; US$ 10 for outpatient costs, US$322 for inpatient costs, US$ 28 for informal caregiver cost, US$ 3030 for disability adjusted life year cost. The benefits or cost saved had the government invested to provide each child under five with an ITN from Table 44 above was 0.5% for outpatient treatment costs, 11% for inpatient treatment costs, 10.84% for an informal caregiver costs, and 16% in DALYs. The cost of providing the net was US$ 44 and 128 per 1000 population for ITNs and LLINs.

Discussion and Conclusions

The results indicate that there is a significant and negative relationship between use of ITNs and U5MC. Result implies that a 1% increase in household use of ITNs would lead to a 11.1% reduction in U5MC. There is also a significant and positive relationship between U5MD and U5MC but a significant and negative relationship between U5MD and GDP. This implies a reduction of 6 cases per 1000 of population and 2.3 deaths per 100,000 of population. Investing in ITNs or LLINs to provide a net for every child under 5 years would have an annual cost to each government of US$44 and US$128 per 1000 of population for ITNs and LLINs. This would have reduced the cost of malaria by 0.5% for outpatient costs, 11% for inpatient costs, 10.84% for informal caregivers, and 16% for DALYs lost annually for these 18 economies.

The results of this paper are consistent with studies of malaria that conclude that use of ITNs led to a reduction in malaria cases and deaths. Cost estimation indicates that even though malaria has a great impact on these economies; it can be controlled for a fraction of this cost. Government policies towards control and prevention of malaria may be essential. The governments stand to gain substantially if they provide nets for the remaining 65% of children given that the benefits greatly out way the costs.

Further theoretical and empirical modeling of malaria in children is warranted. This study was limited by availability of reliable time series data on socio economic and climatic variables that would have greatly improved on estimation of the first model. In estimation caregiver cost, opportunity cost of leisure could be included to obtain better estimation.

CHAPTER V

CONCLUSIONS, LIMITATIONS AND FURTHER RESEARCH

Conclusions

In order to achieve economic development economies have to address issues that relate to climate change, efficient information flow in the market place, and health care. This dissertation assesses the implications of major forces on African welfare. In particular

- climate change is examined in terms of its implications for the Egyptian Agricultural Sector,
- transmission of world price information to small scale coffee growers is examined in Uganda, and
- the cost of malaria in children and the use of insecticide-treated bednets is examined in Africa.

The following sections present the results and conclusions of these studies (essays).

The results on the implications of climate change on the Egyptian Agricultural sector under alternative population, water use and crop yield assumptions (Essay I) indicate that; climate change will cause damages and these will grow over time; water flow to the sea decreases in 2060 (increases in 2030) and this has environmental implications; Egypt is very sensitive to changes in water supply; and protection from land inundation is beneficial. Using water conservative and adaptation strategies under climate change; improving conveyance and irrigation efficiency, efficient PWS, technological yield progress; indicates that there is an increase in welfare, reduction in water value and water reuse and decrease ground water reuse. This implies that if Egypt were to invest in water management strategies and improve on yield progress, the impacts of climate change on Egypt may be reduced. Even without climate change, Egypt would benefit from controlling its population growth because of the limited water resources. Exploring new sources and technologies like desalination of sea water and exploring groundwater in deep aquifers may be considered. The MWRI may also consider modifying the water rights and pricing of municipal and agricultural water and educate farmers about the need to implement and apply better strategies.

Essay II assesses the transmission of world coffee prices to Robusta coffee growers in Uganda. The results imply that access to market information about prices to farmer’s and small traders may improve their decision making in obtaining a better price for the coffee. With better information, farmers may have a choice to either sell at the prevailing market price or hold on to their produce in anticipation for a future price. In addition, knowledge of both the London futures market and the prices at the destination market are important for a complete analysis of the variations in the price that Ugandan growers will receive. Uganda Coffee Development Authority could aid in this effort by providing programs on radio, television or phone that disseminate market information and can educate farmers about the market place. Knowledge of the market may lead to increase in quality of coffee production and participation in futures markets. Also government might encourage creation of cooperatives by farmers so as to improve marketing and price negotiation ability plus be able to participate in futures market and increase access to export market so at to increase the share they receive of the market price.

In Essay III, I analyze the cost of malaria in children and the use of insecticide-treated bednets check on this word. in Africa. The results indicate that there is a significant and negative relationship between use of insecticide treated nets and malaria cases. Result implies that a 1% increase in use of insecticide treated bednet would lead to a 11.1% reduction in malaria cases among children under five. There is also a significant and positive relationship between U5MD and U5MC but a significant and negative relationship between U5MD and GDP. This implies a reduction of 6 cases per 1000 of population and 2.3 deaths per 100,000 of population. Investing in ITNs or LLINs to provide a net for every child under 5 years would have an annual average cost to each government of US$44 and US$128 per 1000 of population for ITNs and LLINs. This is projected to reduce the cost of malaria by 0.5% for outpatient costs, 11% for inpatient costs, 10.84% for informal caregivers, and 16% for DALYs lost annually for these 18 economies. The results of this paper are consistent with studies of malaria that conclude that use of ITNs led to a reduction in malaria cases and deaths. Cost estimation indicates that even though malaria has a great impact on these economies; it can be controlled for a fraction of this cost. Government policies towards control and prevention of malaria may improve the situation. International aid at this time only provides about 35% coverage of bednets for children. The governments may stand to gain substantially if they provide nets for the remaining 65% of households.

Limitations and Further Research

This section discusses the limitations of each study (essay) and proposes possibilities for further research.

Further research is warranted both theoretical and modeling of the implication of climate change on Egyptian Agricultural sector. There is need to improve on the model to assess distributional aspects of climate change to rural populations, incorporating improved data sets more reflective of the effect of climate change on the full set of crop yields, crop water use, livestock performance and M&I water demand. The costs for the changes in water management strategies where not incorporated into the scenarios and this may improve the study. Research could also look into the role of an Egyptian or multi country water market.

Essay II contributes to literature on price transmissions of coffee to Robusta growers but there are some limitations. On the other hand, this study was limited on the data of the price at which the exporters sell green coffee in Uganda. Incorporating this data and the other Robusta markets like Vietnam may produce more comprehensive results. Exploring the market chain and the industrial organization in buying of coffee from the farmers to the exporter, to the destination country may contribute more to our understanding of price movements to Uganda growers.

Further theoretical and empirical modeling of malaria in children is warranted. This study was limited by availability of reliable time series data on socio economic and climatic variables that would have greatly improved on estimation of the first model. In estimation caregiver cost, opportunity cost of leisure could be included to obtain better estimation. Collection of data at a micro level may produce a more comprehensive data set that will be focused on the research question and improve the study results.

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APPENDIX A

FIGURES

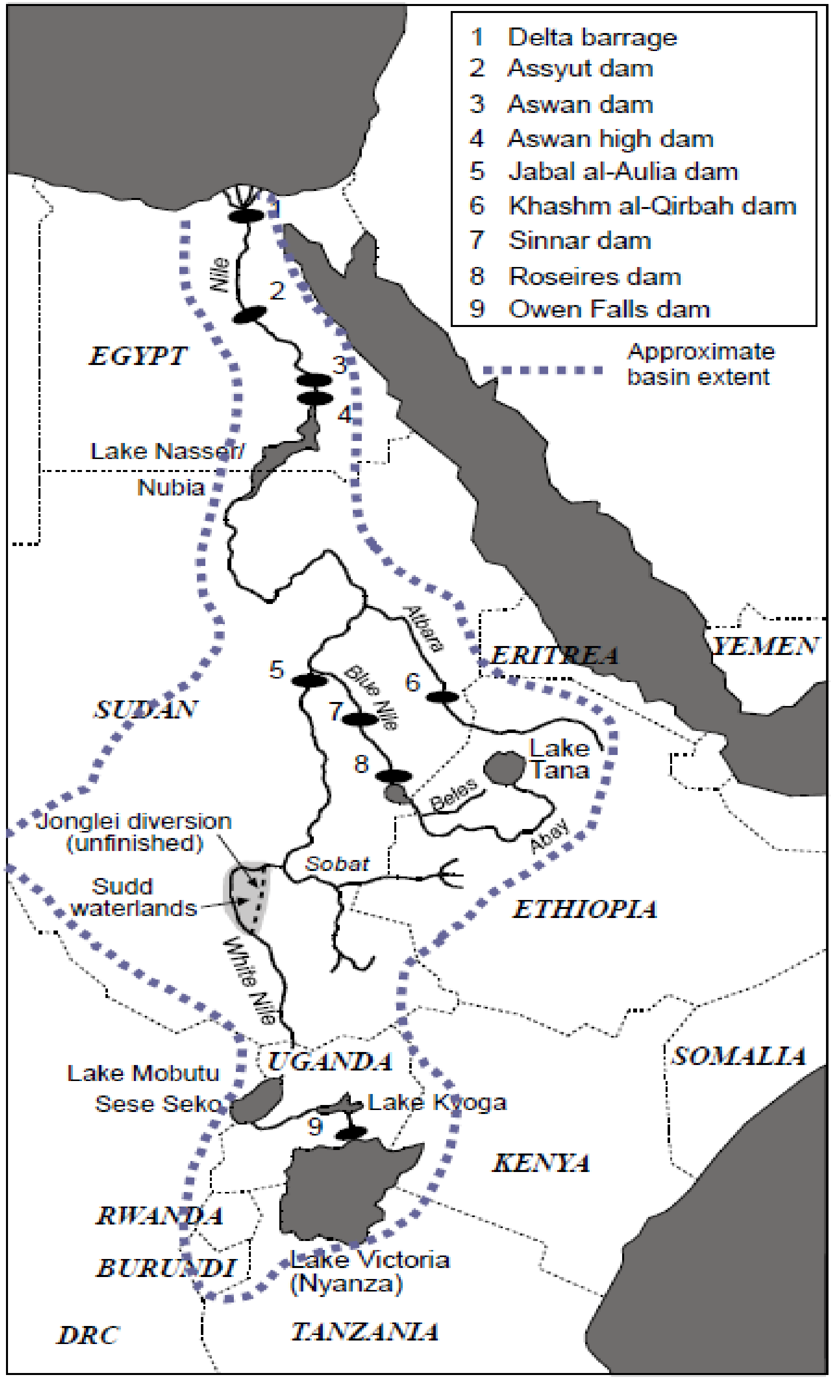

Figure 1. Nile river basin
Source: Nicol, 2003.

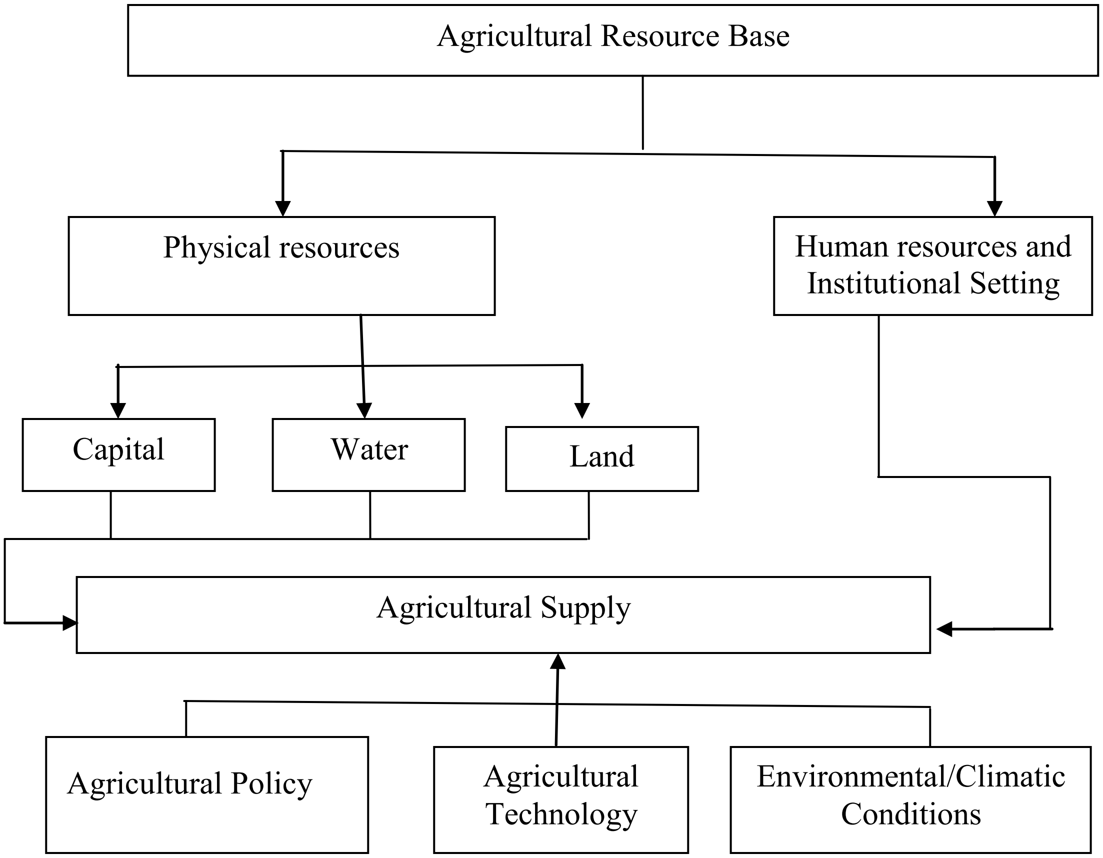

Figure 2. Supply factors for agricultural commodities
Adapted from USAID, 2006.

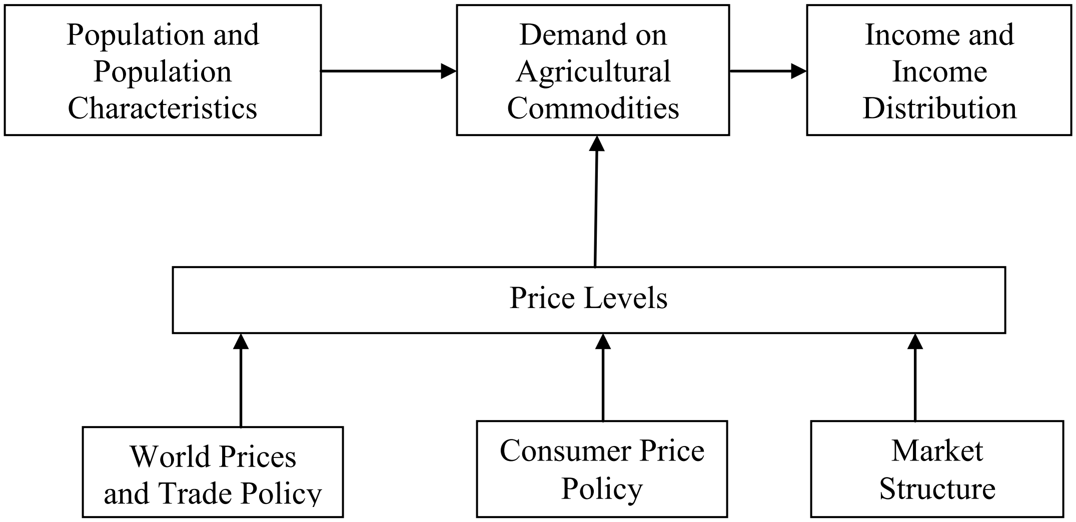

Figure 3. Agricultural commodity demand and influencing factors Adapted from USAID, 2006

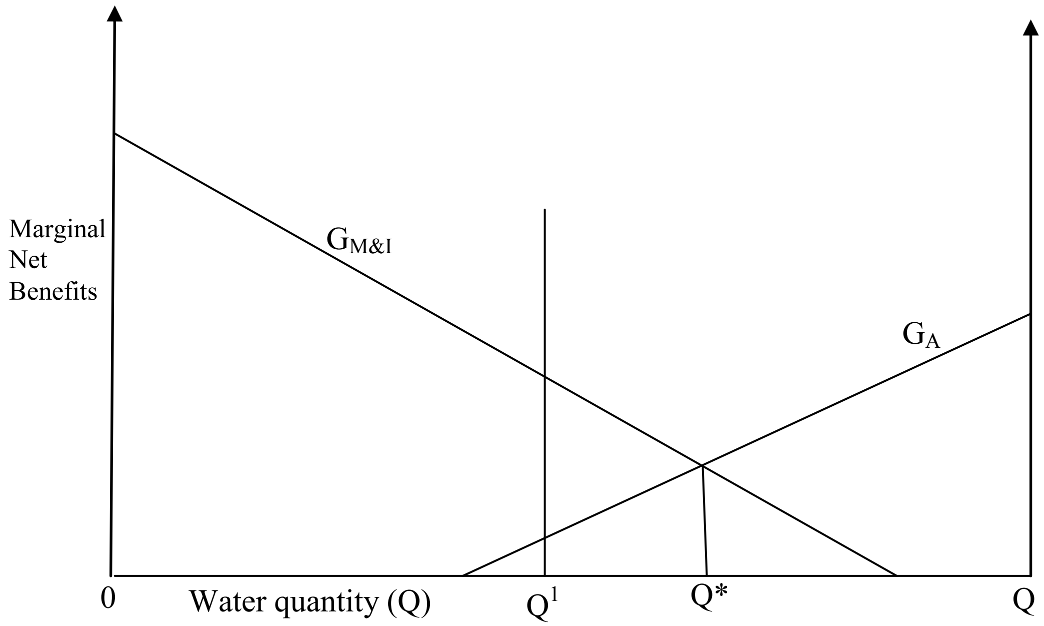

Figure 4. Efficient water allocation between competing users

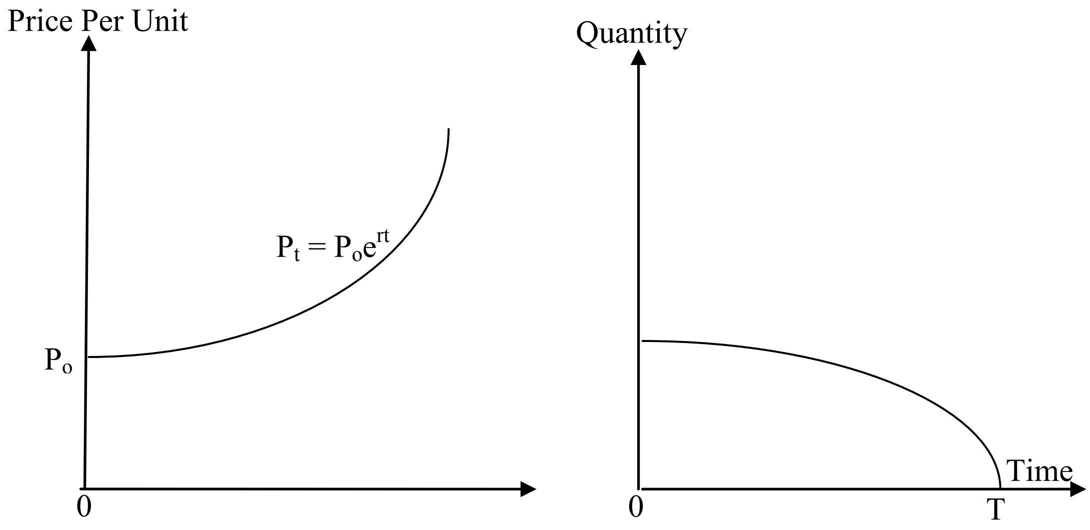

Figure 5. Equilibrium price and quantity path for exploitable water

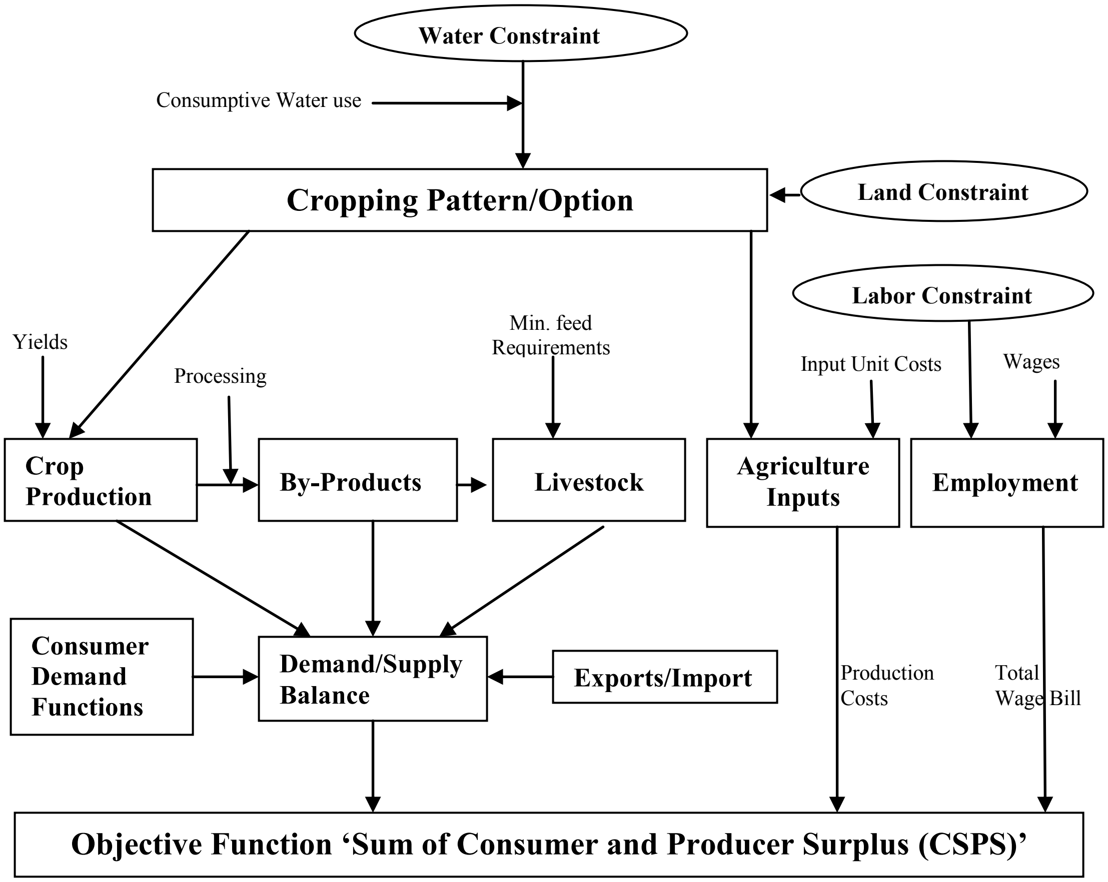

Figure 6. Egyptian agricultural sector model
Adapted from Kieth et al. 1999.

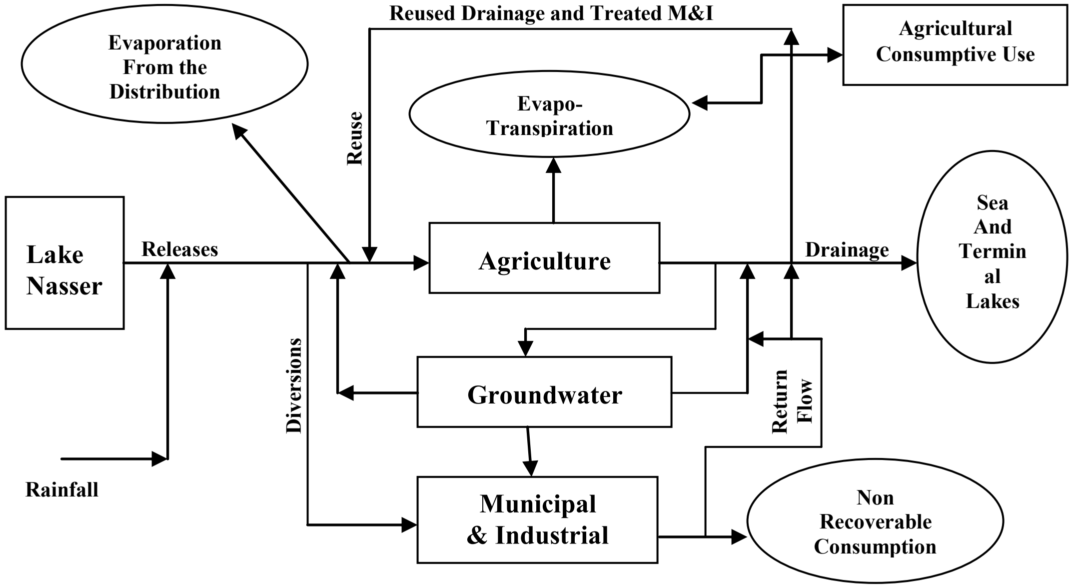

Figure 7. Egypt's national water balance constraint
Adapted from Alnagger, 2003.

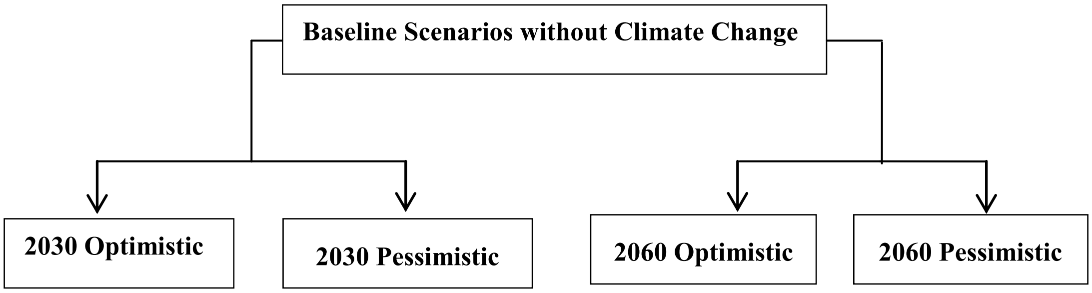

Figure 8. Definition of scenarios run without climate change

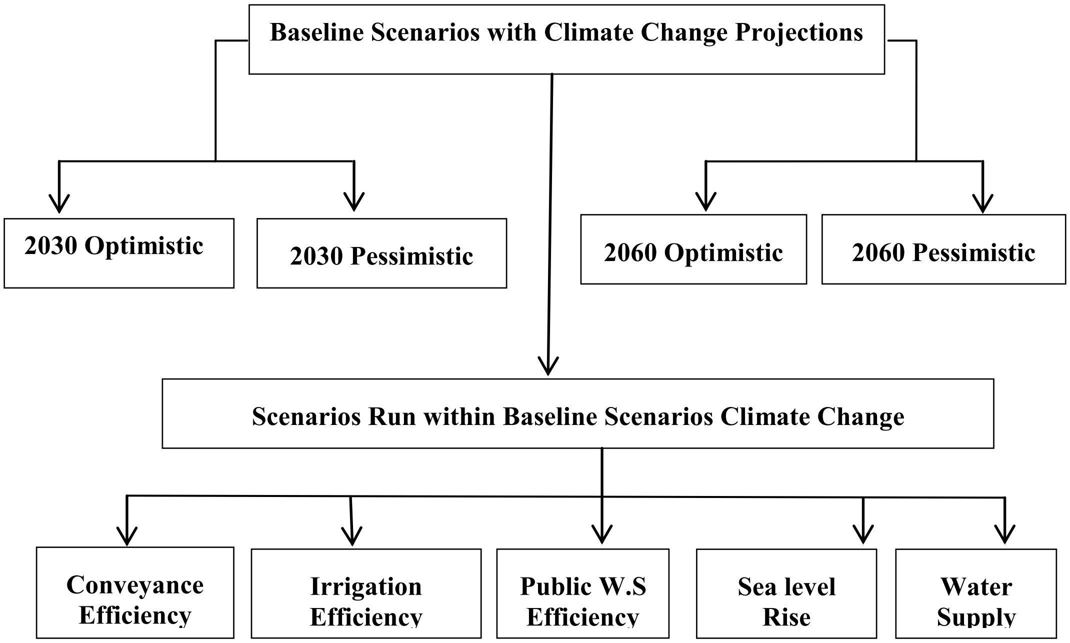

Figure 9. Definition of scenarios run with climate change

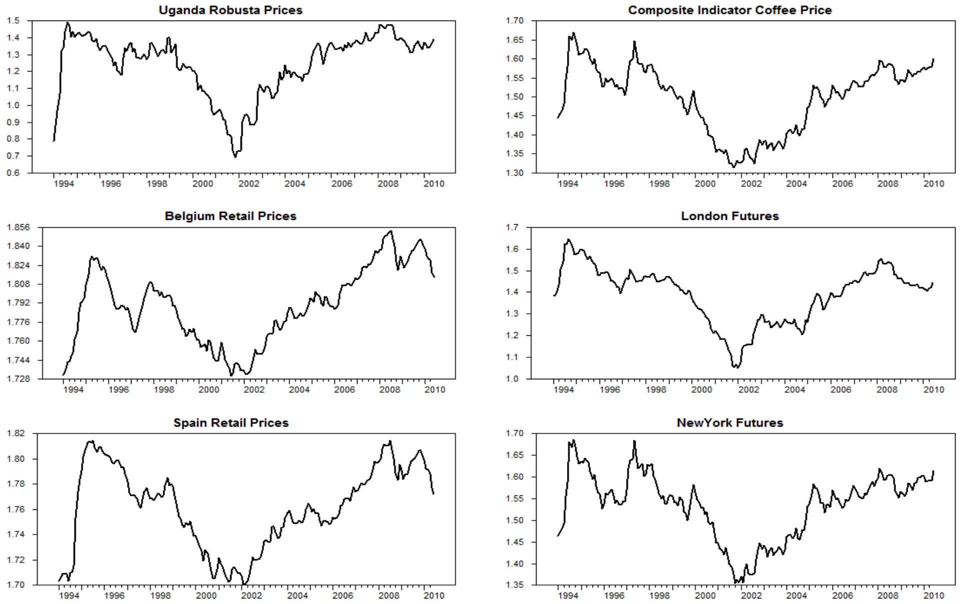

Figure 10. Log of monthly coffee prices from 6 series

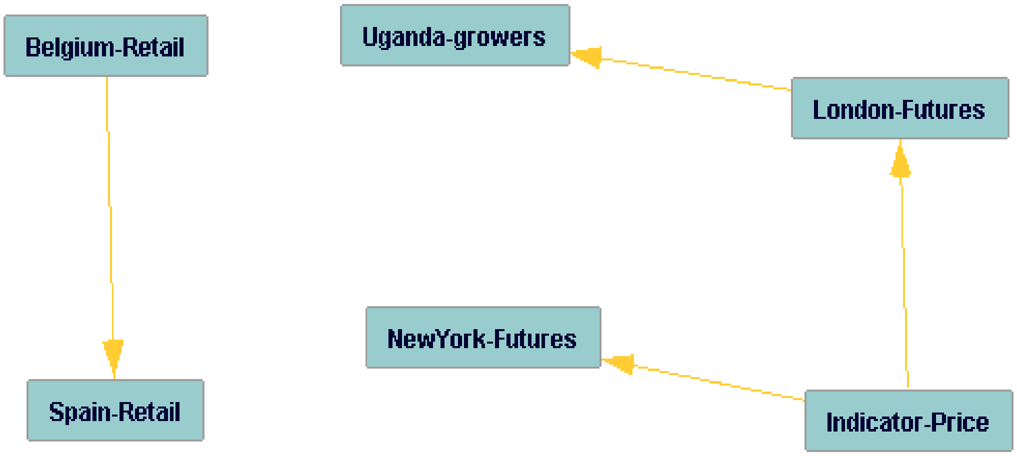

Figure 11. Patterns of causal flows among 6 coffee prices

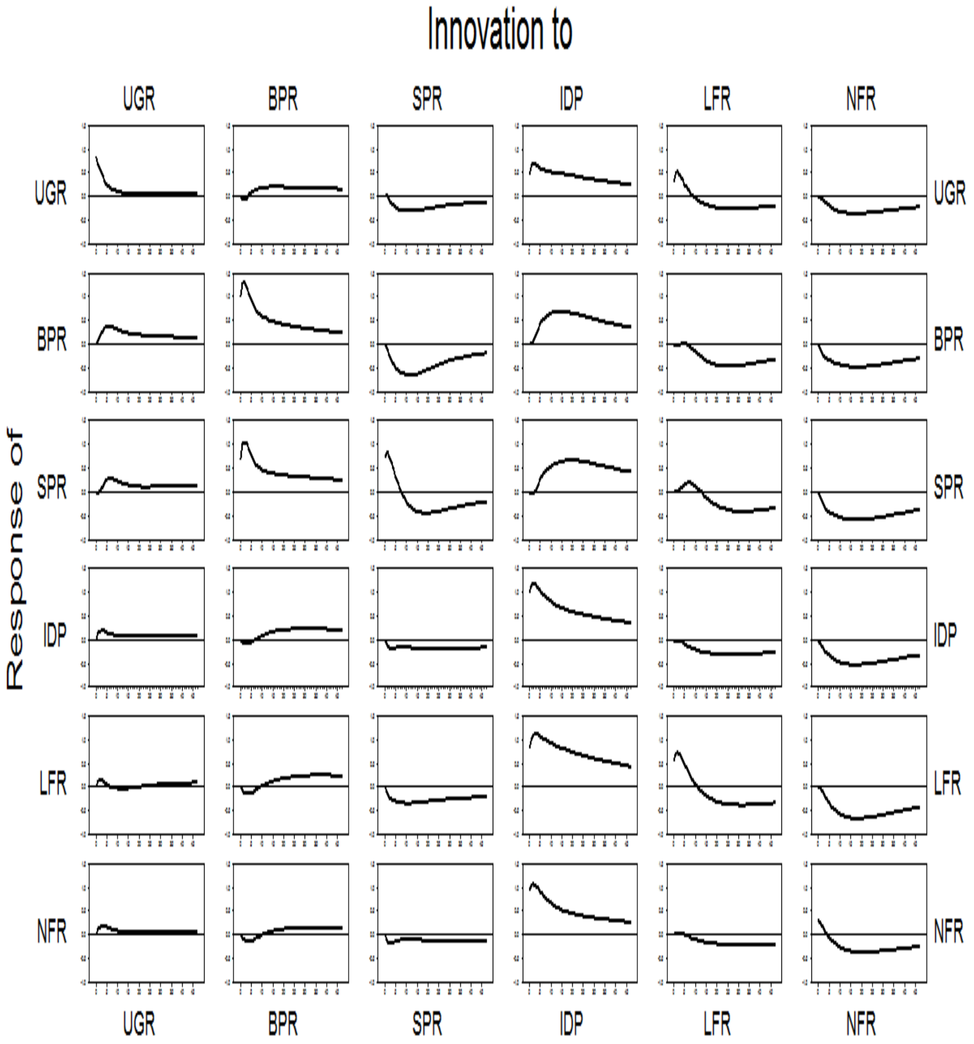

Figure 12. Response of each coffee price series to a one-time only shock in each series

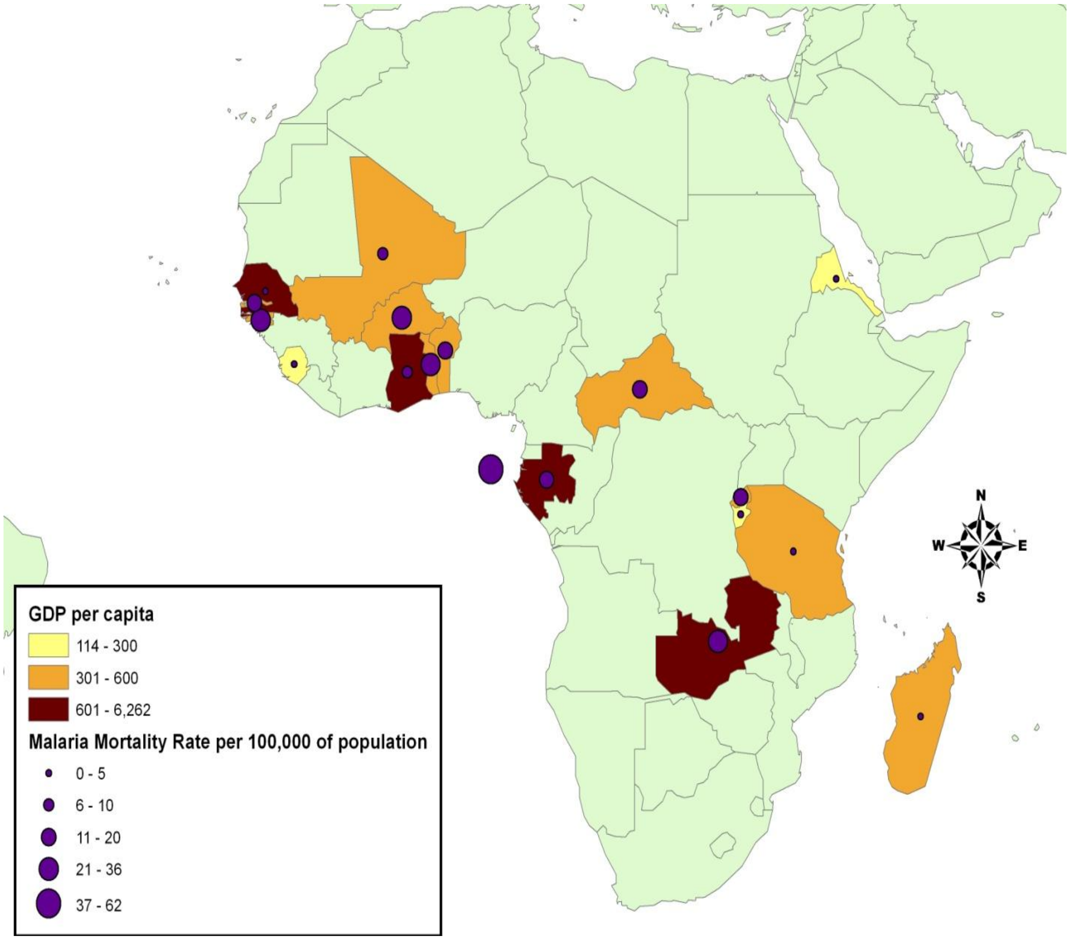

Figure 13. GDP in US$ per capita and mortality rate. The size of the circle indicates the relative magnitude of deaths per 100,000 of population

APPENDIX B

TABLES

Table 1. Agricultural Commodities Used in the ASME Model

Agricultural Commodities	Description
Barley	Production of Barley in 1000 metric tonnes
Berseem	Production of Berseem in 1000 metric tonnes
Lentil	Production of Lentils in 1000 metric tonnes
Onion	Production of Onions in 1000 metric tonnes
Rice	Production of Rice (sfter milling) in 1000 metric tonnes
Sesame	Production of Sesame in 1000 metric tonnes
Sorghum	Production of Sorghum in 1000 metric tonnes
Soybean	Production of Soybeans in 1000 metric tonnes
Sugarcane	Production of Sugar Cane in 1000 metric tonnes
Wheat	Production of Wheat (grain after milling) in 1000 metric tonnes
Vegetables	Production of Vegetables in 1000 metric tonnes
Flax	Production of Flax in 1000 metric tonnes
FlaxFIBer	FlaxFIBer
Potato	Production of Potatos in 1000 metric tonnes
Citrus	Production of Citrus in 1000 metric tonnes
Favabean	Production of Fava Beans in 1000 metric tonnes
Flaxseed	Production of Flax seed in 1000 metric tonnes
Legume	Production of Legumes in 1000 metric tonnes
Maize	Production of Maize in 1000 metric tonnes
Raw_Rice	Production of Raw Rice (before milling) in 1000 metric tonnes
Sugarbeets	Production of Sugar Beets in 1000 metric tonnes
Sugar	Production of Sugar (refined) in 1000 metric tonnes
Tomato	Production of Tomatos in 1000 metric tonnes
Vegetable-Oil	Production of Vegetable-Oil in 1000 metric tonnes
Wheatflour	Production of Wheat Flour in 1000 metric tonnes
Wheatstraw	Production of Wheat Fodder in 1000 metric tonnes
Barleyfodder	Production of Barley Fodder in 1000 metric tonnes
Favabeanfodder	Production of Fava Bean Fodder in 1000 metric tonnes
Lentilfodder	Production of Lentil Fodder in 1000 metric tonnes
Legumefodder	Production of Legume Fodder in 1000 metric tonnes
Ricefodder	Production of Rice Fodder in 1000 metric tonnes
Groundnutfodder	Production of Ground Nut Fodder in 1000 metric tonnes
MaizeStalks	Production of Maize Fodder in 1000 metric tonnes
Sorghumfodder	Production of Sorghum Fodder in 1000 metric tonnes
Sugarcanefodder	Production of Sugarcane Fodder in 1000 metric tonnes

Table 1. Continued

Agricultural Commodities	Description
Sugarbeetfodder	Production of Sugarbeet Fodder in 1000 metric tonnes
Soybeanfodder	Soybeanfodder
Vegetablefodder	Vegetablefodder
Soybeanmeal	Production of Soybean Meal in 1000 metric tonnes
Seedcake	Production of Seed cake in 1000 metric tonnes
CottonSeedcake	Production of Cotton Seed cake in 1000 metric tonnes
Molasses	Production of Molasses in 1000 metric tonnes
Bran	Production of Wheat and rice Bran in 1000 metric tonnes
Sugarbeetpulp	Production of Sugar Beet Pulp in 1000 metric tonnes
Seed_Cotton_ELS	Production of ELS_Raw_Cotton (seed cotton) in 1000 metric tonnes
Seed_Cotton_LS	Production of LS_Raw_Cotton (seed cotton) in 1000 metric tonnes
Lint_Cotton_ELS	Production of ELS Lint_Cotton (after ginning) in 1000 metric tonnes
Lint_Cotton_LS	Production of LS Lint_Cotton (after ginning) in 1000 metric tonnes
Peanuts	Production of Peanuts in 1000 metric tonnes
IndustrialMILK	industrial processing milk
BuffaloMILK	buffalo milk with more than 5.5% fat
CowMILK	cow milk
VEAL	veal
Fattened_Beef	fattener beef and chilled import beef
Cull_and_Frozen_BEEF	cull beef and frozen import beef
Sheepgoatmeat	Product From Sheep And Goats In Metric Tons
Poultrymeat	Product From Broiler Production In Metric Tons
Adult_Female	Adult Females (Cows Or Ewes)
Adult_Male	Adult Males (Bulls Or Rams)
Cull_Adult_Male	Adult Males That Were Culled (Bulls Or Rams)
Calves	Offspring (Calves Or Lambs)
Yearling	Yearling animals
Veal_Animal	Animals After Veal Feeding In Number Of Head
Fat_Animal_M1	Animals After Feeding By Method M1 In Number Of Head
Fat_Animal_M2	Animals After Feeding By Method M2 In Number Of Head
Fat_Animal_M3	Animals After Feeding By Method M3 In Number Of Head
Chicken	Chickens After Being Raised As Broilers In Number Of Head In 1000's
Eggs	Eggs Produced In Number Of Eggs In 1000's
Adult	Adults For Draft Animals In Number Of Head
Draft	Animals That Are Adult And Draft In Number Of Head

Table 2. Egypt's Population Projections for Pessimistic and Optimistic Scenario

Model Year	None	Pessimistic	optimistic
2010	80	80	80
2030	80	117	104
2060	80	162	113

Source: Stratus report, 2009.; and CIA, 2011.

Table 3. Scenarios for Yield Technological Progress of Growing a Particular crop

Crops	Scenario Sloweryield	Scenario growthfaster	Increased use of factors
Grow_Barley	1%	2.1%	0.4
Grow_Berseem_Long	2.1%	2.1%	0
Grow_Berseem_Short	2.1%	2.1%	0
Grow_Cotton_ELS	1%	2.1%	0.4
Grow_Cotton_LS	1%	2.1%	0.4
Grow_Maize	1%	2.1%	0.4
Grow_Rice	1%	2.1%	0.4
Grow_Rice_Short_Season	1%	2.1%	0.4
Grow_Sorghum	1%	2.1%	0.4
Grow_Wheat	1%	2.1%	0.4

Table 4. Scenarios of Projected Crop Yields

Scenario	**Interpolation Description**
None	No change
Natcom_2030_A1	60% of the change in the Data in the 2nd National Communication for the year 2050 for scenario A1
Natcom_2060_A1	80% of 2050 and 20% of 2100 change in the Data in the 2nd National Communication for scenario A1

Table 5. Proxies for Crops without Data on Yield Sensitivity to Climate Change

Crops Without Available Data	Proxy
Grow_Berseem_Long Grow_Berseem_Short Grow_Citrus Grow_Sesame Grow_Sorghum Grow_Sugarcane Grow_Rice Grow_Rice_Short_Season	Grow_Maize
Grow_Favabean Grow_Lentil Grow_Other_Legume Grow_Tomato Grow_Vegetables	Grow_Soybeans
Grow_Flax Grow_Barley Grow_Cotton	Grow_Wheat
Grow_Onion Grow_Peanut Grow_Sugarbeets	Grow_Potato

Table 6. Percentage Change in the Yields of Crops due to Climate Change

Crops	seasons	Natcom 2030_a1 yield	Natcom 2030_a1 water_use	Natcom 2060_a1 Yield	Natcom 2060_a1 water_use
Grow_Barley	Winter	-12	3.6	-20	7.2
Grow_Berseem_Long	Winter	-8.4	3.3	-15.2	6.6
Grow_Berseem_Short	Winter	-8.4	3.3	-15.2	6.6
Grow_Citrus	Annual	-8.4	3.3	-15.2	6.6
Grow_Cotton	Summer	10.2	3.6	19.8	7.2
Grow_Favabean	Winter	-16.8	4.02	-28	7.82
Grow_Flax	Winter	-9	3.6	-19.2	7.2
Grow_Lentil	Winter	-16.8	3.48	-28	7.28
Grow_Maize	Summer	-8.4	3.3	-15.2	6.6
Grow_Maize	Nili	-8.4	3.3	-15.2	6.6
Grow_Onion	Summer	-0.96	4.32	-1.53	7.84
Grow_Onion	Winter	-0.96	4.32	-1.53	7.84
Grow_Other_Legume	Winter	-16.8	3.48	-28	7.28
Grow_Peanut	Summer	-0.96	4.32	-1.53	7.84
Grow_Potato	Summer	-0.96	4.32	-1.53	7.84
Grow_Potato	Nili	-0.96	3.36	-1.53	7.26
Grow_Rice	Summer	-6.6	3.3	-11	6.6
Grow_Rice_Short_Season	Nili	-6.6	3.3	-11	6.6
Grow_Sesame	Summer	-8.4	3.3	-15.2	6.6
Grow_Sorghum	Summer	-8.4	3.3	-15.2	6.6
Grow_Sorghum	Nili	-8.4	3.3	-15.2	6.6
Grow_Soybeans	Summer	-16.8	3.48	-28	7.28
Grow_Sugarbeets	Winter	-0.96	4.32	-1.53	7.84
Grow_Sugarcane	Annual	-8.4	3.3	-15.2	6.6
Grow_Tomato	Summer	-16.8	3.48	-28	7.28
Grow_Tomato	Nili	-16.8	3.54	-28	7.18

Table 6. Continued

Crops	seasons	Natcom 2030_a1	Natcom 2030_a1	Natcom 2060_a1	Natcom 2060_a1
		yield	water_use	Yield	water_use
Grow_Tomato	Winter	-16.8	4.2	-28	8.16
Grow_Vegetables	Summer	-16.8	3.48	-28	7.28
Grow_Vegetables	Nili	-16.8	3.48	-28	7.28
Grow_Vegetables	Winter	-16.8	3.48	-28	7.28
Grow_Wheat	Winter	-9	3.6	-19.2	7.2

Table 7. Climate Change Percentage of Land Lost due to Sea Level Rise in A1F1 Scenario for the Delta Regions

Scenarios Sea Level	E-Delta	M-Delta	W-Delta	Nrth-East-Delta	Nrth-Middle-Delta	West-Delta
A1FI_2030_Protected	0.20	0.10	0.00	0.7	0.18	0
A1FI_2060_Protected	0.50	1.50	0.30	1.76	2.73	0.3
A1FI_2030_Unprotected	7.30	0.90	0.10	25.65	1.64	0.1
A1FI_2060_Unprotected	15.00	5.70	13.20	52.72	10.36	13.2

Table 8. Livestock Performance due to Climate Change

Livestock Species	Average yield reduction
Buffalo	-7.5%
Cattle	-7.5%
Cattle_Exotic	-7.5%
Sheep_Goats	-7.5%

Table 9. Percentage Change in Municipal and Industrial Water Demand

Scenario	Proportional increase in water demand
No Change	0
Average	0.025

Table 10. Description of General Circulation Models Used for Nile Inflows

GCM	Country	Model ID IPCC
GISS	Goddard Institute for Space Studies, USA	GISS-ER
HADCM3	Hadley Center for Climate and Prediction and Research, UK	UKMO - HadCM3
CNRM	Centre National de Recherches Meteoroliques, France	CNRM-CM3
CSIRO	CSIRO Atmospheric Research, Australia	CSIRO-Mk3.0
GFDL	Geophysical Fluid Dynamics Laboratory, USA	GFDL-CM2.0
INMCM	Institute for Numerical Mathematics, Russia	INM-CM3.0
IPSL	Insitut Pierre Simon Laplace, France	IPSL-CM4
MIROC	Center for Climate Systems Research, Japan	Miroc3.2
MPI	Max Planck Institute for Meteorology, Germany	ECHAM5/MPI-OM
PCM	National Center for Atmospheric Research, USA	PCM
MRI	Metreological Research Institute, Japan	MRI-CGCM2.3.2

Table 11. Multimodel Average Annual Releases from the High Aswan Dam

	Flow in BCM		Percentage of Base	
	A2	B1	A2	B1
Base	55.5	55.5	100	100
Multimodel-2030	58.72	60.39	106	109
Multimodel-2060	48.36	49.31	87	89

Table 12. Proposed Allocation of Water to the Nile Basin Countries

	Riparian Countries	BCM	Egypt's Allocation *
Baseline Actual Use	Ethiopia	3.9	
	Sudan	27.3	
	Egypt	65.5	55.5
	Basin	96.7	
Proposed Alternative	Ethiopia	12	
	Sudan	16.3	
	Egypt	61.7	51.7
	Basin	90	
Unilateral	Ethiopia	36.1	
	Sudan	29.3	
	Egypt	33.2	23.2
	Basin	98.5	
Social Planner	Ethiopia	22.3	
	Sudan	15.9	
	Egypt	60.3	50.3
	Basin	98.5	

Source: Nigatu and Dinar, 2011.

** Assume that 10 BCM are lost to evaporation in Egypt*

Table 13. Scenarios of Water Supply Changes in 2030 without Climate Change

Water Release	Flow_Billion_m3	Percentage_of_Base
Release_62_5	62.5	112.6
Release_55_5 (Base)	55.5	100
Release_52_5	52.5	94.6
Release_50_5	50.5	91
Release_45_5	45.5	82
Release_35_5	35.5	64

Table 14. Baseline Projection Scenarios for Comparison without Climate Change

Scenario	Population	Water Supply	Sea Level	Crop Yield	Livestock Yield	M&I Water Use
Baseline_2010	82	55.5	No Change	No change	No change	No change
Pessimistic_2030	117	55.5	No Change	No change	No Change	No Change
Optimistic_2030	104	55.5	No Change	No change	No Change	No Change
Pessimistic_2060	162	55.5	No Change	No change	No Change	No Change
Optimistic_2060	113	55.5	No Change	No change	No Change	No Change

[a] *Population is in millions and Water Supply is in BCM*

Table 15. Basic Item Definition of Results Reported in Tables

Item	Output Definition
Welfare (CSPS), GDP, Imports and Export	Billion Egyptian Pounds (EP)
Water Use	Billion Cubic Meters (BCM))
Land Use	Million Feddans
Marginal Value of Water	Egyptian Pounds per 1000 cubic meters
Labor Use	Billion hours

Table 16. Definition of Items presented in Results Tables

Definition Class	Measurement Units
Welfare	Billion Egyptian Pounds (EGP)
Agricultural GDP	Billion Egyptian Pounds (EGP)
Imports	Billion Egyptian Pounds (EGP)
Exports	Billion Egyptian Pounds (EGP)
Total Agricultural Water Use	Billion Cubic Meters
Total Municipal and Industrial (M&I) consumption of surface Water	Billion Cubic Meters
Total Municipal and Industrial (M&I) consumption of Groundwater	Billion Cubic Meters
Escape of water to Sea	Billion Cubic Meters
Total Agricultural Land Use year round over all seasons	Million Feddans
Total Agricultural labor Use	Billion Hours
Marginal Value of Water	Egyptian Pounds per 1000 Cubic Meters
Total Water Reuse	Billion Cubic Meters

Table 17. Baseline Scenarios with Population Growth Projections but without Climate Change

Year	2030	2030	2060	2060
Population Projection	Pessimistic	Optimistic	Pessimistic	Optimistic
Nile Flow (BCM)	55	55	55	55
Protection from Sea Level rise	none	none	none	none
Agricultural GDP (billion EGP)				
2010 Baseline: 131.69	109.46	55.70	203.36	91.13
Welfare (Billion EGP)				
2010 Baseline : 0.998	40.93	27.13	83.90	36.73
Consumer Prices	44	23	91	39
Agricultural Water use (BCM)				
2010 Baseline : 38	-9.55	-8.25	-16.12	-9.70
M&I Consumption of Surface Water (BCM)				
2010 Baseline: 4.5	36.94	29.53	87.97	32.41
M&I consumption of Groundwater (BCM)				
2010 Baseline: 0.128	376.56	46.09	617.97	354.69
Flow to Sea (BCM				
2010 Baseline: 15.2	27.33	16.58	52.74	24.22
Agricultural Land Use (million feddans)				
2010 Baseline: 17	11.69	13.83	2.55	12.00
Agricultural labor Hours (Billion)				
2010 Baseline: 2.05	22.83	19.96	13.86	20.47
Water Reuse (BCM)				
2010 Baseline : 5.6	46.26	30.01	102.50	41.25
Value of Water (EGP/1000CM)				
2010 Baseline: 370	316.76	125.14	885.41	248.38

Table 18. Scenarios Used for Climate Change Comparison

Scenario Name	Model Year	Yield Progress	Population Growth	Nile Inflow	Sea Level	Livestock Effect	MI Water effect
Base2010	2010	Slower	none	release_55_5	none	none	nochange
Base2030pess	2030	Slower	pessimistic	release_55_5	none	none	nochange
Base2030opt	2030	Slower	optimistic	release_55_5	none	none	nochange
Base2060pess	2060	Slower	pessimistic	release_55_5	none	none	nochange
Base2060opt	2060	Slower	optimistic	release_55_5	none	none	nochange
2030_pess_A2_Pr	2030	Slower	pessimistic	A2_58_7	Protected	Average	Average
2030_pess_B1_Pr	2030	Slower	pessimistic	B1_60_4	Protected	Average	Average
2030_pess_A2_Un	2030	Slower	pessimistic	A2_58_7	Unprotected	Average	Average
2030_pess_B1_Un	2030	Slower	pessimistic	B1_60_4	Unprotected	Average	Average
2030_Opt_A2_Pr	2030	Slower	optimistic	A2_58_7	Protected	Average	Average
2030_Opt_B1_Pr	2030	Slower	optimistic	B1_60_4	Protected	Average	Average
2030_Opt_A2_Un	2030	Slower	optimistic	A2_58_7	Unprotected	Average	Average
2030_Opt_B1_Un	2030	Slower	optimistic	B1_60_4	Unprotected	Average	Average
2060_pess_A2_Pr	2060	Slower	pessimistic	A2_48_4	Protected	Average	Average
2060_pess_B1_Pr	2060	Slower	pessimistic	B1_49_3	Protected	Average	Average
2060_pess_A2_Un	2060	Slower	pessimistic	A2_48_4	Unprotected	Average	Average
2060_pess_B1_Un	2060	Slower	pessimistic	B1_49_3	Unprotected	Average	Average
2060_Opt_A2_Pr	2060	Slower	optimistic	A2_48_4	Protected	Average	Average
2060_Opt_B1_Pr	2060	Slower	optimistic	B1_49_3	Protected	Average	Average
2060_Opt_A2_Un	2060	Slower	optimistic	A2_48_4	Unprotected	Average	Average
2060_Opt_B1_Un	2060	Slower	optimistic	B1_49_3	Unprotected	Average	Average

Table 19. Climate Change Scenarios as a Percentage Change of the Baseline 2030 Scenarios

Year	2030	2030	2030	2030	2030	2030
Population Projection	Optimistic	Optimistic	Pessimistic	Pessimistic	Pessimistic	Pessimistic
Nile Flow (BCM)	A2:	B1:	A2:	B1:	A2:	B1:
Protection from Sea Level rise	Protected	Protected	Protected	Protected	Un Protected	Un Protected
Welfare (Billion EGP)						
Pessimistic: 1.4			-1.59	-1.38	-1.66	-1.45
Optimistic: 1.3	-1.29	-1.14				
Agriculture GDP (Billion EGP)						
Pessimistic: 275.8			15.51	16.25	14.78	15.26
Optimistic: 205	20.42	16.50				
Imports (Billion EGP)						
Pessimistic: 0.033			18.01	13.80	22.95	22.46
Optimistic: 0.026	11.40	9.43				
Exports (Billion EGP)						
Pessimistic: 0.028			-15.20	-4.50	-16.32	-4.50
Optimistic: 0.038	-9.45	-5.22				
Producer Production Base	-6	-5	-5	-4	-6	-5
Consumer Prices	17	16	19	19	19	19
Agricultural Water use (BCM)						
Pessimistic: 34.4			7.15	10.24	7.88	10.24
Optimistic: 34.9	6.91	9.96				
M&I Surface Water Use (BCM)						
Pessimistic: 6.5			4.42	6.01	5.73	7.17
Optimistic: 6.1	2.06	3.34				
M&I Groundwater Use (BCM)						

Table 19. Continued

Year	2030	2030	2030	2030	2030	2030
Population Projection	Optimistic	Optimistic	Pessimistic	Pessimistic	Pessimistic	Pessimistic
Nile Flow (BCM)	A2:	B1:	A2:	B1:	A2:	B1:
Protection from Sea Level rise	Protected	Protected	Protected	Protected	Un Protected	Un Protected
Pessimistic: 0.6			-10.66	-27.38	-24.43	-39.67
Optimistic: 0.2	37.43	-3.74				
Flow to Sea (BCM						
Pessimistic: 19.4			3.67	4.22	3.15	3.86
Optimistic: 17.8	4.65	5.73				
Agricultural labor Hours (Billion)						
Pessimistic: 2.52			4.41	5.74	4.47	3.99
Optimistic: 2.46	0.55	0.90				
Agricultural Land Use (million feddans)						
Pessimistic: 19.2			3.93	4.48	3.24	3.17
Optimistic: 19.5	1.76	3.17				
Marginal Value of Water (EGP/1000CM)						
Pessimistic: 1542			11.02	5.97	8.69	5.90
Optimistic: 833	32.41	21.61				
Water Reuse (BCM)						
Pessimistic: 7.0			-5.67	-5.67	-5.67	-5.67
Optimistic: 6.2	-5.67	-5.67				

Table 20.Climate Change Scenarios as a Percentage Change of the Baseline 2060 Scenarios

Year	2060	2060	2060	2060	2060	2060
Population Projection	Optimistic	Optimistic	Pessimistic	Pessimistic	Pessimistic	Pessimistic
Nile Flow (BCM)	A2:	B1:	A2:	B1:	A2:	B1:
Protection from Sea Level rise	Protected	Protected	Protected	Protected	Un protected	Un protected
Welfare (Billion EGP)						
Pessimistic: 1.8			-6.17	-5.79	-6.28	-5.90
Optimistic: 1.4	-4.47	-4.26				
Agriculture GDP (Billion EGP)						
Pessimistic: 399.5			15.06	16.51	15.18	16.13
Optimistic: 251.7	11.13	13.25				
Imports (Billion EGP)						
Pessimistic: 0.125			18.36	18.21	18.93	18.80
Optimistic: 0.031	135.89	125.08				
Exports (Billion EGP)						
Pessimistic: 0.011			-1.73	-1.73	-1.73	-1.73
Optimistic: 0.032	-57.55	-57.55				
Producer Production Base	-28	-26	-24	-23	-24	-23
Consumer Prices	35	34	69	66	69	65
Agricultural Water use (BCM)						
Pessimistic: 31.9			-17.31	-14.81	-17.49	-15.04
Optimistic: 34.32	-13.22	-10.53				
M&I Surface Water Use (BCM)						
Pessimistic: 9.03			-1.61	-0.58	-0.94	0.02
Optimistic: 6.36	-3.74	-2.30				
M&I Groundwater Use (BCM)						
Pessimistic: 0.92			18.39	8.27	11.86	2.39

Table. 20. Continued

Year	2060	2060	2060	2060	2060	2060
Population Projection	Optimistic	Optimistic	Pessimistic	Pessimistic	Pessimistic	Pessimistic
Nile Flow (BCM)	A2:	B1:	A2:	B1:	A2:	B1:
Protection from Sea Level rise	Protected	Protected	Protected	Protected	Un protected	Un protected
Optimistic: 0.58	43.81	28.01				
Flow to Sea (BCM						
Pessimistic: 23.33			-4.67	-3.89	-4.89	-3.99
Optimistic: 18.97	-4.73	-4.56				
Agricultural labor Hours (Billion)						
Pessimistic: 2.34			-18.35	-17.94	-18.45	-18.02
Optimistic: 2.47	-21.02	-18.28				
Agricultural Land Use (million feddans)						
Pessimistic: 17.6			-12.10	-11.04	-12.60	-11.65
Optimistic: 19.2	-8.70	-7.25				
Value of Water (EGP/1000CM)						
Pessimistic: 3646			68.29	65.88	68.46	63.91
Optimistic: 1289	85.73	83.71				
Water Reuse (BCM)						
Pessimistic: 8.9			9.61	9.61	9.61	9.61
Optimistic: 6.36	9.62	9.62				

Table 21. Scenario of Improvement in Public Water Distribution Network for 2030 Under Climate Change

Year	2030	2030	2030	2030	2030	2030
Population Projection	Optimistic	Optimistic	Pessimistic	Pessimistic	Pessimistic	Pessimistic
Nile Flow (BCM)	A2:	B1:	A2:	B1:	A2:	B1:
Protection from Sea Level rise	Protected	Protected	Protected	Protected	Un Protected	Un Protected
Welfare (Billion EGP)						
Pessimistic: 1.4			-1.20	-1.03	-1.27	-1.10
Optimistic: 1.3	-1.05	-0.94				
Agriculture GDP (Billion EGP)						
Pessimistic: 275.8			14.36	7.66	14.05	8.48
Optimistic: 205	11.24	5.78				
Imports (Bilion EGP)						
Pessimistic: 0.033			10.76	10.54	14.46	12.04
Optimistic: 0.026	9.11	7.78				
Exports (Billion EGP)						
Pessimistic: 0.028			-0.34	-0.34	-0.34	-0.34
Optimistic: 0.038	-5.22	-5.54				
Agricultural Water use (BCM)						
Pessimistic: 34.4			12.87	16.55	12.90	16.43
Optimistic: 34.9	12.64	16.20				
M&I Surface Water Use (BCM)						
Pessimistic: 6.5			-14.58	-13.41	-14.04	-12.51
Optimistic: 6.1	-15.02	-14.33				
M&I Groundwater Use (BCM)						

Table 21. Continued

Year	2030	2030	2030	2030	2030	2030
Population Projection	Optimistic	Optimistic	Pessimistic	Pessimistic	Pessimistic	Pessimistic
Nile Flow (BCM)	A2:	B1:	A2:	B1:	A2:	B1:
Protection from Sea Level rise	Protected	Protected	Protected	Protected	Un Protected	Un Protected
Pessimistic: 0.6			-37.70	-50.00	-43.28	-59.51
Optimistic: 0.2	-66.84	-89.30				
Flow to Sea (BCM						
Pessimistic: 19.4			-8.74	-7.76	-9.50	-7.94
Optimistic: 17.8	-6.07	-5.60				
Agricultural labor Hours (Billion)						
Pessimistic: 2.52			6.03	6.37	5.63	6.06
Optimistic: 2.46	1.01	0.95				
Ag.Land Use (million feddans)						
Pessimistic: 19.2			5.51	6.26	4.23	5.66
Optimistic: 19.5	3.83	4.59				
Value of Water (EGP/1000CM)						
Pessimistic: 1542			0.26	-15.63	-1.69	-17.32
Optimistic: 833	9.60	-10.80				
Water Reuse (BCM)						
Pessimistic: 7.0			-17.23	-17.23	-17.23	-17.23
Optimistic: 6.2	-17.23	-17.23				

Table 22. Scenario of Improvement in Public Water Distribution Network for 2060 Under Climate Change

Year	2060	2060	2060	2060	2060	2060
Population Projection	Optimistic	Optimistic	Pessimistic	Pessimistic	Pessimistic	Pessimistic
Nile Flow (BCM)	A2:	B1:	A2:	B1:	A2:	B1:
Protection from Sea Level rise	Protected	Protected	Protected	Protected	Un protected	Un protected
Welfare (Billion EGP)						
Pessimistic: 1.8			-4.77	-4.47	-4.91	-4.62
Optimistic: 1.4	-3.91	-3.72				
Agriculture GDP (Billion EGP)						
Pessimistic: 399.5			14.01	13.19	13.13	14.69
Optimistic: 251.7	16.35	16.01				
Imports (Bilion EGP)						
Pessimistic: 0.125			17.02	16.38	18.12	17.27
Optimistic: 0.031	107.49	88.96				
Exports (Billion EGP)						
Pessimistic: 0.011			-1.73	-1.73	-1.73	-1.73
Optimistic: 0.032	-57.55	-57.55				
Agricultural Water use (BCM)						
Pessimistic: 31.9			-6.74	-3.99	-6.94	-4.28
Optimistic: 34.32	-6.35	-3.78				
M&I Surface Water Use (BCM)						
Pessimistic: 9.03			-18.21	-17.42	-18.91	-18.40
Optimistic: 6.36	-19.37	-18.05				

Table 22. Continued

Year	2060	2060	2060	2060	2060	2060
Population Projection	Optimistic	Optimistic	Pessimistic	Pessimistic	Pessimistic	Pessimistic
Nile Flow (BCM)	A2:	B1:	A2:	B1:	A2:	B1:
Protection from Sea Level rise	Protected	Protected	Protected	Protected	Un protected	Un protected
M&I Groundwater Use (BCM)						
Pessimistic: 0.92			-4.03	-11.32	3.37	-1.74
Optimistic: 0.58	10.65	-3.78				
Flow to Sea (BCM)						
Pessimistic: 23.33			-17.53	-17.19	-17.59	-17.03
Optimistic: 18.97	-16.83	-16.58				
Agricultural labor Hours (Billion)						
Pessimistic: 2.34			-11.57	-9.54	-13.14	-10.02
Optimistic: 2.47	-14.38	-10.48				
Ag. Land Use (million feddans)						
Pessimistic: 17.6			-7.91	-6.74	-9.30	-8.17
Optimistic: 19.2	-4.34	-2.82				
Value of Water (EGP/1000CM)						
Pessimistic: 3646			34.89	25.78	29.76	27.26
Optimistic: 1289	79.60	63.69				
Water Reuse (BCM)						
Pessimistic: 8.9			-15.40	-15.62	-15.62	-15.62
Optimistic: 6.36	-15.61	-15.61				

Table 23. Scenario of Improvement in Field Irrigation Efficiency for 2060 Under Climate Change

Year	2060	2060	2060	2060	2060	2060
Population Projection	Optimistic	Optimistic	Pessimistic	Pessimistic	Pessimistic	Pessimistic
Nile Flow (BCM)	A2:	B1:	A2:	B1:	A2:	B1:
Protection from Sea Level rise	Protected	Protected	Protected	Protected	Un protected	Un protected
Welfare (Billion EGP)						
Pessimistic: 1.8			-5.54	-5.13	-5.69	-5.28
Optimistic: 1.4	-3.82	-3.60				
Agriculture GDP (Billion EGP)						
Pessimistic: 399.5			17.16	13.42	16.20	12.20
Optimistic: 251.7	15.36	16.51				
Imports (Billion EGP)						
Pessimistic: 0.125			18.13	17.66	18.71	18.27
Optimistic: 0.031	94.86	88.64				
Exports (Billion EGP)						
Pessimistic: 0.011			-1.73	-1.73	-1.73	-1.73
Optimistic: 0.032	-57.55	-57.55				
Agricultural Water use (BCM)						
Pessimistic: 31.9			-14.54	-11.24	-14.52	-11.21
Optimistic: 34.32	-4.51	-1.56				
M&I Surface Water Use (BCM)						
Pessimistic: 9.03			2.38	2.13	2.21	1.87
Optimistic: 6.36	-6.70	-7.41				
M&I Groundwater Use (BCM)						

Table 23. Continued

Year	2060	2060	2060	2060	2060	2060
Population Projection	Optimistic	Optimistic	Pessimistic	Pessimistic	Pessimistic	Pessimistic
Nile Flow (BCM)	A2:	B1:	A2:	B1:	A2:	B1:
Protection from Sea Level rise	Protected	Protected	Protected	Protected	Un protected	Un protected
Pessimistic: 0.92			-20.78	-18.28	-19.15	-15.89
Optimistic: 0.58	76.12	83.68				
Flow to Sea (BCM						
Pessimistic: 23.33			-10.40	-9.88	-10.35	-9.62
Optimistic: 18.97	-12.78	-11.69				
Agricultural labor Hours (Billion)						
Pessimistic: 2.34			-17.93	-14.75	-17.83	-14.86
Optimistic: 2.47	-10.65	-9.17				
Ag. Land Use (million feddans)						
Pessimistic: 17.6			-11.05	-9.44	-11.81	-9.99
Optimistic: 19.2	-3.79	-2.07				
Value of Water (EGP/1000CM)						
Pessimistic: 3646			90.70	65.33	84.12	59.63
Optimistic: 1289	102.87	92.47				
Water Reuse (BCM)						
Pessimistic: 8.9			9.61	9.61	9.61	9.61
Optimistic: 6.36	9.62	9.62				

Table 24. Scenario of Improvement in Field Irrigation Efficiency for 2060 Under Climate Change

Year	2060	2060	2060	2060	2060	2060
Population Projection	Optimistic	Optimistic	Pessimistic	Pessimistic	Pessimistic	Pessimistic
Nile Flow (BCM)	A2:	B1:	A2:	B1:	A2:	B1:
Protection from Sea Level rise	Protected	Protected	Protected	Protected	Un protected	Un protected
Welfare (Billion EGP)						
Pessimistic: 1.8			-5.54	-5.13	-5.69	-5.28
Optimistic: 1.4	-3.82	-3.60				
Agriculture GDP (Billion EGP)						
Pessimistic: 399.5			17.16	13.42	16.20	12.20
Optimistic: 251.7	15.36	16.51				
Imports (Bilion EGP)						
Pessimistic: 0.125			18.13	17.66	18.71	18.27
Optimistic: 0.031	94.86	88.64				
Exports (Billion EGP)						
Pessimistic: 0.011			-1.73	-1.73	-1.73	-1.73
Optimistic: 0.032	-57.55	-57.55				
Agricultural Water use (BCM)						
Pessimistic: 31.9			-14.54	-11.24	-14.52	-11.21
Optimistic: 34.32	-4.51	-1.56				
M&I Surface Water Use (BCM)						
Pessimistic: 9.03			2.38	2.13	2.21	1.87
Optimistic: 6.36	-6.70	-7.41				
M&I Groundwater Use (BCM)						

Table 24. Continued

Year	2060	2060	2060	2060	2060	2060
Population Projection	Optimistic	Optimistic	Pessimistic	Pessimistic	Pessimistic	Pessimistic
Nile Flow (BCM)	A2:	B1:	A2:	B1:	A2:	B1:
Protection from Sea Level rise	Protected	Protected	Protected	Protected	Un protected	Un protected
Pessimistic: 0.92			-20.78	-18.28	-19.15	-15.89
Optimistic: 0.58	76.12	83.68				
Flow to Sea (BCM						
Pessimistic: 23.33			-10.40	-9.88	-10.35	-9.62
Optimistic: 18.97	-12.78	-11.69				
Agricultural labor Hours (Billion)						
Pessimistic: 2.34			-17.93	-14.75	-17.83	-14.86
Optimistic: 2.47	-10.65	-9.17				
Ag. Land Use (million feddans)						
Pessimistic: 17.6			-11.05	-9.44	-11.81	-9.99
Optimistic: 19.2	-3.79	-2.07				
Value of Water (EGP/1000CM)						
Pessimistic: 3646			90.70	65.33	84.12	59.63
Optimistic: 1289	102.87	92.47				
Water Reuse (BCM)						
Pessimistic: 8.9			9.61	9.61	9.61	9.61
Optimistic: 6.36	9.62	9.62				

Table 25. Scenario of Improvement in Conveyance Efficiency for 2030 Under Climate Change

Year	2030	2030	2030	2030	2030	2030
Population Projection	Optimistic	Optimistic	Pessimistic	Pessimistic	Pessimistic	Pessimistic
Nile Flow (BCM)	A2:	B1:	A2:	B1:	A2:	B1:
Protection from Sea Level rise	Protected	Protected	Protected	Protected	Un Protected	Un Protected
Welfare (Billion EGP)						
Pessimistic: 1.4			-0.92	-0.75	-0.98	-0.82
Optimistic: 1.3	-0.80	-0.71				
Agriculture GDP (Billion EGP)						
Pessimistic: 275.8			9.24	8.85	10.60	8.51
Optimistic: 205	2.02	-1.22				
Imports (Bilion EGP)						
Pessimistic: 0.033			5.65	6.08	10.46	11.63
Optimistic: 0.026	2.85	0.95				
Exports (Billion EGP)						
Pessimistic: 0.028			-0.34	-0.34	-0.34	-0.34
Optimistic: 0.038	-5.80	-5.54				
Agricultural Water use (BCM)						
Pessimistic: 34.4			19.52	23.76	19.28	23.57
Optimistic: 34.9	21.01	25.14				
M&I Surface Water Use (BCM)						
Pessimistic: 6.5			-4.65	-4.83	-4.19	-4.22
Optimistic: 6.1	-10.62	-9.51				
M&I Groundwater Use(BCM)						
Pessimistic: 0.6			68.85	70.82	63.93	64.26

Table 25. Continued

Year	2030	2030	2030	2030	2030	2030
Population Projection	Optimistic	Optimistic	Pessimistic	Pessimistic	Pessimistic	Pessimistic
Nile Flow (BCM)	A2:	B1:	A2:	B1:	A2:	B1:
Protection from Sea Level rise	Protected	Protected	Protected	Protected	Un Protected	Un Protected
Optimistic: 0.2	403.74	367.38				
Flow to Sea (BCM						
Pessimistic: 19.4			-10.55	-9.45	-10.72	-9.58
Optimistic: 17.8	-9.82	-9.23				
Agricultural labor Hours (Billion)						
Pessimistic: 2.52			6.66	7.09	6.37	6.75
Optimistic: 2.46	3.13	2.84				
Ag. Land Use (million feddans)						
Pessimistic: 19.2			7.67	8.37	6.61	6.88
Optimistic: 19.5	6.19	6.67				
Value of Water (EGP/1000CM)						
Pessimistic: 1542			-0.58	-15.56	-3.18	-27.30
Optimistic: 833	-12.97	-34.57				
Water Reuse (BCM)						
Pessimistic: 7.0			1.64	1.64	1.64	1.64
Optimistic: 6.2	1.66	1.66				

Table 26. Scenario of Improvement in Conveyance Efficiency for 2060 Under Climate Change

Year	2060	2060	2060	2060	2060	2060
Population Projection	Optimistic	Optimistic	Pessimistic	Pessimistic	Pessimistic	Pessimistic
Nile Flow (BCM)	A2:	B1:	A2:	B1:	A2:	B1:
Protection from Sea Level rise	Protected	Protected	Protected	Protected	Un protected	Un protected
Welfare (Billion EGP)						
Pessimistic: 1.8			-5.38	-4.99	-5.54	-5.15
Optimistic: 1.4	-3.71	-3.50				
Agriculture GDP (Billion EGP)						
Pessimistic: 399.5			15.13	13.72	18.13	12.28
Optimistic: 251.7	16.88	16.78				
Imports (Bilion EGP)						
Pessimistic: 0.125			17.99	17.92	18.75	17.96
Optimistic: 0.031	88.05	82.20				
Exports (Billion EGP)						
Pessimistic: 0.011			-1.73	-1.73	-1.73	-1.73
Optimistic: 0.032	-57.55	-57.55				
Consumer Prices	51	50	95	89	96	91
Agricultural Water use (BCM)						
Pessimistic: 31.9			-13.25	-9.70	-12.72	-10.17
Optimistic: 34.32	-3.29	-0.15				
M&I Surface Water Use (BCM)						
Pessimistic: 9.03			1.46	0.99	1.38	2.21
Optimistic: 6.36	-6.38	-7.96				
M&I Groundwater Use (BCM)						

Table 26. Continued

Year	2060	2060	2060	2060	2060	2060
Population Projection	Optimistic	Optimistic	Pessimistic	Pessimistic	Pessimistic	Pessimistic
Nile Flow (BCM)	A2:	B1:	A2:	B1:	A2:	B1:
Protection from Sea Level rise	Protected	Protected	Protected	Protected	Un protected	Un protected
Pessimistic: 0.92			-11.75	-7.07	-10.99	-19.15
Optimistic: 0.58	72.68	89.86				
Flow to Sea (BCM						
Pessimistic: 23.33			-12.36	-11.92	-12.97	-12.14
Optimistic: 18.97	-16.65	-16.04				
Agricultural labor Hours (Billion)						
Pessimistic: 2.34			-16.96	-14.33	-17.53	-14.23
Optimistic: 2.47	-9.37	-7.86				
Ag. Land Use (million feddans)						
Pessimistic: 17.6			-10.84	-9.45	-11.10	-9.80
Optimistic: 19.2	-3.35	-1.95				
Value of Water (EGP/1000CM)						
Pessimistic: 3646			81.24	66.57	84.04	56.56
Optimistic: 1289	108.69	88.67				
Water Reuse (BCM)						
Pessimistic: 8.9			9.61	9.61	9.61	9.61
Optimistic: 6.36	9.62	9.62				

Table 27. Sensitivity of Egypt to Water Availability Under Conflict

Water Release*	Percentage of Baseline[1]	Scenario	Welfare	Ag. Land Use	Employment	Ag Water Use	Water Value	Flow to Sea
51.7	-7							
		2030 Pessimistic	-0.5	-2.4	-1.0	-7.1	34.3	-3.8
		2030 Optimistic	-0.3	-4.0	-3.3	-7.7	38.1	-2.4
		2060 Pessimistic	-0.8	-5.0	-6.8	-8.1	24.8	-3.3
		2060 Optimistic	-0.4	-2.5	-1.3	-6.3	40.7	-3.6
50.3	-9							
		2030 Pessimistic	-0.7	-3.1	-1.5	-9.9	45.1	-5.0
		2030 Optimistic	-0.4	-5.9	-6.2	-10.4	84.4	-3.7
		2060 Pessimistic	-1.2	-7.1	-10.7	-11.2	35.5	-4.4
		2060 Optimistic	-0.6	-4.0	-1.7	-8.1	59.7	-4.8
45	-19							
		2030 Pessimistic	-1.6	-5.8	-3.0	-20.8	93.5	-9.1
		2030 Optimistic	-1.2	-8.9	-7.3	-19.2	169.3	-6.2
		2060 Pessimistic	-2.8	-13.5	-15.3	-23.6	88.5	-7.1
		2060 Optimistic	-1.5	-5.9	-3.0	-19.3	90.3	-8.3
60	8							
		2030 Pessimistic	0.4	4.1	3.3	7.0	-22.0	2.0
		2030 Optimistic	0.2	3.5	2.0	9.8	-26.2	3.1
		2060 Pessimistic	0.8	5.1	1.6	9.2	-17.9	1.6
		2060 Optimistic	0.4	4.6	3.0	8.0	-24.0	1.6

** Water supply in Billion Cubic Meters (BCM) at Aswan High Dam*

1 Baseline is 55.5 BCM

Table 28. Descriptive Statistics on Natural Logarithms of Coffee Monthly Prices (1994 - 2010)

Price Series[a]	Mean	Standard Deviation	Coefficient of Variation
Uganda Growers (UGR)	3.52	0.58	16.58
Belgium Retail (BRP)	5.99	0.19	3.18
Spain Retail (SPR)	5.82	0.19	3.24
Indicator (IDP)	4.49	0.39	8.65
London Futures (LFR)	4.04	0.50	12.43
New York Futures (NFR)	4.65	0.34	7.40

[a] *Units of measurement are US cents per pound of coffee*

Table 29.Test of Non Stationarity of Logarithms of Monthly Prices and First Differences (1994-2010)

	Augumented Dickey-Fuller Test	Phillip -Perron
Price Series	t-test (k)	Z-test
	(Levels)	
Uganda Growers	-2.26 (2)	-2.54
Belgium Retail	-1.89 (2)	-1.87
Spain Retail	-2.12 (2)	-2.02
Indicator	-1.65 (2)	-1.44
London Futures	-1.71 (2)	-1.38
New York Futures	-2.16(2)	-1.93
	(First Differences)	
Uganda Growers	-6.82 (2)	-12.23
Belgium Retail	-5.85 (2)	-8.88
Spain Retail	-5.80 (2)	-8.51
Indicator	-6.56 (2)	-11.10
London Futures	-6.372 (2)	-9.75
New York Futures	-6.531 (2)	-11.79

The null hypothesis for the augmented Dickey-Fuller test and Phillip-Perron is that the price series are non stationary in levels and first differences. The critical value at 5% critical value is -2.89. The null hypothesis is rejected when the observed value is greater than the critical value.

Table 30. Loss Metric on the Order of Lags (k) in a Level Vector Autoregression on Log Monthly Coffee Prices and 11 Seasonal Dummy Variables (1994-2010)

Number of Lags = k	Schwarz loss (SL)	Hannan and Quinn Metric (Φ)
	Constant, no lags on prices, and no seasonal dummies	
0	-41.09	-41.21
	Constant , no lags of prices and 11 seasonal dummies	
0	-38.90	-40.37
	Constant, lags on prices, and no seasonal dummies	
1	-54.61*	-55.44*
2	-53.36	-54.90
3	-51.64	-53.90
4	-49.93	-52.91
5	-48.39	-52.10
6	-46.68	-51.12
	Constant , lags of prices and 11 seasonal dummies	
1	-52.25	-54.45
2	-51.03	-53.95
3	-49.30	-52.95
4	-47.66	-52.05
5	-45.91	-51.02
6	-44.12	-49.97

Note: We select that model that minimizes the loss metric. ("*") indicated the minimum of each column

Table 31. Test for Cointegration among Logarithms of Monthly Coffee Prices (1994 – 2010)

R	Trace*	C(5)*	P-Value*	Trace	C(5)	P-Value
0	105.93	93.91	0.04	113.13	101.84	0.01
1	67.18	68.68	0.22	71.40	75.74	0.12
2	36.99	47.21	0.63	39.89	53.42	0.48
3	21.21	29.38	0.65	22.92	34.80	0.54
4	10.18	15.34	0.63	11.12	19.99	0.54
5	1.58	3.84	0.85	1.74	9.13	0.82

Note: At a critical value of 5% we stop at the first fail to reject, when starting from across the table and moving from left to right. In this case we stop at R=1.

Table 32. Tests of Stationarity of Each Coffee Monthly Price Series from the Cointegration Space (1994 - 2010)

Price Series	Chi-Squared Test	P-Value	Decision
Uganda Growers	32.82	0.00	R
Beligum Retail	35.54	0.00	R
Spain Retail	34.13	0.00	R
Indicator	38.43	0.00	R
London Futures	37.93	0.00	R
New York Futures	36.81	0.00	R

Note: The test on the null hypothesis is that the logarithm of the particular series listed in the far left-hand column is stationary in levels. The decision heading relates to the decision to reject (R) or fail to reject (F) the null hypothesis at 5% level of significance that the series are stationary in levels.

Table 33. Tests of Exclusion of Each Coffee Monthly Price Series from the Cointegration Space (1994 - 2010)

Price Series	Chi-Squared Test	P-Value	Decision
Uganda Growers	10.22	0.00	R
Belgium Retail	6.72	0.01	R
Spain Retail	0.04	0.84	F
Indicator	0.77	0.38	F
London Futures	4.75	0.03	R
New York Futures	1.33	0.25	F

Note: Tests are on the null hypothesis that the series is not in the cointegrating space. "R" and "F" indicate the decision to reject or fail to reject, respectively.

Table 34. Test of Weak Exogeniety on Monthly Coffee Prices (1994 - 2010)

Price Series	Chi-Squared Test	P-Value	Decision
Uganda Growers	7.42	0.006	R
Belgium Retail	1.78	0.182	F
Spain Retail	0.68	0.409	F
Indicator	0.14	0.707	F
London Futures	0.10	0.748	F
New York Futures	0.53	0.466	F

Note: The null hypothesis is that the coffee series is weakly exogenous. "Decision" relates to the decision to reject "R" or fail to reject "F" the null hypothesis at 5% level of significance

Table 35. Forecast Error Variance Decompositions on Monthly Prices for Coffee (1994- 2010)

Horizons (months)	Percent					
	UGR	**BPR**	**SPR**	**IDP**	**LFR**	**NFR**
			UGR			
0	66.82	0.00	0.00	22.47	10.71	0.00
1	51.06	0.19	0.00	32.06	16.63	0.07
6	30.57	0.44	3.05	46.56	17.05	2.35
12	21.07	2.14	8.34	48.43	11.69	8.33
			BPR			
0	0.00	100.00	0.00	0.00	0.00	0.00
1	0.22	98.60	0.60	0.00	0.02	0.56
6	4.66	77.06	8.44	5.36	0.01	4.48
12	5.58	53.76	16.86	14.91	0.76	8.12
			SPR			
0	0.00	48.72	51.28	0.00	0.00	0.00
1	0.12	54.77	44.41	0.08	0.01	0.62
6	2.24	59.93	26.92	2.32	0.85	7.73
12	3.67	47.29	18.46	12.65	1.29	16.64
			IDP			
0	0.00	0.00	0.00	100	0.00	0.00
1	1.00	0.06	0.64	97.93	0.05	0.32
6	1.83	0.31	2.05	90.68	0.38	4.76
12	1.34	0.42	2.58	81.64	2.02	12.02
			LFR			
0	0.00	0.00	0.00	67.73	32.27	0.00
1	0.62	0.15	0.53	67.31	31.34	0.06
6	0.56	0.73	3.47	69.22	22.49	3.53
12	0.36	0.49	5.78	67.91	13.94	11.53
			NFR			
0	0.00	0.00	0.00	89.87	0.00	10.13
1	0.69	0.11	0.70	91.12	0.00	7.38
6	2.31	1.12	1.77	91.91	0.02	2.87
12	2.00	0.87	1.89	89.27	0.57	5.40

Note: The forecast error variance decomposition are partitions on observed innovations from the estimated error correction model. Each row entry sums to 100. The interpretation is that looking ahead at the given horizon, the variation in that series is attributable to the variation in the series listed in the columns.

Table 36. Sources of Data

Variable	Source of Data
Malaria Mortality in children < 5 years old	WHO, 2010
Malaria Cases in children < 5 years old	WHO, 2010
Percentage of Households with at least one ITN	WHO, 2010
GINI Income inequality Index	African Development Indicator, 2010
GDP per capita in US $	The World Bank, 2010
Health Expenditures per capita in US$	The World Bank, 2010
Adult Literacy Rate	The World Bank 2010
Crude Birth Rates per 1000 of population	The World Bank 2010

Table 37. Average of the Variables from 2001-2009 by Country

Country	U5MC	U5MD	ITN	GDP	LIT	GINI	CDB	HEXP
Benin	48.5	10.2	25.4	562.2	34.6	38.6	40.3	25.3
Burkina Faso	69.8	36.0	19.9	391.1	22.5	39.6	46.4	25.2
Burundi	98.7	3.1	14.2	114.4	60.1	38.3	35.4	12.4
Central African Republic	19.3	11.9	12.9	346.7	49.3	47.5	37.1	14.2
Eritrea	2.1	0.4	67.6	254.1	54.1	41.3	37.9	8.6
Gabon	25.5	11.5	22.2	6261.6	80.4	41.5	28.7	184.7
The Gambia	150.5	10.8	33.0	339.6	37.9	47.3	38.4	20.0
Ghana	44.5	8.9	16.9	682.2	58.9	42.8	33.1	35.2
Guinea Bissau	50.0	23.8	28.1	368.0	42.6	38.3	42.0	13.3
Madagascar	24.9	1.3	32.3	339.9	69.3	47.3	37.8	13.4
Mali	30.1	9.9	34.7	471.5	23.9	39.6	43.0	28.4
Rwanda	45.3	10.7	26.7	318.7	65.5	46.7	41.1	25.6
Sao Tome and Principle	69.5	61.7	42.9	806.6	85.3	51.6	33.6	89.3
Senegal	25.8	4.6	24.2	777.8	39.9	40.1	39.2	43.0
Sierra Leone	44.4	4.5	42.9	259.4	35.5	37.0	41.2	33.8
Tanzania	0.4	0.4	21.4	383.6	68.7	34.6	41.7	16.4
Togo	35.4	20.7	40.2	351.4	54.8	34.4	34.5	27.2
Zambia	183.8	32.3	35.6	677.2	69.2	47.9	43.9	41.0

U5MD, malaria deaths for children under five years per 1,000 of population; U5MC, malaria cases for children under five years per 100,000 of population; ITN, insecticide treated mosquito nets as a percentage of households owning a net; GDP, gross domestic product per capita in US$; HEXP, health expenditure per capita in US$; GINI, income inequality index; LIT , Adult Literacy rate;, CDB, Crude Birth rates per 1,000 of population

Table 38. Average Annual Loss in GDP by Caregiver due Malaria Cases by Country

Country	Loss in GDP *(4 Days)	Loss in GDP *(7 Days)
Benin	2,440,290	4,270,508
Burkina Faso	4,428,980	7,750,716
Burundi	955,273	1,671,728
Central African Rep.	310,375	543,156
Eritrea	24,764	43,338
Gabon	2,467,200	4,317,600
The Gambia	863,111	1,510,445
Ghana	7,461,481	13,057,591
Guinea Bissau	298,014	521,524
Madagascar	1,620,572	2,836,001
Mali	1,907,330	3,337,827
Rwanda	1,478,033	2,586,558
Sao Tome & Principe	92,898	162,572
Senegal	2,523,101	4,415,427
Sierra Leone	654,578	1,145,511
Tanzania	56,940	99,645
Togo	844,672	1,478,176
Zambia	16,300,298	28,525,522
Total	2,484,884	4,348,547

** Days that an informal caregiver takes off to care for a sick child.*
GDP, Gross Domestic Product in US$

Table 39. Average Annual Treatment Cost from 2001-2009 by Country

Country	Outpatient Costs	Inpatient Cost
Benin	803,585	528,160,762
Burkina Faso	2,096,529	925,431,090
Burundi	1,545,941	496,434,624
Central African Rep.	165,705	275,409,508
Eritrea	18,044	298,458,274
Gabon	72,942	91,705,275
The Gambia	470,534	102,237,578
Ghana	2,024,599	1,468,279,607
Guinea Bissau	149,922	98,650,294
Madagascar	882,627	1,181,935,044
Mali	748,922	794,132,895
Rwanda	858,650	608,426,047
Sao Tome & Principe	21,322	10,226,873
Senegal	600,484	757,819,937
Sierra Leone	467,178	339,623,380
Tanzania	27,481	2,624,037,744
Togo	444,998	402,097,872
Zambia	4,456,161	789,219,621
Average	880,868	655,127,024

Table 40. Average Annual Daily Adjusted Life Years Lost from 2001-2009 by Country

		Cost of DALYs in US$	
Country	DALY	DALY(any)	DALY (GFATM)
Benin	25335	159,610,500	276,151,500
Burkina Faso	151866	956,755,800	1,655,339,400
Burundi	8575	54,022,500	93,467,500
Central African Republic	14906	93,907,800	162,475,400
Eritrea	454	2,860,200	4,948,600
Gabon	4652	29,307,600	50,706,800
Gambia	5432	34,221,600	59,208,800
Ghana	60246	379,549,800	656,681,400
Guinea Bissau	10489	66,080,700	114,330,100
Madagascar	7492	47,199,600	81,662,800
Mali	36280	228,564,000	395,452,000
Rwanda	29323	184,734,900	319,620,700
Sao Tome and Principle	2754	17,350,200	30,018,600
Senegal	16185	101,965,500	176,416,500
Sierra Leone	7270	45,801,000	79,243,000
Tanzania	3962	24,960,600	43,185,800
Togo	37545	236,533,500	409,240,500
Zambia	116807	735,884,100	1,273,196,300
Average	29976	188,850,550	326,741,428

DALY, Disability adjusted life years due to malaria disease; DALY(any) calculating the cost of a DALY using the average price of any disease; DALY(GFATM), calculating the cost of each daily using the price of per the Global Fund to fight AIDS, Tuberculosis and Malaria (GFATM).

Table 41. Average per Capita Expenditure on Bednets for Children under 5 each Year

Country	Population	Cost of ITN at $1.7	Cost of LLIN at $5
Benin	7,882,996	0.07	0.20
Burkina Faso	13,812,404	0.08	0.23
Burundi	7,409,472	0.05	0.14
Central African Republic	4,110,590	0.06	0.19
Eritrea	4,454,601	0.06	0.19
Gabon	1,368,735	0.05	0.14
Gambia	1,525,934	0.07	0.19
Ghana	21,914,621	0.06	0.17
Guinea Bissau	1,472,392	0.07	0.21
Madagasca	17,640,822	0.06	0.19
Mali	11,852,730	0.07	0.22
Rwanda	9,080,986	0.07	0.21
Sao Tome and Principle	152,640	0.06	0.17
Senegal	11,310,745	0.07	0.20
Sierra Leone	5,069,006	0.07	0.21
Tanzania	39,164,742	0.07	0.21
Togo	6,001,461	0.06	0.17
Zambia	11,779,397	0.07	0.22
Average	9,778,015	0.06	0.19

ITN cost, cost of an insecticide treated mosquito net at US$1.7 each; LLIN cost, cost of Long Lasting insecticide treated mosquito nets at US$ 5 each.

Table 42. Coefficient Estimates[(a)] for Malaria Cases

Variables	Coef.	Std. err.	T-Stats	Other Stats	Elasticities
Ill	-0.05	0.27	-0.180		-0.047
GINI	1.90	0.80	2.38**		1.481
ITN	-0.31	0.17	-1.83*		-0.171
GDP	-0.66	0.13	-5.24***		-9.338
HEXP	0.51	0.27	1.92*		0.346
POP	0.00	0.00	-2.08**		-0.177
Cons	-8.62	32.662	-0.260		
Wald $\chi^2(6)$ - stats				29.82***	
Hausman				8.19	

***significance at 1%, **significance at 5%, *significance at 10% level

[(a)] The dependent variable is malaria cases in children under 5 per 1,000 of population

[(b)] The insignificance of the Hausman statistic implies failure to reject the null hypothesis that the difference in coefficeints between the random and the fixed effects estimate specification are not systematic, therefore, the random effects model is used.

Table 43. Coefficient Estimates[c] for Malaria Deaths

Variables	Coef.	Std. err.	T-Stats	Other Stats	Elasticities
U5MC	0.39	0.041	9.54***		1.433
GDP	-0.01	0.002	-2.86**		-0.29
Cons	-2.098	2.897	-0.720		
F(2,142)				52.03***	
Hausman[(d)]				17.62***	

***significance at 1%, ** significance at 5%,* significance at 10% level

[(c)] The dependent variable is malaria deaths in children under 5 per 100,000 of population.

[(d)] The significance of the Hausman statistic implies rejection the null hypothesis that the difference in coefficeints between the random and the fixed effects estimate specification are not systematic, and therefore the fixed effects model is used.

Table 44. Cost Saved by Using Insecticide Treated Bednets

	OutPatient	InPatient	Loss in GDP *(4 Days)	Loss in GDP *(7 Days)	DALY (any)	DALY (GFATM)
Average Cost	90	67,000	254	445	19,314	33,416
Average Saved Cost (Benefits)	10	322	28	48	3,030	5,194

Days that a caregiver takes off to care for a sick child by an informal care giver
GDP, Gross Domestic Product in US$
DALY, Disability adjusted life years due to malaria disease; DALY(any) calculating the cost of a DALY using the average price of any disease; DALY(GFATM), calculating the cost of each daily using the price of per the Global Fund to fight AIDS, Tuberculosis and Malaria (GFATM).

The Annual Average costs are US$ per 1,000 of population

APPENDIX C

This appendix presents a mathematical documentation of the Agricultural Sector Model of Egypt (ASME)[27]. The model was updated to assess the implications of climate change on Egypt. The objective function maximizes social welfare as the sum of the areas underneath the demand curves minus the area underneath any supply curves plus price times the quantity of any items sold which are fixed in price minus price times quantity of any factor purchase which are fixed in price. We present the objective function of the model then concentrate on the constraints that are imposed to account for hydrology. The ASME simultaneously portrays the production, marketing, human and livestock consumption, import and export of agricultural products. This model simulates a competitive agricultural sector and model is price endogenous and quadratic in nature. If you take the integral under the linear demand curve as specified in the ASME, one obtains a quadratic expression. Therefore the ASME is a quadratic with squared terms arising in terms of the demand curve slopes for all commodities with sloped demand curves.

The collective objective function of summed integral of areas underneath these curves is known as consumer plus producer surplus. When this objective function is maximized the price of each item supplied equals the price at which those items are demanded and the quantity of the items supplied equals the quantity of those items demanded (McCarl et al. 1989). The ASME therefore portrays what would happen in a perfectly competitive Egyptian agricultural economy. The model assumes that each

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[27] The GAMs code is not publically available only upon request

farmer tries to maximize profit but cannot affect the prices and produce so the price of the product sold equals the marginal cost of delivery those products and similarly the cost of each input used is equal to the marginal value product obtained from utilizing that input. By altering data in the model and comparing the resultant solution, one can study the effect of government decisions regarding resource management policies and innovations like water releases.

The objective function, the consumer plus producer surplus (CPS) is expresses as

(16) $CPS = \sum_K \sum_{NAT_N} \left(\left(\alpha * DSC_{N,K} + 0.5 * \beta * DSC_{N,K} * NDP_{N,K} \right) * NDP_{N,K} \right)$

Plus exports of products which is a product of the quantity of exportable products and export prices

$$+\sum_{NAT_N} EPT_{n,n\subset N} * (EP) * DDT_N$$

Minus the imports; importable commodities times the import prices

$$-\sum_{NAT_N} IMP_{n,n\subset N} * (IP * DDT_N)$$

Government Purchases of products with non zero consumption for its given quota,

$$+\sum_{N} QGP_N * PGV_N$$

Minus the labor costs per region, time period and production process,

$$-\sum_{R} \sum_{WRM_{R,TP}} \left(LUH_{R,T,P} + LUF_{R,T,P} * FRW \right)$$

Production cost for livestock that includes cost of farm managers and labor use that is dependent on livestock numbers and management practices

$$-\sum_{R,LE,FM} LVN_{R,LE,FM} * CI * \sum_{AI} LVB_{AI,LE,FM} + (LUS * FMG) * LVB_{LE,FM} * CFM_{R}$$

$$-\sum_{FAV_{R,FD},CTS_{R,N,S},AIF_{FD,N,FF}} TCST * \left(FCT_{N,FF}\right) * \left(MFD_{R,N,FD,S}\right) * TSTW$$

Crop budget for each crop, region and time (Crop Production Costs)

$$-\sum_{R,C,S,PT,WA}\left(\sum_{MI} CBE_{R,C,S,PT,MI} + 0 * \sum_{CP} CBE_{R,C,S,PT,CP} + \sum_{CI} CBE_{R,C,PT,WA,CI}\right)$$

$$* CLU_{R,C,S,PT,WA}$$

Processing cost and usage by commodity process type and time period

$$-\sum_{WPS_{R,PR,S},CTS_{R,N,S}|PRD_{N,PR}*USG} \left(PGS_{R,PR,S} * (PRD_{PR}) * USG * PRCST\right)$$

Minus the movement of commodities nationally and inter-regional basis with in seasons

(Marketing Channel Cost)

$$-\sum_{R,NAT_{N},CTS_{R,N,S}} \left(MTN_{R,N,S} * MTGC_{N}\right)$$

$$\sum_{R,S,r_{2,r_{2\subset R}},STR_{N}} \left(MIRG_{R,N,S,r_2} * MKGC_{N} | CMTS_{R,N,S} \ \& \ CMTS_{N,S,r_2} \ \& \ R \neq r_2\right)$$

Cost of storing products at national and regional level with in seasons (Storage Cost)

$$-\sum_{R,STR_{N},MSFS_{S},S_{2,S_{2}\subset S}} \left(\left(STRC_{N} * STR_{R,N,S,S_2}\right) | CMTS_{R,N,S} \ \& \ CMTS_{R,N,S_2}\right)$$

Cost of reclaiming new land for agricultural and settlement

$-\sum_{R|PLRS_{R}} LDRC_{R} * CSTRC_{R}$

Minus the cost for irrigation and municipal and industrial water

$-\sum_{R} CSTM\&IW_{R} - \sum_{R} CSTIRRW_{R}$

where the notation for the subscripts, parameters and variables are explained in Tables 45 and 46.

Hydrological Constraints

The Hydrological balance equations in the model are defined (see Table 47). We focus on the municipal and industrial demand balance, regional surface balance, regional drainage balance, municipal and industrial balance, sea balance, agricultural drainage balance, Lake Nasser balance. The cost of irrigation water cost and M&I water cost are also presented.

Municipal and Industrial Demand Balance

The municipal and industrial balance should equal water diverted for municipal and industrial use, pumped groundwater and reclaimed water depending on whether the given region uses drainage water.

(17) $MND_R + INDD_R = DM\&I_R + PGWM\&I_R + RCLMWM\&I_R | DRUR_R$

Regional Surface Water Balance

The surface water balance equation states that the flow from region to region plus the diversion for agriculture and M&I use and evaporation losses should be equal to the return flow from M&I, Lake Nasser regions, rainfall, and agricultural drainage (equation 18).

(18)

$$\sum_{NFP_{R,r_2,r_{2\subset R}}} FL_{R,r_2} + DFAG_R + DFAGR_R + EVAP_R + DM\&I_R =$$

$$\sum_{NFP_{R,r_1,r_{1\subset R}}} FL_{r_1,R} + \sum_{DFP_{R,r_1,r_{1\subset R}}} M\&IRF_{R,r_1} + AGD_{R,r_1} + RN_R + \sum_{RTNFI_R} NASR_R$$

M&I Drainage Balance

The drainage balance for M&I use regions depends on return flow and water reuse. Equation 19 illustrates on the left hand side that the net return from M&I demand use should be equal to the amount of water that is reuse or reclaimed plus the M&I return flow.

(19) $RCLMWM\&I_R|DRUR_R + \sum_{DFP_{R,R_{aR_A \subset R}}} M\&IRF_{R,R_a} = (MND_R * MNRT_R +$

$INDD_R * INDRT_R) * (NPD * RFLD_R)$

Sea Balance

The Sea Balance constraint accounts for the total water that flows to sea after it release at the HAD. The amount that flows to the sea should be equal to M&I return given as a proportion of sea proportional drainage plus Nile flow path to sea for surface water regions, agricultural drainage given the Nile proportional drainage, M&I return flow, loss in conveyance, loss in field application of surface and ground water, and then accounting this total flow to sea with loss to ground water recharge.

(20) $\sum_R(MND_R * MNR_R + IDDR_R * INDR_R) * (RTFLD_R * SPD) + \sum_{NFP_R}(FL_R *$

$SEA)\ |SWR_R + \sum_{DFLP_R}(AGD_R * SEA)\ |(RFLD_R * NPD) + (M\&IRF_R * SEA)|(RFLD_R *$

$NPD)$

Loss in conveyance of surface water

$$+[[DFAG_R * (1 - IRRCE_R)$$

Loss in field application of surface water

$$+(DFAG_R * IRRCE_R) * (1 - IRRCE_R)$$

Loss in field application of pumped ground water (no conveyance loss here)

$$+PGWAG_R * (1 - IRRFE_R)$$

Loss in conveyance of rice percolation water

$$+DFAG_R * (1 - IRRCE_R)$$

Loss in field application of rice percolation water

$$+(DFAG_R * IRRCE_R) * (1 - IRRFE_R)]$$

Remove amount of groundwater recharge

$$* (1 - GWRCHPR_R)] * (RFLD_R * NPD_R)$$

$= FLWTS$

Agricultural Drainage Balance

The agricultural drainage balance constraint is similar to the sea balance with emphasis on agricultural drainage flow path given return flow data available and Nile proportional drainage as accounted for in the model (left hand side of equation 21). The right hand side which is loss in conveyance, loss in field application of surface and ground water, and then accounting this total flow to sea with loss to ground water recharge should equate to the left hand side of the equation.

(21) $\sum_{DFP_{R,R_a\,R,R_a \subset R}|RFD_{R*NPD}} ADR_{R,R_a} =$

Loss in conveyance of surface water

$$+[[DFAG_R * (1 - IRRCE_R)$$

Loss in field application of surface water

$$+(DFAG_R * IRRCE_R) * (1 - IRRCE_R)$$

Loss in field application of pumped ground water (no conveyance loss here)

$$+PGWAG_R * (1 - IRRFE_R)$$

Loss in conveyance of rice percolation water

$$+DFAG_R * (1 - IRRCE_R)$$

Loss in field application of rice percolation water

$$+(DFAG_R * IRRCE_R) * (1 - IRRFE_R)]$$

Remove amount of groundwater recharge

$* (1 - GWRCHPR_R)] * (RFLD_R * NPD_R)$

Lake Nasser Water Balance

The Lake Nasser balance represents the amount of water that is held behind the HAD that is available annually for use in Egypt. The total amount that is release to regions from Lake Nasser should be equal to the amount of water in the Lake Nasser (equation 22).

(22) $\sum_X NASR_X = LNW$

Irrigation Water Cost

The cost of irrigation water as expressed in equation 23, is set equal to the cost of pumping ground water, fossil ground water cost, the annualized cost of metering irrigation water plus the annualized cost per feddan (land tax) for a region that grows these crops.

(23)

$CSTWIRR_R =$

$PGWAG_R + PGWM\&I_R * (GWCST_R | NFGWR_R) + (FGWCST_R | FGWR_R) +$

$(MWATI + CONSCST) * \sum_{DCPE_{R,C,S,PT,WA}} CLU_{R,C,S,PT,WA}$

Municipal and Industrial Water Cost

The cost of municipal and industrial water cost is equated to the sum of annualized cost of treated water in PWS, raising PWS efficiency and metering costs of irrigation water for surface water; plus ground water cost as a proportion of M&I demand for each region; plus cost for fossil ground water regions; plus drainage costs for reclaimed M&I water; and the treatment cost for M&I return for the drainage reuse region (equation 24).

(24) $$CSTM\&IW_R = \big[(CPWAT_R + MWATM + PWSCST) * \big(MND_R * (1 - GWS_R) + INDD_R * (1 - GWS_R)\big) + GWCST_R * (MND_R * GWS_R) + (INDD_R * GWS_R)\big]|NFGWR_R + [(FGWCST_R + MWATM + CPWAT_R + PWSCT) * (MND_R + INDD_R)]|FGWR_R + RCLMWM\&I_R * DRCST_R + TRMCST * [(MND_R * MNR_R)|DRUR_R + (INDD_R * INDR_R)|DRUR_R]$$

Table 45. Subscripts Included in the Formulated Model

Subscripts	Definition
AI	Animal Input
C	Crops
CI	Cost Items
CP	Physical Crop Inputs
FD	Feeds
FF	Feed Form
FM	Feed Method
K	Consumption
LE	Livestock Enterprise
MI	Mechanical Inputs
N	Commodities
PR	Processing Type
PT	Planting Time
R	Regions
R	All Regions
S	Seasons
TP	Time Period
WA	Water Application Rate
X	Region that Lake Nasser Flows into

Table 46. Variable Notation and Definition.

Notation	Definition
AIF	Commodity Allowed in Feed
CBE	Crop Budget Expanded (set)
CFM	Cost Farm Manager
CLU	Crop Land Use
CMTS	Commodity to Season
CONSCST	Annualized Cost in LE per Feddan
CPWAT	Annualized O&M Cost of Treated water PWS
CSTIRRW	Cost of Water for Irrigation
CTS	Cost to Season
DCPE	Does Crop Exist
DDT	Demand Data
DFAG	Divert for Agriculture
DM&I	Divert for Municipal and Industrial Use
DRUR	Drainage Reuse Regions
DSC	Demand Supply Curve
EP	Export Price
EPT	Export Products
EVAP	Evaporation
FAV	Farm Available
FCT	Nutrient Contents of Feed Ingredient
FGWR	Fossil Ground Water Region
FMG	Farm Management
FRW	Reservation Wage Factor for Family Labor
GWCST	Annualized O&M Cost of Pumping Shallow GW
GWRCHPR	Groundwater Recharge
GWS	Ground Water Share
IMP	Import Products
INDD	Industrial Demand
INDD	Industrial Demand
INDRT	Industrial Return
IP	Import Price
IRRCE	Irrigation Conveyance Efficiency
IRRFE	Irrigation Field Efficiency
LDRC	Land Reclamation Cost
LNW	Lake Nasser Water
LUF	Labor Use Family

Table 46. Continued

Notation	Definition
LUH	Labor Use Hired
LUS	Labor Use
LVB	Livestock Budget
LVN	Livestock Numbers
MKGC	Marketing Cost
MNRT	Municipal Return
MSFS	Storage Links (matchseasonfor storage) (set)
MTN	Move to National
MWATI	Annualized Metering Cost for Irrigation Water
NAT	National
NFGWR	Not Fossil Ground Water Region
NFP	Nile Flow Path
NPD	Nile Proportional Drainage
PGV	Government Procurement Price
PLSC	Potential Land Reclamation
PRCST	Process Cost
PRD	Processing Yields (set)
PWSCST	Annualized Cost LE per CM of raising the PWS Network Efficiency
QGP	Quantity Government Purchase
RFLD	Return Flow Data
RN	Rain
RTNF	Regions that Nasser Flows into
SEA	Sea
SPD	Sea Proportional Drainage
STR	Storage
STRC	Storage Cost
SWR	Surface Water Region
TCST	Treatment Cost
USG	Usage
WPS	When Do Processing Alternatives Exist (Set)
WRM	Wage Rate per Day

Table 47. Hydrological Equations

Equation	Definition
Municipal and Industrial Drainage Balance	M&I Drainage Balance where reuse occurs
Municipal and Industrial Demand Balance	Balancing Demand that Includes reuse
Regional Surface Balance	Regional Water Balances
Sea Balance	Water Balance Flow to the Sea
Agricultural Drainage Balance	Agricultural Regional Drainage Balance
Lake Nasser Balance	Allowed Annual Release from Lake Nasser
Irrigation Water Cost	Cost of Irrigation Water
Municipal and Industrial Water Cost	Cost of Public Water Systems

VITA

Name: Mark Musumba

Address: AGLS Building
2124 TAMU
College Station, TX 77845-2124

Email Address: musumba_m@yahoo.com

Education: B.S., Economics, Texas A&M University, 2004
M.S., Agricultural Economics, Texas A&M University, 2006
Ph.D., Agricultural Economics, Texas A&M University, 2012