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Impact Evaluation of Climate Change Adaptation and International
Politics on the Economic Growth and Welfare of Developing Countries:
A computable General Equilibrium Approach

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Rami Sabella

Abstract

This work builds upon a dynamic CGE model to evaluate the impact of different scenarios of climate change shocks on two African countries, Tunisia and Egypt. The model is of a small-open economy that reflects in relative prices the impact of some possible national and international politics of climate change on welfare and economy, as well as the change in local GHG emissions. The scenarios cover different arguments, such as productivity reduction due to climate change, efficiency increase due to CDM projects introduced in Kyoto protocol, the effect of changes in international prices of certain regulated goods given their carbon content, environmental taxes and adaptation financing options. The model builds on GTAP database for Africa and uses GAMS/MPSGE interface.

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1. Introduction

1.1. Motivation and Objectives

North African countries find themselves in front of different risks and options to account for when dealing with climate change; north African countries have a hot weather, scarce clean water sources, cities at sea level and have little resources to handle climate change risks. They are at a point where they have different scenarios to choose from, should they make a move and act unilaterally by setting targets on their own to reduce GHG emissions, or economic development comes first? Should they simply adapt? What is the right environmental tax rate to raise funds for abatement actions? Should they modify their production techniques to reach European market with certain imports tariffs on carbon content?

The agricultural sector plays a major role in the GDP, employment and wellbeing of Tunisia and Egypt, if land rent and agricultural profits decrease, economic resources may start migrating to other industries. One of the study's objectives is to measure the impact of such reallocation of resources on GDP and GHG emissions in case of land productivity decrease due to climate change.

The study goes further to analyze certain "clean" investments in Africa, which are financed by developed countries, the objective is to assess the impact of such investments on the GHG emission reduction and the level of sustainable economic development of the receiving country.

Countries who signed the Kyoto protocol have started to abate GHG emissions using the different abatement options. These governmental interventions have increased the world price of regulated goods; specifically, agricultural and energy-intensive goods, which have a high level of carbon content. The study sheds light on the effect of such higher world-prices on the relevant exporting industries of Egypt and Tunisia.

The study analyzes the existence of a double dividend effect in case Egypt or Tunisia decides to act unilaterally to mitigate CO₂ emissions on voluntary basis, i.e. the possible reduction in distortions when other taxes are reduced to compensate for the new carbon

taxes. Finally, the study sheds light on the impact of raising funds needed for new adaptation initiatives using environmental taxes on the welfare and economic growth.

1.2. Methodological Issues

Climate change risk is a major concern for humankind, initiatives to control the risk are discussed at all levels, abatement mechanisms are becoming more attractive with the continuous technological advancement and research. Planning for mitigation, however, implicitly includes complex decisions such as figuring out the right tax rate or the optimal cap for emissions and measuring the impact of each policy plan ex-ante to achieve targets effectively and efficiently. CGE theory stands out to prove how useful and flexible tool it is to study environmental policies like few other economic theories can. CGE is suitable for environmental research, as energy-producing sectors are deeply related to other sectors. Controlling GHG emissions through energy consumption has a general effect. Moreover, CGE is a great tool to describe factor accumulation and productivity growth, which are needed to describe long-run adjustments to GHGs accumulation.

GTAP is the most widely used database for environmental policy analyses; it is comprehensive global database and regularly updated with integrated CO₂ emission data sets. In this work, the “GTAP Africa 2 Data Base” (Narayanan, G. et al (2012)) has been used. This recent database based on the GTAP 8.1 Data Base that was extended to give details on more African countries. It includes data for 42 regions, the 57 sectors and 5 factors of production. It consists of regional input-output data, bilateral trade flows, macroeconomic data, and energy data for the reference years 2007, measured as money values, in millions of 2001 U.S. dollars.

An often-major weakness of CGE is the lack of literature about parameter estimation; GTAP provides also a set of elasticity parameters that were used in this study, others were retrieved from economic literature or estimated from the social accounting matrix. The robustness of the model was check through sensitivity analysis of key parameters.

1.3. Organization of the Thesis

Chapter 2 discusses climate change risks, the international consensus and internationally proposed mechanisms to mitigate GHGs, abatement timing and possibilities, the role of developing countries and the importance of maintaining sustainable development, and elaborates on the intertemporal allocation of abatement costs and benefits.

Chapter 3 surveys economic literature of climate change, briefly introduces the general equilibrium theory and links it to CGE modeling. It discusses the various structure and design of environmental CGE models, highlights the importance of international trade in environmental CGE models, highlights some of the energy-related datasets, and sheds light on computers' role, available packages and software for CGE programming.

Chapter 4 documents the development of a recursive general equilibrium model for two developing countries of the MENA region -Tunisia and Egypt- based on recent SAMs retrieved from GTAP database released in 2013. The model is designed for policy analysis in a small open economy. The model formulation and analysis are done using the Generalized Algebraic Modeling System (GAMS).

Chapter 5 measures the impact of shocks caused by change in climate change on factors of production, prices and welfare levels. It also measures the impact of relevant regulations and international policies that include environmental taxes, efficiency in energy use and international limitations on exports and of goods with carbon content. Chapter 6 includes the sensitivity analysis and chapter 7 gives a conclusion.

2. Climate Change Risk, Adaptation and Abatement

2.1. Introduction

The various studies, on the average evolution of temperature, overtime have doubtlessly proved that the blue planet has been getting warmer, most noticeably over the past century. Most recent studies by NASA show that the nineteenth century average temperature of the planet has increased of 0.8°C ¹. Starting in 1970, the average increase of temperature was faster; industrialization and changes in human activities played a major role. The current rate of increase in average temperature is around 0.2°C per decade, should this continue at the current pace, the terrestrial atmosphere would heat up by 2°C through the 21st century. The International Panel on Climate Change (IPCC), a global network of scientists attached to the United Nations, explains that an increase of nearly 1°C in average temperature in a century is too fast, and is certainly much faster than average temperature changes observed over known human history (IPCC (2007)). Moreover, it argues that for the first time, these changes are caused by the activity of the human race.

Since the beginning of the 90's, climate change has been widely discussed at all levels. Scientists, scholars and the general public, differ in their views of the phenomenon. Yet two extreme views can be patterned. On one extreme, there is the "Skepticism" view, where skeptics build their doubts on the many uncertainties that enter in the work of climatologists, and the difficulty they face in forecasting the reactions of the climate to the increase (or decrease in case of mitigation) of Greenhouse Gases (GHGs). On the other extreme, there is the "Catastrophism" view. Catastrophism argues that global warming is a fact and a very serious matter that must be dealt with; it builds on the premise that past trends are not sustainable and will lead to inevitable catastrophes as serious as the extinction of human kind. While Catastrophism promotes prompt large-scale actions to reduce GHG emissions, skepticism denies the risk, which may be tempting for decision makers to postpone taking action. Between the two views comes a responsible one, which deals with climate change as a risk to be accounted for; a risk that is not to be ignored since there may come a time when it will be extremely expensive to eliminate or even irreversible. Hence, climate change has to be taken into consideration and accounted for properly in our economic life.

¹ See Hansen et al. (2010) for a detailed review

2.2. Adaptation and Abatement Tools

Is global warming necessarily bad? Does climate change necessarily hurt everyone? As a matter of fact, global warming affects different regions differently creating winners and losers. Let us take agriculture as an example, in a business as usual (BaU) scenario where the increase in average temperature is around 0.2°C. Agriculture in high latitude regions (such as in Canada, Russia and North Europe) will benefit since cold weather is the main reason hindering agricultural activities. On the other hand, some regions will be worst off; sub-tropical regions will face increasing difficulties in gaining access to fresh water needed for farming or to be used for drinking². Hence, confronting the few benefits global warming has with the high cost and scarce resources needed to be allocated to mitigating activities and their opportunity cost, some would argue it would be better to adapt to climate change rather than control it. Adaptation entails severe changes; maritime routes may need to be detoured, ports will have to adapt to the increase in sea level, seasonal demand on energy and water will alter, farmers will change what they grow and some people will have to migrate, especially those in cities at sea level. The majority of such unplanned adaptation will take place ex-post, however, adaptation promoters advise governments to act ex-ante, i.e. provide people with information about the expected outcomes at local level, plan for future urbanization caused by migration, adapt areas for climate change, giving priority to vulnerable regions by transferring needed resources to such areas, otherwise adaptation will rapidly become impossible and people will gradually migrate adding to the problem of adaptation in other regions.

Climatologists argue that in the scenario where average increase in temperature goes beyond 0.3°C; most of these adaptation strategies become ineffective. Such a conclusion leads us to believe that avoiding abatement and counting on adaptation only might mean taking a risk that we cannot afford. Therefore, serious proactive and preventive solutions are essential to prevent catastrophic climate change. Such preventive actions may take the forms of geo-engineering, de-growth and pricing carbon.

² In Stern review 2006, Nicholas Stern estimates the global loss in GDP caused by climate change to be between 5 to 20 percent, where 80 percent of the loss will be in developing countries.

2.2.1. Geo-Engineering

GHG³ work as a green house, they redirect heat emitted by earth in all directions, part of them returns to earth. CO₂ is the type that mankind emits in the largest quantities. CO₂ emissions by mankind can be divided by source into two main categories; agriculture and forestry which account for a third of total emissions, and energy for little less than two-third. CO₂ emitted remains in the atmosphere around a hundred years. Carbon is not only reserved in atmosphere, it rather continuously circulates among different reservoirs: the atmosphere, the biosphere, sediments and oceans. Human activities such as burning Fossil Fuels (Coal, oil and gas), deforestation and soil drainage disturbs the natural carbon cycle leading to a higher concentration of CO₂ in the atmosphere, which causes the greenhouse effect.

Geo-engineering are techniques that maybe categorized into two main approaches. The first is preventing a proportion of the sun's rays reaching the earth's surface. One way to accomplish this is through installing panels that reflect rays back to outer space. The main advantage of this technique is that it leaves the composition of the atmosphere unaltered. Blocking sunrays can also be done by creating artificial clouds or dispersing sulphur into the atmosphere creating layers of sulphates from which parts of the sun's rays rebound. The second available technique of geo-engineering is artificially alternating the carbon cycle by reallocating some of the CO₂ in the atmosphere and storing it in other reservoirs. This is known as Carbon Capture and Storage (CCS). It may be done through pumping CO₂ directly from polluting firms, or indirectly from the atmosphere, into underground reservoirs. Otherwise, it could be carried out by increasing the ocean's storage capacity of carbon by stimulating plankton growth by means of iron sulphate. The effectiveness of such techniques is still questionable, Geo-engineering includes risks that have not been fully explored, and requires technologies that are costly or may only be available in the future.

2.2.2. De-Growth

Nicholas Georgescu-Roegen was the first to advocate the de-growth paradigm in the early 1970's, as he emphasized the dangers of economic growth. The term 'de-growth economics' has been associated with the work of French Economist Serge Latouche. In

³ The six main anthropogenic GHG are water vapor, carbon dioxide (CO₂), methane, nitrous oxide and several families of fluoride gases such as chlorofluorocarbons (CFC) and Hydro fluorocarbons (HFC).

2008, at the Economic De-Growth for Ecological Sustainability and Social Equity conference in Paris, ‘de-growth economics’ emerged as an intellectual movement.

Not to be confused with Green Growth⁴, de-growth as defined by Schneider et al. (2010:512) as “an equitable downscaling of production and consumption that increases human well-being and enhances ecological conditions at the local and global level, in the short and long term”. De-growth emerges as a model that shows a tradeoff between sustainability and economic growth since the latter is responsible for social and environmental degradation. The de-growth model promotes the urgent need to follow equitable ways of reducing production and consumption, to enhance sustainability and benefit human wellbeing, as well as biodiversity. Some people go even further to advocate a reduction in birth rates following Malthus steps. Although de-growth does lead to higher environmental protection, it does not seem convincing neither to developed nor to developing countries.

2.2.3. Pricing Carbon: Taxes and Permits

Since the early 1990’s, responsibilities and possibilities of mitigating emissions have been seriously considered. Attention has been given to controlling the energy sector; producing two-third of the CO₂ emitted. A simple yet effective way to reduce GHGs emissions is through regulatory capos; where a government specifies a maximum allowable rate of pollution. Forcing regulation is a straightforward technique that requires firms to install pollution abatement equipment or limit the rate of output or a combination of both.

Pricing carbon⁵ however, is more appealing; not only does it increase the cost of producing goods that emit GHGs in high quantities and reduce their quantity produced; it also discourages the use of energy sources that emit high quantities of CO₂ for the same unit of power⁶. Pricing carbon discourages the development and exploitation of the most expensive oil reservoirs, and encourages producers to reorient investments into low-carbon energy infrastructure. One last significant advantage of carbon pricing is that it generates a

⁴ An economic growth path that synthesizes economic growth and environmental protection through investing in resource saving and managing the natural capital sustainably.

⁵ Pricing any specific type of the fossil fuels, rather than pricing carbon, would have an effect only in the short run. As a matter of fact, increasing the price of one of the fossil fuels (say oil) may lead to substituting it, in the medium or long run, with another that may emit more CO₂ to produce the same unit of energy (like carbon). Moreover, higher prices of fossil fuels mean investing more money to dig reservoirs currently unfeasible, which would lead to more emissions.

⁶ Coal emits more CO₂ than oil for the same unit of power, the energy produced by burning a tonne of oil releases 3.1 tonnes of CO₂, to get the same energy units using coal, 4 tonnes of CO₂ are released.

new form of rent (tax money) that can be used to invest in mitigation activities, reduce other distortionary taxes on factors of production and boost economic growth. Hence, not only does carbon tax reduce CO₂ emissions, but also may reduce other taxes and increase welfare. This is known as the “double dividend” effect⁷.

Two carbon-pricing avenues are open to governments; they are (i) Pollution Taxes, also known as “effluent fee”, and (ii) Emission Trading Schemes (ETS) also known as “Cap-and-Trade”. The use of taxes to protect the environment dates back to the early 1920’s advocated by the English economist Arthur Pigou. He proposed incorporating in the cost of production an estimated value for the protection of environmental assets by society. In purely theoretical terms, the level’s rate can be easily calculated, that is when marginal cost of the tax equals the environmental benefit. The more value a society assigns to environment protection, the more it will be willing to pay a higher tax. A major advantage for using emission tax lies in the ex-post exogenously fixed and visible price of carbon, which is the tax rate itself. The major disadvantage, however, is that fixing a price tax for carbon usage, makes anticipating the volume of emissions a difficult task, at least at the early stages of implementation. Since, the environmental outcomes of this policy are uncertain, it may not be the optimal choice when aiming for specific reduction targets in CO₂ emissions.

Emission trading schemes, on the other hand, dates back to the 1960’s when two economists, Tom Crocker and John Dales, explored it, building on the early work of Ronald Coase. The first time the theory was put into practice was in 1995 when the USA started to fight acid rain. In contrast to taxes, in an ETS the volume of emissions allowed is capped in advance, while the price of carbon is left to be determined by the market. In other words, we are certain of the outcome of the environmental policy adopted, but uncertain about its cost for the economic actors. The first large-scale trial for CO₂ emissions reduction was initiated by the EU in 2005 where 11,000 industrial institutions were involved, accounting for about half of the total EU CO₂ emissions⁸. The EU system of Cap-and-Trade started by allocating allowances for free at the beginning of the year, the cap for each firm, and the corresponding allowances received, was determined using the “Grandfathering Model”⁹

⁷ See section 6 for an elaborated discussion

⁸ For discussions of the design of the EU trading scheme see Ellerman, A. Denney, et al (2010) and Weisbach A. David (2011).

⁹ Other models of distributing allowances were proposed yet not adopted; the “Egalitarian Model” where every inhabitant of the planet gets an equal share of emission allowance, and the Carbon Sink Model” where

adopted by the Kyoto protocol. The grandfathering model takes a historical trend of emissions then chooses a target level that relates to this historical base. This way, major emitting regions keep the major share of emissions and its rent. The year after, firms have to hand in the allowances corresponding to their emissions level of CO₂, if emissions were less than their cap, they could sell the surplus or keep it for the following year, which is known as “banking”. In case of shortage, however, firms could buy from others who had surplus, use some allowances from those designated for next year, or pay a fine corresponding to the extra CO₂ emitted. It is worth noting that emission taxes and ETS are not necessarily in competition, in fact, some countries, like Sweden, Finland and Ireland, use a combination of both.

2.2.4. GHGs International Abatement Mechanisms

The Kyoto protocol succeeded to introduce three exciting mechanisms to help reduce GHGs, the first is International Emission Trading mechanism (IET) defined in article 17, where countries committed to reduce GHGs can trade the “not used” allowances in the international carbon credit market to cover their shortfall and meet their targets. Another mechanism adopted by the Kyoto protocol was the Joint Implementation mechanism (JI) that was defined in Article 6, allowing credits to be earned by a developed country who implements GHG reduction projects in other developed countries (both listed in Annex B of the protocol), it was initially introduced to encourage projects in countries in transition to a market economy¹⁰. The third mechanism is Clean Development Mechanism (CDM) that was defined in Article 12 of the protocol. Under the CDM a developed country can implement or sponsor a GHG reduction project in any developing country of those who have ratified the protocol. The world is getting excited about this mechanism because of the low cost of GHG reduction in developing regions compared to developed ones, in addition to the capital investment and clean technology transferred to developing countries.

Under Kyoto protocol and within a cap-and trade system framework, the concept of “Tradable Carbon Credits” was introduced. A carbon credit is a certificate that allows the holder to emit a certain amount of CO₂, or certifies that the holder has paid to have a certain amount of CO₂ (usually equivalent to one ton) removed from the environment. A tradable credit can be an unused emission allowance issued and assigned under a Cap-and-

allowanced are allocated to owners of carbon sinks, every time an owner extracts a barrel, it surrenders the corresponding number of allowances, for a detailed explanation see De Perthuis (2000).

¹⁰ Such as Russia, Ukraine, and Eastern European countries.

Trade system. A carbon credit may be traded, held for later use, sold or retired. On one hand, Carbon credits can be traded “over the counter” where firms try to obtain the needed credits directly from its counterparts or turn to a broker who connects buyers and sellers. Bilateral and brokered transactions are totally based on mutual trust. On the other hand, there exist organized markets for carbon credits; such markets provide participants with two types of services, which lack in over the counter transactions, namely continuous transparency of the bid asking price with the possibility to buy or sell credits all the time and the possibility of spot or future trading.

Certified Emission Reductions (CERs) is another kind of carbon credits that take the form of “offsets”; those are real reductions of CO₂ emissions that usually take place outside the four walls of a firm. Examples of offsets are planting trees and preserving forests. GHGs have a global impact; once they are released, they easily merge with other gases and spread rapidly affecting the entire planet, hence, offsets were also made possible to acquire through mitigation activities implemented in developing countries. Abatement activities of CO₂ in developing regions are usually at a fraction of the cost, to obtain the same magnitude of reduction in the developed part of the world. Take for example a highly efficient German firm that needs to reduce its emission by 10% versus a primary and inefficient one in China. Such a German firm (or UNFCCC¹¹-certified agents in developing countries who are parties of the convention) may invest in mitigation projects in the developing world to achieve a huge reduction in CO₂ at a relatively low cost. Yet such projects need to meet certain standards designed by the UNFCCC, and may only take place in developing countries who have ratified the Kyoto protocol. Once approved by the UNFCCC such offsets become accredited as CERs and function as tradable carbon credits.

2.3. Developing Countries: Between Sustainable Development and Abatement

The Kyoto Protocol and the UNFCCC before that, managed to secure unilateral commitments by developed countries to reduce their emission of GHG before the developing world initiates similar actions. Unlike developed countries, developing ones face vital urgent priorities, which certainly exceed those related to GHG emissions. The real challenge facing the international community, when dealing with the developing world, is reconciling the objective of preventing dramatic climate change and that of local

¹¹ In 1992, countries adopted the United Nations Framework Convention on Climate Change (UNFCCC) as a response to the problem of global warming. The 195 countries that have ratified the Convention are called Parties to the Convention (PC).

development. Over the past twenty-five years, many CGE models for developing economies have been developed to analyze the relationship between economic development, trade policy and environment, the OECD took the lead as it developed ad-hoc CGE models for various Latin American and Asia Pacific economies. Many policies and measures have been suggested to bridge the gap, some of which are discussed in a World Resource Institute publication titled “Growing in the Greenhouse, Protecting the Climate Change by Putting Development First” (Bradley, R., and K. Baumert 2005). These measures aim at meeting the domestic objectives of sustainable development, yet bring significant benefits to the climate through reduced GHG emissions.

The unilateral action of developed regions brings out two concerns: the first is whether such unilateral actions are enough to avoid worst-case scenarios, especially with poor countries industrializing at a rapid pace. Research, where CGE models prove to be exceptionally useful, continuously tries to estimate possible outcomes with and without commitments by developing countries. The second concern is the problem of “carbon leakage”, which is the flee of energy-intensive production to regions without controls raising the overall emission level of CO₂ once again. When this debate was at peak, a break-through paper by Manne and Martins (1994) explained the reasons of such a possible leakage, it concluded that there are two causes of carbon leakage; Firstly, firms - highly dependent on energy- paying for carbon in countries committed to limiting their emissions would relatively lose competitiveness to the advantage of other firms in regions with no commitments who, as a consequence, tend to produce and emit more. Secondly, a reduction of fossil fuel consumption in committed regions would lead to a reduction in fuel prices worldwide; this would result in more fuel consumption in non-committed regions. CGE models have proved to be a helpful tool to analyze these concerns and provide different scenarios and expectation to better deal with the risk. In fact, a well-designed environmental global CGE model should take into consideration the possibility of quantifying carbon leakage in cases of unilateral mitigation policy.

Since the Kyoto protocol agreement, many CGE models have been developed to measure whether the leakage had been significant, each giving different results, some registered a leakage of less than 5 percent, while others up to 70 percent¹². There have been trials, by countries taking unilateral actions to eliminate or at least limit the leakage effect, some analysts recommend imposing border import tax and border export subsidies as mechanism

¹² (see Rutherford (1992), Joshua et al. (2012), McKibbin and Wilcoxon (1995))

to neutralize the leakage risk. Border taxes can be imposed on embedded carbon in imported goods or may take the form of a rebate of taxes paid on exported energy-intensive goods. Adjustment through boarder taxes is a complex process; calculating carbon content in tradable goods is complex as different firms emit different amounts of carbon to produce identical units depending on the technology used, information about the emissions of the imported goods produced abroad are difficult to account for, especially those produced in developing regions.

2.4. Intertemporal Allocation of Abatement Costs and Benefits

Apart from sharing cost and responsibility among countries, comes the concept of distributing costs and benefits due to global warming between current and future generations. Global warming negatively affects the welfare and productive abilities of future generations, how much cost should current or future generations forgo to make future ones better off? Main economic discussions of global warming such as “the stern Review” (Stern, 2006) and Nordhaus comments on it (Nordhaus, 2006) seem to implicitly consider that investment in global warming needs to be paid for by cutting current consumption levels. Current generations need to reallocate their resources by reducing their consumption and emissions to invest more in mitigation. This will decrease current standards of living and increase those of future generations.

While many analysts continuously try to weigh the cost against the benefits for current and future generations, other views argue that this trade-off is an erroneous belief (see Foley, 2007). Investing more in GHG mitigation, if implemented properly, will not reduce the consumption levels of current generation, as a matter of fact, both generations may share the benefits and become better off. This is done by alternating the nature of investments; there should be a reduction in conventional investment (in productive facilities and technology) and an increase in investment in GHG emission while keeping current consumption constant. They argue that output is typically divided between consumption (that affects the welfare of current generations) and investment (that affects the productive capabilities of future generations). Hence, by reducing conventional investments and increasing investment in green energy and mitigation (both affecting future generations) the current generation may maintain a steady level of consumption. Furthermore, current the generation may be compensated for its reduction in consumption of carbon intensive

energy by subsidizing their consumption or reducing certain distortionary taxes using some of the rent generated through pricing carbon.

In an interesting paper by Foley and two other ecological economists (Rezai, Foley and Taylor 2010), they argue that “inter-generation trade-offs” due to climate change policies exist only because of a misleading representation of externality internalization in economic growth models. They argue that much of the available growth models for climate change analysis compare the optimal scenario, where externality is corrected and fully internalized with a “constrained optimum”; externality is partially corrected rather than a BaU where it is totally uncorrected. This “erroneous” partial representation of externality has been directing attention toward intergenerational distribution issues because partial internalization typically leads to higher per capita consumption for current generations for several decades to come.

In addition to the debate of who should pay for it, questions such as: who should benefit from carbon tax money? What is the best way to spend it? When to use it? Have also been a source of controversial debate. Many CGE models have been developed to analyze the possible scenarios and measure their effects¹³. The rent may simply be reinvested in GHG emission reduction, used to reduce taxes on production factors, reduce distortionary taxes or subsidize consumption. Using tax money for such purposes could lead to what is known as the “double dividend” effect. Promoters for the double dividend effect explain that besides carbon pricing’s first “environmental dividend” that is a CO₂ emission reduction, a second dividend comes from the use of the rent to reduce distortionary taxes, which is known as the “non-environmental dividend”. A very important contribution to the topic was made by Goulder (1995a), in his work he introduced the concept of “strong double dividend”. Strong double dividend refers to a case where substituting a distortionary tax with an environmental tax (keeping the same tax revenue level) would lead to a non-positive welfare cost. This shows that regardless of the environmental benefits of an environmental tax, at an economic level it can improve welfare.

¹³ see Repetto (1992), Goulder (1995a) and Bovenberg and Goulder (2001) for an elaborate discussion

3. General Equilibrium Theory and CGE Modeling

3.1. Introduction

The General Equilibrium (GE) theory dates back to the 1870's, in particular, to the early work of Léon Walras "Elements of Pure Economics"¹⁴ when he proved the existence of a unique equilibrium in all markets simultaneously. Later, the theory was substantially developed at the hands of Gérard Debreu and Kenneth Arrow (1954) in a breakthrough paper "Existence of an Equilibrium for a Competitive Economy". The theory entails that for every household income equals expenditure, for every productive sector, price equals marginal cost and for every commodity demand equals supply. Opposite to partial equilibrium models that analyze every sector of the economy separately under *ceteris paribus* assumptions, GE models account for adjustments in all sectors. This allows the interactions between intermediate input market, factor markets, other commodities and consumer expenditures.

A Computable General Equilibrium (CGE)¹⁵ model is an empirical implication of the GE theory, designed to solve models that describe an economy (or more) as a whole. The word computable refers to the ability of such models to quantify the effects of a shock on the overall economy. A typical CGE model contains exogenous and endogenous variables with a set of behavioral equations explaining the economic behavior of the different economic agents, the markets of productive factors, goods and services, and the constraints faced by the productive sectors or other constraints imposed by economic policy. These equations are built to interact respecting the balance of payment, government deficit and the saving-investment identity.

The main reason for the rapid development and outreach of CGE modeling is that it bridges the gap between the economic theory and applied research. CGE models are not intended to test economic theory, they are rather developed for policy analysis; they are used to analyze scenarios of potential policies and their outcomes in regard to resource allocation, income distribution and welfare. CGE models are not intended to analyze business cycle or disequilibria phenomena, they rather focus on resource allocation and

¹⁴ (1874-1877) 1954 *Elements of Pure Economics: Or, the Theory of Social Wealth*. Translated by William Jaffé. Homewood, 111.: Irwin; London: Allen & Unwin. First published in French as *Éléments d'économie politique pure*. The definitive French edition appeared in 1926.

¹⁵ Alternatively called Applied General Equilibrium Models or SAM-Based General Equilibrium Model

growth paths; they study the real side of the economy. A typical CGE model determines relative prices for goods, factor inputs and real exchange rate. Hence nominal prices or nominal exchange rate are beyond their computing capabilities.

3.2. Environmental CGE Models: Their structure and Design

Modern CGE models descend from the early work of Leif Johansen¹⁶ who developed the first CGE model for his doctoral dissertation “A multi-sectoral study of economic growth” in 1960, calibrated to fit the Norwegian economy. With the rapid development of computers and relevant software, CGE models have been developed further to cover a wide range of topics, such as tax reforms, trade policy, trade liberalization, structural adjustments, agricultural policy, economic integration, and a range of development-specific issues.

Since the 1990’s CGE models have been widely used in the analysis of environmental policy. The first environmental CGE model was developed by Hudson and Jorgenson in 1975. It was an econometric model for analysis of energy supply policy in the USA to be used as a tool for analyzing the soaring oil prices that started in 1972. Starting in 1990’s, along with the success of Kyoto protocol, CGE modeling has become extensively used to cover a wider range of environmental and natural resource management policies. A comprehensive survey of all available environmental CGE models is well beyond the scope of this work, or indeed, of any one survey article¹⁷. Yet this work offers an introduction to the basics of the economic theories, general structure, modeling approaches and techniques used in the well-known environmental CGE models. In the following, the expression environmental CGE models will refer to those only dealing with climate change and natural resource issues.

¹⁶ See Kehoe et. Al (2005) for a clear description of the model

¹⁷ For solid surveys of available environmental CGE models see Bergman (1988, 2003 and 2005) and Bhattacharyya (1996). Burniaux and Truong (2002) for details of the modeling approaches to climate change in several prominent CGE-based models. Conrad (1999) for a survey on CGE models for Environmental Economics and Policy Analysis

3.3. Categories of CGE Models

Economic literature, so far, could not provide a crystal clear classification of CGE models¹⁸, as a matter of fact, there are different criteria by which CGE models may be classified. CGE models can be top-down versus bottom-up, static versus dynamic, single-country, multi-country, or global. CGE models can also be classified according to the approach of “closure” used, the method to determine the parameters (as models may be calibrated, as in most cases, or econometrically calculated as in large-scale econometric models), or “externality internalizing” versus “resource management” models.

3.3.1. Top-down versus Bottom-up CGE models

Top-down and bottom-up are two different approaches of analyzing environmental policy at different levels of aggregation, the different approaches result in two structures of environmental CGE models. The IPCC provide an extensive discussion of the difference between the different approaches (see IPCC 1996a, chapter 8). Bottom-up models concentrate on technologically based treatment of the energy system by a specific sector emitting GHGs, such models capture technology in a very detailed “engineering-based” prospective. They are built with a large number of energy technologies to capture energy substitution, demand or supply with emphasis of technical performance (efficiency, improvement and emission reduction) and costs. They are generally used to find the most efficient method of meeting sectorial demand of energy, subject to certain constraints, such as emission reduction targets. Top-down models, however, put more emphasis on theoretically consistent description of the general economy using aggregate economic variables. They give basic details at a sectorial level on energy consumption and technology representation. They describe the energy system in a highly aggregated way using neoclassical production functions, which build on “cost-shares” and “substitution elasticities” to describe substitutability and intensity of productive factors. Hence, top-down models focus on the costs caused by the increase in the cost of production due to mitigation policy and lower investment in other sectors. One noteworthy outcome of the comparison made by the IPCC was that bottom-up models tend to give lower mitigation costs. There have been several trials to mix both types such as the CETM model by

¹⁸ See Thissen M. (1998) for a detailed classification of CGE models.

Rutherford et al. (1997), given the rapid expansion of CGE based models that try to bridge the gap between the two approaches, the difference is not clear cut anymore¹⁹.

3.3.2. Static, Recursive and Intertemporal CGE Models

Static CGE models work for equilibrium quantities and prices at a given moment, they abstract from past or future events, hence they simply provide a “before and after” comparison of an economy when exposed to shock. Their main weakness is that they cannot describe the “adjustment path”. Yet some static models can be used to analyze certain environmental policies over multi periods, i.e. solutions obtained each period are used as input for the next over a consecutive number of periods (e.g. firms obtain the initial stock of capital at year t from the solution found in the year $t-1$). This type of multi-period static models may be called “recursive” or quasi-dynamic where households and firms are assumed to have myopic expectations or, in other words, they don’t have rational expectations. Examples of recursive environmental models are GEM-E3 (Capros et al. 2013), GREEN (Burniaux et al. 1992), CRTM (Rutherford 1992) and MIT-EPPA (Yang et al. 1996). Fully-dynamic models are commonly called “intertemporal” models, however, assume that economic agents have a forward-looking behavior. In such models an explicit behavioral equations appear that determine the consumption-saving of the households and the capital formation decisions of the firms over the whole period covered by the model. Examples of well-known intertemporal environmental CGE models are G-Cubed (McKibbin et al. 1995), RICE (Nordhaus and Yang 1996) and Global 2100 (Manne and Richels 1992). Given the nature of environmental problems, environmental CGE models need to be dynamic, or at least quasi-dynamic, as they need to describe factor accumulation and productivity growth, which are needed to describe long-run adjustments to GHGs accumulation (or degradation in case of mitigation).

3.3.3. Single-country, Multi-country and Global CGE Models

CGE models may also differ in the number and size of regions to be analyzed, which consequently defines what is considered to be the rest of the world (ROW). A model may be a single-country, multi-country or a global model. On one hand, multi-country and global models are good at analyzing trans-boundary pollution problems such as water or air pollution, emission trading schemes and the worldwide sustainable exploitation of

¹⁹ see Böhringer (1998) and Böhringer and Rutherford (2008) for further distinction

natural recourses. On the other hand, single-country models concentrate on analyzing a country-specific policy; they are more detailed in terms of the number of agents, productive factors, goods and services. Examples of country-specific environmental issues analyzed by a single-country model are the carbon leakage and resource management issues.

3.3.4. Externality Internalizing versus Resource Management CGE Models

The most common type of environmental CGE models aims at internalizing a negative externality such as GHGs mitigation. These models incorporate policies which assure that costs and benefits will affect mainly parties who choose to incur them (such as carbon taxes and ETS). Resource management models²⁰, however, focus on the excessive exploitation of such resources, the involved pollution or the efficient use of resources as an intertemporal allocation problem. Motivated by the Reducing Emissions from Deforestation and Forest Degradation (REDD) mechanism²¹ initiated by the United Nations, resource management policies are increasingly studied, but still moderately present in the environmental CGE analysis. Issues usually covered include excessive exploitation of natural resources, ill-defined property rights, deforestation reduction policies. Since externality internalizing CGE models are more present in economic literature, they will be the main focus of the remaining discussion.

3.4. Accounting for Cost and Benefit of Environmental Policy in a CGE Model

One of the most difficult tasks in environmental CGE modeling is to measure the economic benefit of environmental policy. Economic benefits resulting from environmental policy are non-economic, i.e. a better environment quality cannot be directly quantified in money terms or in utility units. CGE models intended to evaluate environmental policies should quantify the benefits of such policies and express them in monetary units. In the case of climate change mitigation policies, this is typically achieved through a “benefit function” that quantifies the benefits of mitigation activities and provides a monetary measure for it.

Such a function is developed over two stages; stage one is where ‘a damage function’ is developed. A damage function transforms GHGs emissions or deforestation into measures of physical environmental damage (or improvements in case of mitigation). Apparently

²⁰ See Persson and Munasinghe (1995) and Pohjola (1996) for elaborate examples

²¹ REDD involves giving credits at a national level for spared emissions in relation to a national benchmark scenario.

this is more the work of natural scientists than economists, yet economists have to figure out a way to illustrate such physical damage and incorporate it in an environmental CGE model. Two ways have been utilized to model such damage, the first is a direct way that assumes environmental damage to affect the supply of environmental public goods and services, such as clean air, available to households, i.e. environmental damage that reduces welfare. In this approach damage may be explicitly accounted for in the utility function of the household. The second, known as the ‘feedback effect’, assumes that environment deterioration affects the productivity of some factors of production. For example, environmental damage reduces the factor of productivity in forestry caused by sulfur emissions. This treatment of damage indirectly affects the welfare of households by increasing the cost of producing certain goods and services using factors whose productivity is negatively affected by environmental damage.

Stage two is where “quantifying functions” are introduced; these functions calculate environmental cost or benefit by assigning monetary value to environmental damage of improvements. One common way to do this is through accounting for the ‘feedback effect’ on the economy²², which is already measurable if adopted in stage one. Another approach of quantifying cost and benefits is what is called “counterfactual mode”²³. In this approach a BaU scenario (for so many periods) is constructed, and the model is solved for solutions to which model parameters are calibrated. This BaU baseline fully describes a no environmental policy intervention. Later on, carbon emission reduction initiatives are introduced and new “counterfactual equilibrium” are calculated. With the solutions of both scenarios at hand, one can undertake cost-benefit analysis by comparing between BaU versus counterfactual.

3.5. Technological Change in CGE Models

Climate damage occurs through the slow accumulation of GHGs over a long period of time, some times as long as a century while the effect is expected in the long run. Since there is a significant time difference between emissions today and the future effect, we may witness a possible “time-lag”. That is as CGE models cover a long period of time, they need to account for potential changes that may alternate all results as they happen at a certain point of time in the future. One example is the potential impact of new technologies

²² See Nordhaus (1994) for and elaborate example

²³ See Shoven and Whalley (1984 and 1992) for further details.

that may significantly change the outcomes of any possible scenario. Technological progress is an important variable to account for as future technologies might significantly reduce emissions.

Technological progress may take many forms such as higher energy-efficiency of capital or durable goods, low-emission capital as a substitute, and improvement in protecting and conserving GHGs or fossil reservoirs. In most environmental CGE models, technical change is modeled as an exogenous factor that makes the total factor of productivity an increasing function of time. However, some environmental models²⁴ treat technological progress as endogenous, induced by future relative prices of fossil fuels, taxes, caps, and regulations. Generally, the incorporation of induced technical progress in environmental models tends to facilitate the abatement, reduce its costs and causes a positive spillover (or positive externality).

3.5.1. Exogenous Representation of Technological Change

Most models who treat technology as an exogenous factor assume an annual growth in productivity between a number very close to zero and three percent²⁵. Such a technological change can be introduced to a CGE model in two ways. The first is known as the Autonomous Energy Efficiency Improvements (AEEI). The AEEI-factor is assumed to reflect all non-price driven technology improvements that make the input of energy in a production sector grow slower than the output of that sector. It is normally assumed to be between zero and two percent a year. It is simply incorporated as a separate coefficient in the production or cost function of a production sector. The AEEI-factor can be incorporated as a “price diminishing” technological change or incorporated as a “factor augmenting” technological factor. For example, in a unit CES cost function $C(I)$ the AEEI-factor γ_i ($\gamma_i > 0$) may be introduced as a “price diminishing” technical change as follow:

$$C(1) = \sum_i [\theta_i (w_i e^{-\gamma_i t})^{1-\sigma}]^{\frac{1}{1-\sigma}} \quad (1)$$

²⁴ See Löschel (2002) for a recent survey on the CGE models with endogenous technical progress and the available methods endogenizing it.

²⁵ See Azar (1999)

Where w_i is the price of input, σ is the substitution elasticity and θ is the cost share parameter.

The second way of exogenously incorporating technological progress is through introducing exogenously determined new technologies generally known as “Back-stop” technology. They are energy sources already known to mankind, but have not gone commercial yet and may become available sometime in the future. Even though it is exogenously determined, whether it will be used at that date, some later date or not at all is endogenously determined in the model²⁶. Such new technologies are assumed to reach markets and be used at larger scale, their costs will fall with the associated technological progress, while costs of conventional technologies rise due to environmental policies or reservoir depletion.

3.5.2. Endogenous Representation of Technological Change

One of the first initiatives to endogenize technical change in an environmental CGE model was made by Jorgenson and Wilcoxon (1990). They did not model technical change in a way that produces tangible or intangible products they rather partially endogenized technical change using a productivity growth function where productivity growth lead to reduction in production cost. They introduced productivity growth as a function of prices of all inputs used in an industry, when a price of one input rises (say due to a carbon tax) it will be substituted with another input, this should decrease the industries productivity level and result in a smaller cost reduction.

Different CGE models have different approaches of endogenizing technological change, yet the new generation of CGE models build upon the new growth theory²⁷ where innovation is treated as an economic activity where investment in R&D result in knowledge growth. Technical change adopted by most models employ the concept of technical change formulated by Schumpeter (1942). Schumpeter explained technical change as a process of three stages; it starts with the “invention” stage where an idea is transformed into an invention, the second stage is “innovation” that is transforming the invention into a commercial product through further development, and finally the

²⁶ see Nordhaus (1997) for an overview of optimal timing of abatement measures and inducing technological change and Burniaux et al. (1992) for an illustrative example.

²⁷ Inspired by Romer in his work “*Endogenous Technical Change*” (1990)

“diffusion” stage, which is the spread of the knowledge outside the four walls of a firm by learning-by-doing, learning-by-using and networking.

One of these is the RICE model by Nordhaus (1999), it treats that innovation as an outcome of investing in R&D, since the latter leads to innovation which leads to productivity growth. The model analyzes the impact of changes in prices (say carbon tax) on innovation in a neoclassical optimal growth framework. In his model, abatement can happen in two ways; the traditional factor substitution possibility and the induced technical change caused by R&D increase when prices of fossil fuels or carbon intensive inputs rise. Another example is the work of Buonanno et al. (2001), who introduced technological change as a production factor in the production activity Q , as a function of conventional physical capital K , knowledge capital K_R and labor L . All represented in a Cobb-Douglas production function:

$$Q = AK_R^\beta (L^\gamma K^{1-\gamma}) \quad (2)$$

Where A represents the exogenous technological change. Any positive change in knowledge capital (investments in R&D) leads to a 1) non-environmental outcome, which is an increase in productivity of resources, and 2) environmental one where emission-output²⁸ rate is decreased.

A third noteworthy analytical approach was developed in a Goulder and Schneider (1999), which directly linked technical change to abatement measures. In their dynamic two-period neoclassical model they represented the abatement cost function, of a cost-minimizing firm, in case of constraining environmental policy as $c(A_t, H_t)$ where c is the cost function of abatement, A_t is the abatement cost this firm incurs when it alternates the mix of fuels to reduce its emissions and H_t is the current stock of knowledge. Abatement costs are assumed to be increasing in A and decreasing in H . In the first period, H_1 is the current stock of knowledge and is assumed to be exogenous, the second period knowledge H_2 is the result of innovation from R&D investments plus the previous knowledge H_1 . So,

$$H_2 = H_1 + a\zeta(R_1) \quad (3)$$

²⁸ Emission-output ration is accounted for in the model with an explicit formula

$$\frac{E}{Q} = [\sigma + \chi e^{-\alpha K_R}](1 - \mu)$$

Where a is an arbitrary cost (when a is equals zero means the firm is not investing in R&D, hence no induced technical change) and ζ is an increasing cost function of R&D expenditure R . In the case of a carbon tax, for instance, a firm tries to minimize its future costs through R&D, which eventually brings about technical change. They induced technical change as a shift in the entire production function. The nested production function they used distinguishes between conventional carbon-emitting energy and non-conventional clean energy. This allowed them to observe how an environmental policy affecting the price of carbon influences R&D in clean energy. It is noteworthy that in the new growth theory framework, positive externality (represented in spillovers from innovation) shape the base of the long-term growth. World regions are highly linked through international trade, flows of capital and technology. Models that account for spillover effects assume that advanced technologies developed in industrialized countries and spread to developing ones. Hence, many top-down macroeconomic models incorporate spillovers to induce endogenous technical change.

One more way of incorporating technical change in environmental models is through learning by doing (LBD). LBD has proven to have a key role in reducing production cost that usually increases when a firm installs a new technology, like clean-energy units²⁹. Some global climate change models³⁰ incorporate learning curves as a meaningful representation of technical change, they follow Arrow (1962) steps by assuming that accumulated experience shape technological progress. The common way of accounting for increasing technological progress is through a “decreasing” cost function of technology with the accumulation of capital stock³¹.

The absence of technological change incorporation in an environmental model will definitely lead to an overestimation of the abatement costs and expected emissions. Nevertheless, some models not only incorporate technical change to reflect a more realistic cost estimation of abatement, but go further to account for the Jevon’s paradox³². i.e. as technological progress reduces cost of energy consumption -through enhancing efficiency- technical change increases energy consumption and relative emissions. Dowlatabadi (1998) shows in his work that additional abatement efforts are needed because of

²⁹ see McDonald and Schramm (2001) for a review of experience accumulation and cost reduction.

³⁰ See Grubler et. al. for a review of approaches which use the concept of technological learning and aid modeling of technological change.

³¹ See Anderson (1999) for an elaborate discussion of LBD representation in models

³² Jevon highlighted for the first time in his work *Theory of Political Economy* (1888) that increasing efficiency of an input leads to increase in its use.

efficiency caused by technological progress.

3.6. Abatement Technology

Apart from cutting output to meet certain regulations of cap, a polluting firm can react to environmental policy in two different ways; they can substitute carbon-intensive inputs, undertake abatement activities or a combination of both. In a typical CGE model the modeling of the substitution possibility of the carbon-intensive input is represented in the technology of the production function. Modeling abatement activities, on the other hand, need a special explicit treatment in environmental models. Abatement costs function, for polluting firms, are explicitly introduced to figure out the appropriate abatement level by equating marginal cost to the marginal benefit. In case a firm decides to undertake abatement activities the marginal cost function of such activities is equated to the tax rate on emission. Bergman (1990) considers a separate “cleaning activities” that reduce air pollutants. Such activities are available to all productive sectors at a price equal to marginal cost of abatement. The price of the cleaning activities is determined in the market of tradable permits. Carpos et al. (1996) model abatement activities in a way to increase the production cost of firms using polluting inputs. This additional cost will cause polluting firms to alter their input choices substituting high-emitting ones.

3.7. Technology and Production Functions

Typical CGE models are made of several behavioral equations explaining consumption, production, factor markets, international trade, taxation and auxiliary constraints that are calibrated to benchmark data. In environmental CGE models technology and production functions representation stand out among all the others. They play the most crucial part in reflecting polluting firms’ reaction to changes in policy such as carbon taxes or regulations. Production functions substantially differ in environmental models, they are profoundly elaborated to significantly reflect current and future capabilities of technology, and how it may respond to environmental policy depends on the technology assumed in each production sector. Hence representing technology available and production nesting is crucial. Moreover, cost and subsequently demand on factor inputs functions are both derived from production functions.

In typical neoclassical environmental CGE models, production costs are derived from the production function assumed. Let us consider a cost minimization problem of a cost-

minimizing firm operating under perfect competition producing X with a production function

$$X = f(N_i, L, K), \quad i=1, \dots, n \quad (4)$$

where N_i denotes the of intermediate inputs obtained from different i activities, L is labor and K is capital. The corresponding cost function is:

$$C = C(X, w, PL, PK) \quad (5)$$

Where w is the price vector of intermediate inputs, PL is the wage rate and PK is the rental price of capital. If we solve the system as:

$$\begin{aligned} & \min_{w, L, K} C(w, PL, PK) \\ \text{s.t.} \quad & f(N_i, L, K) \geq 1 \end{aligned} \quad (6)$$

we find L^* and K^* which minimize costs, substituting them in the total cost function with $X=1$ gives the unitary cost function:

$$C(1) = c(w, PL, PK) \quad (7)$$

Hence, the shape of the unitary cost function is totally dependent on the technology representation within the production function. As this firm is assumed to operate in a competitive market, the zero profit condition that determines the quantity that maximizes the is:

$$PX = c(w, PL, PK) \quad (8)$$

Demand functions, in turn, are derived from the cost functions. In firm theory, Shepard's Lemma proves that the factor demand for specific input i for a given level of output \bar{X} and a given level of factor price \bar{w} , equals the derivative of the total cost function with respect to the factor price. In our example, the demand, the factor input L by activity X is given by:

$$D_L = \frac{\partial C}{\partial PL} \quad (9)$$

Where C is the total cost. Under the assumption of perfect competition and constant return to scales equation (10) can be rewritten as

$$D_L = \frac{\partial c}{\partial PL} X \quad (10)$$

where c is the marginal cost of producing a unit of X . Since cost functions and, consequently, demand functions build upon the structure of the production function, its nesting and assumed technology, further elaboration on this matter is so worth doing.

3.7.1. Calibrated Share Forms Versus Coefficient Forms of Production Functions

Economic literature provides many forms of numerical production functions. The purpose of this section is not to undertake an exhaustive review of the literature, but rather, to highlight the most used functions and approaches in applied general equilibrium models. Within the neoclassical framework a combination of three main types are generally used, namely Constant Elasticity of Substitution (CES), Cobb-Douglas (CD), and Leontief. While the CES production function is the general form, the latter two are special cases. These functions have specific characteristics that allow for relatively easy numerical analysis and still flexible enough to appropriately represent of economic behavior. In this section the three functions will be briefly highlighted and reintroduced in a very efficient and easy-to-apply form widely used in environmental models called the “calibrated share forms”.

A CES production function is the general form used in environmental CGE models to represent energy sectors and industries that heavily utilize fossil fuels. This production function entails a fixable mechanism to account for substitutability among factors. Hence, in this section some emphasis will be put on this peculiar type of production functions. A CES function derives its name from the fact that factor substitution elasticity remains constant throughout an isoquant. The coefficient form of the function for a firm producing Y is given by

$$Y = \gamma \{ \theta L^\rho + (1 - \theta) K^\rho \}^{\frac{1}{\rho}} \quad \sigma \in (0,1) \quad (11)$$

where the variables Y , L and K are total output, labor and capital respectively. The parameter γ denotes total productivity of production, in other words the efficiency of factors. For instance, with a given amount of labor and capital, a factory can produce 8

units an hour while another one can produce 10 with the same input level. The more total productivity is, the higher is the value of γ . The parameter θ represents the importance of a factor input (or its intensity) relative to the others. The substitution parameter ρ can be used to derive the elasticity of substitution as $= \frac{\sigma-1}{\sigma}$, where σ denotes the elasticity of substitution (curvature of the isoquant) between factor inputs. Modelers can use this parameter to incorporate their assumptions about the level of substitution among factors of production. The lower σ the more difficult it becomes to substitute factor inputs. In a CES σ may range from anywhere between zero and one, when it is large, the technology is flexible, and the isoquant becomes flatter. In this case, alternating factor intensities (θ) has little effect on factors' marginal products. If σ is the substitution elasticity between fossil and non-fossil fuels, producers can therefore make large shifts towards clean inputs to take advantage of changing relative factor prices (say carbon tax) while being sure that marginal product of either input won't change significantly. When σ equals one, the CES function takes a special form with a lot of implications, in this case it is the Cobb-Douglas production function³³. However, when σ equals zero the isoquant takes an L shape, no substitution is possible among production factors. This peculiar case of the CES is the Leontief³⁴. A Leontief production function treats factor inputs as perfect complements, one frequent use of the Leontief is to represent the demand for intermediate inputs; molders typically assume that intermediate inputs are used in "fixed proportions" to produce the bundle of intermediate goods (which is later on combined with the value-added bundle to produce the final good). Finally, when σ goes to infinity, the isoquant becomes a straight line labeling the factor inputs as perfect substitutes³⁵.

These coefficient forms of production function are difficult to handle when calibrating parameters, they also imply restrictions on representing certain economic features. In a non-technical paper Böhringer et. al (2003) introduced the equivalent "calibrated share forms" showing how their approach to "...substantially reduces the efforts as well as sources of errors in the determination of free function parameters." Using this approach enables modelers to avoid the use of the complicated coefficient forms which entail calibration formulae that are complex and difficult to remember. Calibrated share forms contain benchmark factor demands, factor prices, cost shares, output, value shares and

³³ $Y = \gamma L^\alpha K^{1-\alpha}$ $\sigma = 1$

³⁴ $Y = \min \{aL, bK\}$ where $a, b > 0$ $\sigma = 0$

³⁵ $Y = \gamma \{\theta L + (1 - \theta)K\}$ $\sigma = \infty$

elasticity of substitution. The previous CES production function, for instance, may be rewritten in calibrated share form as³⁶

$$Y = \bar{Y} \left[\theta_L \left(\frac{L}{\bar{L}} \right)^\rho + \theta_K \left(\frac{K}{\bar{K}} \right)^\rho \right]^{\frac{1}{\rho}} \quad (12)$$

where \bar{Y} is benchmark the total output level, \bar{L} is the benchmark quantity demanded of labor, \bar{K} is the benchmark quantity demanded of capital, θ_L is the benchmark value share of labor input, and θ_K is the benchmark value share of capital. All these parameters can be easily calculated using benchmark data. A calibrated share for cost functions is also much easier to deal with when compared to the coefficient form. The calibrated share form cost function corresponding to the production function in equation (13) is:

$$C(P_L, P_K) = \bar{C} \left[\theta_L \left(\frac{P_L}{\bar{P}_L} \right)^{1-\sigma} + \theta_K \left(\frac{P_K}{\bar{P}_K} \right)^{1-\sigma} \right]^{\frac{1}{1-\sigma}} \cdot \frac{Y}{\bar{Y}} \quad (13)$$

where \bar{C} is the benchmark total cost of producing Y , θ_L and θ_K are the cost share of labor and capital in total cost respectively, \bar{P}_L and \bar{P}_K are the benchmark prices of labor and capital respectively, and \bar{Y} is the benchmark total product. Apart from σ , all remaining parameters can be easily calibrated using benchmark data. The same argument is valid for demand functions, the corresponding demand functions for labor and capital by this firm using Shepard's Lemma are:

$$K(P_L, P_K, Y) = \bar{K} \frac{Y}{\bar{Y}} \left(\frac{P_K C}{\bar{P}_K \bar{C}} \right)^\sigma \quad (14)$$

$$L(P_L, P_K, Y) = \bar{L} \frac{Y}{\bar{Y}} \left(\frac{P_L C}{\bar{P}_L \bar{C}} \right)^\sigma \quad (15)$$

3.7.2. Nested Production Function for Environment Policy Analysis

Estimating parameters of unit cost functions and of the factor demand functions can be estimated econometrically. Unfortunately, this approach is very demanding in terms of data requirements. The common approach in CGE modeling is therefore to choose nested production of CES type and calibrate the shift and share parameters from benchmark data

³⁶ for CD and Leontief forms see Böhringer et. al (2003)

while import substitution elasticities from other sources, usually econometric literature, or in extreme cases they are simply “guessed”³⁷.

In standard CGE models production functions are nested to a degree where they explicitly define the substitution and complementarity level of all input factors. Environmental models developed for climate change analysis usually have an elaborated representation of supply and demand of energy. More specifically, they should represent an elaborated treatment of possibilities to substitute other forms of energy, or other factors of production for fossil fuels. These additional nests allow a model to account for substitution or complementarity possibilities between capital and energy or, at a lower level, between electricity and fuels and among the different types of energy within an overall energy bundle such as oil, coal or gas.

The existing literature, so far, does not provide definite answers about the most appropriate nesting structure environmental models should adopt. The most crucial part is how to represent the various inputs; either as substitutes, or compliments and to what degree. A representative nested production function of a productive sector i in an environmental CGE model can be expressed as:

$$X_i = f_i(L_i, K_i, N_i, F_i, E_i) \quad (16)$$

Where X is total output, L labor, K capital, N non-energy intermediate inputs (domestic and imported), F Fuel (fossil and non-fossil), and E electricity. Non-energy intermediate goods are usually treated as true complements among themselves, they are represented by a CES production function, i.e. If the price of one input increases, its demand as well as the demand for other inputs should decrease. To achieve the final product, non-energy intermediate inputs and the value-added bundle inputs are combined together as perfect substitutes (Leontief), as illustrated in figure 1.

A robust CGE model adds additional nests to describe substitution among the different types of energy. Often fuels F and electricity E are combined to form the energy H nest represented with a relatively high substitution elasticity using a CES function. In most models, the fuels F nest is made of different types of fossil and non-fossil fuels. A CES function is used to incorporate the possibility of substituting carbon intensive energy

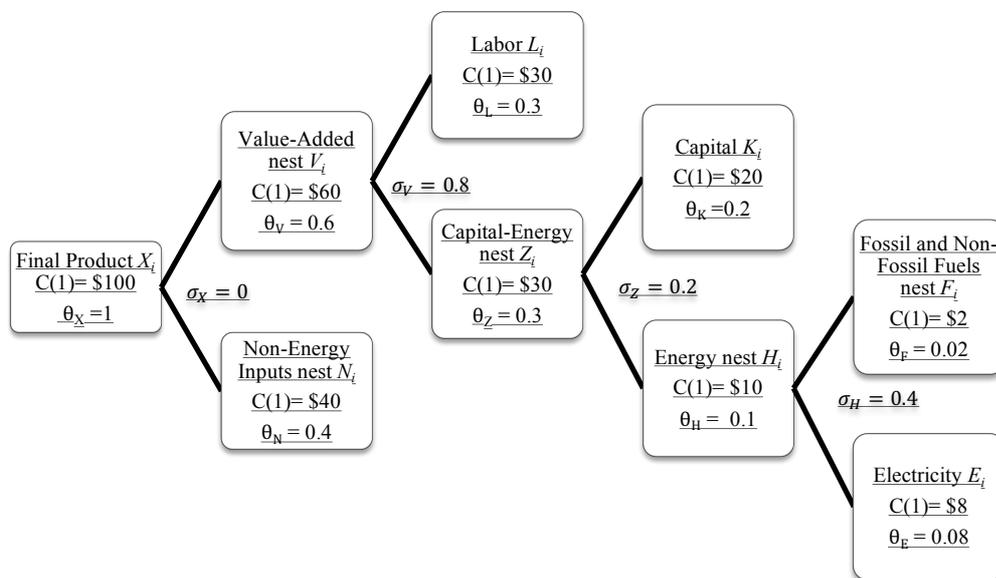
³⁷ see Mansur and Whalley (1984) for more on this topic

sources with clean ones. A more detailed algebraic representation of the sector production function (17) is:

$$X_i = f_i(N_i(N_{i1}, \dots, N_{ij}), V_i(L_i, Z_i(K_i, H_i(E_i, F_i(F_{i1}, \dots, F_{in})))))) \quad (17)$$

Where j is the number of non-energy intermediate inputs and n is the number of fossil and non-fossil fuels used in production.

Figure 3-1. Production technology tree in typical environmental CGE model



The most important part of designing any sector production function in an environmental CGE model is the representation of energy. In a typical non-energy CGE model, energy is typically represented in the intermediate nest as other non-energy inputs, however in environmental CGE models it is moved to the value added nest. Similar to the representation in figure one, some models combine capital K and energy H into a composite nest Z . At the higher level, the Z bundle of capital-energy is combined with labor to form V the Value-Added nest. It is worth noting that another common way of nesting labor, capital and energy is to combine capital with labor capital, rather than capital with energy, and at a higher level energy is combined with the labor-capital bundle to form the value-added nest.

The evidence of substitutability between capital and energy is rather conflicting, some econometric studies indicate that energy and capital are substitutes, at an adequate level of

aggregation, while others suggest they are compliments, at least in the short-run. If the unit cost of Z (capital-energy) bundle rises due to an increase in energy price, the producer will shift toward labor and away from Z . this means that the substitution effect between labor L and Z is dominant, which makes both capital and energy complements. However, if the substitution effect between capital and energy dominates, an increase in the energy price will cause demand for capital to rise (and that of energy to decrease) making energy and capital substitutes.

In 1980 a Dutch economist named Wouter Keller developed a formula to calculate the overall substitution parameter for nested inputs (see Keller 1980). It is very enlightening if applied to analyze the overall substitutability in energy-capital nest. Taking the elasticity parameters and cost shares in the example represented in the technology tree in figure 1 above, Keller's formula is:

$$\widetilde{\sigma}_Z = \sigma_Z(\theta_Z^{-1}) - \sigma_V(\theta_Z^{-1} - \theta_V^{-1}) - \sigma_X(\theta_V^{-1} - \theta_X^{-1}) \quad (18)$$

Where $\widetilde{\sigma}_Z$ is the overall substitution parameter between energy and capital, σ_Z is the elasticity substitution between energy and capital that is assumed to be 0.2, σ_V is the elasticity substitution between energy-capital and labor that is assumed to be 0.8, σ_X is the substitution elasticity between non-energy intermediate inputs and the value-added, it is usually assumed to be 0 (Leontief) since intermediary goods are neither substitutable with labor, capital nor energy. θ_Z is the cost share of energy and capital bundle in the overall cost, in our example it is assumed to be 0.3. θ_V is the share of the value-added bundle in the overall cost, in the example it is assumed to be 0.6, and θ_X is the cost share of the final product itself, which has to sum to one. Equation 20 shows the substitution of the values in the example above in Keller's formula; this gives an overall elasticity of substitution between energy and capital equal to minus 0.66.

$$\widetilde{\sigma}_Z = 0.2\left(\frac{1}{0.3}\right) - 0.8\left(\frac{1}{0.3} - \frac{1}{0.6}\right) - 0\left(\frac{1}{0.6} - 1\right) \quad (19)$$

This shows that, in our example, they are overall complements, so an increase in energy price leads to substituting energy and capital with labor. Modifying our assumptions of elasticity parameters or cost shares may result in contrasting conclusion, let's for instance assume σ_Z to be 0.8 rather than 0.2, resolving the formula gives an overall elasticity parameter equal to positive 1.66, which indicates that capital and energy are overall

substitutes, so an increase in energy price will substitute capital for energy at their level of nesting. It is worth noting though that the majority of environmental CGE models treat capital and energy as substitutes with a low level of substitutability.

3.8. International Trade in Environmental CGE Models

It is beyond the scope of this work to discuss the treatment of trade in CGE models, yet some major points need to be highlighted. The representation of trade is one of the most important aspects in modeling an environmental CGE model. Carbon leakage, unilateral action, spillovers and emission patterns are topics that build on the international trade, thus different representations of international trade give different outcomes.

Economic literature provides different views of international trade that explain why countries engage in international trade; Ricardo (1817) proposed the comparative advantage theory, it has been considered the backbone and the foundation of trade representation. A second major advancement was the work of Ohlin (1933), who proposed the H-O-S model that builds on Ricardo's theory, it is a neoclassical model that shows how countries tend to export goods that are produced with the country's abundant and cheap factors of production. These two theories prevailed and managed to explain international trade in a solid way. Their main shortfall, however, was that if a country exports certain goods it shouldn't import them, apparently data of international trade tells a different story.

Krugman (1979-8-9) proposed the "New Trade Theory" that explained possible trade between countries with similar economic characteristics which couldn't be explained by the comparative advantage theory. He assumed that consumers prefer to have different brands to select from; for instance, this explains car trade between two car-producing countries. He also assumed that producers prefer economies of scale; since large-scale production to reach more countries entails diseconomies of scale, it limits the quantity produced of a certain car brand and allows for others to compete in the same market. Building on the work of Krugman, Melitz (2003) introduces the basics of another neoclassical theory called the "New New Trade Theory" (NNTT). This theory puts emphasis on the firm-level differences within the same industry, it doesn't stop at the industry level, it rather analyzes the intra-industry reallocation of market shares and resources given the rapid liberalization of trade that helps firms with comparative advantage to expand and those of comparative disadvantage to shrink.

The standard approach in CGE modeling, however, is the adoption another trade theory known as the Armington approach (Armington 1969). It uses the neoclassical theory of isoquant/costs and budget lines, which is symmetric for consumption and production, to explain trade of similar goods among countries. When explaining consumer preferences, it assumes that goods with the same statistical classification, but different countries of origin are non-perfect substitutes. This approach provides a great solution to the overspecialization problem. Armington explains that a SAM displays aggregations of goods and services (e.g. food, beverage, medicine and textile) by looking at this level of aggregation, there is a clear difference between tradable domestic and imported goods. i.e. an Italian food basket cannot be a perfect substitute to a Mexican one. Hence the domestically consumed goods are represented with a CES function of domestically produced while imported goods with a substitution elasticity larger than zero.

When explaining producers' preferences of supplying domestically or exporting their production, Armington assumes that producers don't mind where to sell products, as long as the profits are the same, yet he explains the selling domestically produced goods to foreign markets includes an additional "transformation costs". To export domestically-produced goods, producers need to modify their products to match the needs of foreign customers, which includes cost, this additional cost is increasing in marginal terms, which explains why producers do not export all their production even if international prices are higher than local ones but rather sell domestically and abroad. Models incorporate export supply functions that are derived from constant elasticity of transformation (CET) functions, which define the output of an economic activity as aggregate of goods for domestic and foreign markets. The elasticity of transformation in this case explains how difficult it is to transform a good from being domestic to exportable.

3.9. Energy-based Databases and the Social Accounting Matrix

CGE models are based on real-world databases that include input-output tables, transport costs, bilateral trade flows, tax and tariff information, etc. These databases may be organized and displayed as a Social Accounting Matrix (SAM), which provides an easy-to-read visual display of the transactions as flow of national income and spending over a specific period of time, usually a year, among agents in an economy in addition to the flow of trade and foreign savings inflows or outflows. A balanced SAM is a snapshot of an economy in equilibrium. It serves as an initial starting point for the values of a model's

variables and as a benchmark to which the models parameters are calibrated. Databases are usually gathered by governmental entities, special research centers or international organizations, modelers later on decide how to aggregate economic activity balancing the need for details.

Given the difficulty of collection and, often, poor data availability especially that of CO₂ emission in different regions, some models³⁸ tend to collect from various sources such as OECD national accounts, UN national account statistics, IEA energy statistics and energy balances, Eurostat national accounts and others. Fortunately, over the last years, Multi Region Input Output (MRIO) databases have been remarkably developed³⁹. The environmental accounting literature documents some well-detailed energy-based databases⁴⁰, which are continuously developed and maintained by researchers and available for public. GTAP⁴¹ is one good example of an energy based database used in the evaluation of abatement costs of environmental policy. It is regularly updated with integrated CO₂ emission data sets. As a matter of fact, most well-known environmental CGE models, such as MIT-EPPA (Yang et al. 1996), CIM-EARTH (Elliott J. et al. 2012), G-Cubed (McKibbin et al. 1995), GEM-E3 (Capros et al. 2013), ENVISAGE (van der Mensbrugge, D. 2010), GTAP-E (Burniaux, JM. and Truong T., 2002) and Linkage (van der Mensbrugge, D. 2011) are built with GTAP as the core database.

3.10. Computer Use and Prominent Software

The development of fast computers and suitable software has rapidly supported the advancement of CGE modeling. Computers enabled modelers to solve a complex system of equations with more sectors, factors and agents, they save time and effort when conducting sensitivity analyses to evaluate the robustness of a model. They also facilitate dynamic analysis that solve for many periods. A full range of user-friendly commercial packages of economic modelling solvers for nonlinear equation systems are now available. Examples are: (CONOPT (Drud 1985), MINOS (Murtagh and Saunders 1995) or PATH (Dirkse and Ferris 1995). Moreover, higher-level programming languages exist such as GAMS (Brooke, Kendrick, and Meeraus 1988) or GEMPACK (Harrison et al. 2014)

³⁸ GREEN model by the OECD is a representative example.

³⁹ See Tukker and Dietzenbacher (2013) a short historical context of Global Multiregional input-output tables and their development.

⁴⁰ See Wiedmann (2009) for a detailed review

⁴¹ There exist modified versions of GTAP that incorporate more environmental data or compatible with other softwares such as GTAPinGAMS. See Rutherford T. and Paltsev S. (2000) for further details.

MATLAB (1997), MATHEMATICA (Wolfram 1996), AMPL (Fourer, Gay, and Kernighan, 1987). Some of these languages have a user-friendly interface and programming logic that enables environmental economists who are not specialized in numerical methods to model using fundamental economic concepts and logic.

4. A Computable General Equilibrium Model

4.1. Introduction

The analysis of the impact of climate change and international economic policy in a micro-consistent framework demands solid theory, as much as data. The model developed in this section follows the Shoven-Whalley (1992) applied general equilibrium framework; this framework is a widespread theoretical base for economic analysis, including but limited to environmental policy. This approach is normally based on a multi-sectoral dataset, which can be provided by SAMs generated from the GTAP database. Besides the core model, this section documents two SAMs for two developing countries of the MENA region, namely Egypt and Tunisia.

4.2. Social Accounting Matrix

4.2.1. Introduction

GTAP database is the most widely used for environmental policy analyses; it is comprehensive global database and regularly updated with integrated CO₂ emission data sets. In this work, the “GTAP Africa 2 Data Base” (Narayanan, G. et al (2012)) has been used. This most recent database based on the GTAP 8.1 Data Base that was extended to give details on more African countries. It includes data for 42 regions, the 57 sectors and 5 factors of production. It consists of regional input-output data, bilateral trade flows, macroeconomic data, and energy data for the reference years 2007, measured as money values, in millions of 2001 U.S. dollars.

4.2.2. Aggregation method

The GTAP database comes with a helpful tool that aggregates the database into a SAM for any of the 42 available regions. The resulting SAM’s format still too detailed and needs further formatting to suit the model at hand. For this reason, a specific GAMS code was developed to further aggregate the SAM into a format compatible with the model at hand.

The code redistributes the values present under the regional household account and pays factor income directly from factors to households. It adds depreciation to household savings and transfers it into savings, pays taxes directly to government and residually calculates the private and government savings.

Taxes on factors of production are added to the production taxes, trade margins are moved to imports and exports, and sales tax are moved from individual activities to the general sales tax account. The final format is shown Table 4-1.

Table 4-1: Social Accounting Matrix for a Representative Region

	Commodities	Activities	Factors	Households	Government	CGDS	ROW	Totals
Commodities	0	Intermediate Use matrix	0	Private Consumption	Government Consumption	Investment Consumption	Exports of Commodities (cif)	Total Demand for Commodities
Activities	Domestic Supply Matrix	0	0	0	0	0	0	Total Domestic Supply by Activity
Factors	0	Expenditure on Primary inputs	0	0	0	0	0	Total Factor Income
Households	0	0	Distribution of Factor Incomes	0	0	0	0	Total Household Income
Government	Taxes on Commodities	Taxes on Production	Direct Taxes	Direct taxes	0	0	0	Total Government Income
CGDS	0	0	0	Households Savings	Government Savings	0	Foreign Savings	Total Savings
Row	Imports of Commodities (cif)	0	0	0	0	0	0	Total Income from Imports
Totals	Total Supply of Commodities	Total Expenditure on Inputs by Activities	Total Factor Expenditure	Total Private Expenditure	Total Government Expenditure	Total Investment	Total Expenditure on Exports	

4.2.3. Factor, Regional and Sectorial Aggregations

Two separate Social Accounting Matrices for two African developing regions (Tunisia and Egypt) were aggregated into the preceding format. Each separate SAM shows the regional input-output data, bilateral trade flows, macroeconomic and energy data for reference years 2004 and 2007, measured as money values, in millions of 2001 USD.

At the factors' level, the five production factors in the GTAP database (land, natural resources, skilled labor, unskilled labor and capital) were aggregated into four; the two immobile factors, namely land and natural resources, were aggregated into one productive factor called Land and Natural-Resources. The 57 productive sectors in the GTAP database were aggregated into 13, representing major productive activities with a high level of emphasis and aggregation for industries that are energy-intensive, CO2 emitting, and energy producing as shown in Table 4-2. This detailed classification will permit scenario analysis of environmental tax, and increasing the efficiency of energy use.

Table 4-2. Sectorial Disaggregation

No.	New Code	Description	Comprising GTAP Countries
1	AGRI	Primary Agric., and Fishing	Paddy rice; wheat; cereal grains n.e.c.; vegetables, fruit, nuts; oil seeds; sugar cane, sugar beet; plant-based fibers; crops n.e.c.
2	FORS	Forestry	Forestry.
3	LSTK	Livestock and Fishing	Bovine cattle, sheep and goats; animal products n.e.c.; rat milk; wool, silk-worm cocoons; meat; meat products n.e.c; fishing
4	EIND	Energy-intensive Industries	Chemical, rubber, plastic products; mineral products n.e.c; Ferrous metal; metals n.e.c; electronic equipment; machinery and equipment.
5	RIND	Rest of Industries	Minerals n.e.c; vegetables, oils and fats; dairy products; processed rice; sugar; food products n.e.c; beverages and tobacco products; textiles; wearing apparel; leather products; wood products; paper products, publishing; metal products; motor vehicles and parts; transport equipment n.e.c; manufacturers; water.
6	COAL	Coal Mining	Coal
7	OIL	Crude Oil	Oil
8	PETR	Refined Oil	Petroleum, coal products

		Products	
9	GAS	Natural Gas Extraction	Gas; gas manufacture, distribution
10	ELCT	Electricity	Electricity
11	CNST	Construction	Construction
12	TRNS	Transportation	Trade; transport n.e.c; sea transport; air transport; communication.
13	OSER	Other Services	Financial services n.e.c; insurance; business services n.e.c; recreation and other services; public administration, defense, health and education; dwellings.

4.3. The Static version of a Single Country Model

4.3.1. Introduction

The model will be developed over two stages; in this section the static one is developed, the next section introduces the dynamic part. This section builds a standard static single country CGE model; structured in a “top-down” approach, and presented as a standard Arrow-Debreu (1954) for a small economy.

The model accounts for abatement technology through the availability of substitution between carbon-intensive inputs, as well as energy and other primary factors such as capital, in an overall structure that allows for sensitivity analysis in elasticity of consumption, production and mobility of factors.

Production tax, sales tax, export tax, and tariffs are expressed as simple ad valorem tax rates, while direct income tax is defined as a fixed proportion of household income. Households are assumed to save a proportion of disposable income given fixed propensity to save.

In this model, the rest of the world is not explicitly modelled; as common in CGE models of this nature, a nominal exchange rate has been introduced for each of the countries analyzed and trade possibilities are modelled by the transformation of domestic goods by the local productive factors into "Foreign Exchange" and vice versa. The model at hand is a model of a single economy open to the rest-of-the-world (RoW), yet it is not a global model (in which domestic and foreign economies are both explicitly represented). As common in such models, it is not necessary to create an explicit agent called "RoW". What really matters is to allocate foreign savings (essentially net loans from abroad) to national

agents. This is done by taking into account the fundamental identity private savings, governmental savings and foreign savings must equal total investments. Code-wise, it is sufficient to treat a loan from abroad as getting a positive endowment of foreign exchange and, simultaneously, a negative endowment of future welfare.

4.3.2. Cost and Benefit of Environmental Policy Using the “Feedback Effect”

The model accounts for the cost and benefit of environmental policy using the “feedback effect”; it assumes that environment deterioration affects the productivity of some factors of production and indirectly affects the welfare of households by increasing the cost of producing certain goods and services using factors whose productivity is negatively affected by environmental damage.

The “feedback effect” was adopted in this model; it assumes that environment deterioration affects the productivity of labor (i.e. you need more labor to produce the same output each time). The labor productivity reduction is assumed to be 0.1% per period. This treatment of damage indirectly affects the welfare of household by increasing the cost of producing certain goods and services. To quantify the cost of such a decrease in productivity, the “counterfactual mode” can be simulated by the model, i.e. a BaU scenario (for so many periods) is constructed, and the model is solved for solutions to which model parameters are calibrated. This BaU baseline fully describes a no environmental policy intervention. Later on, a labor productivity reduction is introduced and new “counterfactual equilibrium” is calculated. With the solutions of both scenarios at hand, one can undertake cost-benefit analysis by comparing between BaU versus counterfactual.

4.3.3. Exogenous Representation of Technical Change Using AEEI Technology

The model accounts for the fundamental concept of technological change using an exogenous representation through an AEEI technology. The AEEI-factor is assumed to reflect all non-price driven technology improvements that make the input of energy in a production sector grow slower than the output of that sector. It is normally assumed to be between zero and two percent a year. It is simply incorporated as a separate coefficient in the production or cost function of a production sector.

In this model, technical change is represented exogenously in the form of a higher energy-efficiency of factors of production, mainly capital. For this matter, the AEEI technology is

adopted where technology improvements are assumed to make the input of energy in a production sector grow slower than the output of that sector. The AEEI factor (percentage of reduction) is assumed to increase from 1% to 15% over 15 periods that the model simulates.

4.3.4. Production Technology and Substitution Elasticities

Modeling the economy with its energy, environment and trade linkages has a key-role in the analysis of economic policy. The real question is what structure should be used to represent the macro production technology and substitution/transformation elasticities. In environmental CGE models, in particular, a great importance is given to the substitution possibility between alternative fuels (inter-fuel) and that between energy, as an aggregate, and other primary factors such as labor and capital (fuel-factor).

In a breakthrough paper GTAP-E (Burniaux, M., & Truong, T. (2002)), the authors managed to survey the most prominent environmental models, analyze them and construct their model using the most plausible ideas. They provided a summary of substitution and transformation elasticities used in the literature; they calculated the “averages” of these elasticities and personally adopted them for their model GTAP-E. For this reason, the following model uses a nesting similar to that of GTAP-E model; this should allow the use of the “averages of substitution and transformation elasticities” of the most prominent models calculated in the previously mentioned work besides the elasticities available in the GTAP database.

Figure 4-1 highlights the structure of a representative productive sector with a nested production function. Figure 4-2 shows the Capital-Energy composite structure.

Figure 4-1. Structure of a Single-Country CGE Model

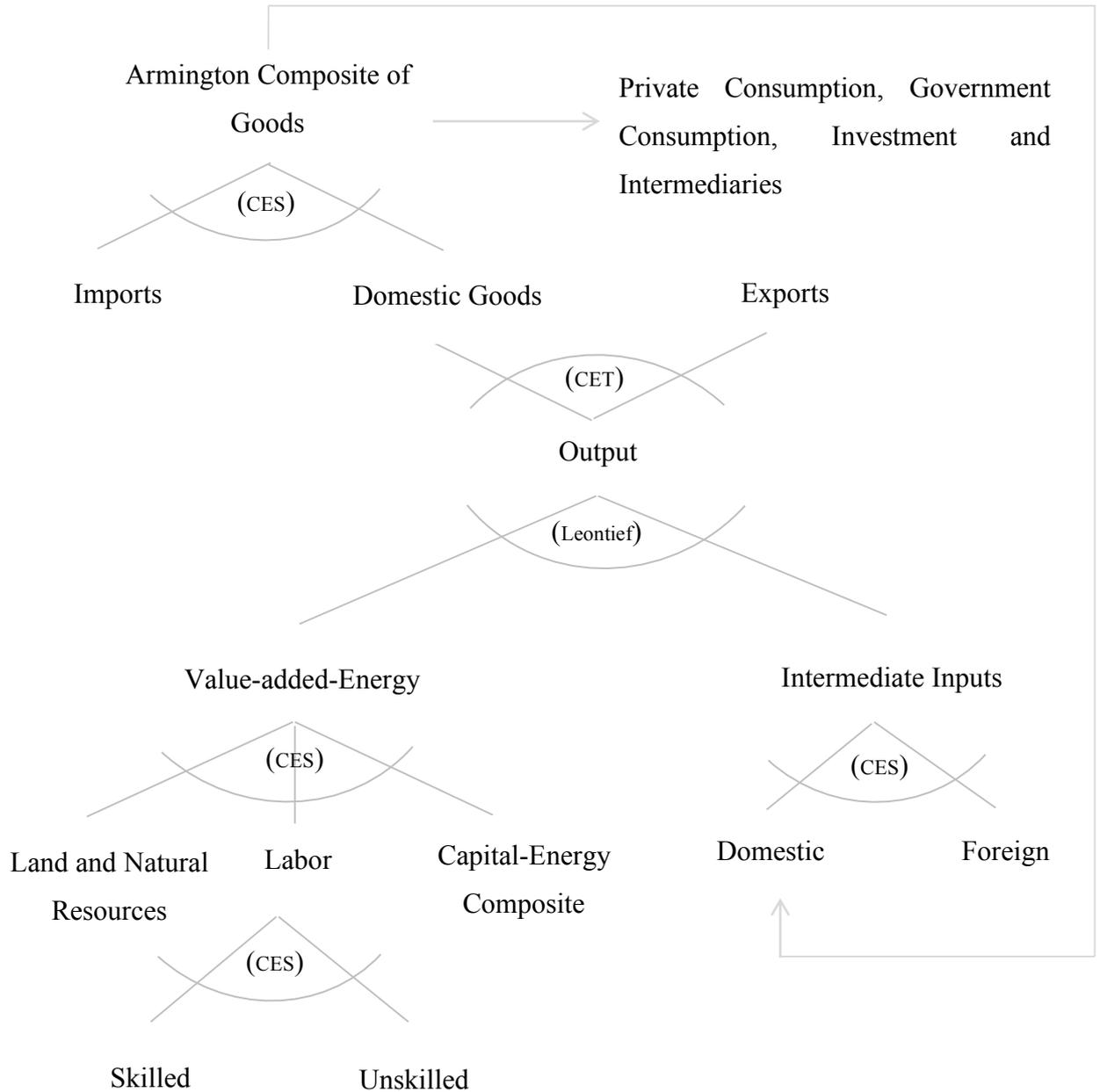
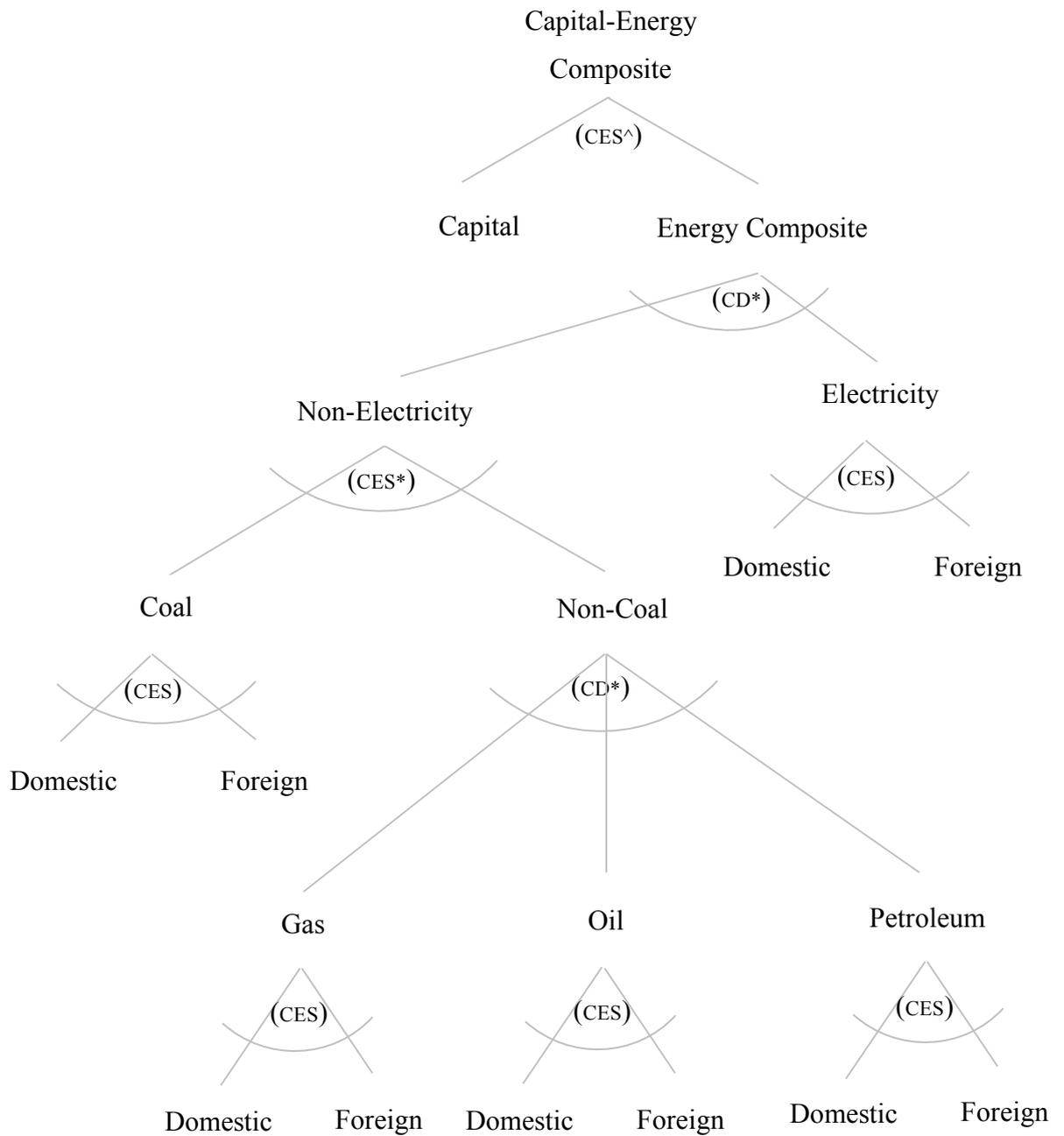


Figure 4-2. Capital-Energy Composite Structure



^ For all sectors except for: Agriculture, forestation, livestock, coal, oil and petroleum products where elasticity of substitution is zero (Leontief)

* For all sectors except for: Coal, Oil and Petroleum products where elasticity of substitution is zero (Leontief)

As illustrated in Figure 4-1, users (consumers, government, investment, and producing firms) regard domestic output and imports as imperfect substitutes, and these goods are assumed to have a constant elasticity of substitution. Each production sector produces two types of commodities: domestic goods that are sold domestically, and exported, these two types are assumed to be imperfect substitutes, represented with a constant elasticity of transformation function. Intermediate input to a sector i from a sector j is an Armington composite of domestic output and import. As common in CGE models, intermediate goods (from different sources and productive sectors) and value-added bundles trade off at a zero elasticity of substitution, represented in a Leontief function.

As common in environmental CGE models, the energy commodity is separated from labor and capital within the value-added bundle to allow for substitutability among them and within the inner nest of energy, at least in the long run. Energy is incorporated into the 'value-added' nest where it trades off with capital. Energy commodities are then classified into 'electricity' and 'non-electricity' groups, non-electricity bundle is further nested into a coal and non-coal nest. Finally, the non-coal bundle is nested into gas, oil and petroleum where all trade off in CES functions with different elasticities as shown in Table 4-3.

Energy is a fundamental commodity in many economic activities, modeling it correctly and fairly reflecting its ability to be substituted, mainly with capital, affects the outcomes of the model, and consequently, the final effects on environment. The debate of energy-capital complementarity or substitutability is crucial in determining possible changes in output and other energy commodities when energy prices change.

In economic literature, the evidence of substitutability between capital and energy is rather conflicting, some econometric studies indicate that energy and capital are substitutes, at an adequate level of aggregation, while others suggest they are compliments, at least in the short-run. To adopt this concept of complementarity in the short run and substitutability in the long run, the elasticity of substitution between capital and energy aggregate is set lower than the elasticity between capital and other primary factors as shown in Table 4-3; the elasticity of substitution between capital and energy is assumed to be 0.5 for energy-intensive industry, rest of industry, electricity, construction, transportation and other services. While it is set equal to 0.0 for agriculture, forestry, fishery, coal, oil, gas and petroleum products.

As explained with the example of Keller formula in section 3.7.2 before, if the unit cost of capital-energy bundle rises due to an increase in energy price, the producer will shift toward labor away from the capital-energy bundle, this means that the substitution effect between labor and this bundle is dominant, which makes both capital and energy complements. However, if the substitution effect between capital and energy dominates, an increase in the energy price will cause demand for capital to rise (and that of energy to decrease) making energy and capital substitutes. Hence, by assuming that elasticity of substitution between energy and capital composite is positive, capital and energy become substitutes in the ‘inner nest’. Moreover, assigning a value of substitution elasticity among components of the value-added nest higher than the value of substitution elasticity between capital and energy provides overall substitution elasticity (in the ‘outer nest’) between capital and energy that may still be negative.

Table 4-3 below shows the various elasticities of substitution. Energy-producing sectors (Gas, Oil, Coal and Petroleum products) are assumed to have a Leontief representation of the composite with a zero substitution elasticities among all the components of the bundle. On the other hand, the remaining nine productive sectors in the economy are assumed to have an elasticity of substitution equal to one in the Electricity and non-coal bundles, and a substitution of elasticity equal to 0.5 in the capital-energy and non-electricity bundles

Table 4-3. Energy Substitution Elasticities

Sector	Prim. Factors vs Capital-Energy*	Capital- Energy	Electric vs non- electric	Coal vs other non- coal	Non-coal (non- electric)
Agriculture	0.27	0.0	1.0	0.5	1.0
Forestation	0.2	0.0	1.0	0.5	1.0
Livestock	0.46	0.0	1.0	0.5	1.0
Energy-intensive industry	1.26	0.5	1.0	0.5	1.0
Rest of industry	1.17	0.5	1.0	0.5	1.0
Coal	0.2	0.0	0.0	0.0	0.0
Oil	0.2	0.0	0.0	0.0	0.0
Petroleum products	1.26	0.0	0.0	0.0	0.0
Gas	0.61	0.0	0.0	0.0	0.0
Electricity	1.26	0.5	1.0	0.5	1.0
Construction	1.4	0.5	1.0	0.5	1.0
Transportation	1.63	0.5	1.0	0.5	1.0
Other services	1.26	0.5	1.0	0.5	1.0

Source: GTAP-E model (Burniaux, M., & Truong, T. (2002)). Where values are chosen to be in the middle range of the values adopted in other models.

* GTAP database

4.3.5. Functional Forms

The nesting is assumed to be the same among all the 13 productive sectors. In the following, variables marked with a bar are parameters that denote the benchmark value of the variable.

General Sets

- i, j commodities/sectors
- f subset of j : (Gas, Oil, Coal and Petroleum products)
- g subset of j that includes the remaining sectors

- Non-coal – non-electric energy bundle (nc)

Since coal combustion is considered the most emitting of CO₂ among all, it is usually separated from other energy inputs. Energy productive sectors are assumed to have a Leontief representations of this bundle while the rest of are represented through a CD.

Sets

- s subset of j : non-coal energy inputs (Gas, Oil and Petroleum products)

Gas, Oil and Petroleum product demand function

Sectors f

$$D_{s,j} = \bar{D}_{s,j} \cdot \frac{Y_j^{nc}}{\bar{Y}_j^{nc}} \quad \forall f \quad (20)$$

Sectors g

$$D_{s,j} = \bar{D}_{s,j} \cdot \frac{Y_j^{nc}}{\bar{Y}_j^{nc}} \cdot \frac{c_j^{nc}}{\bar{c}_j^{nc}} \cdot \frac{\bar{w}_s}{w_s} \quad \forall g \quad (21)$$

Non-coal representation of the production function

Sectors f

$$Y_j^{nc} = \bar{Y}_j^{nc} \cdot \min_j \left(\frac{D_{s,j}}{\bar{D}_{s,j}} \right) \quad \forall f \quad (22)$$

Sectors g

$$Y_j^{nc} = \bar{Y}_j^{nc} \cdot \prod_j \left(\frac{D_{s,j}}{\bar{D}_{s,j}} \right)^{\theta_j^s} \quad \forall g \quad (23)$$

Variables

$D_{s,j}$	demand of non-coal inputs s by sector j
c_j^{nc}	non-coal bundle unit cost of
w_s	price of input s
Y_j^{nc}	non-coal output level

Parameters

σ_j^{nc}	substitution elasticity among inputs s
θ_j^s	value share of input s

- Non-electricity energy bundle (ne)

The non-coal bundle is then added to coal to form the non-electricity bundle, which has a Leontief representation for the energy-sectors and a CES for non-energy sectors.

Sets

q	non-electricity inputs (Coal and non-coal)
-----	--

Coal and Non-coal demand function

Sectors f

$$D_{q,j} = \bar{D}_{q,j} \cdot \frac{Y_j^{ne}}{\bar{Y}_j^{ne}} \quad \forall f \quad (24)$$

Sectors g

$$D_{q,j} = \bar{D}_{q,j} \cdot \frac{Y_j^{ne}}{\bar{Y}_j^{ne}} \cdot \left(\frac{c_j^{ne}}{\bar{c}_j^{ne}} \cdot \frac{\bar{w}_{q,j}}{w_{q,j}} \right)^{\sigma_j^{ne}} \quad \forall g \quad (25)$$

Non-electricity representation of the production function

Sectors f

$$Y_j^{ne} = \bar{Y}_j^{ne} \cdot \min_j \left(\frac{D_{q,j}}{\bar{D}_{q,j}} \right) \quad \forall f \quad (26)$$

Sectors g

$$Y_j^{ne} = \bar{Y}_j^{ne} \left[\sum_j \left(\theta_j^q \cdot \left(\frac{D_{q,j}}{\bar{D}_{q,j}} \right)^{\rho_j^{ne}} \right) \right]^{\frac{1}{\rho_j^{ne}}} \quad \forall g \quad (27)$$

Variables

- $D_{q,j}$ demand for input q
- Y_j^{ne} output level of non-electricity energy bundle
- c_j^{ne} unit cost
- $w_{q,j}$ price of input q

Parameters

- θ_j^q value share of input q
- ρ_j^{ne} substitution parameter where $\rho = \frac{\sigma-1}{\sigma}$
- σ_j^{ne} substitution elasticity among inputs q

- Energy bundle (en)

The energy bundle is where electricity is added to all other types of energy already joined in the non-electricity one. The energy producing sectors have a Leontief representation of the energy bundle while the remaining sectors have a CD one.

Sets

- l energy inputs (Electricity and non-electricity)

Demand functions for electricity and non-electricity

Sectors f

$$D_{l,j} = \bar{D}_{l,j} \cdot \frac{Y_j^{en}}{\bar{Y}_j^{en}} \quad \forall f \quad (28)$$

Sectors g

$$D_{l,j} = \bar{D}_{l,j} \cdot \frac{Y_j^{en}}{\bar{Y}_j^{en}} \cdot \frac{c_j^{en}}{\bar{c}_j^{en}} \cdot \frac{\bar{w}_l}{w_l} \quad \forall g \quad (29)$$

Energy representation of the production function

Sectors f

$$Y_j^{en} = \bar{Y}_j^{en} \cdot \min_j \left(\frac{D_{l,j}}{\bar{D}_{l,j}} \right) \quad \forall f \quad (30)$$

Sectors g

$$Y_j^{en} = \bar{Y}_j^{en} \cdot \prod_j \left(\frac{D_{l,j}}{\bar{D}_{l,j}} \right)^{\theta_j^l} \quad \forall g \quad (31)$$

Variables

- $D_{l,j}$ demand for input l
- Y_j^{en} output level of energy
- c_j^{en} unit cost
- w_l price of input l

Parameters

- σ_j^{en} substitution elasticity among inputs l
- θ_j^l value share of input l
- ρ^{en} substitution parameter where $\rho = \frac{\sigma-1}{\sigma}$

- Capital-Energy bundle (ken)

At the higher stage, capital and energy are added in a capital-energy bundle. Since the price of capital is to be used for household initial endowment calculation, we the equations of capital and energy are split for clarity.

Demand functions for capital

Sectors f

$$D_{k,j} = \bar{D}_{k,j} \cdot \frac{Y_j^{ken}}{\bar{Y}_j^{ken}} \quad \forall f \quad (32)$$

Demand functions for energy

Sectors f

$$D_{en,j} = \bar{D}_{en,j} \cdot \frac{Y_j^{ken}}{\bar{Y}_j^{ken}} \quad \forall f \quad (33)$$

Demand functions for capital

Sectors g

$$D_{k,j} = \bar{D}_{k,j} \cdot \frac{Y_j^{ken}}{\bar{Y}_j^{ken}} \cdot \left(\frac{c_j^{ken}}{\bar{c}_j^{ken}} \cdot \frac{\bar{w}_{k,j}}{w_{k,j}} \right)^{\sigma_j^{ken}} \quad \forall g \quad (34)$$

Demand functions for energy

Sectors g

$$D_{en,j} = \bar{D}_{en,j} \cdot \frac{Y_j^{ken}}{\bar{Y}_j^{ken}} \cdot \left(\frac{c_j^{ken}}{\bar{c}_j^{ken}} \cdot \frac{\bar{w}_{en,j}}{w_{en,j}} \right)^{\sigma_j^{ken}} \quad \forall g \quad (35)$$

Capital-energy representation of the production function

Sectors f

$$Y_j^{ken} = \bar{Y}_j^{ken} \cdot \min_j \left(\frac{D_{k,j}}{\bar{D}_{k,j}}, \frac{D_{en,j}}{\bar{D}_{en,j}} \right) \quad \forall f \quad (36)$$

Sectors g

$$Y_j^{ken} = \bar{Y}_j^{ken} \left[\theta_j^k \cdot \left(\frac{D_{k,j}}{\bar{D}_{k,j}} \right)^{\rho^{ken}} + \theta_j^{en} \cdot \left(\frac{D_{en,j}}{\bar{D}_{en,j}} \right)^{\rho^{ken}} \right]^{\frac{1}{\rho^{ken}}} \quad \forall g \quad (37)$$

Variables

$D_{k,j}$ demand for input capital k by firm j

$D_{en,j}$ demand for energy bundle en

Y_j^{ken} output level of capital-energy bundle ken

c_j^{ken} unit cost of capital-energy bundle ken

$P_{k,j}$ price of capital k

$P_{en,j}$ price of energy bundle en

Parameters

- σ_j^{ken} substitution elasticity among capital and energy bundle
- θ_j^k value share of capital k
- θ_j^{en} value share of energy en
- ρ^{ken} substitution parameter where $\rho = \frac{\sigma-1}{\sigma}$

- Labor bundle (lab)

The GTAP database classify labor into skilled and unskilled, these two are combined in a CES representation as follow:

Sets

- b labor kind (Skilled and Unskilled)

Demand functions for skilled and unskilled labor

$$D_{b,j} = \bar{D}_{b,j} \cdot \frac{Y_j^{lab}}{\bar{Y}_j^{lab}} \cdot \left(\frac{c_j^{lab}}{\bar{c}_j^{lab}} \cdot \frac{\bar{P}_b}{P_b} \right)^{\sigma_j^{lab}} \quad \forall j \quad (38)$$

Labor representation of the production function

$$Y_j^{lab} = \bar{Y}_j^{lab} \left[\sum_j \left(\theta_j^b \cdot \left(\frac{D_{b,j}}{\bar{D}_{b,j}} \right)^{\rho^{lab}} \right) \right]^{\frac{1}{\rho^{lab}}} \quad \forall j \quad (39)$$

Variables

- $D_{b,j}$ demand for input b
- Y_j^{lab} output level of labor as value added
- c_j^{lab} unit cost
- P_b price of input b

Parameters

- σ_j^{lab} substitution elasticity among inputs b
- θ_j^b value share of input b
- ρ^{lab} substitution parameter where $\rho = \frac{\sigma-1}{\sigma}$

- Value-added – energy bundle (*vae*)

The value added-energy bundle is where all factors of production (land and natural resources, capital and labor) are added to the capital as inputs. Since the prices of production factors are to be used for household initial endowment calculation, the factors' equations are split for clarity.

Demand functions for land & natural resources, both kinds of labor and capital-energy

$$D_{lnr,j} = \bar{D}_{lnr,j} \cdot \frac{Y_j^{vae}}{\bar{Y}_j^{vae}} \cdot \left(\frac{c_j^{vae}}{\bar{c}_j^{vae}} \cdot \frac{\bar{w}_{lnr,j}}{w_{lnr,j}} \right)^{\sigma_j^{vae}} \quad \forall j \quad (40)$$

$$D_{lab,j} = \bar{D}_{lab,j} \cdot \frac{Y_j^{vae}}{\bar{Y}_j^{vae}} \cdot \left(\frac{c_j^{vae}}{\bar{c}_j^{vae}} \cdot \frac{\bar{w}_{lab,j}}{w_{lab,j}} \right)^{\sigma_j^{vae}} \quad \forall j \quad (41)$$

$$D_{ken,j} = \bar{D}_{ken,j} \cdot \frac{Y_j^{vae}}{\bar{Y}_j^{vae}} \cdot \left(\frac{c_j^{ken}}{\bar{c}_j^{ken}} \cdot \frac{\bar{w}_{ken,j}}{w_{ken,j}} \right)^{\sigma_j^{vae}} \quad \forall j \quad (42)$$

Value-added - Energy representation of the production function

$$Y_j^{vae} = \bar{Y}_j^{vae} \left[\theta_j^{lnr} \cdot \left(\frac{D_{lnr,j}}{\bar{D}_{lnr,j}} \right)^{\rho^{vae}} + \theta_j^{lab} \cdot \left(\frac{D_{lab,j}}{\bar{D}_{lab,j}} \right)^{\rho^{vae}} + \theta_j^{ken} \cdot \left(\frac{D_{ken,j}}{\bar{D}_{ken,j}} \right)^{\rho^{vae}} \right]^{\frac{1}{\rho^{vae}}} \quad \forall j \quad (43)$$

Variables

$D_{lnr,j}$ demand for land and natural resources *lnr*

$D_{lab,j}$ demand for both kinds labor *lab*

$D_{ken,j}$ demand for capital energy bundle *ken*

Y_j^{vae} output level of value-added – energy bundle *vae*

c_j^{vae} unit cost

$w_{lnr,j}$ price of input *lnr*

$w_{lab,j}$ price of input labor *lab*

$w_{ken,j}$ price of input capital-energy bundle *ken*

Parameters

- σ_j^{vae} substitution elasticity among inputs *lnr*, *lab* and *ken*
- θ_j^{lab} value share of input *lab*
- θ_j^{lnr} value share of input *lnr*
- θ_j^{ken} value share of input *ken*
- ρ^{vae} substitution parameter where $\rho = \frac{\sigma-1}{\sigma}$

- Gross output bundle (*Y*)

The value-added - energy nest trades off with the non-energy intermediate input, at a constant elasticity of substitution of 0 (Leontief) to produce the final product.

Demand functions for gross intermediate inputs

$$D_{n_{i,j}} = \bar{D}_{n_{i,j}} \cdot \frac{Y_j}{\bar{Y}_j} \cdot \left(\frac{c_j^y}{\bar{c}_j^y} \cdot \frac{\bar{P}_{n_{i,j}}^A}{P_{n_{i,j}}^A} \right)^{\sigma_j^y} \quad \forall j \quad (44)$$

Demand functions for gross value-added – energy bundle

$$D_{vae,j} = \bar{D}_{vae,j} \cdot \frac{Y_j}{\bar{Y}_j} \cdot \left(\frac{c_j^y}{\bar{c}_j^y} \cdot \frac{\bar{P}_{vae,j}}{P_{vae,j}} \right)^{\sigma_j^y} \quad \forall j \quad (45)$$

Gross output (final product) representation of the production function

$$Y_j = \bar{Y}_j \cdot \min \left(\frac{D_{n_{i,j}}}{\bar{D}_{n_{i,j}}}, \frac{D_{vae,j}}{\bar{D}_{vae,j}} \right) \quad \forall j \quad (46)$$

Variables

- $D_{vae,j}$ demand for *vae* bundle
- $D_{n_{i,j}}$ demand for intermediate input *i*
- Y_j output level of the productive activity
- c_j^y unit cost
- $P_{vae,j}$ price of input *vae*
- $P_{n_{i,j}}^A$ price of intermediate input *i* as an Armington composite of domestic and imported goods

Parameters

σ_j^y substitution elasticity among inputs

- Gross output transformation function

Producers decide whether to sell at home or abroad according to a constant elasticity of transformation CET criteria, i.e. goods sold locally or abroad can only be transformed into each other at a positive and increasing cost. Domestic production either enters the formation of an Armington mix of for domestic consumption, or it is exported to ROW to satisfy its demand.

CET transformation function

$$Y_i = \bar{Y}_i \left[\theta_i^E \cdot \left(\frac{S_{Ei}}{\bar{S}_{Ei}} \right)^{\eta_i} + \theta_i^D \cdot \left(\frac{S_{Di}}{\bar{S}_{Di}} \right)^{\eta_i} \right]^{\frac{1}{\eta_i}} \quad \forall i \quad (47)$$

Supply function for exported goods

$$S_{E,i} = \bar{S}_{E,i} \cdot \frac{Y_i}{\bar{Y}_i} \cdot \left(\frac{(1 + \tau_i^Y) c_i^y \cdot \bar{P}_{Ei} (1 - \bar{\tau}_i^E)}{(1 + \bar{\tau}_i^Y) \bar{c}_i^y \cdot P_{Ei} (1 - \tau_i^E)} \right)^{\varphi_i} \quad \forall i \quad (48)$$

Supply function for domestic goods

$$S_{D,i} = \bar{S}_{D,i} \cdot \frac{Y_i}{\bar{Y}_i} \cdot \left(\frac{(1 + \tau_i^Y) c_i^y \cdot \bar{P}_{Di}}{(1 + \bar{\tau}_i^Y) \bar{c}_i^y \cdot P_{Di}} \right)^{\varphi_i} \quad \forall i \quad (49)$$

Variables

$S_{E,i}$ supply of exported goods

$S_{D,i}$ supply of domestic goods

$P_{DG,i}$ price of goods supplied domestically

P_{Di} price of domestic goods

P_{Ei} price of exported goods

Exogenous Variables

- τ_i^Y production tax rate on output (both exports and domestic goods)
- τ_i^{ex} exports tax or subsidy rate

Parameters

- θ_i^{DG} value share of domestic goods
- θ_i^{EG} value share of exported goods
- η_i parameter for elasticity of transformation between good i supplied domestically or exported ($\eta = \frac{1+\varphi}{\varphi}$), where φ_i is the elasticity of transformation

- Armington Composite representation

Being an open economy, trade is specified following the Armington approach, which implies that consumers, investors, the government and productive sectors treat imports and domestic goods as imperfect substitutes.

Demand functions for imports

$$D_{M_i} = \bar{D}_{M_i} \cdot \frac{A_i}{\bar{A}_i} \cdot \left(\frac{c_i^a}{\bar{c}_i^a} \cdot \frac{\bar{P}_{M_i}(1 + \bar{\tau}_i^m)}{P_{M_i}(1 + \tau_i^m)} \right)^{\sigma_i^a} \quad \forall i \quad (50)$$

Demand functions for domestic goods

$$D_{D_i} = \bar{D}_{D_i} \cdot \frac{A_i}{\bar{A}_i} \cdot \left(\frac{c_i^a}{\bar{c}_i^a} \cdot \frac{\bar{P}_{D_i}}{P_{D_i}} \right)^{\sigma_i^a} \quad \forall i \quad (51)$$

Armington composite production function

$$A_i = \bar{A}_i \left[\theta_i^M \cdot \left(\frac{D_{M_i}}{\bar{D}_M} \right)^{\rho^a} + \theta_i^D \cdot \left(\frac{D_{D_i}}{\bar{D}_{D_i}} \right)^{\rho^a} \right]^{\frac{1}{\rho^a}} \quad \forall i \quad (52)$$

Supply function for Armington composite

$$S_{A_i} = \bar{S}_{A_i} \cdot \frac{A_i}{\bar{A}_i} \cdot \left(\frac{(1 + \tau_i^S) c_i^a \bar{P}_i^A}{(1 + \bar{\tau}_i^S) \bar{c}_i^a \cdot P_i^A} \right)^{\sigma_i^a} \quad \forall i \quad (53)$$

Variables

D_{M_i}	demand for imported goods
D_{D_i}	demand for domestic goods
A_i	output level of Armington composite
c_i^a	unit cost
P_i^A	price of an Armington composite

Exogenous variables

τ_i^m	import tax rate
τ_i^s	sales tax rate

Parameters

σ_j^a	substitution elasticity among inputs
θ_j^M	value share of imports
θ_j^D	value share of domestic goods
ρ^a	substitution parameter where $\rho = \frac{\sigma-1}{\sigma}$

- Balance of payment

$$\sum_i p_i^{WE} \cdot S_{E_i} + Def = \sum_i p_i^{WM} \cdot D_{M_i} \quad \forall i \quad (54)$$

- Prices of exports and imports

$$P_{E_i} = \varepsilon p_i^{WE} \quad (55)$$

$$P_{M_i} = \varepsilon p_i^{WM} \quad (56)$$

Exogenous variables

p_i^{WE}	world export price
------------	--------------------

p_i^{WM} world import price
 Def government deficit

- Household

Consumer utility consists of a Cobb-Douglas utility index defined over Armington aggregation of domestic and imported commodities. Household's income is the sum of the factor endowments she receives minus direct taxes.

Aggregate consumption

$$C^P = \bar{C}^P \prod_i D_i^{P\alpha_i} \quad \forall i \quad (57)$$

Demand function for private consumption

$$D_i^P = \bar{D}_i^P \cdot \frac{(P_{k,j}^z \cdot D_{k,j}^k + P_{b,j}^v \cdot D_{b,j}^b + P_{lnr,j}^m \cdot D_{lnr,j}^{lnr}) \cdot \bar{P}_i^A}{(\bar{P}_{k,j}^z \cdot \bar{D}_{k,j}^k + \bar{P}_{b,j}^v \cdot \bar{D}_{b,j}^b + \bar{P}_{lnr,j}^m \cdot \bar{D}_{lnr,j}^{lnr}) \cdot P_i^A} - T^D - S^P \quad \forall i \quad (58)$$

Variables

D_i^P private demand of an Armington composite of good i
 C^P total private consumption
 c_i composite consumption of good i
 c_i^{DG} consumption of domestic good i
 c_i^{MG} consumption of imported good i

Parameters

ξ_i^{DG} share of domestic good of total consumption of good i
 ξ_i^{MG} share of imported good of total consumption of good i
 T^D direct tax
 S^P private savings
 α_i share parameter of household consumption

- Government

The government income is composed of direct tax, sales tax, export tax and tariffs. It spends on and Armington composite of goods.

Demand function for government consumption

$$D_i^G = \bar{D}_i^G \frac{T^D + \sum_j T_j^Y + \sum_j T_j^M \sum_j T_j^E \sum_j T_j^S - S^G \bar{P}_i^A}{\bar{T}^D + \sum_j \bar{T}_j^Y + \sum_j \bar{T}_j^M \sum_j \bar{T}_j^E \sum_j \bar{T}_j^S - \bar{S}^G \cdot \bar{P}_i^A} \quad \forall i \quad (59)$$

Direct tax revenue

$$T^D = \tau^D \sum_b P_b FE_b + P_{lnr} FE_{lnr} + P_k FE_k \quad (60)$$

Production tax revenue

$$T_j^Y = \tau^Y P_{E_j} S_{E_j} + \tau^Y P_{D_j} S_{D_j} \quad \forall j \quad (61)$$

Export tax revenue

$$T_j^E = \tau^E P_j^E S_{E_j} \quad \forall j \quad (62)$$

Import tax revenue

$$T_j^M = \tau^M P_j^M D_{M_j} \quad \forall j \quad (63)$$

Endogenous variables

D_i^G	government demand of an Armington composite of good i
T^D	direct tax
T^S	sales tax
T^M	tariffs
T^Y	output tax
S^G	government savings

Exogenous variables

FE_b	initial factor endowment of labor to household
FE_{lnr}	initial factor endowment of land and natural resources to household
FE_k	initial factor endowment of capital to household
τ^D	direct tax rate
τ^Y	output tax rate
τ^M	tariffs rate
τ^E	export tax rate

- Investment

Given the propensity to save for households and government, investment agents spends on goods to have future welfare. A CES function is assumed for the investment behavior.

Demand function for goods by investment

$$D_i^I = \bar{D}_i^I \cdot \frac{I}{\bar{I}} \cdot \left(\frac{c_i^I}{\bar{c}_i^I} \cdot \frac{\bar{P}_i^A}{P_i^A} \right)^{\sigma^I} \quad \forall i \quad (64)$$

Private savings

$$S^p = p_s^p \sum_b P_b FE_b + P_{lnr} FE_{lnr} + P_k FE_k \quad (65)$$

Government savings

$$S^g = p_s^g \cdot \left(\sum_j T_j^m + \sum_j T_j^E + \sum_j T_j^S \right) \quad (66)$$

Endogenous Variables

I_i investment uses

Parameters

S^p private propensity to save

S^g propensity to save for government

σ^I substitution elasticity of inputs

- Commodities' market-clearing conditions

$$A_i \cdot \bar{A}_i = D_i^P + D_i^G + D_i^I + \sum_j D_{i,j} \quad \forall i \quad (67)$$

- Primary Factors' market-clearing conditions

$$S_k = \sum_j D_{k,j} \quad (68)$$

$$S_{lnr} = \sum_j D_{lnr,j} \quad (69)$$

$$S_b = \sum_j D_{b,j} \quad \forall b \quad (70)$$

Calibration

Model calibration consists of calculating the shift and share parameters used in the production and utility functions in the CGE model so that solutions to the equation replicate the benchmark (initial equilibrium in the database). Once the model is calibrated, the calibrated model solution is used as the benchmark equilibrium, against which the results of the model experiments are compared. Given that in a Neo-classical CGE model, the prices are assumed to be one at initial equilibrium as prices are normalized, the one unit of a certain quantity of any commodity is what an agent can buy for one unit of the currency used in the model. Hence, in following calibration explanation benchmark prices, which are equal to one, are not mentioned. The following is an illustration of how the scale and share parameters of Cobb-Douglas, CES and CET functions. Since the calibrated share form of a Leontief function neither has shift nor share parameters, it isn't discussed below.

Calibration of parameters is a Cobb-Douglas function

$$C^P = \bar{C}^P \prod_i D_i^{P\alpha_i} \quad \forall i \quad (71)$$

$$\alpha_i = \frac{\bar{D}_i^P}{\sum_i \bar{D}_i^P} \quad \forall i \quad (72)$$

Calibration of parameters is a CES function

$$A = \bar{A}_i \left[\theta_i^M \cdot \left(\frac{D_{M_i}}{\bar{D}_M} \right)^{\rho^\alpha} + \theta_i^D \cdot \left(\frac{D_{D_i}}{\bar{D}_{D_i}} \right)^{\rho^\alpha} \right]^{\frac{1}{\rho^\alpha}} \quad \forall i \quad (73)$$

$$\theta_i^M = \frac{(1 + \bar{\tau}_i^m) \bar{D}_{M_i}^{(1-\rho^\alpha)}}{(1 + \bar{\tau}_i^m) \bar{D}_{M_i}^{(1-\rho^\alpha)} + D_{D_i}^{(1-\rho^\alpha)}} \quad \forall i \quad (74)$$

$$\theta_i^D = \frac{\bar{D}_{D_i}^{(1-\rho^\alpha)}}{(1 + \bar{\tau}_i^m) \bar{D}_{M_i}^{(1-\rho^\alpha)} + D_{D_i}^{(1-\rho^\alpha)}} \quad \forall i \quad (75)$$

Calibration of parameters is a CET function

$$Y_i = \bar{Y}_i \left[\theta_i^E \cdot \left(\frac{S_{E_i}}{\bar{S}_{E_i}} \right)^{\eta_i} + \theta_i^D \cdot \left(\frac{S_{D_i}}{\bar{S}_{D_i}} \right)^{\eta_i} \right]^{\frac{1}{\eta_i}} \quad \forall i \quad (76)$$

$$\theta_i^E = \frac{\bar{S}_{E_i}^{(1-\eta_i)}}{\bar{S}_{E_i}^{(1-\eta_i)} + \bar{S}_{D_i}^{(1-\eta_i)}} \quad \forall i \quad (77)$$

$$\theta_i^D = \frac{\bar{S}_{D_i}^{(1-\eta_i)}}{\bar{S}_{E_i}^{(1-\eta_i)} + \bar{S}_{D_i}^{(1-\eta_i)}} \quad \forall i \quad (78)$$

4.3.1. CO2 accounting

GTAP database provides a full presentation of carbon emissions associated with (proportional to the use of) fossil fuels, using a satellite data array that is based on energy data provided by the International Energy Agency.

CO2 emissions can be classified into direct and indirect carbon emissions embodied in commodities, to determine the full carbon content of carbon in commodities the model must account for both kinds. The direct carbon emissions are those emissions resulting from the combustion of fossil fuel inputs. Direct emissions per unit of commodity i produced are accounted for as follow:

$$DCE_j = \sum_i CE_{ij}/Y_j \quad \forall j \quad (79)$$

$i = \text{oil, coal, gas, petroleum}$

DCE_j direct carbon emission resulting from fossil fuel i combustion to produce one unit of j .

CE_{ij} carbon emissions linked to input of fuel i in the production of commodity j .

Y_j total output of commodity j

Indirect emissions are those emissions associated with intermediate non-fossil inputs. As common in environmental CGE models, and for the sake of simplicity, the model retrains

the indirect emissions accounting to electricity inputs, which make the bulk part of indirect emissions. Indirect emissions are accounted for as follow:

$$ICE_j = \left(\frac{D_{ele,j}}{Y_j} \right) \cdot DCE_{ele} \quad \forall j \quad (80)$$

ICE_j indirect carbon emission resulting from electricity use to produce one unit of j .

$D_{ele,j}$ intermediate demand for domestic and imported electricity (Armington composite) by commodity j .

DCE_{ele} direct carbon emission per unit of production of electricity.

The total embodied carbon content per unit produced is calculated as follow:

$$CC_j = DCE_j + ICE_j \quad \forall j \quad (81)$$

CC_j total embodied carbon content per unit of j .

4.3.2. Model closure

Since the choice of closure can affect model results in significant ways, closures for the model were chosen to best describe the two developing economies at hand. As is common with all known neoclassical CGE models, the price system is homogeneous, hence the focus is on relative rather than absolute prices. To express all prices in relative terms the model fixes the consumer price index as the numeraire.

Unemployment has always been a hot topic in developing countries, reducing its rate has also been on within the top priorities of their governments. Unemployment was introduced to the model using the minimum wage rate theory; assuming that the economy wide wage is exogenous, and an endogenous labor supply adjusts until national labor supply and demand are equal. This classical theory allows for easy analysis of possible shocks, such as productivity reduction, health problems, sanctions on exports, on the rate of unemployment and eventually on relative prices. Rates of unemployment have been retrieved from the formal websites of each country's bureau of statistics.

Current account closure describes whether foreign savings inflows (current account) are exogenous and the exchange rate is endogenous, or vice versa. For this model, the current account deficit or surplus is assumed to be fixed and assumed exogenous at their initial levels and the exchange rate adjusts to maintain it.

For government account closure, it is assumed that government deficit is an exogenous policy objective, which means that government spending must adjust endogenously. This type of closure fits more the nature of a developing country where governments need to abide by certain macroeconomic constraints and maintain a specific deficit.

The macroclosure describes which of the three macroeconomic variables –savings or investments – will adjust to maintain the identity that investment and savings are equal. In this model the savings rate is assumed to be exogenous and constant, so the quantity of savings changes whenever income changes, and investment spending then changes to accommodate the change in supply of savings. This classifies the model at hand to be a “savings-driven” Neo-Classical model that fixes a Marginal Propensity to Save (MPS) calculated for each of the two countries using the GTAP Database.

4.4. The Recursive Version of a Single Country Model

4.4.1. Introduction

The model at hand is a recursive semi-dynamic one that is solved 15 consecutive periods after growth rate mechanism has been integrated. Growth is the result of the saving decisions taking by the representative agent based on her current levels. Forecast, however, is introduced in an indirect way through a “social planner” who is represented through “conditional interventions” programmed to be launched when certain thresholds are reached (as in the case of introducing a carbon tax upon reaching a certain level of CO₂ emissions).

Decisions of investment are taken by consumers at time t , based on her savings. Resulting capital is incorporated in production at $t+1$. New capital in each period is assumed to be fully mobile among sectors, thus, capital is endogenously assigned until its marginal products is equal in all sectors. Therefore, growth of the different industries is endogenously determined too. Capital mobility is a fundamental foundation for this model; the final results may be significantly dependent on the level of capital mobility among industries and with the rest of the world. For instances, when capital is assumed to be fully mobile (locally and internationally) a tax imposed on a certain productive sector would have the heavier impact on those fixed factors, or on consumers depending of the elasticities of substitutions assumed. However, if the capital is assumed to be fixed in that sector, the tax would be absorbed as a reduction of the rental price of capital in that sector.

With sensitivity analysis; it is possible to analyze different levels of mobility among domestic industries and with the rest of the world, especially when dealing with new capital that is still to be allocated. Such sensitivity analysis allows a better understanding of the differences in the sensitivity level of the outcomes in the short and long run.

To model the growth rate of the economy, it is assumed that population growth is equal to zero. In the model, though, population growth is accounted for; it is introduced exogenously through the increase of labor endowment to households each year. Moreover, it is assumed that domestic fixed capital does not grow; the only variable determining growth rate is the domestic mobile capital, which varies over the periods.

4.4.2. Capitalization

How realistic is it to assume that capital mobile is perfectly mobile among sectors? Is it still plausible when studying poor developing countries such as Egypt? Unlike global models such as GTAP and GTEM, which assume perfect mobility of capital among sectors, this model allows the study of the effect of alternating the levels of capital mobility. Under section 6, the sensitivity of capital mobility levels is analyzed to measure their eventual effect on the effectiveness of measurements and final outcomes.

While labor is assumed to be perfectly mobile among sectors, land is assumed to be fixed and sector specific. Capital, however, is assumed to be partially mobile; this allows the classification of capital into fixed (sector-specific) and mobile (among sectors).

Let's assume that GDP (Y) is produced using three factors, labor (L) land and natural resources (N) and physical capital (TK). let KT_{t-1} denote total capital, K_{t-1} fixed capital, KM_{t-1} mobile capital in year t-1, and θ the percentage of mobile capital in total capital, then fixed and mobile capital are calculated as in:

$$KM_{t-1} = \theta KT_{t-1} \text{ and } K_{t-1} = (1 - \theta)KT_{t-1}; \quad (82)$$

Assuming a CRS Cobb-Douglas production function such as:

$$Y_{t-1} = A(K_{t-1}^\alpha KM_{t-1}^\beta L_{t-1}^\lambda N_{t-1}^\rho)^\gamma \quad (83)$$

Where Y_{t-1} is total output in year t-1, and A is total factor productivity (TFP), γ measures the extent of return to scale, since the production function is assumed to be a CRS, γ is equal to 1. While α , β , λ and ρ measures the importance of each factor in output. By expressing this equation in growth rates

$$\frac{\Delta Y}{Y_{t-1}} = \alpha \frac{\Delta K}{K_{t-1}} + \beta \frac{\Delta KM}{KM_{t-1}} + \lambda \frac{\Delta L}{L_{t-1}} + \rho \frac{\Delta N}{N_{t-1}} + \frac{\Delta A}{A} \quad (84)$$

Assuming that fixed capital, land and natural resources and labor⁴² are fixed, the growth rate of mobile capital is given by:

$$\frac{\Delta KM}{KM_{t-1}} = \frac{1}{\beta} \left[\frac{\Delta Y}{Y_{t-1}} - \frac{\Delta A}{A} \right] \quad (85)$$

The growth rate of the economy can be calculated as in

$$\frac{\Delta Y}{Y_{t-1}} = \frac{\Delta TK}{TK_{t-1}}; \quad \frac{\Delta TK}{TK_{t-1}} = \frac{I_{t-1} - \delta TK}{TK_{t-1}} \quad (86)$$

Unfortunately, the SAM doesn't provide information about the real capital stock available in an economy; it simply gives the value of physical capital, not the quantity. To surmount this problem, the concept of capital/output ratio is introduced to equation 85 as follow:

$$\frac{\Delta KM}{KM_{t-1}} = \frac{1}{\beta} \left[\frac{I_{t-1} - \delta k Y_{t-1}}{k Y_{t-1}} - \frac{\Delta A}{A} \right] \quad (87)$$

Where I_{t-1} is total investment is in period $t-1$, δ is depreciation rate, and k is capital/output ratio. Since the production function is a Cobb-Douglas, β takes the value of:

$$\beta = \frac{RPK_M KM_{t-1}}{Y_{t-1}} \quad (88)$$

Where RPK_M is the rental price of mobile capital. Substituting β and setting $\frac{\Delta A}{A}$ equal to τ we get:

$$\frac{\Delta KM}{KM_{t-1}} = \left[\frac{I_{t-1} - \delta k Y_{t-1}}{RPK_m KM_{t-1} k} \right] - \left[\tau * \frac{Y_{t-1}}{RPK_m KM_{t-1}} \right] \quad (89)$$

This capitalization factor is utilized to increase the endowment of mobile capital by household each period. The following parameters are assumed to be exogenously given: the total factor productivity τ , capital output ration, k , and depreciation rate δ .

⁴² While population growth is assumed to be zero in calculating the growth rate of capital, it is important to recall that the model accounts for population growth in the form of an increase of household endowment of labor at a constant rate, which is exogenously introduced to the model (year by year) in the dynamic recursive simulations. Moreover, the TFP calculation also takes into consideration the percentage growth rate of labor, whose effect cannot be neglected of the percentage growth rate of output.

Rearranging the variables, total factor productivity (TFP) growth can be calculated as growth in output less a weighted average of growth in inputs:

$$\frac{\Delta A}{A} = \frac{\Delta Y}{Y_{t-1}} - \beta \frac{\Delta KM}{KM_{t-1}} - \lambda \frac{\Delta L}{L_{t-1}} \quad (90)$$

Table 4-4 below summarizes the technological progress rate calculated for both countries. It is worth noting here that labor data was retrieved from ILO online database and using the World Bank's population estimates, the GDP growth rate was from the World Bank online database, and the rest of data regarding capital from the GTAP database.

Table 4-4. Inputs Summary

Parameters	Tunisia	Egypt
Percentage of Mobile Capital (%) [^]	100	100
Technological Progress (%) [€]	2.6	1.6
Depreciation Rate (%) [†]	4	3.9
Capital/Output Ratio [†]	3.26	2.37
Population Growth Rate (%) [☐]	0.95	1.7
Sources: [^] Capital is initially assumed to be fully mobile; the sensitivity of this assumption is tested later on. [€] Calculated using equation 91. [†] GTAP database.		

The capital-output ratio is calculated as an input-output coefficient. Input-output coefficients represent the ratio of the quantities of intermediate/factor inputs per unit of output. Since the data represented in the SAM is normalized by assuming that it shows quantities per dollar, then we can interpret the division of the value reported in the capital column divided by total income or output.

As mentioned earlier, production factors were aggregated in Labor (fully mobile) Land and Natural Resources (sector-specific) and Capital is initially assumed to be fully mobile among jobs until wage and rent differentials disappear, full factor mobility is quite realistic for labor and capital markets in the medium and long run because of transition costs, such as retaining and job search costs, become less important when they get amortized over a long time.

The model allows the study of various levels of capital mobility and their effect on final outcomes. Using sensitivity analysis, the model allows capital to be partially mobile “sector-specific” since existing equipment and machinery are typically hard to transform for use in different industries. This assumption implies that transition costs are large enough to discourage some equipment from changing industry; rents can therefore diverge across production activities. It is important to remember that even with the assumption of partial capital mobility; the mobility of capital will always be assumed to be high given that the model at hand is a semi-dynamic model that tackles topics that need to be analyzed over the long-run, such as climate change.

It is worth noting that the factor mobility assumption influences the slope of industries’ supply curves, hence it has a big influence on the supply response to any type of economic shocks. This is why -through sensitivity analysis in (section 6)- the alternative factor market mobility assumptions are tested, measuring to what limit they can alternate results.

5. Results of simulations with the dynamic model

5.1. Introductions

In this section, some climate change-related simulations are run for Tunisia and Egypt. Simulations take the forms of (i) shocks to the productivity of fertile land (ii) shocks to efficiency of energy use, (iii) change in the prices of agricultural goods due to international politics with respect to the content of carbon in exports (iv) taxing carbon content in exports.

5.2. Scenario 1: Diminished productivity of agricultural land

Climate change may have a severe impact on African countries, whose climate can generally be described as already hot; a further increase in temperature may decrease the size of arable land, cause drought and lack of water. The agricultural sector plays a major role in the GDP, employment and wellbeing of the two countries analyzed, if land rent and agricultural profits decrease, economic resources may start migrating to other industries. What impact does such a reallocation of resources have on the GDP? Given that emissions from fuel combustions to produce non-agricultural goods might be larger, will such a reallocation cause further emissions?

A shock to the total productivity is modeled by alternating the parameter ($\theta > 1$), which influences the production function as in $Y = \theta F(L, K, LNR)$. In case of introducing a shock to the productivity of fertile land, the decrease is introduced as in θLNR ($\theta > 1$). The following simulation introduces an exogenous shock to land productivity in the form of a constant 5% reduction in arable land in the periods 6 to 10.

Agriculture, where the majority of unskilled labor are employed, contributes to GDP in Tunisia and Egypt with 7.6% and 7.4% respectively where the majority of poor population are employed. A shock of 5% to land productivity made agricultural production to drop by 21% in both countries; it increased unemployment mostly among unskilled labor as expected. The overall reduction in GDP was 2.8% in Tunisia and 3.8% in Egypt, which is relatively high given a 5% only of productivity reduction.

Figure 5-1. Tunisia, shock to productivity of agricultural land

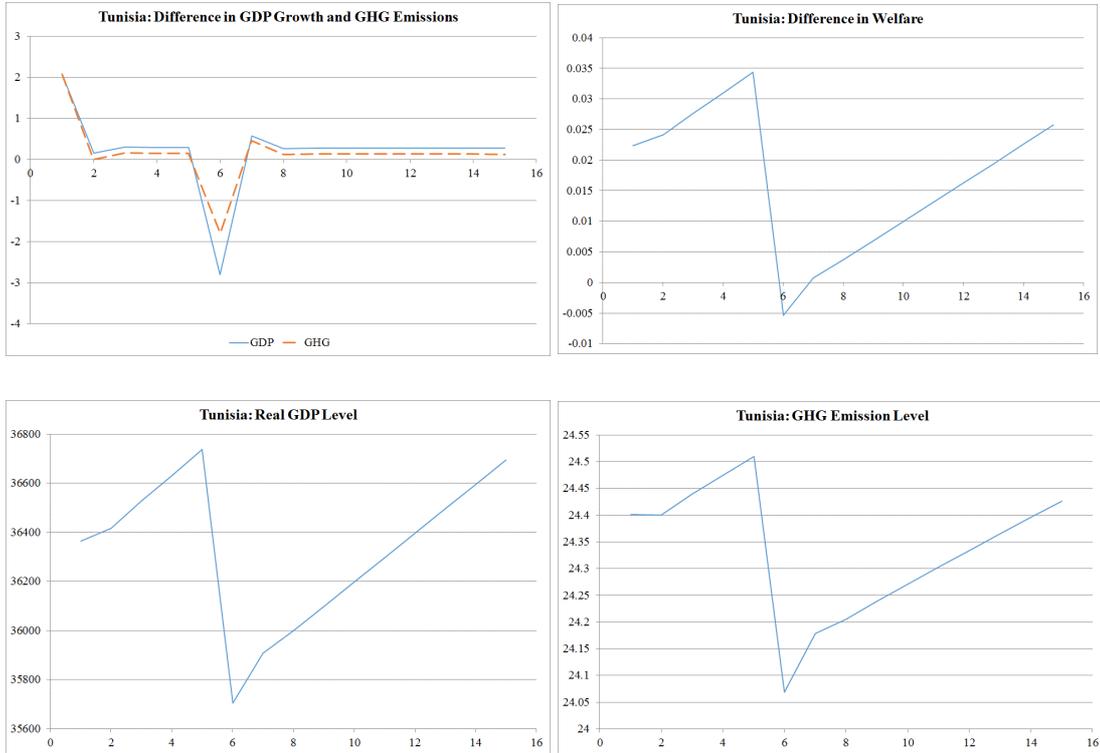


Figure 5-2. Egypt, shock to productivity of agricultural land

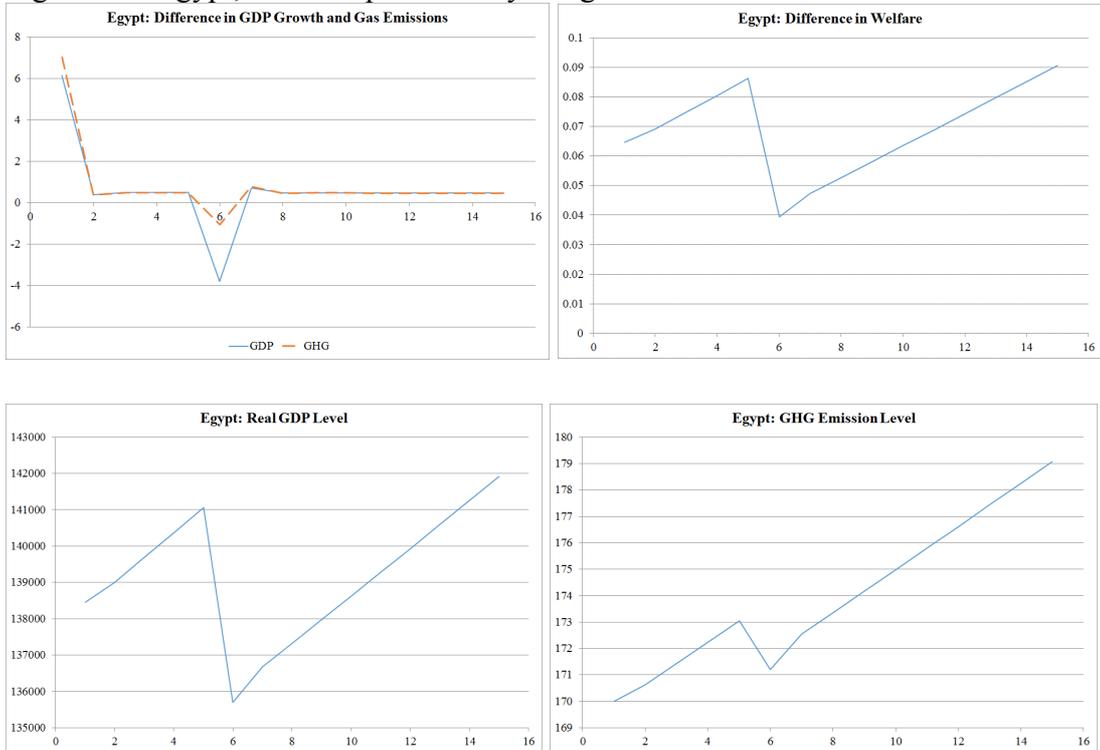


Table 5-1 Tunisia: Shock to productivity of agricultural land

	Periods														
	P1	P2	P3	P4	P5	P6	P7	P8	P9	P10	P11	P12	P13	P14	P15
Macroeconomic Indicators															
GDP growth rate	2.09	0.15	0.30	0.29	0.29	-2.80	0.56	0.25	0.28	0.27	0.27	0.27	0.27	0.27	0.27
Welfare	1.02	1.02	1.03	1.03	1.03	0.99	1.00	1.00	1.01	1.01	1.01	1.02	1.02	1.02	1.03
Unemployment rate															
Skilled	0.11	0.12	0.12	0.12	0.13	0.17	0.17	0.18	0.18	0.19	0.19	0.19	0.20	0.20	0.21
Unskilled	0.11	0.12	0.12	0.13	0.13	0.20	0.20	0.21	0.21	0.22	0.22	0.23	0.23	0.23	0.24
Contamination Indicator															
GHG Emissions	24.40	24.40	24.44	24.47	24.51	24.07	24.18	24.21	24.24	24.27	24.30	24.33	24.37	24.40	24.43

Table 5-2 Egypt: Shock to productivity of agricultural land

	Periods														
	P1	P2	P3	P4	P5	P6	P7	P8	P9	P10	P11	P12	P13	P14	P15
Macroeconomic Indicators															
GDP growth rate	6.15	0.40	0.49	0.49	0.49	-3.80	0.72	0.47	0.47	0.47	0.47	0.47	0.47	0.47	0.47
Welfare	1.06	1.07	1.07	1.08	1.09	1.04	1.05	1.05	1.06	1.06	1.07	1.07	1.08	1.09	1.09
Unemployment rate															
Skilled	0.05	0.06	0.07	0.08	0.09	0.15	0.16	0.17	0.18	0.19	0.19	0.20	0.21	0.22	0.22
Unskilled	0.05	0.06	0.07	0.08	0.09	0.18	0.18	0.19	0.20	0.21	0.22	0.22	0.23	0.24	0.25
Contamination Indicator															
GHG Emissions	169.99	170.61	171.43	172.24	173.05	171.21	172.54	173.35	174.16	174.98	175.80	176.61	177.43	178.25	179.07

5.3. Scenario 2: An increase in the efficiency of energy use and the effect of CDM.

CDM is one of the great mechanisms suggested in Kyoto protocol for an easy technology transfer and in correspondence with the demand for international support from developing countries to reach their targets. By June 2017, the number of registered CDM projects undertaken worldwide was 10,183 projects, out of which, only 59 were undertaken in Africa⁴³. Egypt had the share of 9 projects financed by different European countries and Japan, while Tunisia got 3 financed by Italy and Spain. Should developed countries invest more in Africa? Is the impact worth it at the GHG emission reduction and the level of sustainable economic development of the developing country? The following analysis shows the overall effect of such projects on the welfare and reduction in CO₂ emissions.

The United Nations⁴⁴ classifies CDM projects in 8 major types, the major four types that make the bulk of the emission reduction are: renewables making 71% of total number of projects, CH₄ reduction & cement & coal min/bed making 15%, supply-side (in production) energy efficiency enhancing making 6% and demand-side energy (in consumption) efficiency enhancing making 3%, all remaining types of project make 5% of total number of projects. Energy efficiency projects have a good share of the total number of CDM projects, this scenario analysis the effect of such efficiency increasing projects in Egypt and Tunisia and measures the outcomes of such projects on the GHG emissions and the economic development of the host developing country.

The simulation measures the gain of 10% in efficiency of energy consumption in production thought multiplying the quantities of intermediate consumption of energy goods by a parameter, θ where ($\theta < 1$).

On one hand, results show that increasing efficiency of energy use in production has a great effect on economy level of both countries; GDP witnessed a remarkable growth rates as shown in Figure 5-3 and Figure 5-4. On the other hand, results show a clear rebound effect (Jevons effect); in Egypt, for instance, prices of electricity and petroleum dropped by 11% and 14% respectively; the decrease in their prices increased their consumption at all levels resulting in a clear rebound effect.

In conclusion, if the main goal of CDM initiatives in these countries is reducing GHG emissions, it is worth considering undertaking different projects such as investing in new

⁴³ UNFCCC website

⁴⁴ UNEP website

green technologies and GHG absorption, which would have a greater effect on the overall GHG emissions than technology transfer for efficiency increase.

Figure 5-3. Tunisia, shock to efficiency of energy use

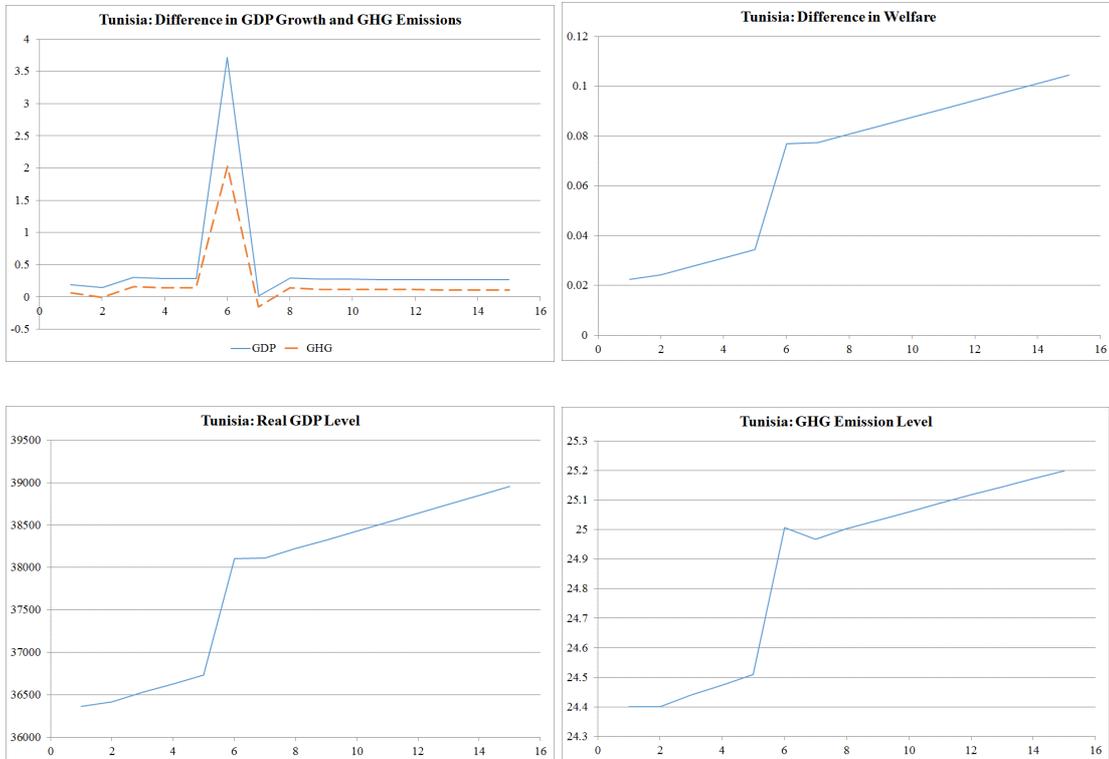


Figure 5-4. Egypt, shock to efficiency of energy use

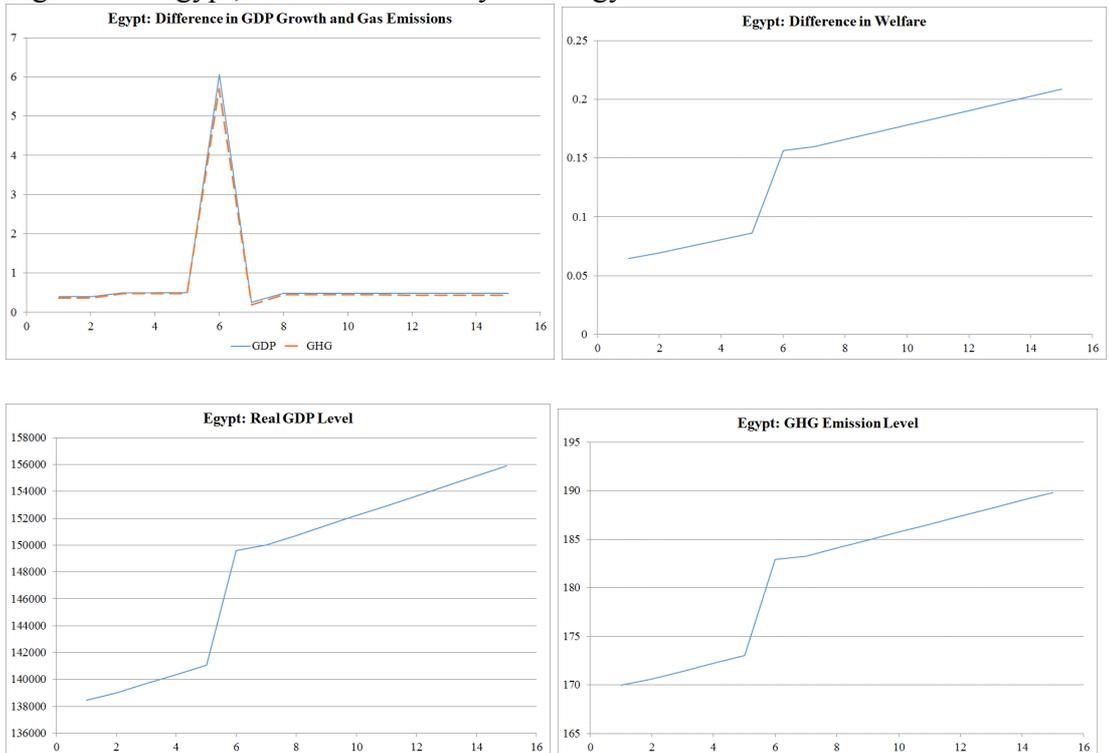


Table 5-3 Tunisia, shock to efficiency of energy use

	Periods														
	P1	P2	P3	P4	P5	P6	P7	P8	P9	P10	P11	P12	P13	P14	P15
Macroeconomic Indicators															
GDP growth rate	0.39	0.15	0.30	0.29	0.29	3.72	0.02	0.29	0.27	0.27	0.27	0.27	0.27	0.27	0.27
Welfare	1.02	1.02	1.03	1.03	1.03	1.08	1.08	1.08	1.08	1.09	1.09	1.09	1.10	1.10	1.10
Unemployment rate															
Skilled	0.11	0.12	0.12	0.12	0.13	0.09	0.10	0.10	0.11	0.11	0.12	0.12	0.13	0.13	0.13
Unskilled	0.11	0.12	0.12	0.13	0.13	0.10	0.11	0.11	0.12	0.12	0.13	0.13	0.13	0.14	0.14
Contamination Indicator															
GHG Emissions	24.40	24.40	24.44	24.47	24.51	25.01	24.97	25.00	25.03	25.06	25.09	25.12	25.14	25.17	25.20

Table 5-4 Egypt, shock to efficiency of energy use

	Periods														
	P1	P2	P3	P4	P5	P6	P7	P8	P9	P10	P11	P12	P13	P14	P15
Macroeconomic Indicators															
GDP growth rate	0.35	0.40	0.49	0.49	0.49	6.06	0.26	0.49	0.48	0.48	0.48	0.48	0.48	0.48	0.48
Welfare	1.06	1.07	1.07	1.08	1.09	1.16	1.16	1.17	1.17	1.18	1.18	1.19	1.20	1.20	1.21
Unemployment rate															
Skilled	0.05	0.06	0.07	0.08	0.09	0.03	0.04	0.05	0.06	0.07	0.08	0.09	0.10	0.11	0.12
Unskilled	0.05	0.06	0.07	0.08	0.09	0.03	0.04	0.05	0.06	0.07	0.08	0.09	0.10	0.11	0.12
Contamination Indicator															
GHG Emissions	169.99	170.61	171.43	172.24	173.05	182.91	183.26	184.09	184.91	185.73	186.55	187.37	188.19	189.00	189.82

5.4. Scenario 3: Change in the prices of agricultural and energy intensive goods due to international politics.

Countries who signed the Kyoto protocol have started to abate GHG emissions using the different abatement options. These governmental interventions have increased the world price of taxed goods; namely agricultural and energy intensive goods which have a high level of carbon content. What are the effect of such higher prices on the exporting industries of such goods in Egypt and Tunisia?

The following simulation explains the indirect impact of international politics on the economies such as Tunisia and Egypt. This scenario simulates an increase of world prices of agricultural and energy-intensive goods –due to regulations- by 20%. Exogenous shocks to the prices of agricultural goods and energy-intensive goods are introduced through changing the world prices of exports. World prices of exports are defined as θWPE , with $(\theta < 1)$.

Results show that both countries would benefit greatly from higher prices (assuming no sanctions on exports of these two countries by abating ones). Results show a great response in GDP growth in the case of Tunisia; GDP increased by 11.78 in the first period, caused mainly by in remarkable growth in the energy-intensive industry sector. In the case of Tunisia, energy-intensive industry makes 13.5% of GDP. Given the increase in world prices, the production of energy-intensive sector almost doubled; mobile resources moved intensively into this sector, which exports more than 50% of its total exports. Exports of energy-intensive goods increased by 63%. In the case of Egypt, the effect of such international policy is less visible; the major growth is again witnessed in the energy-intensive sector. Total exports of the sector increased by 45%, however, since the sector makes less than 1% of the Egyptian GDP the eventual effect on the GDP was a growth of 3.75%.

Figure 5-5 Tunisia, increase in world price of agricultural and energy-intensive goods

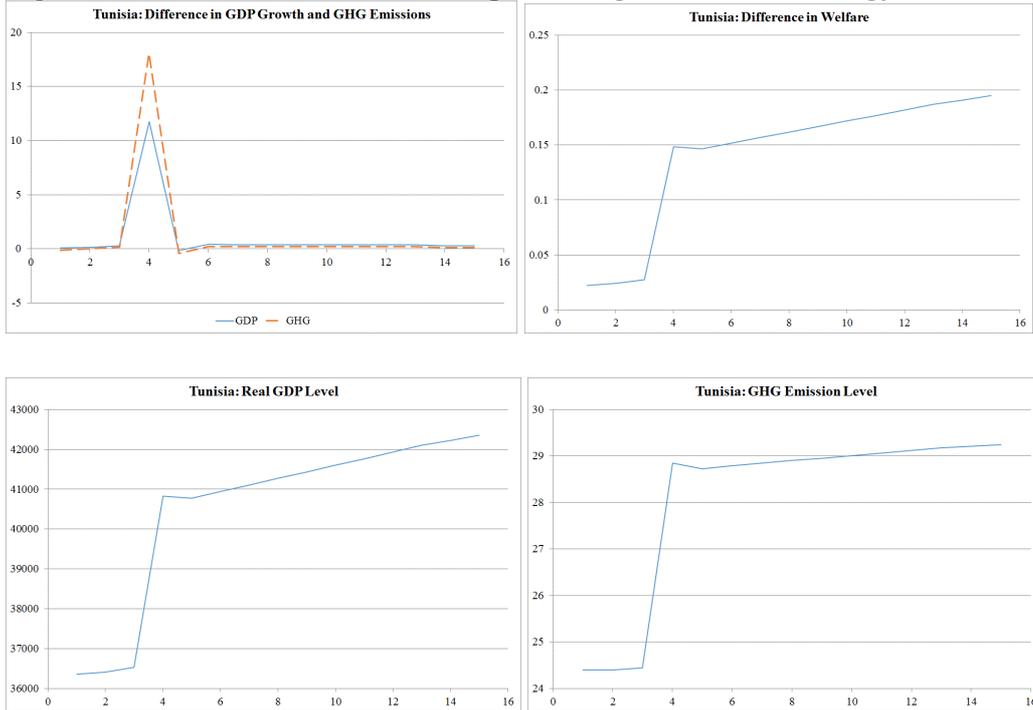


Figure 5-6 Egypt, increase in world price of agricultural and energy-intensive goods

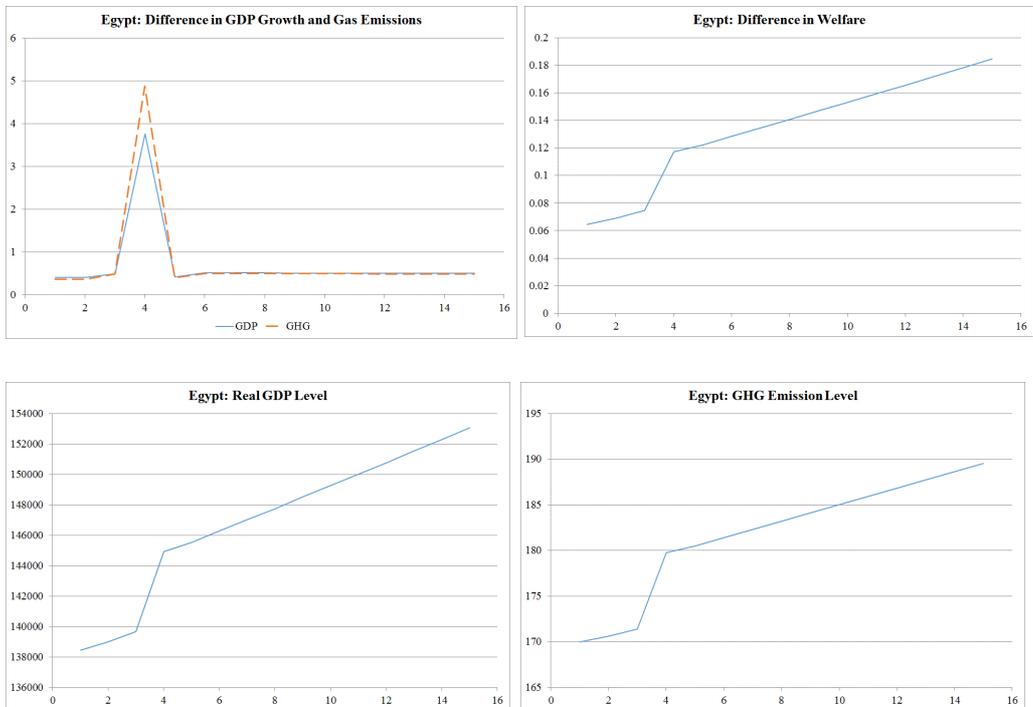


Table 5-5 Tunisia, increase in world price of agricultural and energy-intensive goods

	Periods														
	P1	P2	P3	P4	P5	P6	P7	P8	P9	P10	P11	P12	P13	P14	P15
Macroeconomic Indicators															
GDP growth rate	0.19	0.15	0.30	11.78	-0.14	0.43	0.40	0.40	0.40	0.40	0.40	0.40	0.40	0.30	0.29
Welfare	1.02	1.02	1.03	1.15	1.15	1.15	1.16	1.16	1.17	1.17	1.18	1.18	1.19	1.19	1.19
Unemployment rate															
Skilled	0.11	0.12	0.12	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01
Unskilled	0.11	0.12	0.12	0.01	0.01	0.02	0.02	0.02	0.03	0.03	0.03	0.04	0.04	0.05	0.05
Contamination Indicator															
GHG Emissions growth rate	0.07	0.00	0.16	18.04	-0.43	0.23	0.19	0.19	0.19	0.19	0.19	0.19	0.19	0.11	0.11
Activity Level by Sector															
Agriculture	1.02	1.02	1.02	1.00	1.00	1.00	1.00	1.00	1.00	1.01	1.01	1.01	1.01	1.01	1.01
Forestation	1.00	1.00	1.00	0.16	0.16	0.16	0.15	0.15	0.15	0.15	0.15	0.14	0.14	0.14	0.14
Livestock	1.02	1.02	1.02	1.04	1.04	1.04	1.04	1.05	1.05	1.05	1.05	1.06	1.06	1.06	1.06
Energy-intensive Industry	1.03	1.03	1.03	1.99	1.99	2.00	2.01	2.01	2.02	2.03	2.04	2.05	2.06	2.06	2.07
Rest of Industry	1.02	1.02	1.02	0.76	0.76	0.76	0.76	0.76	0.76	0.76	0.76	0.76	0.76	0.76	0.76
Coal	1.00	1.00	1.00	0.94	0.94	0.93	0.93	0.93	0.92	0.92	0.92	0.91	0.91	0.91	0.91
Oil	1.00	1.00	1.00	0.88	0.88	0.88	0.87	0.87	0.87	0.86	0.86	0.85	0.85	0.85	0.84
Petroleum	1.02	1.02	1.03	1.06	1.06	1.06	1.07	1.07	1.08	1.08	1.09	1.09	1.10	1.10	1.10
Gas	1.00	0.98	0.97	0.43	0.41	0.40	0.39	0.38	0.37	0.36	0.34	0.33	0.32	0.32	0.31
Electricity	1.02	1.02	1.02	1.24	1.23	1.23	1.23	1.23	1.23	1.23	1.23	1.22	1.22	1.22	1.22
Construction	1.01	1.01	1.01	1.06	1.06	1.06	1.07	1.07	1.07	1.07	1.07	1.08	1.08	1.08	1.08
Transportation	1.02	1.02	1.02	1.12	1.12	1.12	1.13	1.13	1.14	1.14	1.14	1.15	1.15	1.15	1.15
Other Services	1.02	1.02	1.03	1.14	1.14	1.15	1.15	1.16	1.16	1.17	1.17	1.18	1.18	1.18	1.19

Table 5-6 Egypt, increase in world price of agricultural and energy-intensive goods

	Periods														
	P1	P2	P3	P4	P5	P6	P7	P8	P9	P10	P11	P12	P13	P14	P15
Macroeconomic Indicators															
GDP growth rate	0.15	0.40	0.49	3.75	0.42	0.51	0.51	0.51	0.51	0.51	0.51	0.50	0.50	0.50	0.50
Welfare	1.06	1.07	1.07	1.12	1.12	1.13	1.13	1.14	1.15	1.15	1.16	1.17	1.17	1.18	1.18
Unemployment rate															
Skilled	0.05	0.06	0.07	0.04	0.05	0.06	0.07	0.08	0.09	0.10	0.11	0.12	0.12	0.13	0.14
Unskilled	0.05	0.06	0.07	0.04	0.05	0.06	0.07	0.08	0.09	0.10	0.10	0.11	0.12	0.13	0.14
Contamination Indicator															
GHG Emissions growth rate	0.02	0.37	0.48	4.87	0.39	0.50	0.50	0.49	0.49	0.49	0.49	0.49	0.49	0.48	0.48
Activity Level by Sector															
Agriculture	1.05	1.05	1.06	1.07	1.07	1.07	1.07	1.07	1.07	1.08	1.08	1.08	1.08	1.08	1.09
Forestation	1.02	1.02	1.02	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.01
Livestock	1.05	1.06	1.06	1.07	1.07	1.07	1.08	1.08	1.08	1.09	1.09	1.09	1.10	1.10	1.10
Energy-intensive Industry	1.09	1.10	1.12	1.34	1.36	1.37	1.39	1.40	1.42	1.43	1.45	1.46	1.48	1.49	1.51
Rest of Industry	1.07	1.07	1.08	1.07	1.07	1.08	1.08	1.08	1.09	1.09	1.09	1.10	1.10	1.10	1.11
Coal	1.01	1.01	1.01	1.01	1.01	1.01	1.01	1.01	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Oil	1.02	1.02	1.02	1.00	1.00	0.99	0.99	0.99	0.98	0.98	0.98	0.98	0.97	0.97	0.97
Petroleum	1.05	1.05	1.06	1.08	1.09	1.10	1.11	1.12	1.13	1.14	1.15	1.16	1.17	1.18	1.19
Gas	1.04	1.04	1.03	1.02	1.01	1.00	1.00	0.99	0.98	0.97	0.97	0.96	0.95	0.94	0.94
Electricity	1.07	1.07	1.07	1.11	1.11	1.12	1.12	1.12	1.13	1.13	1.13	1.14	1.14	1.14	1.15
Construction	1.05	1.05	1.06	1.09	1.09	1.10	1.10	1.11	1.11	1.11	1.12	1.12	1.13	1.13	1.14
Transportation	1.07	1.08	1.08	1.08	1.09	1.09	1.10	1.10	1.11	1.11	1.12	1.12	1.13	1.13	1.14
Other Services	1.05	1.06	1.06	1.08	1.08	1.08	1.09	1.09	1.09	1.10	1.10	1.10	1.11	1.11	1.11

5.1. Scenario 4: Taxing final and intermediate consumer of energy and the double dividend effect

The model internalizes the negative externality of GHGs mitigation by incorporating an environmental tax, which assures that costs and benefits will affect mainly parties who choose to incur them. What if Egypt or Tunisia decides to act unilaterally to mitigate CO₂ emissions on voluntary basis? This scenario illustrates the effects of newly imposed taxes on final consumer and intermediate user of energy. The model introduces an add-valorem environmental tax of 10% on intermediate and final consumption of energy starting automatically when total emissions exceeds the base year emission by a certain limit (3% for Tunisia and 10% for Egypt). Since environmental taxes are distortionary taxes, when introduced, they cause a redistribution of spending and increase cost through the distortion of relative prices. If the total tax revenue increased, other taxes may be reduced or even relieved. In the case of the two countries analyzed, will the reduction in emissions be accompanied by a reduction in distortions when other taxes are reduced to compensate for the new carbon taxes? If such a double dividend effect exists, will it be distributed equivalently?

Results show that a tax rate of 10% on intermediate and final consumption of energy has a great effect on GHG emissions as shown in Figure 5-7 and Figure 5-8 below. What is worth discussing, however, is the impact of the tax on welfare and GDP levels. In case of Tunisia, GDP dropped by -0.38% when the shock was introduced, which expected given the fundamental role of energy in production. What is worth highlighting is that the value of production tax decrease by -1.44%.

In the Egyptian case, the environmental tax did not cause GDP to shrink, the effect was a slower GDP growth. Even though the GDP was still growing -in the first year for instance- the value of production tax revenue decreased by -1.97%. Hence, the part of this reduction in production tax revenue due to reduction in GDP is little, the double dividend effect exists as other taxes are reduced to compensate for the new carbon taxes. Hence, may benefit from the tax revenue generated by the environmental tax to reduces distortions caused by other distortionary taxes, in addition to the positive environmental effect.

Figure 5-7 Tunisia, 10% tax on energy intermediate and final consumption

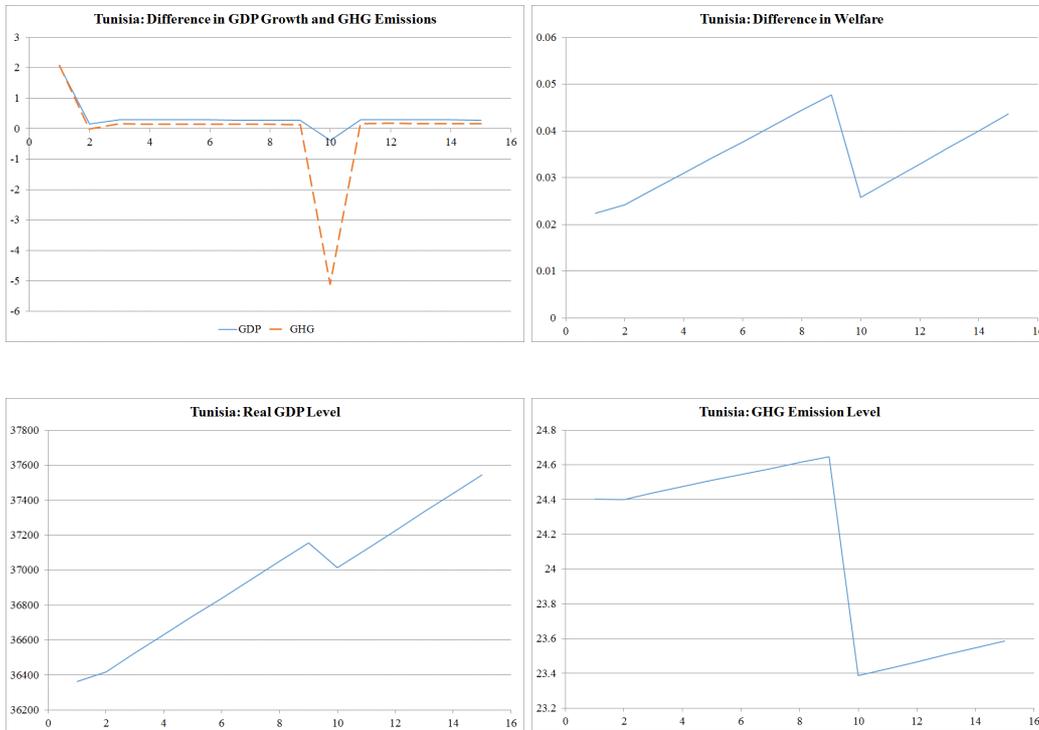


Figure 5-8 Egypt, 10% tax on energy intermediate and final consumption

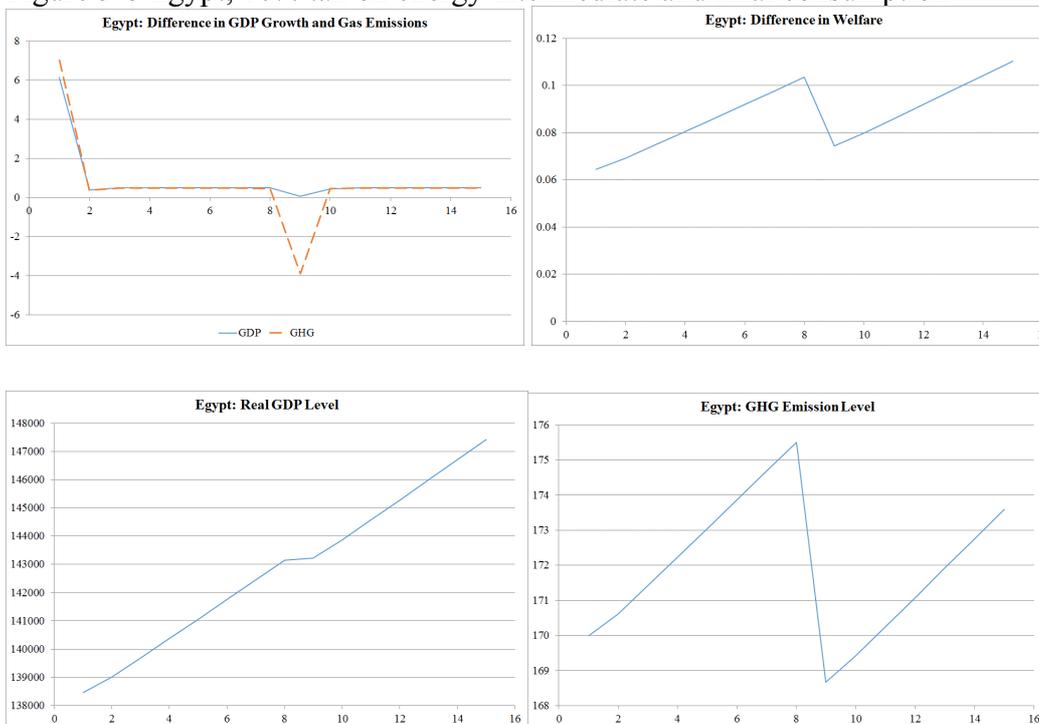


Table 5-7 Tunisia, 10% tax on energy intermediate and final consumption

	Periods														
	P1	P2	P3	P4	P5	P6	P7	P8	P9	P10	P11	P12	P13	P14	P15
Macroeconomic Indicators															
GDP growth rate	0.19	0.15	0.30	0.29	0.29	0.29	0.28	0.28	0.28	-0.38	0.29	0.29	0.29	0.29	0.28
Welfare	1.02	1.02	1.03	1.03	1.03	1.04	1.04	1.04	1.05	1.03	1.03	1.03	1.04	1.04	1.04
Unemployment rate															
Skilled	0.11	0.12	0.12	0.12	0.13	0.13	0.14	0.14	0.15	0.14	0.15	0.15	0.16	0.16	0.17
Unskilled	0.11	0.12	0.12	0.13	0.13	0.14	0.14	0.15	0.15	0.17	0.17	0.18	0.18	0.19	0.19
Contamination Indicator															
GHG Emissions	0.07	0.00	0.16	0.14	0.14	0.14	0.14	0.14	0.14	-5.11	0.17	0.17	0.17	0.17	0.17
Activity Level by Sector															
Agriculture	1.02	1.02	1.02	1.02	1.02	1.02	1.02	1.02	1.02	1.01	1.01	1.02	1.02	1.02	1.02
Forestation	1.00	1.00	1.00	0.99	0.99	0.99	0.99	0.98	0.98	0.98	0.98	0.98	0.98	0.97	0.97
Livestock	1.02	1.02	1.02	1.02	1.03	1.03	1.03	1.03	1.03	1.02	1.02	1.02	1.03	1.03	1.03
Energy-intensive Industry	1.03	1.03	1.03	1.04	1.04	1.05	1.05	1.06	1.06	0.99	1.00	1.01	1.01	1.02	1.02
Rest of Industry	1.02	1.02	1.02	1.02	1.02	1.02	1.02	1.02	1.02	1.00	1.00	1.00	1.00	1.00	1.00
Coal	1.00	1.00	1.00	0.99	0.99	0.99	0.99	0.99	0.98	0.98	0.97	0.97	0.97	0.97	0.96
Oil	1.00	1.00	1.00	0.99	0.99	0.99	0.99	0.99	0.99	0.99	0.98	0.98	0.98	0.98	0.98
Petroleum	1.02	1.02	1.03	1.04	1.04	1.05	1.05	1.06	1.07	0.97	0.97	0.98	0.98	0.99	1.00
Gas	1.00	0.98	0.97	0.95	0.93	0.91	0.90	0.88	0.86	0.87	0.85	0.84	0.82	0.80	0.79
Electricity	1.02	1.02	1.02	1.02	1.02	1.02	1.02	1.02	1.02	0.90	0.90	0.90	0.90	0.90	0.90
Construction	1.01	1.01	1.01	1.01	1.01	1.02	1.02	1.02	1.02	1.01	1.01	1.02	1.02	1.02	1.02
Transportation	1.02	1.02	1.02	1.03	1.03	1.03	1.03	1.04	1.04	1.01	1.02	1.02	1.02	1.03	1.03
Other Services	1.02	1.02	1.03	1.03	1.03	1.03	1.04	1.04	1.04	1.07	1.08	1.08	1.08	1.08	1.09
Distortionary tax effect															
Production tax value	5020	5022	5032	5041	5050	5059	5068	5077	5086	5013	5023	5033	5043	5052	5062

Table 5-8 Egypt, 10% tax on energy intermediate and final consumption

	Periods														
	P1	P2	P3	P4	P5	P6	P7	P8	P9	P10	P11	P12	P13	P14	P15
Macroeconomic Indicators															
GDP	0.15	0.40	0.49	0.49	0.49	0.49	0.49	0.49	0.06	0.45	0.49	0.49	0.49	0.49	0.49
Welfare	1.06	1.07	1.07	1.08	1.09	1.09	1.10	1.10	1.07	1.08	1.09	1.09	1.10	1.10	1.11
Unemployment rate															
Skilled	0.05	0.06	0.07	0.08	0.09	0.10	0.11	0.12	0.11	0.12	0.13	0.14	0.15	0.16	0.17
Unskilled	0.05	0.06	0.07	0.08	0.09	0.09	0.10	0.11	0.13	0.14	0.15	0.16	0.17	0.18	0.18
Contamination Indicator															
GHG Emissions growth rate	0.02	0.37	0.48	0.47	0.47	0.47	0.47	0.47	-3.89	0.45	0.49	0.49	0.49	0.49	0.48
Activity Level by Sector															
Agriculture	1.05	1.05	1.06	1.06	1.06	1.06	1.07	1.07	1.06	1.06	1.06	1.06	1.07	1.07	1.07
Forestation	1.02	1.02	1.02	1.02	1.03	1.03	1.03	1.03	1.03	1.03	1.03	1.03	1.03	1.04	1.04
Livestock	1.05	1.06	1.06	1.06	1.07	1.07	1.07	1.07	1.06	1.07	1.07	1.07	1.08	1.08	1.08
Energy-intensive Industry	1.09	1.10	1.12	1.13	1.14	1.15	1.16	1.18	1.13	1.14	1.16	1.17	1.18	1.19	1.21
Rest of Industry	1.07	1.07	1.08	1.08	1.08	1.09	1.09	1.09	1.09	1.09	1.09	1.10	1.10	1.10	1.11
Coal	1.01	1.01	1.01	1.01	1.01	1.01	1.01	1.00	0.99	0.99	0.99	0.99	0.99	0.99	0.99
Oil	1.02	1.02	1.02	1.01	1.01	1.01	1.01	1.00	0.97	0.96	0.96	0.96	0.96	0.95	0.95
Petroleum	1.05	1.05	1.06	1.07	1.08	1.09	1.10	1.11	1.02	1.03	1.04	1.05	1.06	1.07	1.08
Gas	1.04	1.04	1.03	1.02	1.01	1.01	1.00	0.99	0.94	0.93	0.93	0.92	0.91	0.91	0.90
Electricity	1.07	1.07	1.07	1.08	1.08	1.08	1.09	1.09	1.00	1.00	1.01	1.01	1.01	1.02	1.02
Construction	1.05	1.05	1.06	1.06	1.07	1.07	1.07	1.08	1.06	1.06	1.07	1.07	1.08	1.08	1.08
Transportation	1.07	1.08	1.08	1.09	1.09	1.10	1.10	1.11	1.09	1.09	1.10	1.10	1.11	1.11	1.12
Other Services	1.05	1.06	1.06	1.06	1.07	1.07	1.07	1.08	1.13	1.13	1.14	1.14	1.14	1.15	1.15
Distortionary tax effect															
Production tax value	289.4	289.9	290.8	291.6	292.4	293.2	294	294.9	289.1	289.9	290.8	291.6	292.5	293.4	294.3

5.2. Scenario 5: Financing adaptation with carbon taxes

Climate change adaptation for relatively hot countries is just a matter of time. Adaptation entails severe changes; maritime routes may need to be detoured, ports will have to adapt to the increase in sea level, seasonal demand on energy and water will alter, farmers will change what they grow and some people will have to migrate, especially those in cities at sea level. Governments of African countries one day will have to act; either ex-ante through systematic urbanization to absorb migration, adapt vulnerable areas for climate change, or ex-post as in aiding affected sea-level cities, spending on health and deal with water scarcity.

Developing African countries such as Egypt and Tunisia are two examples of countries with scarce resources to invest in adaptation for climate change. What are the suitable sources of extra funds to undertake adaptation measures to deal with the inevitable changes to their economy and economic resources? Should these investments be in preventive or compensatory forms?

Raising money through environmental taxes is one of the possible ways. The following scenario simulates financing new governmental expenditures for adaptation purposes using a new environmental tax on intermediate use of electricity. The exercise measures what tax rate is appropriate to enable the government to increase its real expenditure by 5% starting on the 6th period and increasing at a constant rate of 1% per period.

Outcomes differ in the two cases; in the case of Tunisia, taxing electricity in production causes the GDP to increase at a decreasing scale as shown in Figure 3-1, up to a point where the high taxes start causing a negative GDP growth in the 12th period. At that level, tax rate reached as high as 65%. The effect of taxing electricity on GHG emission reduction is very evident; this is explained by the fact that electricity is the second most utilized fossil fuel in Tunisia after petroleum.

In the Egyptian case outcomes differ; although the new tax allowed the GDP to grow at a decreasing rate (tax rate in the last period reaches 55%), yet it does not reach the point where it hits zero or witnesses a negative growth. Electricity –as input for production- is the third major source of energy in Egypt after oil and petroleum respectively. The resistance in GDP growth is explained by the substitutability of electricity in production.

The energy-intensive sector witness a 16% decrease in electricity consumption, compensated by a 20% and 11% increase in petroleum and gas respectively.

Figure 5-9 Tunisia, Increasing government real expenditure via environmental tax

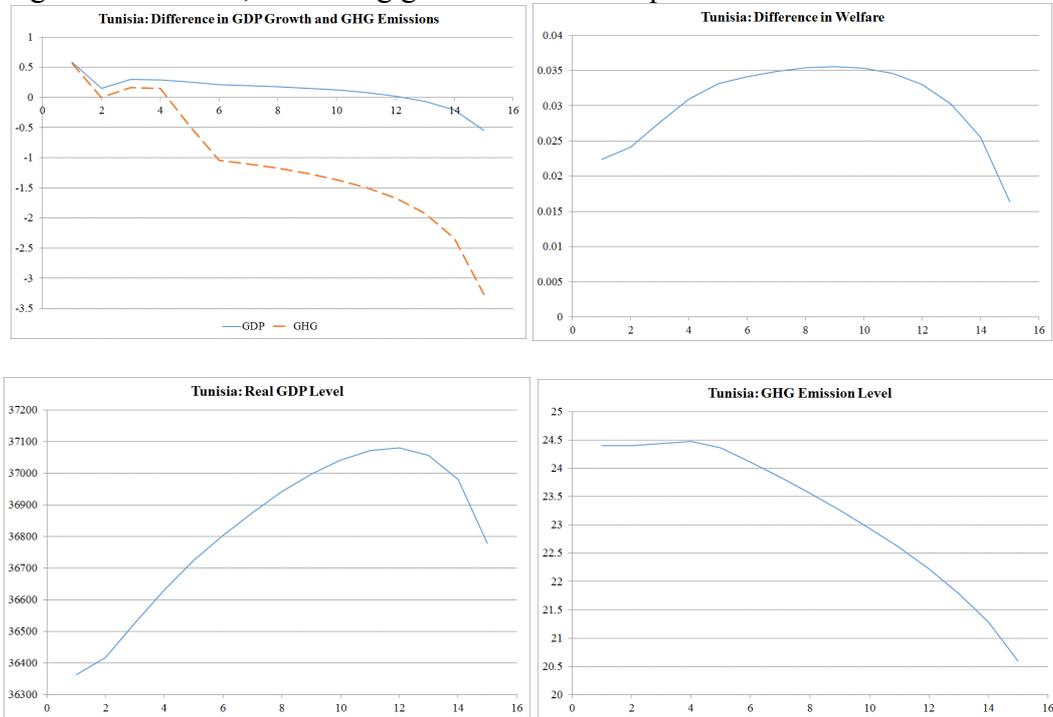


Figure 5-10 Egypt, Increasing government real expenditure via environmental tax

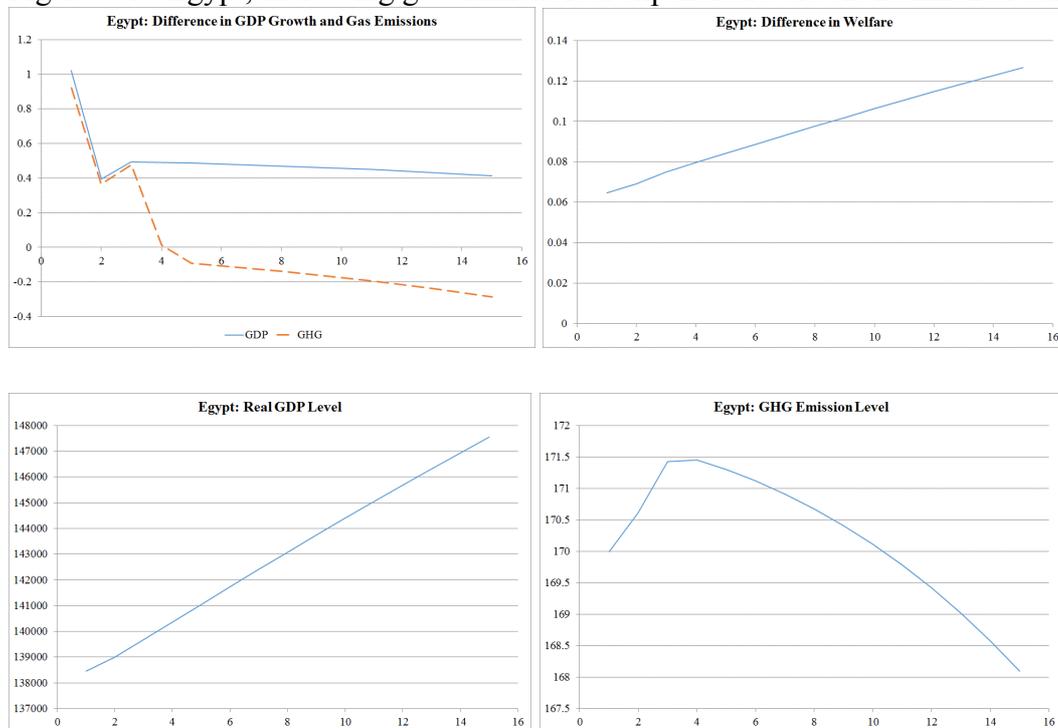


Table 5-9 Tunisia, Increasing government real expenditure via environmental tax

	Periods														
	P1	P2	P3	P4	P5	P6	P7	P8	P9	P10	P11	P12	P13	P14	P15
Macroeconomic Indicators															
GDP growth rate	0.06	0.15	0.30	0.29	0.26	0.21	0.20	0.18	0.15	0.12	0.08	0.02	-0.06	-0.21	-0.54
Welfare	1.02	1.02	1.03	1.03	1.03	1.03	1.03	1.04	1.04	1.04	1.03	1.03	1.03	1.03	1.02
Unemployment rate															
Skilled	0.11	0.12	0.12	0.12	0.13	0.13	0.14	0.14	0.14	0.15	0.15	0.16	0.16	0.17	0.18
Unskilled	0.11	0.12	0.12	0.13	0.13	0.14	0.14	0.15	0.16	0.16	0.17	0.18	0.19	0.19	0.21
Contamination Indicator															
GHG Emissions	0.05	0.00	0.16	0.14	-0.47	-1.04	-1.11	-1.18	-1.26	-1.37	-1.50	-1.67	-1.92	-2.34	-3.26
Activity Level by Sector															
Agriculture	1.02	1.02	1.02	1.02	1.02	1.02	1.02	1.02	1.02	1.02	1.02	1.02	1.02	1.02	1.02
Forestation	1.00	1.00	1.00	0.99	0.99	0.99	0.99	0.99	0.99	0.99	0.99	1.00	1.00	1.00	1.01
Livestock	1.02	1.02	1.02	1.02	1.02	1.03	1.03	1.03	1.03	1.03	1.03	1.03	1.02	1.02	1.02
Energy-intensive Industry	1.03	1.03	1.03	1.04	1.04	1.03	1.02	1.01	1.00	0.99	0.98	0.96	0.94	0.92	0.88
Rest of Industry	1.02	1.02	1.02	1.02	1.02	1.02	1.01	1.01	1.01	1.01	1.01	1.00	1.00	0.99	0.99
Coal	1.00	1.00	1.00	0.99	0.99	0.99	0.99	0.98	0.98	0.98	0.97	0.97	0.97	0.97	0.96
Oil	1.00	1.00	1.00	0.99	0.99	0.99	0.99	0.99	1.00	1.00	1.00	1.00	1.00	1.01	1.02
Petroleum	1.02	1.02	1.03	1.04	1.04	1.05	1.05	1.06	1.07	1.08	1.09	1.10	1.11	1.12	1.14
Gas	1.00	0.98	0.97	0.95	0.93	0.92	0.91	0.89	0.88	0.87	0.86	0.86	0.85	0.85	0.87
Electricity	1.02	1.02	1.02	1.02	1.00	0.97	0.94	0.90	0.87	0.83	0.79	0.75	0.70	0.65	0.58
Construction	1.01	1.01	1.01	1.01	1.01	1.01	1.01	1.02	1.02	1.01	1.01	1.01	1.01	1.01	1.01
Transportation	1.02	1.02	1.02	1.03	1.03	1.03	1.03	1.03	1.03	1.03	1.03	1.02	1.02	1.02	1.01
Other Services	1.02	1.02	1.03	1.03	1.03	1.04	1.04	1.05	1.05	1.06	1.06	1.07	1.07	1.07	1.07

Table 5-10 Egypt, Increasing government real expenditure via environmental tax

	Periods														
	P1	P2	P3	P4	P5	P6	P7	P8	P9	P10	P11	P12	P13	P14	P15
Macroeconomic Indicators															
GDP	1.02	0.40	0.49	0.49	0.49	0.48	0.48	0.47	0.46	0.46	0.45	0.44	0.43	0.42	0.41
Welfare	1.06	1.07	1.07	1.08	1.08	1.09	1.09	1.10	1.10	1.11	1.11	1.11	1.12	1.12	1.13
Unemployment rate															
Skilled	0.05	0.06	0.07	0.08	0.09	0.10	0.10	0.11	0.12	0.13	0.14	0.14	0.15	0.16	0.17
Unskilled	0.05	0.06	0.07	0.08	0.09	0.10	0.10	0.11	0.12	0.13	0.14	0.15	0.16	0.17	0.18
Contamination Indicator															
GHG Emissions growth rate	0.92	0.37	0.48	0.01	-0.09	-0.11	-0.12	-0.14	-0.16	-0.17	-0.19	-0.21	-0.24	-0.26	-0.29
Activity Level by Sector															
Agriculture	1.05	1.05	1.06	1.06	1.06	1.06	1.06	1.07	1.07	1.07	1.07	1.08	1.08	1.08	1.08
Forestation	1.02	1.02	1.02	1.02	1.03	1.03	1.03	1.03	1.03	1.03	1.03	1.03	1.03	1.04	1.04
Livestock	1.05	1.06	1.06	1.06	1.06	1.07	1.07	1.07	1.07	1.08	1.08	1.08	1.08	1.08	1.08
Energy-intensive Industry	1.09	1.10	1.12	1.12	1.13	1.14	1.14	1.15	1.16	1.16	1.17	1.17	1.17	1.18	1.18
Rest of Industry	1.07	1.07	1.08	1.08	1.08	1.08	1.09	1.09	1.09	1.10	1.10	1.10	1.10	1.11	1.11
Coal	1.01	1.01	1.01	1.01	1.01	1.01	1.01	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Oil	1.02	1.02	1.02	1.01	1.01	1.01	1.01	1.01	1.01	1.01	1.00	1.00	1.00	1.00	1.00
Petroleum	1.05	1.05	1.06	1.07	1.08	1.09	1.10	1.11	1.12	1.13	1.14	1.15	1.17	1.18	1.19
Gas	1.04	1.04	1.03	1.02	1.01	1.00	0.99	0.98	0.97	0.96	0.95	0.95	0.94	0.93	0.92
Electricity	1.07	1.07	1.07	1.06	1.05	1.04	1.03	1.02	1.00	0.99	0.98	0.96	0.95	0.93	0.92
Construction	1.05	1.05	1.06	1.06	1.06	1.07	1.07	1.07	1.08	1.08	1.08	1.08	1.09	1.09	1.09
Transportation	1.07	1.08	1.08	1.09	1.09	1.09	1.10	1.10	1.11	1.11	1.12	1.12	1.13	1.13	1.14
Other Services	1.05	1.06	1.06	1.07	1.07	1.08	1.08	1.08	1.09	1.09	1.10	1.10	1.11	1.11	1.12

6. Sensitivity Analysis

6.1. Introduction

Elasticities are crucial to model results; hence, modelers tend to seek relevant econometric studies. Often, however, elasticities available in the literature are either weakly related to the model's parameter requirements or statistically weak. Econometric studies may include different aggregation of commodities, parameters may be estimated using different functional forms, or the estimates may be statistically weak. Therefore, sensitivity analysis are carried out to check the robustness of results to changes in central parameters of the model.

The key parameters analyzed through this section are capital mobility percentage, capital-output ratio, elasticity of substitution between capital and energy, elasticity of substitution between other types of energy. Analysis show that the overall macroeconomic prospective is not excessively sensitive to significant variations in parameter values. Besides, no qualitative alterations are observed in terms of the direction of impacts of any of the five simulations of different policies proposed. This positive feedback on the robustness of the model to changes in key parameter values is confirmed also by the inspection of the complete set of results of the robustness check. For the sake of clarity, the following section shows the results of the three parameters that showed some sensibility during analysis and for one country only -Egypt.

6.1. Capital mobility

All previous analysis and scenarios were conducted with the assumption that capital is fully mobile, which is plausible since the analysis tackled long run phenomena. Most environmental CGE models assume full mobility of capital. Yet it is interesting to see the effect of relaxing such an important generally accepted assumption.

Generally speaking, results are sensible to the mobility level of factors of production. Take the case of sector-specific capital assumption, a tax in that sector will be absorbed as a reduction in the rental price of capital, and will have a direct impact on the standard of living of its owners. In case of full mobility of capital, though, the tax will be distributed on other non-mobile factors or on final consumers.

The following results explain the sensitivity analysis of capital mobility among industries. Conducting three similar simulations with different assumptions about mobility, allows the understanding of the differences and the level of sensibility of results in the short or long run. The assumption of total capital mobility is released gradually assuming the values of 100%, 80% and 60% of capital mobility. Table 6-1, Table 6-2 and Table 6-3 show the sensitivity of capital mobility analyzed over a tax rate of 10% imposed on energy use, effective when GHG emissions gets 10% higher than the benchmark level, which is the ninth or tenth period depending on the capital mobility assumption.

Results show the, as expected, some sensibility in GDP growth rate to higher capital mobility; this assures that the assumption of full mobility of capital, at least in the long run, have a clear effect on the implications and results of environmental policy analysis. Literature doesn't provide trustworthy estimations of capital mobility, still the common practice is to assume its full mobility in environmental CGE models, since they target the long run given the nature of the problem.

Table 6-1 Egypt, 10% tax on energy intermediate and final consumption with 60% capital mobility

	Periods														
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Macroeconomic Indicators															
GDP growth rate	0.14	0.55	0.48	0.47	0.47	0.47	0.47	0.47	0.47	0.30	0.44	0.46	0.46	0.46	0.46
Welfare	1.06	1.07	1.07	1.08	1.08	1.09	1.10	1.10	1.11	1.08	1.09	1.09	1.10	1.11	1.11
Unemployment rate															
Skilled	0.05	0.06	0.07	0.08	0.09	0.10	0.11	0.12	0.13	0.12	0.13	0.14	0.15	0.16	0.17
Unskilled	0.05	0.06	0.07	0.08	0.09	0.10	0.11	0.12	0.12	0.14	0.15	0.16	0.17	0.18	0.19
Contamination Indicator															
GHG Emissions growth rate	0.01	0.53	0.45	0.45	0.44	0.44	0.44	0.43	0.43	-3.05	0.43	0.45	0.45	0.44	0.44
Activity Level by Sector															
Agriculture	1.05	1.05	1.06	1.06	1.06	1.06	1.06	1.07	1.07	1.06	1.06	1.06	1.06	1.07	1.07
Forestation	1.03	1.03	1.03	1.03	1.03	1.03	1.03	1.03	1.03	1.04	1.04	1.04	1.04	1.04	1.04
Livestock	1.05	1.06	1.06	1.06	1.06	1.07	1.07	1.07	1.07	1.07	1.07	1.07	1.07	1.08	1.08
Energy-intensive Industry	1.08	1.09	1.10	1.11	1.12	1.13	1.14	1.15	1.16	1.13	1.14	1.15	1.16	1.17	1.18
Rest of Industry	1.07	1.07	1.07	1.08	1.08	1.08	1.09	1.09	1.09	1.08	1.09	1.09	1.09	1.10	1.10
Coal	1.01	1.01	1.01	1.01	1.01	1.01	1.01	1.01	1.01	1.00	1.00	1.00	1.00	1.00	1.00
Oil	1.03	1.03	1.03	1.02	1.02	1.02	1.02	1.02	1.02	0.99	0.99	0.99	0.99	0.99	0.98
Petroleum	1.05	1.06	1.07	1.08	1.09	1.10	1.10	1.11	1.12	1.05	1.06	1.07	1.08	1.09	1.10
Gas	1.04	1.04	1.04	1.03	1.03	1.03	1.02	1.02	1.01	0.99	0.98	0.98	0.98	0.97	0.97
Electricity	1.06	1.07	1.07	1.08	1.08	1.09	1.09	1.09	1.10	1.03	1.03	1.03	1.04	1.04	1.05
Construction	1.05	1.05	1.06	1.06	1.06	1.07	1.07	1.07	1.08	1.07	1.07	1.07	1.08	1.08	1.08
Transportation	1.07	1.07	1.08	1.08	1.09	1.09	1.10	1.10	1.11	1.09	1.09	1.10	1.10	1.11	1.11
Other Services	1.05	1.06	1.06	1.06	1.07	1.07	1.07	1.08	1.08	1.13	1.13	1.13	1.13	1.14	1.14

Table 6-2 Egypt, 10% tax on energy intermediate and final consumption with 80% capital mobility

	Periods														
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Macroeconomic Indicators															
GDP growth rate	0.15	0.46	0.48	0.48	0.48	0.48	0.48	0.48	0.19	0.45	0.48	0.48	0.47	0.47	0.47
Welfare	1.06	1.07	1.07	1.08	1.09	1.09	1.10	1.10	1.08	1.08	1.09	1.09	1.10	1.10	1.11
Unemployment rate															
Skilled	0.05	0.06	0.07	0.08	0.09	0.10	0.11	0.12	0.11	0.12	0.13	0.14	0.15	0.16	0.17
Unskilled	0.05	0.06	0.07	0.08	0.09	0.10	0.11	0.11	0.13	0.14	0.15	0.16	0.17	0.18	0.18
Contamination Indicator															
GHG Emissions growth rate	0.02	0.43	0.46	0.46	0.46	0.45	0.45	0.45	-3.46	0.44	0.47	0.47	0.46	0.46	0.46
Activity Level by Sector															
Agriculture	1.05	1.05	1.06	1.06	1.06	1.06	1.06	1.07	1.06	1.06	1.06	1.06	1.07	1.07	1.07
Forestation	1.03	1.03	1.03	1.03	1.03	1.03	1.03	1.03	1.03	1.03	1.04	1.04	1.04	1.04	1.04
Livestock	1.05	1.06	1.06	1.06	1.06	1.07	1.07	1.07	1.06	1.07	1.07	1.07	1.07	1.08	1.08
Energy-intensive Industry	1.09	1.10	1.11	1.12	1.13	1.14	1.15	1.16	1.13	1.14	1.15	1.16	1.17	1.18	1.19
Rest of Industry	1.07	1.07	1.07	1.08	1.08	1.08	1.09	1.09	1.08	1.09	1.09	1.09	1.10	1.10	1.10
Coal	1.01	1.01	1.01	1.01	1.01	1.01	1.01	1.01	1.00	0.99	0.99	0.99	0.99	0.99	0.99
Oil	1.02	1.02	1.02	1.02	1.02	1.02	1.01	1.01	0.98	0.98	0.98	0.97	0.97	0.97	0.97
Petroleum	1.05	1.06	1.07	1.07	1.08	1.09	1.10	1.11	1.03	1.04	1.05	1.06	1.07	1.08	1.09
Gas	1.04	1.04	1.03	1.03	1.02	1.02	1.01	1.00	0.97	0.96	0.96	0.95	0.95	0.94	0.94
Electricity	1.07	1.07	1.07	1.08	1.08	1.09	1.09	1.09	1.01	1.01	1.02	1.02	1.03	1.03	1.03
Construction	1.05	1.05	1.06	1.06	1.06	1.07	1.07	1.08	1.06	1.06	1.07	1.07	1.08	1.08	1.08
Transportation	1.07	1.07	1.08	1.08	1.09	1.09	1.10	1.10	1.08	1.09	1.09	1.10	1.11	1.11	1.12
Other Services	1.05	1.06	1.06	1.06	1.07	1.07	1.07	1.08	1.13	1.13	1.13	1.13	1.14	1.14	1.14

Table 6-3 Egypt, 10% tax on energy intermediate and final consumption with 100% capital mobility

	Periods														
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Macroeconomic Indicators															
GDP growth rate	0.15	0.40	0.49	0.49	0.49	0.49	0.49	0.49	0.06	0.45	0.49	0.49	0.49	0.49	0.49
Welfare	1.06	1.07	1.07	1.08	1.09	1.09	1.10	1.10	1.07	1.08	1.09	1.09	1.10	1.10	1.11
Unemployment rate															
Skilled	0.05	0.06	0.07	0.08	0.09	0.10	0.11	0.12	0.11	0.12	0.13	0.14	0.15	0.16	0.17
Unskilled	0.05	0.06	0.07	0.08	0.09	0.09	0.10	0.11	0.13	0.14	0.15	0.16	0.17	0.18	0.18
Contamination Indicator															
GHG Emissions growth rate	0.02	0.37	0.48	0.47	0.47	0.47	0.47	0.47	-3.89	0.45	0.49	0.49	0.49	0.49	0.48
Activity Level by Sector															
Agriculture	1.05	1.05	1.06	1.06	1.06	1.06	1.07	1.07	1.06	1.06	1.06	1.06	1.07	1.07	1.07
Forestation	1.02	1.02	1.02	1.02	1.03	1.03	1.03	1.03	1.03	1.03	1.03	1.03	1.03	1.04	1.04
Livestock	1.05	1.06	1.06	1.06	1.07	1.07	1.07	1.07	1.06	1.07	1.07	1.07	1.08	1.08	1.08
Energy-intensive Industry	1.09	1.10	1.12	1.13	1.14	1.15	1.16	1.18	1.13	1.14	1.16	1.17	1.18	1.19	1.21
Rest of Industry	1.07	1.07	1.08	1.08	1.08	1.09	1.09	1.09	1.09	1.09	1.09	1.10	1.10	1.10	1.11
Coal	1.01	1.01	1.01	1.01	1.01	1.01	1.01	1.00	0.99	0.99	0.99	0.99	0.99	0.99	0.99
Oil	1.02	1.02	1.02	1.01	1.01	1.01	1.01	1.00	0.97	0.96	0.96	0.96	0.96	0.95	0.95
Petroleum	1.05	1.05	1.06	1.07	1.08	1.09	1.10	1.11	1.02	1.03	1.04	1.05	1.06	1.07	1.08
Gas	1.04	1.04	1.03	1.02	1.01	1.01	1.00	0.99	0.94	0.93	0.93	0.92	0.91	0.91	0.90
Electricity	1.07	1.07	1.07	1.08	1.08	1.08	1.09	1.09	1.00	1.00	1.01	1.01	1.01	1.02	1.02
Construction	1.05	1.05	1.06	1.06	1.07	1.07	1.07	1.08	1.06	1.06	1.07	1.07	1.08	1.08	1.08
Transportation	1.07	1.08	1.08	1.09	1.09	1.10	1.10	1.11	1.09	1.09	1.10	1.10	1.11	1.11	1.12
Other Services	1.05	1.06	1.06	1.06	1.07	1.07	1.07	1.08	1.13	1.13	1.14	1.14	1.14	1.15	1.15

6.2. Capital-energy substitution elasticity

In the short-run, literature does not prove a clear-cut substitution between capital and energy, and the concept of complementarity prevails. However, since environmental policies need to be studied in the long run, the models assumes a certain level of capital-energy substitutability. This elasticity of substitution is analyzed assuming values 0.25, 0.5 and 1.

Results prove not to be excessively sensitive to significant variations in substitution elasticity between capital and energy. However, one should keep in mind that increasing the capital-output ratio could reduce the quantity of energy needed per unit of production. This is why the next step is the capital-output ratio sensitivity analysis.

Table 6-4 Egypt, 10% tax on energy intermediate and final consumption with 0.25 elasticity of substitution between capital and energy

	Periods														
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Macroeconomic Indicators															
GDP growth rate	0.15	0.40	0.49	0.49	0.49	0.48	0.48	0.48	0.10	0.46	0.48	0.48	0.48	0.48	0.48
Welfare	1.06	1.07	1.07	1.08	1.09	1.09	1.10	1.10	1.07	1.08	1.09	1.09	1.10	1.10	1.11
Unemployment rate															
Skilled	0.05	0.06	0.07	0.08	0.09	0.10	0.11	0.12	0.11	0.12	0.13	0.14	0.15	0.16	0.17
Unskilled	0.05	0.06	0.07	0.08	0.09	0.09	0.10	0.11	0.13	0.14	0.15	0.16	0.17	0.18	0.18
Contamination Indicator															
GHG Emissions growth rate	0.02	0.31	0.41	0.41	0.41	0.41	0.40	0.40	-3.40	0.40	0.43	0.43	0.42	0.42	0.42
Activity Level by Sector															
Agriculture	1.05	1.05	1.06	1.06	1.06	1.06	1.06	1.07	1.06	1.06	1.06	1.06	1.07	1.07	1.07
Forestation	1.02	1.02	1.02	1.02	1.03	1.03	1.03	1.03	1.03	1.03	1.03	1.03	1.03	1.04	1.04
Livestock	1.05	1.06	1.06	1.06	1.07	1.07	1.07	1.07	1.06	1.07	1.07	1.07	1.07	1.08	1.08
Energy-intensive Industry	1.09	1.10	1.12	1.13	1.14	1.15	1.16	1.17	1.13	1.14	1.16	1.17	1.18	1.19	1.21
Rest of Industry	1.07	1.07	1.08	1.08	1.08	1.09	1.09	1.09	1.09	1.09	1.09	1.10	1.10	1.10	1.10
Coal	1.01	1.01	1.01	1.01	1.01	1.01	1.00	1.00	0.99	0.99	0.99	0.99	0.99	0.99	0.99
Oil	1.02	1.02	1.02	1.01	1.01	1.01	1.00	1.00	0.97	0.96	0.96	0.96	0.95	0.95	0.95
Petroleum	1.05	1.06	1.06	1.07	1.08	1.09	1.09	1.10	1.03	1.03	1.04	1.05	1.06	1.07	1.08
Gas	1.05	1.04	1.03	1.02	1.01	1.00	0.99	0.98	0.95	0.94	0.93	0.92	0.91	0.90	0.89
Electricity	1.07	1.07	1.07	1.07	1.08	1.08	1.08	1.08	1.00	1.01	1.01	1.01	1.01	1.01	1.01
Construction	1.05	1.05	1.06	1.06	1.07	1.07	1.07	1.08	1.06	1.06	1.07	1.07	1.08	1.08	1.08
Transportation	1.07	1.08	1.08	1.09	1.09	1.10	1.10	1.11	1.09	1.09	1.10	1.10	1.11	1.11	1.12
Other Services	1.06	1.06	1.06	1.06	1.07	1.07	1.07	1.08	1.13	1.13	1.14	1.14	1.14	1.14	1.15

Table 6-5 Egypt, 10% tax on energy intermediate and final consumption with 0.5 elasticity of substitution between capital and energy

	Periods														
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Macroeconomic Indicators															
GDP growth rate	0.15	0.40	0.49	0.49	0.49	0.49	0.49	0.49	0.06	0.45	0.49	0.49	0.49	0.49	0.49
Welfare	1.06	1.07	1.07	1.08	1.09	1.09	1.10	1.10	1.07	1.08	1.09	1.09	1.10	1.10	1.11
Unemployment rate															
Skilled	0.05	0.06	0.07	0.08	0.09	0.10	0.11	0.12	0.11	0.12	0.13	0.14	0.15	0.16	0.17
Unskilled	0.05	0.06	0.07	0.08	0.09	0.09	0.10	0.11	0.13	0.14	0.15	0.16	0.17	0.18	0.18
Contamination Indicator															
GHG Emissions growth rate	0.02	0.37	0.48	0.47	0.47	0.47	0.47	0.47	-3.89	0.45	0.49	0.49	0.49	0.49	0.48
Activity Level by Sector															
Agriculture	1.05	1.05	1.06	1.06	1.06	1.06	1.07	1.07	1.06	1.06	1.06	1.06	1.07	1.07	1.07
Forestation	1.02	1.02	1.02	1.02	1.03	1.03	1.03	1.03	1.03	1.03	1.03	1.03	1.03	1.04	1.04
Livestock	1.05	1.06	1.06	1.06	1.07	1.07	1.07	1.07	1.06	1.07	1.07	1.07	1.08	1.08	1.08
Energy-intensive Industry	1.09	1.10	1.12	1.13	1.14	1.15	1.16	1.18	1.13	1.14	1.16	1.17	1.18	1.19	1.21
Rest of Industry	1.07	1.07	1.08	1.08	1.08	1.09	1.09	1.09	1.09	1.09	1.09	1.10	1.10	1.10	1.11
Coal	1.01	1.01	1.01	1.01	1.01	1.01	1.01	1.00	0.99	0.99	0.99	0.99	0.99	0.99	0.99
Oil	1.02	1.02	1.02	1.01	1.01	1.01	1.01	1.00	0.97	0.96	0.96	0.96	0.96	0.95	0.95
Petroleum	1.05	1.05	1.06	1.07	1.08	1.09	1.10	1.11	1.02	1.03	1.04	1.05	1.06	1.07	1.08
Gas	1.04	1.04	1.03	1.02	1.01	1.01	1.00	0.99	0.94	0.93	0.93	0.92	0.91	0.91	0.90
Electricity	1.07	1.07	1.07	1.08	1.08	1.08	1.09	1.09	1.00	1.00	1.01	1.01	1.01	1.02	1.02
Construction	1.05	1.05	1.06	1.06	1.07	1.07	1.07	1.08	1.06	1.06	1.07	1.07	1.08	1.08	1.08
Transportation	1.07	1.08	1.08	1.09	1.09	1.10	1.10	1.11	1.09	1.09	1.10	1.10	1.11	1.11	1.12
Other Services	1.05	1.06	1.06	1.06	1.07	1.07	1.07	1.08	1.13	1.13	1.14	1.14	1.14	1.15	1.15

Table 6-6 Egypt, 10% tax on energy intermediate and final consumption with elasticity of substitution between capital and energy equal to 1

	Periods														
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Macroeconomic Indicators															
GDP growth rate	0.15	0.39	0.50	0.50	0.50	0.50	0.50	0.00	0.43	0.50	0.50	0.50	0.50	0.50	0.50
Welfare	1.06	1.07	1.07	1.08	1.09	1.09	1.10	1.07	1.07	1.08	1.09	1.09	1.10	1.10	1.11
Unemployment rate															
Skilled	0.05	0.06	0.07	0.08	0.09	0.10	0.11	0.11	0.11	0.12	0.13	0.14	0.15	0.16	0.17
Unskilled	0.05	0.06	0.07	0.08	0.09	0.09	0.10	0.13	0.13	0.14	0.15	0.16	0.17	0.18	0.18
Contamination Indicator															
GHG Emissions growth rate	0.02	0.46	0.58	0.58	0.58	0.58	0.58	-4.72	0.52	0.59	0.59	0.59	0.59	0.59	0.59
Activity Level by Sector															
Agriculture	1.05	1.05	1.06	1.06	1.06	1.06	1.07	1.05	1.06	1.06	1.06	1.06	1.07	1.07	1.07
Forestation	1.02	1.02	1.02	1.02	1.03	1.03	1.03	1.03	1.03	1.03	1.03	1.03	1.04	1.04	1.04
Livestock	1.05	1.06	1.06	1.06	1.07	1.07	1.07	1.06	1.06	1.06	1.07	1.07	1.08	1.08	1.08
Energy-intensive Industry	1.09	1.10	1.12	1.13	1.14	1.15	1.16	1.12	1.13	1.14	1.16	1.17	1.18	1.20	1.21
Rest of Industry	1.07	1.07	1.08	1.08	1.08	1.09	1.09	1.08	1.08	1.09	1.09	1.10	1.10	1.10	1.11
Coal	1.01	1.01	1.01	1.01	1.01	1.01	1.01	0.99	0.99	0.99	0.99	0.99	0.99	0.99	0.99
Oil	1.02	1.02	1.02	1.01	1.01	1.01	1.01	0.97	0.96	0.96	0.96	0.96	0.96	0.96	0.95
Petroleum	1.04	1.05	1.06	1.07	1.09	1.10	1.11	1.01	1.02	1.03	1.04	1.05	1.06	1.07	1.09
Gas	1.04	1.03	1.03	1.02	1.02	1.01	1.01	0.94	0.93	0.93	0.93	0.92	0.92	0.91	0.91
Electricity	1.06	1.07	1.07	1.08	1.09	1.09	1.10	0.99	0.99	1.00	1.00	1.01	1.02	1.02	1.03
Construction	1.05	1.05	1.06	1.06	1.07	1.07	1.07	1.06	1.06	1.06	1.07	1.07	1.08	1.08	1.09
Transportation	1.07	1.08	1.08	1.09	1.09	1.10	1.10	1.08	1.09	1.09	1.10	1.10	1.11	1.11	1.12
Other Services	1.05	1.06	1.06	1.06	1.07	1.07	1.07	1.13	1.13	1.13	1.14	1.14	1.14	1.15	1.15

6.3. Capital-output ratio sensibility

A change in the capital-output ratio may have a strong influence on results for two reasons; the first is that it might alternate the quantity of energy needed per unit of output (the more capital is used, the less/more energy is consumed in production). The second and most importantly, is that growth in this model builds of change in capital, reducing capital-output ratio should boost economic growth (less capital is needed to produce the same output) and vice versa, the question is how sensible the model is to such a change in this ratio.

Analysis were conducted with very different values up to a 0.5 points difference. The results show sensibility to this key parameter. For the sake of clarity, the following results show the extreme cases of two different scenarios; the value of 1.87 and a value of 2.87, each is 0.5 points different from the benchmark value of 2.37. At this high level of variance, GHG emissions reach there a level of 10% higher than the initial phase in the base year at very different timing given by the different growth paths. When capital-output ratio is as low as 1.87, GDP grows so fast that GHG emissions reach the 10% limit in the second period. While in case of a very high value of capital-output ratio of 2.87, GDP grows at a lower growth rate to push the GHG emissions to the same limit as late as in the last period.

Table 6-7 Egypt, 10% tax on energy intermediate and final consumption with capital-output ratio equal to 1.87

	Periods														
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Macroeconomic Indicators															
GDP	3.85	-0.09	0.51	0.49	0.49	0.49	0.49	0.49	0.49	0.49	0.49	0.49	0.49	0.49	0.49
Welfare	1.10	1.07	1.08	1.08	1.09	1.09	1.10	1.11	1.11	1.12	1.12	1.13	1.14	1.14	1.15
Unemployment rate															
Skilled	0.02	0.02	0.03	0.04	0.05	0.06	0.07	0.08	0.09	0.10	0.10	0.11	0.12	0.13	0.14
Unskilled	0.01	0.04	0.05	0.06	0.07	0.08	0.09	0.10	0.10	0.11	0.12	0.13	0.14	0.15	0.16
Contamination Indicator															
GHG Emissions growth rate	4.35	-4.28	0.52	0.50	0.50	0.50	0.49	0.49	0.49	0.49	0.49	0.49	0.49	0.48	0.48
Activity Level by Sector															
Agriculture	1.08	1.07	1.07	1.08	1.08	1.08	1.08	1.09	1.09	1.09	1.09	1.09	1.10	1.10	1.10
Forestation	1.04	1.04	1.04	1.04	1.04	1.04	1.04	1.04	1.04	1.04	1.05	1.05	1.05	1.05	1.05
Livestock	1.09	1.07	1.07	1.08	1.08	1.08	1.09	1.09	1.09	1.10	1.10	1.10	1.11	1.11	1.11
Energy-intensive Industry	1.15	1.10	1.11	1.12	1.14	1.15	1.16	1.17	1.19	1.20	1.21	1.23	1.24	1.25	1.27
Rest of Industry	1.11	1.10	1.11	1.11	1.11	1.12	1.12	1.12	1.13	1.13	1.14	1.14	1.14	1.15	1.15
Coal	1.01	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Oil	1.03	1.00	1.00	0.99	0.99	0.99	0.99	0.98	0.98	0.98	0.98	0.97	0.97	0.97	0.97
Petroleum	1.07	0.99	1.00	1.00	1.01	1.02	1.03	1.04	1.05	1.06	1.07	1.08	1.09	1.10	1.11
Gas	1.08	1.02	1.02	1.01	1.00	0.99	0.99	0.98	0.97	0.96	0.96	0.95	0.94	0.93	0.93
Electricity	1.11	1.01	1.02	1.02	1.02	1.03	1.03	1.04	1.04	1.04	1.05	1.05	1.05	1.06	1.06
Construction	1.08	1.06	1.07	1.07	1.08	1.08	1.08	1.09	1.09	1.10	1.10	1.10	1.11	1.11	1.12
Transportation	1.12	1.09	1.10	1.10	1.11	1.11	1.12	1.12	1.13	1.14	1.14	1.15	1.15	1.16	1.16
Other Services	1.09	1.15	1.15	1.15	1.16	1.16	1.16	1.16	1.17	1.17	1.17	1.18	1.18	1.18	1.19

Table 6-8 Egypt, 10% tax on energy intermediate and final consumption with capital-output ratio equal to 2.37

	Periods														
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Macroeconomic Indicators															
GDP	0.15	0.40	0.49	0.49	0.49	0.49	0.49	0.49	0.06	0.45	0.49	0.49	0.49	0.49	0.49
Welfare	1.06	1.07	1.07	1.08	1.09	1.09	1.10	1.10	1.07	1.08	1.09	1.09	1.10	1.10	1.11
Unemployment rate															
Skilled	0.05	0.06	0.07	0.08	0.09	0.10	0.11	0.12	0.11	0.12	0.13	0.14	0.15	0.16	0.17
Unskilled	0.05	0.06	0.07	0.08	0.09	0.09	0.10	0.11	0.13	0.14	0.15	0.16	0.17	0.18	0.18
Contamination Indicator															
GHG Emissions growth rate	0.02	0.37	0.48	0.47	0.47	0.47	0.47	0.47	-3.89	0.45	0.49	0.49	0.49	0.49	0.48
Activity Level by Sector															
Agriculture	1.05	1.05	1.06	1.06	1.06	1.06	1.07	1.07	1.06	1.06	1.06	1.06	1.07	1.07	1.07
Forestation	1.02	1.02	1.02	1.02	1.03	1.03	1.03	1.03	1.03	1.03	1.03	1.03	1.03	1.04	1.04
Livestock	1.05	1.06	1.06	1.06	1.07	1.07	1.07	1.07	1.06	1.07	1.07	1.07	1.08	1.08	1.08
Energy-intensive Industry	1.09	1.10	1.12	1.13	1.14	1.15	1.16	1.18	1.13	1.14	1.16	1.17	1.18	1.19	1.21
Rest of Industry	1.07	1.07	1.08	1.08	1.08	1.09	1.09	1.09	1.09	1.09	1.09	1.10	1.10	1.10	1.11
Coal	1.01	1.01	1.01	1.01	1.01	1.01	1.01	1.00	0.99	0.99	0.99	0.99	0.99	0.99	0.99
Oil	1.02	1.02	1.02	1.01	1.01	1.01	1.01	1.00	0.97	0.96	0.96	0.96	0.96	0.95	0.95
Petroleum	1.05	1.05	1.06	1.07	1.08	1.09	1.10	1.11	1.02	1.03	1.04	1.05	1.06	1.07	1.08
Gas	1.04	1.04	1.03	1.02	1.01	1.01	1.00	0.99	0.94	0.93	0.93	0.92	0.91	0.91	0.90
Electricity	1.07	1.07	1.07	1.08	1.08	1.08	1.09	1.09	1.00	1.00	1.01	1.01	1.01	1.02	1.02
Construction	1.05	1.05	1.06	1.06	1.07	1.07	1.07	1.08	1.06	1.06	1.07	1.07	1.08	1.08	1.08
Transportation	1.07	1.08	1.08	1.09	1.09	1.10	1.10	1.11	1.09	1.09	1.10	1.10	1.11	1.11	1.12
Other Services	1.05	1.06	1.06	1.06	1.07	1.07	1.07	1.08	1.13	1.13	1.14	1.14	1.14	1.15	1.15

Table 6-9 Table 6-10 Egypt, 10% tax on energy intermediate and final consumption with capital-output ratio equal to 2.87

	Periods														
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Macroeconomic Indicators															
GDP	3.71	0.44	0.49	0.49	0.49	0.49	0.49	0.49	0.49	0.49	0.49	0.49	0.49	0.06	0.41
Welfare	1.04	1.04	1.05	1.06	1.06	1.07	1.07	1.08	1.08	1.09	1.09	1.10	1.11	1.08	1.08
Unemployment rate															
Skilled	0.07	0.08	0.09	0.10	0.11	0.12	0.12	0.13	0.14	0.15	0.16	0.17	0.18	0.17	0.18
Unskilled	0.07	0.08	0.09	0.10	0.11	0.11	0.12	0.13	0.14	0.15	0.16	0.17	0.17	0.19	0.20
Contamination Indicator															
GHG Emissions growth rate	4.18	0.41	0.48	0.47	0.47	0.47	0.47	0.47	0.47	0.46	0.46	0.46	0.46	-3.74	0.40
Activity Level by Sector															
Agriculture	1.03	1.03	1.04	1.04	1.04	1.04	1.04	1.05	1.05	1.05	1.05	1.06	1.06	1.05	1.05
Forestation	1.01	1.01	1.02	1.02	1.02	1.02	1.02	1.02	1.02	1.02	1.02	1.02	1.02	1.03	1.03
Livestock	1.03	1.03	1.04	1.04	1.04	1.05	1.05	1.05	1.06	1.06	1.06	1.07	1.07	1.06	1.06
Energy-intensive Industry	1.06	1.07	1.08	1.09	1.10	1.11	1.13	1.14	1.15	1.16	1.17	1.18	1.20	1.16	1.17
Rest of Industry	1.04	1.04	1.05	1.05	1.05	1.06	1.06	1.06	1.07	1.07	1.07	1.08	1.08	1.07	1.08
Coal	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	0.99	0.99
Oil	1.01	1.01	1.01	1.00	1.00	1.00	1.00	0.99	0.99	0.99	0.99	0.99	0.98	0.94	0.94
Petroleum	1.03	1.04	1.05	1.06	1.06	1.07	1.08	1.09	1.10	1.11	1.12	1.13	1.14	1.05	1.06
Gas	1.02	1.01	1.01	1.00	0.99	0.98	0.98	0.97	0.96	0.95	0.95	0.94	0.93	0.89	0.88
Electricity	1.04	1.04	1.05	1.05	1.05	1.06	1.06	1.06	1.07	1.07	1.07	1.08	1.08	0.99	0.99
Construction	1.03	1.03	1.04	1.04	1.04	1.05	1.05	1.06	1.06	1.06	1.07	1.07	1.08	1.06	1.06
Transportation	1.04	1.05	1.05	1.06	1.06	1.07	1.07	1.08	1.08	1.09	1.09	1.10	1.10	1.08	1.09
Other Services	1.03	1.03	1.04	1.04	1.04	1.05	1.05	1.05	1.06	1.06	1.06	1.07	1.07	1.12	1.12

7. Conclusion

7.1. Introduction

Current and future loss in land productivity and migration caused by climate change call for a prompt action. Moreover, developing countries suffer the scarcity of their resources, on the top of their agendas comes sustainable development. Yet how sustainable can development be with high risk of increasing their vulnerability due to climate change? As a matter of fact, to take either direction, the international community needs to seriously consider climate change risks.

The question is what developing countries and the international community can do in this regard. International community need to give such countries time and space to sit goals and environmental targets to achieve and join abating countries. Developing countries, however, should start to think their future through the eyes of a world with a changing climate and sever consequences.

7.2. Policy implications

Tunisia and Egypt may clearly benefit from the potential double dividend effect, which occurs thanks to new environmental taxes. Such taxes, not only do they contribute to the international effort of controlling climate change, but also generate funds that can be used for redistributing tax weights, encouraging emerging industries and setting different adaptation project which are, as many argue, the best way to spend such tax revenue. With the correct level of environmental tax rate, governments may start right.

Relatively speaking, African countries such as Egypt and Tunisia are not considered of the great polluters, yet results show that reduction in GHG emissions is quite responsive to environmental taxes, off course at some economic cost. What could be a sound strategy is to combine abatement initiatives (through pricing carbon) with adaptation as their primary goal though. These two countries already have a relatively hot weather, scarce sources of clean water, and long coasts with seaports. With the right and gradual environmental tax rates, the adaptation process shall be efficient and effective.

While in least developing countries of Africa, a simple cooking stove makes a great difference to burning wood (as to the traditional source of energy), Tunisia and Egypt are at a higher level of efficiency when it comes to energy use in production. In fact, increasing efficiency of energy use in production should have a little impact on CO₂ emissions in Tunisia and Egypt. Annex B countries of Kyoto protocol willing to undertake CDM projects in Tunisia and Africa -if primarily aiming to reduce GHG emissions rather than the economic development of these countries- should invest in project with higher GHG emission reduction outcomes, transportation enhancement, sewerage treatment plant and geothermal power stations are maybe better alternatives and a good area for future studies and research.

7.3. Limitations of research

The revolutionary wave of demonstrations, protests, and riots named “Arab Spring” in North Africa and the Middle East was a milestone in their political and economic life. It started on 17 December 2010 in Tunisia with the Tunisian Revolution, followed by the Egyptian revolution on 25 January 2011. These events caused a dramatic leadership change and left both countries with new challenges to confront. These political aspects are not considered in the analysis. The study assumes the possibility of forcing certain economic environmental policies, which are politically sensitive given the economic and political instability of both countries. The study demonstrates the potential advantages and disadvantages from certain policies. Implementation will definitely depend on the current regimes and their priorities. Moreover, the database utilized for the study goes back to year 2007. Even though it is the most recent database released on these two countries that allow such analysis, it does not include the later shock to both economies caused by the so-called Arab spring.

An often-major weakness of CGE is the lack of literature about parameter estimation; GTAP provides also a set of elasticity parameters that were used in this study, others were retrieved from economic literature or estimated from the social accounting matrix. The robustness of the model was checked through sensitivity analysis of key parameters. The primary conclusions were checked through sensitivity analysis. Most of elasticities among energy goods, factors of production, show no extensive sensibility, results show relative sensibility to the assumptions on full capital mobility, and capital-output ratio.

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