Essays on Water Resources and the Ugandan Economy

University of Pretoria

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Certification

The undersigned certify that they have read and hereby recommend for acceptance by the University of Pretoria the thesis titled: ***Essays on Water Resources and the Ugandan Economy***, in fulfilment of the requirements for the degree, Doctor of Philosophy in Economics.

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I, **Nicholas Kilimani,** do declare that this thesis is my own original work and it contains nothing which is the outcome of work done in collaboration with others, except as specified in the text or acknowledgements. In addition, it has never been presented and will not be presented to any other University for a similar or any other degree award.

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"Let us not despise what we don't understand"
(Unknown)

Dedication

To my family

May the Almighty Bless You

Preface

This thesis contains three empirical papers that investigate issues with respect to water resources and economy.

1. *Water resource accounting for Uganda: Use and policy relevancy*
   (with Jan van Heerden, & Heinrich Bohlmann)

   This paper has been published as an Economic Research Southern Africa (ERSA) Working Paper 365, and a Journal article in *Water Policy*. It is cited as: Kilimani, N., Van Heerden, J., Bohlmann, H. (2015). Water resource accounting for Uganda: Use and policy relevancy. *Water Policy*, xxx(2015) 1-22.
   DOI: http:// doi:10.2166/wp.2015.035.
   It was presented during a Brown Bag seminar session within the Department of Economics on18th September 2013, and at the Economic Society of South Africa (ESSA) Biennial Conference, University of Free State (25-27th September 2013).

2. *Counting the cost of drought induced productivity losses in an agro-based economy: The case of Uganda*
   (with Jan van Heerden, Heinrich Bohlmann, & Louise Roos)

   This paper has been submitted for publication as an Economic Research Southern Africa (ERSA) Working Paper, and as a Journal article in *Environment and Development Economics.*
   It was presented at Economic Society of South Africa (ESSA) Biennial Conference, University of Cape Town (2-4th September 2015).

3. *Water taxation and the double dividend hypothesis*
(with Jan van Heerden, & Heinrich Bohlmann)

This paper has been published as an Economic Research Southern Africa (ERSA) Working Paper 462 and a Journal article in *Water Resources and Economics*. It is cited as: Kilimani, N., Van Heerden, J., & Bohlmann, H. (2015). Water taxation and the double dividend hypothesis. *Water Resources and Economics*, 10, 68-91. DOI: http://dx.doi.org/10.1016/j.wre.2015.03.001.

A synthesised version of this article is published as a policy brief with the Global Water Forum. It can be accessed at: http://www.globalwaterforum.org/2015/07/13/water-taxation-and-the-double-dividend-hypothesis/.

This paper was also presented at Economic Society of South Africa (ESSA) Biennial Conference, University of Cape Town (2-4th September 2015).

Abstract

This thesis analysed the link between water resources and the Ugandan economy. The study was motivated by the fact that Uganda is largely an agro-based economy. In addition, agricultural activity on which many socioeconomic activities are anchored is rain-fed, with less than 1 percent of the country's arable land being currently under irrigation. Furthermore, reports suggest that many episodes of economic instability are attributed to disruptions in agricultural activities which, in many cases have been due to changes in water availability.

This study first, used the System of Economic and Environmental Accounting for Water (SEEAW) in order to establish the available volume as well as use of water resources across the major sectors of the economy. It was established that the current level of water supply is adequate to meet the country's current demands. In addition, a framework for analysing the link between water resource policies and other socioeconomic policies in the economy was developed. This framework is envisaged to guide researchers and policy practitioners in the analysis of environment-economy policy issues.

Second, the study investigated the economy-wide impact of drought on the Ugandan economy using a computable general equilibrium model (UgAGE-Water) for Uganda. An assessment of the resulting losses with respect to GDP, employment, the trade balance and household welfare was undertaken. Overall, the results show that even a short-term drought can cause substantial losses to the economy.

Third, the effects of a water tax policy on the economy were investigated. Specifically, an investigation of the possibility of designing a tax that is capable of minimising the costs of environmental regulation while achieving the economic objective of raising tax revenue was undertaken. Underpinned by the "double dividends hypothesis", the results show that whatever the degree of regressivity resulting from the tax, it is possible to design it in a way that benefits the economy.

The overall findings in this thesis are designed to highlight the challenges which the economy faces whenever there are changes in water availability. It further articulates the possible interventions which can be used to mitigate such water related challenges in a developing country context.

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Acronyms

BOTE	Back of the Envelope
CES	Constant Elasticity of Substitution
CET	Constant Elasticity of Transformation
CGE	Computable General Equilibrium Model
DPSV	Dixon-Parmenter-Sutton-Vincent
DWD	Directorate of Water Development
DWRM	Department of Water Resources Management
EEA	European Environmental Agency
ENSO	El Niño and La Niña-Southern Oscillation
FAO	Food and Agricultural Organisation
FEWSNET	Famine Early Warning Systems Network
GDP	Gross Domestic Product
GEMPACK	General Equilibrium Modelling PACKage
GIS	Geographical Information System
GTAP-W	Global Trade Analysis Project Water CGE Model
IDP	Internally Displaced Peoples' Camps
IFPRI	International Food Policy Research Institute
IMPACT	International Model for Policy Analysis of Agricultural Commodities and Trade
IMPLAN	Impact Analysis for Planning CGE Model
I–O	Input –output
IPCC	Inter-governmental Panel on Climate Change
IRF	In-stream Flow Requirements
ITCZ	Inter-Tropical Convergence Zone
IWMI	International Water Management Institute
IWRM	Integrated Water Resource Management
KDS	Kampala Declaration on Sanitation
km^2	Square Kilometres
LES	Linear Expenditure System
m^3	Cubic Millimetres
mm	Millimetres
MAAIF	Ministry of Agriculture Animal Industry and Fisheries
MAR	Mean Annual Run-off
MEB	Marginal Excess Burden
MFPED	Ministry of Finance Planning and Economic Development
Mt	Mount

MTTI	Ministry of Tourism Trade and Industry
MWE	Ministry of Water and Environment
MGLSD	Ministry of Gender, Labour and Social Development
MoES	Ministry of Education and Sports
MoH	Ministry of Health
MWLE	Ministry of Water Lands and Environment
NEMA	National Environmental Management Authority of the Republic of Uganda
NPA	National Planning Authority
NWSC	National Water and Sewerage Corporation
OECD	Organisation for Economic Cooperation and Development
OPM	Office of the Prime Minister, Republic of Uganda
PSUT	Physical Supply and Use Tables
RWS	Rural Water Supply
SACCOs	Savings and Cooperative Societies
SAM	Social Accounting Matrix
SEEAW	System of Economic and Environmental Accounting for Water
SIWI	Stockholm International Water Institute
SUTs	Supply and Use Tables
TERM-H2O	The Enormous Regional Model for Water
UBOS	Uganda Bureau of Statistics
UgAGE	Uganda Applied General Equilibrium Model
UGX	Uganda Shillings
UN	United Nations
UNDESA	United Nations Department of Economic and Social Affairs
UNDP	United Nations Development Programme
UNSD	United Nations Statistics Division
UPGEM	University of Pretoria General Equilibrium Model
UWSS	Urban Water Supply and Sewerage
VAT	Value Added Tax
VMP	Value of Marginal Product
WCED	World Commission on Environment and Development
WESWG	Water and Environment Sector Working Group
WfP	Water for Production
WRM	Water Resources Management
WWAP	World Water Assessment Programme of the United Nations
yr	Year

Chapter One

General Introduction

1 Setting the context

This thesis focuses on issues that underlie the interaction between water resources and the Ugandan economy. The research is motivated by the fact that this interaction is important for an agro-based economy such as Uganda's whose agricultural activity is heavily rain-fed, with less than 1 percent of its arable land being currently under irrigation. The agricultural sector is a key foreign exchange earner and supplier of inputs to other sectors of the economy. In addition, the sector is a vital source of livelihood since over 76 percent of household income is related to agricultural production.

Various household surveys by the Uganda Bureau of Statistics (UBOS) show that 42 percent of households report agriculture as a major source of income while 26 percent cite it as their only source of income. Therefore, any changes in the availability of especially, water for production have the potential to lead to socioeconomic instability at a micro and macro-level. Whereas the current level of total available freshwater resources in Uganda is still adequate to meet current demand, these water resources are unevenly distributed. In addition, the existing water resources, if not well managed, might soon become depleted on account of population growth, rapid urbanisation, increasing consumption of water per capita due to economic growth, as well as the increasing climate variability (Bates et al., 2008).

Results from climate models suggest that average global rainfall is poised to increase as global temperature rises. This is expected to result in increased water availability although regional differences in climatic conditions imply that large differences in rainfall will still persist (Calzadilla et al., 2011). These climatic changes will further influence the regional distribution of freshwater resources which in turn will also influence the demand for water. Higher temperatures and changes in precipitation patterns are expected to increase water demand for crops and livestock (see e.g., Fischer et al., 2007). In the wake of reduced water availability, adaptation mechanisms for ensuring optimal use of the existing water resources will become necessary in order to limit the severity of impacts. The outcome is that such interventions will potentially reduce the cost of water scarcity on the economy (IPCC, 2007).

Whereas the adverse effects of climatic change and variability have become central to the debate on issues of long-term global social and economic stability, the policy interventions in Uganda do not seem to be paying adequate attention to the potential impact of these climatic changes on water resources from a socioeconomic point of view. In fact, most of the existing studies on water resources in Uganda have largely focused on hydrological aspects, with little or no link to the rest of the economy. This is despite the fact that among the country's economic challenges which policy makers regularly highlight, are issues such as the erratic changes in the availability of water for production and the subsequent downstream effects (see MFPED, 2011, p.80). Among the notable causes are the changes in climatic conditions which are being experienced through decreased rainfall and rising temperatures (FEWSNET, 2012). These are posing a serious threat to the country's long-term development prospects since they directly affect water availability. The motivation for this research is informed by the existence of an intricate economy-environment relationship that has far-reaching implications for the socioeconomic set up of any country.

Agriculture is the largest consumer of freshwater resources, with global estimates indicating that approximately 70 percent of all freshwater withdrawals are used for food production. Furthermore, innovations within the agricultural sector such as irrigation have contributed to an increase in global crop yields, allowing global food production to keep pace with population growth (United Nations, 2006). However, the agricultural sector in Uganda is heavily reliant on rainfall for production. This implies that any increase in rainfall variability can greatly affect the socioeconomic conditions of the country. For instance, droughts are variously cited to have had negative effects on the performance of the agricultural sector in Uganda. Empirical studies show that during periods of drought, all crop varieties across the country experience substantial moisture deficits in both perennial and non-perennial crops (see DWRM, 2011). Similarly, a study by the Government of Uganda notes that the 2010/11 drought episode caused a loss in real GDP of 7.5 percent— equivalent to US$1.2 billion (see OPM, 2012). Therefore, variability in rainfall patterns which primarily affect key, but climate sensitive sectors such as agriculture can impact the economy in a very broad manner.

The agricultural sector contributes approximately 13.9 percent of Uganda's GDP and employs over half of the country's labour force (MFPED, 2011). In addition, it has strong forward and backward linkages with the rest of the economy. As a consequence, the adverse effects of climatic variability on the agricultural sector are being reflected in rising prices[1] of both food and agricultural inputs used by other sectors like the agro-processing component of the manufacturing sector, famine, unemployment and reduced agricultural export growth. Therefore, it is clear that the increasing climatic variability might jeopardise the country's long-term socioeconomic development path unless when interventions to reduce the heavy reliance on rainfall as well as efforts to harness the efficient use of the existing water resources are put in place.

[1] For instance, there were periods when headline inflation reached double digit (MFPED, 2011).

As noted earlier, current estimates indicate that the supply of freshwater resources is still adequate to meet the country's needs. However, those water resources are unevenly distributed. In addition, rainfall patterns are also varied. Whereas the country's average annual rainfall stands at 1200 mm, only the Lake Victoria shores and the mountainous areas of Rwenzori, Elgon and the Kisoro-Kabale area experience annual rainfall surpluses relative to the national average. The average rainfall deficit is less than 200 mm in 20 percent of the country, while another 35 percent of Uganda experiences a deficit between 200-400 mm. The average annual deficit in the northeast and sections of the Rift valley is above 600 mm. Moreover, the positive effects of the country's average rainfall of 1200 mm are eroded by the high rates of potential evaporation — most notably in areas that receive rainfall in the range of 1350-1750 mm.

Van Steenbergen and Luutu (2012) indicate that a big proportion of rainfall (approximately 70-90 percent) goes back into the atmosphere through evapo-transpiration. Only a small proportion of this rainfall stays on the land surface to contribute to surface flow via run-off and to groundwater recharge via infiltration through the unsaturated zone. They further note that given the nature of the aquifers, groundwater resources are mainly recharged only during heavy rainfall episodes. As such, the high evaporation rates have implications for the performance of the economy e.g., via agricultural sector activity with regard to soil moisture capacity which is vital for crop production, and range land productivity for livestock. This is in addition to overall water availability through the reduction in the ability for groundwater and surface water resources to recharge (DWRM, 2011). In the absence of sustained rainfall episodes, it is clear that the water resources recharge capacity is greatly compromised (Bates et al., 2008). This is being exacerbated by the increasing temperatures which are adversely affecting areas where the intensity of rainfall is less than potential evapo-transpiration (see FEWSNET, 2012). Furthermore, effective utilisation of the existing water resources to address rainfall shocks is being curtailed by limited water supply infrastructure and a mismatch between the location of water resources and the regions where demand is high, i.e., the arid and semi-arid areas of the country.

To ensure food security, export performance, employment and poverty reduction over the medium to long-term especially in the water-scarce regions, the development and expansion water supply infrastructure such as irrigation needs to be undertaken as a matter of priority. Additional interventions such as improved crops and soil moisture conservation techniques should lead to improvements in the performance of the agricultural sector (Kamara and Sally, 2004; Calzadilla et al., 2011). However, it is vital to note that whereas irrigation development is crucial for food security, economic growth, and poverty alleviation, it can adversely affect the environment as well. For instance, in many regions and river basins around the globe, surface and groundwater resources are being overexploited thereby damaging ecosystems through the resulting reduction in water flows to rivers, lakes, and wetlands (see Rosegrant et al., 2002). In Uganda, as indeed for most sub-Saharan African economies, the situation is different. The existing water resources are largely underutilised and these are expected to generate economic opportunities for intensive, but sustainable use in agriculture (Villholth and Giordano, 2007). In this regard, one of the central challenges for the future development of agriculture is how to utilise the existing water resources in a sustainable manner (Shah et al., 2000). This is a critical issue which, among others, is explored in this thesis.

In order to analyse the issues which have been highlighted in the foregoing discussion, first, we build national water accounts, and second, a single-country computable general equilibrium (CGE) model, UgAGE-Water. In this version of UgAGE, water is used as a factor of production in order to analyse water related issues and how these impact the economy. The analytical approach used in this thesis differs from most other related studies in the literature on linking water resources and the economy. The critical points of departure from the existing literature and other additional innovations of this research are articulated in the remainder of this subsection as well as in Chapter 2.

Investigating the link between water resources and the economy is not a new phenomenon. In fact, as the literature shows, a number of studies have attempted to investigate the impact of water resources on the economy in different contexts. Some have investigated the physical impact of climate change and its economic consequences (Faust et al., 2012). Others have analysed the economic impacts using descriptive techniques (IPCC, 2007), whilst some have sought to investigate the structural relationship between economic activities and water use (Gonzalez, 2011). Some studies employ partial equilibrium analysis to estimate the effects of water on specific sectors the economy within a limited geographical area (see Schlenker and Lobell, 2010; Jones and Thornton, 2003). However, by definition, partial equilibrium models often do not consider markets or sectors outside of those directly affected, and as a result, cannot provide a comprehensive analysis of the resulting changes in a wider context. In this thesis, we use general equilibrium modelling because of its ability to investigate the economy-wide impacts of policies or any other shocks on an economy.

Second, even within a general equilibrium framework, many studies employ global or and multi-regional models which use aggregated data e.g., the GTAP-W (see Hertel, 1997; Burniaux and Truong, 2002; Berrittella et al., 2007; Calzadilla et al., 2011; Calzadilla et al., 2014), IMPACT (Rosegrant et al., 2008; Zhu et al., 2008), and IMPLAN (Giesecke, 2011). The aggregation and assumptions made when developing such large-scale models often reduces their accuracy. This largely emanates from the fact that analysis is based on regional or global averages. Hence differences between countries are not accounted for, as individual effects are averaged out.[2]

Third, studies on water resources and the economy have been undertaken in different contexts and for various motivations. For instance, most studies have been undertaken for developed or upper-middle income countries (see e.g., Calzadilla et al., 2014; Calzadilla et al., 2011, for South Africa; Reilly et al., 2003, for the USA; Falloon and Betts, 2009 for Europe). Some focus on virtual water trade in specific sectors (see e.g., Hoekstra and Hung, 2005). Even for studies that employ single-country CGE models to analyse water resources and the economy, their focus is often limited to specific sectors or even aspects of a given sector (see Pauw et al., 2011; Hertel et al., 2010; Skjeflo, 2013).

In this thesis, the methodology used allows the focus of our empirical analysis to highlight the costs of water scarcity say, from a drought, and policies which are aimed at ensuring efficient and sustainable management and use of water resources in the county. This approach is informed by the fact that the benefits of any intervention say, from a drought or policy on water taxation, can easily be approximated using the estimated costs of non-action.

[2] See Wittwer (2012); Horridge and Wittwer (2008) for detailed regional CGE model.

2 Objectives and contribution of the thesis

Based on the System of Economic and Environmental Accounting for Water (SEEAW) and the UgAGE-Water model, this thesis aims to investigate the role of water resources in an economy from a developing country perspective. Population growth, and increased economic growth, have resulted in rapid urbanisation, thereby increasing the demand for water resources. These, coupled with the increasing variability in rainfall patterns are increasingly posing a threat to long-term water resource availability. This has implications for economic performance in many of the developing countries. In Chapter 3, we undertake a water resource accounting exercise and develop a framework for analysing the linkage between water sector policies and the policies of the different sectors of the economy. In the Chapter, we establish the available volume as well as use of water resources across the major sectors of the economy. This is done in order to assess whether or not, there is room for possible measures to increase sustainable water resource use. In Uganda, there are some regions with an abundant supply of surface and groundwater resources while others experience extreme water scarcity. Water scarcity can result either from the spatial distribution of ground and surface water sources, from frequent drought conditions or from both. This investigation is timely because the country is experiencing regular drought episodes which are affecting economic activity since many economic activities such as agriculture are heavily rainfall dependent.

The policy analysis framework developed in Chapter 3 is aimed at providing an analytical tool for water resource management. It is therefore envisaged to act as a guide for researchers and practitioners who seek to identify the policy and non-policy variables which are critical for Integrated Water Resource Management (IWRM) in an economy. The developed framework facilitates the analysis of policies using any choice of modelling technique for any economy, stemming from a meticulous categorization of both policy and non-policy variables needed for analysis. As such, a researcher or policy practitioner is in a position to analyse the effects of a given policy intervention, including the integration of new variables into their model of choice. Most importantly, the systematic way in which the framework is developed is such that other researchers do not require substantial expertise in the realm of environmental-economic modelling to use it for their analysis. In the subsequent Chapters, we analyse the impact of changes in water availability due to drought, as well as policies which could engender sustainable water use in Uganda.

A practical implementation using the framework developed in Chapter 3 is undertaken in Chapters 4 and 5 through the investigation of shocks to the economy via changes in water resources or policies. This analysis was undertaken using the UgAGE-Water model after identifying the existing gaps from a detailed survey of the existing literature on the link between water resources and the economy. In each of the Chapters, we include a methodology section which articulates the contextualized features of the UgAGE-Water model that make it amenable for the analysis of the Chapter specific issues under investigation. In this regard, we describe in detail the modifications made for each Chapter. The modified model structure is also described, giving special emphasis on its implementation and changes made to the TABLO code.

Chapter 4 titled "*Counting the cost of drought induced productivity losses in an agro-based economy: The case of Uganda",* analyses the socioeconomic impact of drought on the Ugandan economy. Climate variability affects developing economies both directly through the impact on agricultural output and indirectly through its effect on the activities of down-stream industries and household welfare. The case of Uganda is interesting because as it is the case with most developing countries, its economy is largely agro-based with an agricultural sector which is heavily rain-fed. In the absence of steady rainfall, the sector is bound to suffer since there are no feasible alternatives to rainfall with respect to water for production. This is due to the fact that less than 1 percent of the arable land is under irrigation. In this Chapter, we investigate the impact of drought via productivity shocks on the agricultural sector as well as other down-stream industries such as the agro-processing component of the manufacturing sector. We then undertake further analysis of the effect of these shocks on other sectors of the economy.

As a contribution, Chapter 4 introduces a novel analytical approach to modelling climate anomalies using an economy-wide model. Specifically, the research introduces the use of "quasi-sequential" modelling when identifying productivity shocks. This yields more accurate results than the arbitrary and sometimes uniform productivity shocks which some of the existing studies impose. In this regard, we deviate from the 'what if' scenarios which are common in economy-wide modelling and instead use actual productivity losses to the agricultural sector associated with a typical drought event. These actual losses were derived from an extensive survey of literature on the use of econometric and crop yield models to measure productivity losses. As such, the results from the analysis approximate the true costs of a typical drought to the economy, once the limitations of the model are taken into account. It is envisaged that the approach used in this model can provide insights into the potential cost of a drought in any agro-based economy. The findings are critical for weighing the benefits of drought mitigation, and can therefore be used to shape adaptation programmes in economies which are susceptible to droughts.

In Chapter 5 titled *"Water taxation and the double dividend hypothesis",* we analyse the potential impacts of introducing a water tax policy on the Ugandan economy in a CGE framework. This part of the thesis aims to contribute to the policy discourse on environmental and economic management from a developing country perspective. Specifically, we investigate the possibility of designing a tax policy that is capable of minimising the costs of environmental regulation while achieving the economic objective of raising tax revenue. This aspect of the thesis is motivated by a Uganda Government tax on commercially distributed water. This Chapter is underpinned by the "double dividends hypothesis" in the literature on environmental resource management.

The large volume of literature in the field of environmental taxation has found no conclusive evidence of a strong double dividend following the implementation of an environmental tax policy. This finding has largely been on account of the fact that the price interaction effect tends to outweigh the revenue recycling effect. However, the findings in this thesis on the double dividend hypothesis go beyond the general conclusions made by most studies through the modelling procedure used. In Chapter 5, we demonstrate that the ability for a tax policy to yield any dividends depends on the state of the economy, the environmental good being taxed, as well as the tax regime. For developing the countries whose use of environmental taxes in environmental regulation is still limited, the thesis highlights the critical issues which researchers and policy makers need to pay close attention to in order to design a beneficial environmental tax policy. These include: i) the choice and condition of the environmental good being taxed, ii) the tax rate imposed, iii) the existing tax policy, and iv) the payment vehicle for the proposed tax.

In the subsequent Chapters of this thesis, critical methodological and policy gaps which were identified in the literature are highlighted, as well as measures that need to be undertaken in order to have them addressed. These include: i) the linkage of the water sector policies with those of other sectors in order to assess the possible socioeconomic impact of any changes from either sector (Chapter 3); ii) the implementation of productivity shocks in the agricultural sector in order to assess the impact of a typical drought on the economy (Chapter 4); and iii) the use of the double dividend hypothesis to analyse the potential benefits of a tax on water resources in the context of a developing economy (Chapter 5).

3 Outline of the thesis

The thesis comprises of six Chapters. This section has been presented in summary form for the reader to have a snapshot of what appears in the subsequent Chapters. A detailed summary of the thesis is in the concluding Chapter of the thesis– Chapter 6. Chapter 2 presents a review of the analytical approaches used in modelling water resources and the economy. It also provides a concise summary of the existing literature that underlies the thesis theme with the view to highlight the existing gaps. Some of these gaps have been dealt with in the thesis. It also includes a justification for the choice of analytical procedures used in the thesis as well as a demonstration of the transition from a conventional Social Accounting Matrix to a CGE model and later into a water-CGE model.

Chapter 3 undertakes a water resource accounting exercise for Uganda, and goes further to develop an analytical framework which can be used for linking water sector policies with the policies of other sectors of the economy. Chapter 4 investigates the social economic impact of drought induced productivity losses on the Ugandan economy, while Chapter 5 uses the basic tenets of the double dividend hypothesis to establish the possibility of using fiscal tools to induce efficient management and use of water resources in a way that is beneficial to the economy. The thesis ends with Chapter 6, which concludes, recaps the key study findings, highlights the emerging policy issues, and limitations of the study as well as suggested issues for future research.

Chapter Two

Modelling Water in Economic Activity

1 Introduction

Water scarcity discussions have brought to the fore, issues that concern food security, poverty, unemployment, public health as well as the overall contribution of water resources to the development of especially the developing economies. The contribution to the debate on water resource management has involved a number of analytical models. These models have been employed in order to explore the relationship between water related policies and other issues under various settings. As water is an economic good, it can easily be added into existing models as a factor of production.

Partial and general equilibrium models are the major categories of models used in the analysis of water resources in various socioeconomic settings. This is because they allow for objective oriented specification of the economic phenomena under consideration. Hence, they are suitable for making case specific analysis without loss of generality of the basic tenets of analytical framework chosen (Chumi and Dudu, 2008). In this Chapter, we present an overview of the literature on modelling water resources in an economy. We present the two key analytical approaches used in the literature with the view to set the context for the choice of analytical methods used in the thesis.

1.1 Partial equilibrium models

Partial equilibrium analysis is based on the equilibrium conditions of a market for a good/sector which is a part of the overall economy. As such, partial equilibrium models assume that prices are fixed in the other markets. Marshall (1920) argued that when the share of the good in question is a small proportion of consumer's total budget, the income effect is minimised. This implies that the market under analysis can be assumed to be independent of the macroeconomic relationships that affect the whole economy (Chumi and Dudu, 2008). Secondly, there is minimal interaction between prices of different goods. Given the assumptions of partial equilibrium modelling, a single good is independent of the rest of the economy. Therefore, any changes in the dynamics of a specific market are assumed to have no effect on the rest of the economy.

In partial equilibrium analysis, demand is found by maximising the objective function subject to a constraint. For example, in water market analysis, farmers are consumers while the water distribution authorities are producers. Thus, demand is found by maximising either the profits or producers surplus. Alternative approaches include the use of biophysical farm models to determine crop and time specific water demand. However, this entails the sourcing of detailed data on yields, water requirements, irrigation areas and crops produced. Under the assumption of a functional relationship between inputs and output, the optimisation method is rather simple and water demand can be obtained from the first order conditions of the objective function (Mas-Colell et al., 1995).

On the supply side, water resources are more difficult to model due to the element of uncertainty. This is because; water supply is largely dependent on unpredictable weather conditions. Partial equilibrium studies often overcome this difficulty by using outputs from hydrological models or historical data in a bid to determine the level of future water availability. As such, water availability is made exogenous to the model variables and thus supply side shocks are applied exogenously (Chumi and Dudu, 2008). If water availability is taken to be a non-binding constraint, then the uncertainty problem can be ignored. In such a case, supply can be determined in the same way as the other economic goods, i.e., by maximising the profits of suppliers under appropriate market structure assumptions about the water market. The general practice in partial equilibrium modelling however is, water supply functions are calibrated to historical data and effects of changes in water supply are analysed exogenously (see Schlenker and Lobell, 2010; Jones and Thornton, 2003).

1.2 General equilibrium models

Partial equilibrium models are not suited for making economy-wide inference and policy recommendations. This is more so the case when water resources are involved. For instance, in modelling irrigation water demand, any change in environment, either from a policy or physical point of view, is likely to affect the whole economy. Any shock is likely to have significant effects on the key macroeconomic variables. Therefore, in order to analyse the macroeconomic effects of changes in water availability and management policies, a broader framework needs to be used. To this end, computable general equilibrium models have been developed, and are more favoured to interrogate the complex relationship between water resources and the economy. It is important to note that water resources are used to satisfy many different demands within an economy. For example, water within a river basin may be limited generally to being used within that basin, but not limited to any one use (Fadali et al., 2012). Furthermore, some uses of the water do not consume the water. E.g., hydroelectricity generation belongs to the non-consumptive use category in water resource accounting. In addition, flood irrigation only partially consumes water, i.e., only water that is evaporated or transpired is consumed since the rest is returned to the environment by the irrigation systems (return flows).

Water is therefore used by different agents in an economy for various uses. For instance, it can be an input for a retail business, or used as a source of irrigation for household landscaping. Each of the mentioned uses makes a contribution to the economy, either by producing goods and services or as a final demand product. As such, each of these uses has a different value associated with the water used. Thus, it is not possible to state any single value for water, but rather a water resource used within an economy results in welfare changes for that economy. Hence, a general equilibrium approach to understanding an economy through the different industries and market inter-linkages presents a more robust way of assessing the contribution of water resources. CGE models allow for the multiple uses of water in an economy and return estimates of changes in social welfare for increases or decreases in the water resources. This gives a mechanism for providing an estimate of the marginal value of water to the economy (Fadali et al., 2012). Estimates of the marginal value imply that where necessary, a water market can be created to allocate water.

1.3 Water as an input: Partial versus General equilibrium analysis

Partial equilibrium analysis may be the best approach for analysing economic impacts for small changes in water attributes (supply, quality, timing, flow, prices) that are unlikely to affect prices of other goods and services throughout the economy in an appreciable manner. This is because, partial equilibrium approaches hold other prices and markets constant, while focusing on a specific water use. Partial equilibrium analysis has been applied to hedonic price models for purposes of property valuation, stated and revealed preference studies, non-market valuation of water to recreation and ecosystem services, estimation of production functions or demand functions, the residual methods (subtracting all other input costs from total revenue), and linear programming input-output models where prices are fixed (Young, 2005). However, for non-marginal changes in water supplied or pricing associated with different types of water policies, the direct and secondary effects on other commodity and factor markets may be of consequence throughout an economy. Partial equilibrium approaches cannot therefore account for any resulting secondary effects. Therefore estimates of changes in water demand and prices from partial equilibrium approaches could lead to inaccurate estimates of changes in water values, depending on the extent and type of linkages in the economy. Furthermore, potential changes in prices in other commodity and factor markets in turn also affect incomes and can have fiscal impacts on the different agents in the economy. CGE models are specifically built to represent these interrelationships among markets and sectors in an economy, where water pricing and supply can affect multiple sectors in non-marginal ways. CGE models provide an analysis such that the impact of changes in any one (or combination of) sector(s) can be traced through to predict changes that will result throughout the economy.

A CGE modelling approach allows for complete exploration of the complex feedbacks throughout the economy, so that the modeller can experiment and isolate the effects of many variables and identify the linkages between them with regard to say, shadow prices for water in the industrial sector. Specifically, CGE modelling breaks down the net effect of a shock to the system (the 'value' of an increase or decrease in the supply of water to a region or industry, for example) into individual changes in prices, outputs and incomes by each affected industry, so that a complete set of gainers and losers are identified, along with the measurements of change (Fadali et al., 2012).

To illustrate the difference between partial and general equilibrium approaches in modelling water resource impacts, we briefly consider the application of each approach to the case where water is in input into production. Consider a case where water levies are set administratively, and are unlikely to be equal to what would be the market clearing price for water in an economy. The value of the marginal product (VMP) of water to producers may be either less or more than the administratively set rate for its delivery. If more water is demanded than is available at the given administrative levy, then water becomes a binding constraint and the value of an additional unit of water is indicated by its shadow price, which exceeds the administrative price (Diao and Roe, 2000; Fadali et al., 2012). Conversely, if the producer has more water than they can profitably use, the VMP for water is zero for that producer. In the case of an administratively set levy that is not market clearing, water purchases and uses across the various industries may be distorted from what is socially optimal. In order to determine the associated welfare losses, we can consider the problem of determining the social cost associated with non-optimal water pricing. This is done by considering the counterfactual, where well-functioning markets for water purchases and sales exist. Assuming that there are no additional distortions in the economy, the equilibrium market clearing price of water would be equalized across all producers and will be the socially optimal price. In either case, that of an administratively set levy or market clearing prices for water, we can assume that producers who use water as a variable input in their production processes choose how much to purchase depending on the marginal value of that input to the value of outputs.

From the foregoing scenario, it is clear that a general equilibrium analysis of the value of water in production is different from the partial equilibrium analysis. The key difference between the two approaches is that all else will not be held constant in a general equilibrium setting. All prices in all markets adjust supply and demand to clear the market. The water input into production is reallocated elsewhere to other consumers or producers.

In a general equilibrium approach, all prices and all quantities are allowed to adjust to a new equilibrium when any other price or quantity changes anywhere in the entire system. Other prices in the market are no longer considered to be parameters. Where trading is allowed, water prices equilibrate, and all other markets that are affected through incomes, prices of competing or substitute inputs and outputs, government revenues, and investments are all potentially affected. Thus the net effect of a given change is modelled to include primary and secondary effects in all related activity in the economy.

If we consider the impact of a drought on the availability of water in a given economy, a policy maker may wish to know what the value of water would be to a particular sector e.g., agriculture under such drought conditions. Ordinarily, widespread drought conditions could increase the market price of agricultural products. The increase in the price of agricultural products could attract more labor to agriculture. As the share of household income spent on food increases, the share spent on other types of goods could fall, causing firms in non-agricultural sectors to lay-off workers. Higher unemployment could change consumer demands. All of these changes in other markets for factors and goods ultimately affect the value of water in agriculture. It is in taking into account this cascade of indirect effects that a general equilibrium model is better at analysing changes that are of an economy-wide nature than a partial equilibrium model.

The literature includes many examples of CGE models that have been used to examine the economic consequences of alternative water projects, allocations, or prices, as well as the effects of increasing scarcity. The existing literature on water-CGE models gives examples of the types of general equilibrium effects that cannot be accounted for in partial equilibrium methods. For instance, Hassan and Thurlow (2011) used a multi-regional CGE model for South Africa to compare water trade liberalisation policies. They found that creating a water market amongst rural farmers improved their welfare, but hurt the urban poor. This is because the prices of cereals increased as a result of the increase in the price of irrigation water, which encouraged farmers to grow higher value vegetable and fruit crops rather than grains. In their study, higher water prices led to different crop mixes, price changes for agricultural commodities, and different income effects for urban and rural poor.

Due to the complex nature of water resource interactions with the rest of the economy, water related CGE analysis tends to include the following elements: (a) the value of water as an input into one or more industries in an economy is a relatively high proportion of the total value of the output of those industries, (b) those industries are integrated into the rest of the economy, so that secondary effects in other markets are likely as a result of changes in industries that rely directly on water resources, (c) in the case of regional models, the regional borders of the economy to be modelled are well defined in terms of water use, such as a river or lake basin.

2 A summary of empirical evidence

Empirically, the increase in global consciousness about water issues has also been reflected in the efforts spent on models which can help interrogate the different water related issues. As a result, a number of studies have been undertaken in different settings to answer different issues. In this section, we briefly catalogue some of the studies that use CGE modelling to analyse water related issues. This exposé highlights a synthesis of CGE based studies with a bias towards those that investigate policy related issues in the water sector.

In this section, we synthesise the existing literature into five sets of studies. The first set of studies, analyses competition for water resources between different sectors. For such studies, the policy scenarios modelled aim at identifying the more efficient uses of water among different sectors. This among other things involves investigating the impact of quantitative restrictions on water supply in a given setting. In this case, water is modelled explicitly as a factor of production or as an intermediate input in fixed proportions with land (see Berrittella et al., 2008; Berck et al., 1991; Seung et al., 1998; Horridge et al., 2005; Dwyer et al., 2005; Wattanakuljarus, 2005; Goodman, 2000). Boccanfuso et al. (2005) extended the EXTER model of Decaluwé et al. (2001)'s integrated multi-household (IMH) model to assess the effects of different water related policies on households. Specifically, they investigated the distributional impact of privatisation of the water utility and isolated the winners and losers as a result of a privatisation policy in Senegal. They modelled a water market with two water utilities that sell water to water suppliers at an exogenously determined price. Their conclusion was that price changes have different general equilibrium effects and winners and losers depend on these effects.

The second group of studies considers water pricing policies and tariffs. In these studies, the focus is on micro-macro linkages, namely water allocation reforms at a micro level, say a change in water pricing methods at a regional level or the introduction of mechanisms for water trading among farmers (Roe et al., 2005). Given the complexities in water pricing, this cohort of studies mainly deals with economic efficiency and issues of redistribution within the framework of water scarcity under climate change (see Decaluwé et al., 1999; Diao et al., 2005; Briand, 2004; Blignaut et al., 2008). Robinson and Gehlhar (1995) developed a static CGE model with a disaggregated agricultural sector in order to analyse the structural adjustments in a number of developing countries. One study of interest was on the welfare and structural implications of a major reform of Egypt's industrial and agricultural policy. In the study, they found that the elimination of agricultural policy distortions led to a decrease in returns to the water/land aggregate.

Velazquez et al. (2007) assessed the impact of several tax policies where they compared the effects of different taxation schemes within a water market setting. Specifically, they aimed to analyse the effects of an increase in the price of the water delivered to the agriculture sector on the efficiency of the water consumption and the possible reallocation of water to the remaining sectors in Andalusia, Spain. In their study, water was modelled as a factor of production that is subject to taxes. The study found that although the tax policy did not yield significant water saving in the agricultural sector, a more efficient and more rational reallocation of water was achieved. Letsoalo et al. (2007) tested the triple dividend hypothesis which argues that taxes on the environment can simultaneously stimulate economic growth, poverty reduction and environmental protection. The latter two were direct effects of an environmental tax while the former followed from the increase in the resulting government revenue. Using a 65 sector/48 household CGE for South Africa they showed that an environmental tax policy can yield triple dividends for the economy.

The third group of studies deals with investigating the impact of water scarcity, mostly as a result of exogenous factors such as climatic shocks e.g., a drought on the different aspects of the economy. In such studies, there are attempts to include the different water sources in the model and to also account for substitution between say, rain-fed and irrigated agricultural land (see Calzadilla et al., 2011; Calzadilla et al., 2014). Other studies model water scarcity as a productivity shock (see Skjeflo, 2013). Horridge et al. (2005) modelled the effects of drought on national GDP using a multi-regional CGE model of the Australian economy. The results highlighted the severity of the 2002-03 drought on the economy to the extent that it cost the economy 1.6 percent of GDP. Other studies have even included urban water use in the basic agricultural water-CGE model (see Qureshi et al., 2012; Gomez et al., 2004; Goodman, 2000; Mukherjee, 1996; Hassan and Thurlow, 2011; Watson and Davies, 2011).

Qureshi et al. (2012) used the static version of TERM-H2O for Australia to examine how water resources and their prices are affected by an increase in the urban population and decreases in water availability. The baseline year was shocked with population growth and decreasing water availability under four different policy alternatives. They found that without new water sources or water trading, Australian cities would face an eightfold increase in the shadow price of a kilolitre of water. Furthermore, water trade between urban and rural regions would reduce production in water intensive crops as the shadow price of water increases in rural areas and decreases in urban areas to equilibrate urban and rural water prices. In these studies, water is taken as an input or a factor of production along with the agricultural sectors. For the non-agricultural sectors, water is taken as an intermediate input from the water sector, used in fixed proportions. In the different models, water as an input in the non-agricultural sectors is treated differently.

Goodman (2000) used water as a factor of production in four production sectors in the economy, in addition to employing it directly into the consumers' utility functions. Diao et al. (2008) attempted to analyse the role of different water sources in dealing with climatic shocks. Specifically, they analysed groundwater resources in a general equilibrium framework where ground water was modelled as an input into agricultural production. The results showed that ground water is important in lessening the severity of economic and climatic shocks. Peterson et al. (2004) developed a 48 sector/20 region CGE model, based on TERM where they analysed the effect of water trade under water scarcity. Their results showed that allowing for both intra and interregional water trade among irrigators substantially lessened the impact of reducing water availability on the gross regional product. Their model was extended by Dywer et al. (2005) to investigate the effects of expanding trade through the inclusion of both irrigators and urban water users. They found that water trade compensated the losses from water reductions.

The fourth group of studies focuses on the interaction between trade and water allocation at the country, regional and global scale. In this group of studies, issues of international specialisation in the trade of commodities, based on water intensity are analysed. The common finding is that trade policies have a stronger impact on national economies than water policies (see Diao and Roe, 2003 for Morrocco; Berrittella et al., 2008). Berrittella et al. (2007) developed a GTAP-W model in which they introduced a water module into a GTAP model. In the study, they relate water scarcity with international trade and analysed the possible effects of reductions in water availability on global trade. Using both a non-market and market-based scenarios, they found that welfare losses were substantially larger in the non-market scenario. In a related study, Berrittella et al. (2008) introduced tax policies to their GTAP-W model in which they found that water taxes reduced water use and led to shifts in production, consumption, and international trade patterns. They found that countries that did not levy water taxes were also affected by the taxes levied by other countries. Finally, the effects of the water tax on production, and final consumption were found to be different.

Kohn (2003) employed the Heckscher-Ohlin framework to illustrate the effects of international water trade with a focus on the Middle East. In the model, water is both a produced good in which one of the countries has a comparative advantage, and as an input used to produce another good. Both countries were found to be better off with international trade. They concluded that water markets were a better alternative to warfare for the case of regions where competition for water resources can potentially result in conflict. Even within an economy, Diao et al. (2005) highlight the role of water markets where, they presented a detailed inter-temporal CGE model for Morocco with 88 activity types producing 49 final products in 20 regions. Their results showed that water markets were likely to significantly increase the agricultural output in Morocco. The fifth strand of models combines CGE models and other bio-economic models being largely derived from the second and third (see e.g., Smajgl et al., 2005)

2.1 Emerging research issues from the literature

Although great improvements have been made in modelling economic-wide impacts of water resources, some caveats remain. These limitations are related to lack of reliable data, as well as model specification. On data, two major issues emerge. The first one is related to industrial water demand. Most of the existing studies consider only one industrial sector, and thus there is no option to reallocate water across sub-sectors according to differences in water productivity. The second one is related to the water price elasticities used. For instance the GTAP-W model parameters for most of the existing studies are based on Rosegrant et al. (2002) of which most of them are based on 1997/2000 data.

Regarding model specification, many of the models that analyse water issues do not provide for explicit water resource accounting. As such, many of these studies simulate changes in productivity as a consequence of exogenous shocks instead of changes in water availability (see Skjeflo, 2013). Given that water productivity is not considered in some of the existing studies, these approaches exclude substitution options between water and other inputs. Calzadilla et al. (2008; 2014) attempt to differentiate between rain-fed and irrigation land. However, this too, does not analyse substitution options between water and other inputs, such as capital in the irrigation composite (Ponce et al., 2012). Furthermore, many country studies lack representation of other economic sectors beside agriculture, in more detail. At a country level, it is possible to build a model that accounts for water competition among sectors: urban, industrial, environmental, and agricultural. The assumption of ceteris paribus for other markets does not seem plausible.

Finally, the integration of top-down and bottom-up models takes advantage of the best of both approaches by integrating the geographical scale dimension (see e.g., Horridge et al., 2005). This is an important approach when analysing water related issues considering that decisions concerning water resources taken at the local level can be affected by national and international policies. Future research should aim at improving the data used especially in the global models. Critical issues of interest include the potential substitution of inputs across sectors, with a special focus on the agricultural sector. Considering the increasing threats of climate variability on water resources, substitution among inputs arises as an adaptation strategy. On the other hand, given that irrigation is a large consumer of capital, both country and global models could go further to disaggregate the agricultural sector in order to account for the impact of capital movements across regions and sectors. In the thesis efforts have been made to deal with some of the limitations identified in the existing literature.

3 Incorporating water into a CGE model

A CGE model is a simplified representation of an economy. The basic approach to constructing one is through the notion of the circular flow of income in the economy (see Fadali et al., 2012, p.11; Ghadimi, 2007; Löfgren et al., 2002). Starting with the producers, a CGE model contains multiple producing sectors such as the agriculture, manufacturing, trade, services, among others. The number of sectors (and model complexity) varies from only two sectors to hundreds, depending on the level of disaggregation of industry activity needed for a particular policy analysis. Some water-CGE models often include a water utility sector that captures, stores, treats and delivers water for its customers. Each industry is represented in the model in aggregate over all firms and therefore with a specific production function (Fadali eta l., 2012).

Producers purchase inputs to produce commodities to sell in the product market. For example, the agricultural sector purchases fertiliser, seed, tractors, gasoline etc from the product market. These are referred to as inter-industry purchases. Producers also purchase the services of factors of production. The agricultural sector, for example, purchases labor, capital and land from their owners. In water-CGE models, water is considered a factor of production, either as intermediate input or final output (Decaluwé et al., 1999; Tirado et al., 2004). This entails the introduction of a water industry which produces for the final consumers (households) or for the other economic activities (industry, agriculture, services). Conventionally, the use of this approach requires sourcing data for the water sector from the water accounts (see e.g., Wittwer, 2006). Conversely, water can be modelled implicitly or explicitly. For instance, Seung et al. (1998, 2000) modelled water as an implicit factor in fixed proportions with land. In the analysis, the simulations are based on land allocations such that water use is drawn indirectly. Other studies using national, regional and multi-country models have used water as an explicit factor of production which can be substituted for other primary factors, typically land, capital and labour (see Berck et al., 1991, for a regional analysis; Sahlen, 2007, for a single country study; and Berrittella et al., 2008, for a multi-country setting).

Three concepts from neoclassical theory that link firms and households in the circular flow emerge. They and make up the core of CGE modelling include. They include:

i) Pure profits: Because of constant returns to scale and competitive markets, producers make zero profit. Total revenue is equal to total costs. All firm revenue is used to purchase intermediate inputs or to rent the factors of production from households.

ii) Market clearing conditions: The value of a firm's output will be equal to the value of household and other firms' intermediate purchases. That is, in each market, supply is equal to demand. This will also hold true for the factor market.

iii) Income balance conditions: In order to maximise utility, all the income which households earn by renting out factors are spent on purchases of commodities from the product market. This is the case when savings and taxes are not included in the model.

In addition to the aforementioned basic structure, CGE models typically also contain representations of a government sector, investment and savings, and trade. For instance, the government sector is important to help model the lack of a water factor market or water commodity market. Government collects taxes, consumes commodities, and redistributes some taxes. In the case of some water-CGE models, water 'prices' are specified as taxes or fees, as opposed to market clearing prices that are determined endogenously through the model, which are redistributed back to households. For dynamic CGE models savings and investment specifications are included in order to connect the two in the initial time-period with capital formation. This can be especially critical for dynamic water-CGE models that consider policy questions regarding say, investment in water supply infrastructure over time.

3.1 Practical implementation of a Water-CGE model

Data for the Social Accounting Matrix (SAM) is collected, adjusted and balanced so that total receipts are equal to total outlays for each account. The SAM is developed using macroeconomic data and represents the 'benchmark' in general equilibrium modelling. This data, along with specific assumptions regarding utility and production functions, represents one equilibrium solution of the economic model. A water-CGE model usually includes a set of water accounts that accompany the SAM, which represent water use by industry and final demand sectors at the equilibrium solution. Since the benchmark is considered to represent an equilibrium solution, once specific functional forms are chosen, the benchmark data is used to calibrate the parameter values for the different functional forms. Depending on the functional forms chosen for producers and consumers, some parameter values are determined via calibration while others are supplied exogenously. Values are either taken from the literature or chosen using the modeler's best judgment. After calibration, the model is checked to see if it correctly replicates the baseline data in the SAM. When it is established that the baseline data can be replicated, the model is "shocked". For example, an increase in export demand may be imposed exogenously or a tax may be eliminated. The model is solved once again to find the "counterfactual" equilibrium set of prices and quantities for all sectors. These results can then be compared to the base line solution or other counterfactual scenarios.

3.2 Development of the UgAGE-Water model

The issues investigated in this thesis are informed by analysis using the UgAGE-Water model. This version of the model was specifically developed for analysing water related issues identified in the literature. It is based on the official Applied General Equilibrium model (UgAGE) for Uganda, built in collaboration with the Centre of Policy Studies in Melbourne, Australia[3]. UgAGE is a comparative-static CGE model that contains neoclassical foundations with respect to production functions and price-responsive demand functions. Producers are assumed to maximise profits, while consumers maximise utility. Factor market clearing requires that supply equal demand for agricultural and non-agricultural skilled and unskilled labor and capital, natural resources and agricultural land,

[3] See Annex A, Figure 1-II and Table A1 for a look at the core model as well as the water accounts data which were used to develop UgAGE-Water.

and adjustments in each of these markets in response to a given shock determine the resulting wage and rental rate impacts.

The UgAGE model's theoretical structure is based on the ORANI-G model (Horridge, 2001) with various modifications in order to facilitate the detailed modelling of water resources and the economy. It is constituted of a linearised system of equations describing the theory underlying the behaviour of participants in the economy. The equations describe the nature of markets; intermediate demand for inputs; final demand for goods and services by households; demand for inputs for capital creation and the determination of investment; government demand for commodities; and foreign demand for exported goods. In this version of UgAGE, we make changes to the basic structure to include the separation of water from the intermediate inputs as well as primary factors. Second, the database and model are extended to account for water use in relation to other sectors of the economy.

The model is solved with GEMPACK® using Euler's multi-step solution technique that eliminates any linearisation errors. The theory of the model is set out in equations that describe how the values in the model's database shift through time in response to a given shock. Finally, the model results for any given shock are presented as percentage changes away from an unperturbed projection of the economy and its structure, represented by the base year data. Each industry is set to produce one or more commodities, using combinations of domestic and imported commodities as inputs, different types of labour, capital and land. The production function specification is kept manageable by a series of separability assumptions. This nested production structure reduces the number of estimated parameters required by the model.

Optimising equations determining the commodity composition of industry output are derived subject to a Constant Elasticity (CET) production function, while production functions determining industry inputs are determined by a series of nests. At the top level, intermediate commodity composites and a primary-factor composite are combined using a Leontief production function. Both intermediate and primary factor inputs are all demanded in direct proportion to each industry's level of activity. Each commodity composite is a Constant Elasticity of Substitution (CES) function of a domestic good and its imported counterpart. This incorporates Armington's assumption of imperfect substitution for goods by place of production (see Armington, 1969).

The primary-factor composite is a CES aggregate of composite labour, capital and in the case of primary sector industries, land. Composite labour demand is itself a CES aggregate of the different types of labour distinguished in the model's database. All industries share this common production structure, but input proportions and behavioural parameters vary between industries based on available base year data and econometric estimates respectively. The model parameters used in our analysis are derived from the IFPRI model for Uganda (see Dimaranan et al., 2006), in addition to other relevant studies in the literature (see Hertel et al., 2007; Boysen and Mathews, 2012; Boysen, 2012; Roos et al., 2014) and informed by the author's knowledge of the Ugandan economy. Those sets of parameters in various ranges include: (i) The Armington elasticity between domestic and imported commodities (1.5-2.5); (ii) Export elasticities (2-2.5); (iii) Elasticity of substitution among labour types (or skills) (0.3); (iv) Elasticity of substitution among primary factors (0.4); (v) CET transformation for industries with multiple commodities; (vi) Expenditure elasticity for the Linear Expenditure System (LES) household demand system (0.95-1.05); (vii) The Frisch parameter (elasticity of marginal utility of income) (-2) and (viii) The Armington elasticity for investment (1.5).

The demand and supply equations are derived from the solutions to the optimisation problems which are assumed to underlie the behaviour of private sector agents. Each industry minimises costs subject to given input prices using a constant returns to scale production function. Households maximise a Klein-Rubin utility function subject to their budget constraint. Units of new industry-specific capital are constructed as cost-minimising combinations of domestic and imported commodities. Export demand for any locally produced commodity is inversely related to its foreign-currency price. Government consumption is set to be exogenous or linked to changes in household consumption. Direct and indirect taxation is also accounted for in the model and so, are profits which are assumed to be zero for all industries. The model's database is based on the 2009 Social Accounting Matrix (SAM) for Uganda published by UBOS. In the SAM, households are categorized into 4 regional groups by rural-urban and by income quintiles. In all, there are 37 industries and commodities. Standard model validation and database checks were successfully completed throughout the thesis using the techniques described in Dixon and Rimmer (2013).

Annex A

Figure 1-II: Structure and aggregates of the 2009 UgAGE database

← All intermediate (1) and final (2-6) users or buyers in the economy are shown across these columns →

		1	2	3	4	5	6	
		Producers	Investors	Households	Export	Government	Inventories	
	Dimension	← IND →	← IND →	← HOU →	← 1 →	← 1 →	← 1 →	
Basic Flows	COMxSRC ↕	V1BAS ("dom") V1BAS ("imp")	V2BAS ("dom") V2BAS ("imp")	V3BAS ("dom") V3BAS ("imp")	V4BAS ("dom") V4BAS ("imp")	V5BAS ("dom") V5BAS ("imp")	V6BAS ("dom") V6BAS ("imp")	DOM 41,665.49 IMP 11,038.11
Margins	COMxSRCxMAR ↕	V1MAR	V2MAR	V3MAR	V4MAR	V5MAR	zero	MARUSE 4,087.99
Indirect Taxes	COMxSRC ↕	V1TAX	V2TAX	V3TAX	V4TAX	V5TAX	zero	TLSP 1,909.22
BAS+MAR+TAX equal PUR Values	COM ↕	V1PUR USE TABLE 14,598	V2PUR INVESTMENT 7,309	V3PUR CONSUMPTION 25,634	V4PUR EXPORTS 7,787	V5PUR GOVERNMENT 3,281	V6PUR INVENTORIES 0	INDUSTRY plus FINAL DEMAND 58,609
Labour Inputs	OCC ↕	V1LAB 13,998.4						
Capital Rentals	1 ↕	V1CAP 14,024.55						
Land Rentals	1 ↕	V1LND part of V1CAP						
Production Taxes	1 ↕	V1PTX 1092.84						
Other Costs	1 ↕	V1OCT part of COSTS						
		INDUSTRY COSTS 45,753						

COM = number of commodities ; IND = number of industries ; SRC = ("dom", "imp")
MAR = commodities used as margins ; OCC = occupation types

	MAKE MATRIX
Dimension	← IND →
COM ↕	SUPPLY TABLE incl MARSUP 45,753

	IMPORT DUTIES
Dimension	← 1 →
COM ↕	V0TAR

Table A1: Water accounts data

	Unit	Account	Volume	Source/notes
Mean Annual Rainfall	mm	a	1237	Source: FAO-AQUASTATS
Precipitation	Million (m^3)	b	296.19	Source: FAO-AQUASTATS
Evapotranspiration & deep seepage	Million (m^3)	c	279.69	Source: FAO-AQUASTATS
Net Annual Runoff	Million (m^3)	d = b-c	**19.5**	
Surface water flows	Million (m^3)	e	33,700	
Ground water	Million (m^3)	f	9,500	
Total supply	Million (m^3)	i = d-e+f	**43.2**	
Net outflows(RoW)	Million (m^3)	j	3,301	
Total economic use	Million (m^3)	l = m+n+o+p+q+r+s+t+u+v+w	**1294**	
Agric	Million (m^3)	m	819	includes livestock, irrigation, crop and fisheries
Mining	Million (m^3)	n	9.8	mining
Manufac	Million (m^3)	o	17.8	formal and informal manufacturing
Electricity	Million (m^3)	p	80	electricity generation
Water	Million (m^3)	q	83.4	commercial water supply
Construc	Million (m^3)	r	39	construction
TradeAcc	Million (m^3)	s	34	includes hotels, restaurants and financial services
TransComm	Million (m^3)	t	34.3	transport and communication
Business	Million (m^3)	u	20.6	includes other business services
GenGov	Million (m^3)	v	32	includes public administration
OthServices	Million (m^3)	w	124.1	includes house consumption
Total use	Million (m^3)	Ab = j+aa	4,595	

Notes: The water use shares were disaggregated from the aggregates in the Water SUTs, by the size of the sectors in GDP. Note that the actual water use ratios for each of these sectors may be vary, depending on sector specific water use intensity. However, in the absence of disaggregated raw data on water use by industry, the only way to disaggregate was to use the size of each of these sub-sectors in GDP (MFPED, 2011, page 16).

Chapter Three

Water Resource Accounting for Uganda: Use and Policy Relevancy

Abstract

This Chapter uses the system of economic and environmental accounting for water (SEEAW) to demonstrate how the water sector interacts with the socioeconomic sectors of the economy. Furthermore, it reviews the existing institutional and policy framework in Uganda, and proposes an analytical framework which can be used to provide sound inter-sectoral planning in order to achieve sustainable water resource use. The proposed framework also articulates how outcomes of water policies and socioeconomic policies can be analysed. In Uganda, the uneven distribution of water resources both in space and time, poses constraints to economic activity particularly in the water-scarce regions of the country. The problem is being exacerbated by the increasingly erratic rainfall and rising temperatures. The accounting results show that the current level of water use within the economy is less than the available quantity. In this regard, there is room for the development of mechanisms to increase its utilisation. This would serve to mitigate the scarcity especially of water for production which primarily emanates from climate variability. This in turn affects the performance of the economy, as key sectors such as agriculture are rainfall-dependent.

Key words: Institutional framework; Policy analysis; SEEAW; Water Accounting
JEL Classification code: E01; Q56

1 Introduction

This Chapter uses an analytical framework which demonstrates how water resources interact with the economic system. It also proposes a framework for analysing the interaction between the water sector policies and the policies of other sectors of the economy. The World Commission on Sustainable Development (WCED) recognizes the close link between the environment and the economy where it stresses that:

> *"..no region in the world faces separate environmental challenges, development challenges or energy challenges. They are all one"* (WCED, 1987, p.257).

Hence, the existing challenges cannot be solved by fragmented institutions or policies. These call for trans-disciplinary competencies and approaches that are geared towards advancing a sustainable development agenda for economic growth and well-being (NEMA, 2010).

This study is motivated by the prevailing environmental-economic challenges faced by Uganda to investigate the level of use vis-à-vis the amount of water resources available in the economy. In addition, a framework for policy analysis is developed in order to demonstrate how water resource policies can be linked with other socioeconomic policies in a national development planning process, with a view to ensuring sustainable use of the existing water resources in an economy. This study is vital since water resources are increasingly coming under threat from climatic variability which is manifesting in the form of increasing frequency and severity of climatic shocks as well as shifts in temperature and rainfall patterns (IPCC, 2007; Hepworth and Goulden, 2008).

For the case of Uganda, studies on water resources have largely focused on the hydrological dynamics with little or no attempt to link water resources and the rest of the economy (see Sutcliffe and Parks, 1999; Awange et al., 2008; Nyenje and Batelaan, 2009;

Kizza et al., 2009; Swenson and Wahr, 2009; Nsubuga et al., 2011; Smith and Semazzi, 2014; Nsubuga et al., 2014a; Nsubuga et al., 2014b). Those which attempt to include other aspects of water resources and the economy focus on river or lake basins, of which some are transboundary in nature (see e.g., Awange and Ong'ang'a, 2006; Kayombo and Jorgensen, 2006; IWMI, 2012). In fact, IWMI (2012) cite the Nile basin as wide and complex, with varying dimensions with respect to poverty, productivity, vulnerability, water access, and socioeconomic conditions. It therefore recommends that further in-depth research and local analysis be undertaken in order to bolster further understanding of issues and systems, with a view to designing appropriate interventions.

This study seeks to add to the literature on water resource accounting and integrated policy analysis at a national level. In addition, it seeks to contribute to the very limited evidence on water resource accounting and policy analysis from a developing country perspective, amid threats of water scarcity. This is important because Uganda, like most developing countries, has no established water accounts and yet, as a developing country, it is susceptible to the adverse effects of water scarcity. This is because a considerable proportion of its economic output is rooted in climate-sensitive sectors such as agriculture. Miguel et al. (2004) found that rainfall shocks constitute a good proxy for household income shocks in Uganda. Therefore, the development of national water accounts provides a vital tool for economy-wide water resource planning at a national level. This can result in interventions which are geared towards efficient use of the available water resources, and a reduction in the dependency on rainfall for the water-dependent sectors of the economy.

According to the Organisation for Economic Co-operation and Development (OECD, 2008), over half of the world's population will be living under water scarcity due to the effects of climate change by 2030. Rainfall, which is a key input into the hydrological cycle, is increasingly showing significant variations both regionally and globally (Nsubuga et al., 2014a). Such variations can have adverse effects on the availability of water resources especially for those water sources whose recharge is derived from it (Ngongondo, 2006). Furthermore, a number of sectors of most developing economies are dependent upon rainfall whose seasonality is increasingly becoming volatile and intensity is reducing. This has the effect of reducing water availability through reduction in the recharge of both surface and groundwater sources. River basins which depend on a monsoon-type regime such as the Nile— one of Uganda's major surface water sources— and the Ganges in India, have been cited as being vulnerable to changes in the seasonality of run-off. This has adverse ramifications for water resource availability in countries that lie within these basins (World Bank, 2012). In the case of Uganda, there exists a contrast in seasonality between the sub-basins that lie above and below latitude 2°N (i.e., the northern and southern sub-basins) (see Nsubuga et al., 2014a, p.284).

It is therefore important to closely monitor the available water resources in order to ensure their proper management and utilisation. In Uganda, 80 percent of the total catchment of Lake Victoria— the largest basin in East Africa— relies on direct rainfall while the remaining 20 percent is derived from river and underground discharges (Awange et al., 2008). Studies of rainfall fluctuations in Uganda have demonstrated that total rainfall during the March to May season, and the number of wet days in a number of weather stations, are decreasing (see Nsubuga et al., 2011). FEWSNET (2012), in a study of climate trends in Uganda, showed that the period 1975–2009 witnessed an increase in temperature and a reduction in rainfall. Average temperatures in Uganda are projected to increase by up to 1.5°C in the next two decades (LTS International, 2008). In fact, increases in the temperature and pollution of surface water sources tend to increase the abundance of hazardous toxins in the water. Consequently, domestic water supply, the ecology of surface water sources and aquatic life are threatened. There is already evidence of such pollution in some bays of Lake Victoria (LTS International, 2008).

Furthermore, changes in rainfall patterns and increases in temperature are swiftly translating into yield reductions in many crops (Glantz et al., 2009). Such changes present adverse effects on the economy to the extent that they affect export performance, foreign exchange earnings and employment. It is therefore evident that an intricate relationship exists between the water resources and other sectors of the economy. Hence the water sector policies and those of other sectors have feedback loops on each other. This therefore calls for policy analysis to be carried out in an integrated manner. To demonstrate this interrelationship, water is primarily a critical resource for the agricultural sector. In turn, agriculture is a major source of employment; it supplies primary inputs to other sectors; it provides food security to households, and is a major source of export earnings (MFPED, 2011). However, the increasingly unreliable rainfall, coupled with the uneven distribution of water sources, is threatening the sustainability of socioeconomic activity in the country.

1.1 Objectives

This Chapter seeks to:

a) examine the state of water resources in Uganda;

b) undertake national water accounting using the SEEAW framework;

c) propose a framework for policy analysis of integrated water resources management;

d) highlight policy issues which arise from the analysis.

The rest of the Chapter is organised as follows. Section 2 provides a situational analysis of water resources in the country, a review of the institutional and policy framework is presented in Section 3, and the methodological steps for resource accounts development and findings are articulated in Section 4. A framework for linking analysis of water policies and other social economic policies is developed in Section 5, and Sections 6 and 7 respectively provide the conclusions and emerging issues.

2 Situational analysis of water resources in Uganda

This section provides insights into the state of water resources in Uganda with the aim of providing a basis for the need to develop a link between water resources and the economy. Approximately 25 percent of the country's surface area (241,000 km^2) is covered by lakes and rivers. From a biophysical perspective however, much of the country experiences high rates of potential evaporation— approximately 75 percent — within the range 1350-1750 mm/year (DWRM, 2011). Similarly, Van Steenbergen and Luutu (2012) indicate that a large proportion of rainfall (approximately 70-90 percent) goes back into the atmosphere through evapotranspiration. Only a small proportion of this rainfall stays on the land surface and contributes to surface flow via run-off, and to groundwater recharge via infiltration through the unsaturated zone. They further note that, given the nature of the aquifers, groundwater is recharged mostly during heavy rainfall events. As such, these high rates of evaporation have implications for economic activity with regard to soil moisture for crop production, groundwater recharge, and rangeland productivity (DWRM, 2011).

The country receives a mean annual rainfall of 1200 mm. However, only the Lake Victoria shores and the mountainous areas (Mt Rwenzori, Mt Elgon, and the Kisoro-Kabale region) experience, on average, an annual rainfall surplus (i.e., annual rainfall that exceeds potential evaporation). Average annual rainfall exceeds potential evaporation in only 10.6 percent of the land area. In 20 percent of the country, the average rainfall deficit is less than 200 mm per annum, while another 35 percent is in the range of 200-400 mm (DWRM, 2011). In addition, the north-eastern region (approximately 35 percent of the country) experiences an annual rainfall deficit exceeding 400 mm. However, DWRM (2011) notes that "a rainfall deficit does not necessarily translate into an equal amount of moisture deficit during plant growth, as traditional agricultural production systems are well adapted to these seasonal weather patterns" (DWRM, 2011, p.8). This observation notwithstanding, empirical evidence suggests that the prevalence of rainfall deficits can have adverse implications for economic performance (Glantz et al., 2009).

In terms of surface water, River Nile flows exceed 25 km^3 per year, coupled with large combined storage capacities in the lakes: Victoria, Albert, Edward and Kyoga (DWRM, 2011, p.7). However, while Uganda is generally endowed with water resources, socioeconomic activity still continues to depend on rainfall. As noted earlier, studies show that rainfall is on the decline and this is likely to pose socioeconomic challenges in the medium to long-term. In fact, this view has been reinforced by recent experiences in the areas of demography and climate. Specifically, the country is registering rapid population growth of 3.2 percent and increasing climatic volatility which is being attributed to climate change (MFPED, 2011, p.80).[4] Droughts have become frequent and severe, thereby posing a threat to the prospects of stable long-term economic performance.

Findings from FEWSNET (2012) show that the spatial pattern of warming corresponds largely to the areas associated with reduced rainfall. Temperatures are reported to have increased by up to 1.5°C across much of the country, with typical rates of warming of approximately 0.2°C per decade. This trend is envisaged to continue as well as the expansion of warm areas in the medium to long-term, as the earth's temperature continues to rise. The western and north-western regions of the country are cited as the most affected by these changes. The rising temperature has specifically been cited as a threat to coffee production, a key cash crop for the economy. Therefore, the effects of a warmer climate are likely to exacerbate the impact of the decreasing rainfall and periodic droughts. This would ultimately have an adverse impact on the economy. Generally, the FEWSNET (2012) findings show that the country is becoming drier and hotter.

[4] The country is increasingly experiencing severe and regular waves of hydrologic droughts in the different regions.

Current water consumption is estimated at 21 m^3 per capita (NPA, 2010). However, it is projected to rise gradually to approximately 30 m^3 per capita by 2035 (MWE, 2009). Table 2-III presents the growth in per capita water availability against the conventional benchmarks for water stress.

Table 2-III: Water demand projections against the benchmarks for water stress[b]

	Water demand projections (Millions m^3)			**Benchmarks for water stress**	
Year	*Population ('000)*	*Total water demand*	*Available water per capita (m^3)*	*Annual renewable fresh water per capita (m^3)*	*Stress level*
2009	32,864	707	2,171	>1,700	Occasional water stress
2015	40,141	994	1,740	1,000-1,700	Regular water stress
2020	47,088	1,266	1,480	500-1,000	Chronic water shortage
2035	72,691	2,113	896	<500	Absolute water scarcity

Notes: [b] Conventional definitions of water stress following Falkenmark & Widstrand (1992).
Source: MWE (2009); FAO (2012); UNDESA (2015).

In Table 2-III, the Falkenmark and Widstrand (1992) indicator of national water scarcity is used to compare the available per capita renewable water in Uganda against the water stress threshold values of 500, 1,000 and 1,700 m^3/per capita/year. Based on this criterion, countries or regions are considered to be facing absolute water scarcity if their renewable water resources are <500 m^3 per capita; chronic water shortage if renewable water resources are between 500 and 1,000 m^3 per capita; and regular water stress if resources are between 1,000 and 1,700 m^3 per capita. According to this criterion, Uganda will be a water stressed country by 2020.

However, it is critical to note that, although this measure has its merits, it is based on an oversimplified perspective of the water situation of a country. This is because the approach is largely based on estimates of the number of people that can reasonably live with a certain unit of water resources (see Falkenmark, 1984; FAO, 2012). This approach ignores critical local factors that determine access to water, as well as the feasibility of solutions aimed at water provision in the different locations. Most importantly, it does not account for the prevailing climatic conditions; inter- and intra-annual variability of water resources and environmental water requirements which tend to vary from region to region and also affect water availability (Molle and Mollinga, 2003; FAO, 2012).

In the case of Uganda, averages at the country level may be indicative but not particularly meaningful, since the country has strong regional variations in the spatial distribution of water resources. What is vital to note is that even with this simplified basic indicator, the country will be water stressed by 2020. In fact, if we factor in the adverse effects of climatic variability on water resource availability via the interference with the recharge system and the rising temperatures, it suggests that the stress levels will become evident faster than the projections reveal. In addition, the level of severity will be more acute than otherwise thought. Additional pressure on water availability is bound to emanate from economic growth, population growth, and rapid urbanisation. A combination of these factors is likely to lead to the extraction of significant amounts of water, thereby further contributing to water scarcity.

3 Legal institutional and policy framework for the water sector in Uganda[5]

The national policy objectives for the water and environment sector have been developed with a view to ensuring water resources management, domestic water supply, sanitation, and water for production. Specifically, the framework is designed to:

a) manage and develop the water resources in an integrated and sustainable manner, in order to ensure an adequate quantity and quality of water for all social and economic needs of current and future generations, with the active involvement of all stakeholders;

[5] This section draws from MWE (2009).

b) achieve sustainable provision of safe water within easy reach, and hygienic sanitation facilities based on management responsibility and ownership by the users, to 77 percent of the population in rural areas and 100 percent of the urban population by 2015 with 80–90 percent effective use and functionality of facilities; and

c) develop and efficiently use water supply for production (agriculture, irrigation, livestock, aquaculture, rural industries, hydropower, and tourism).

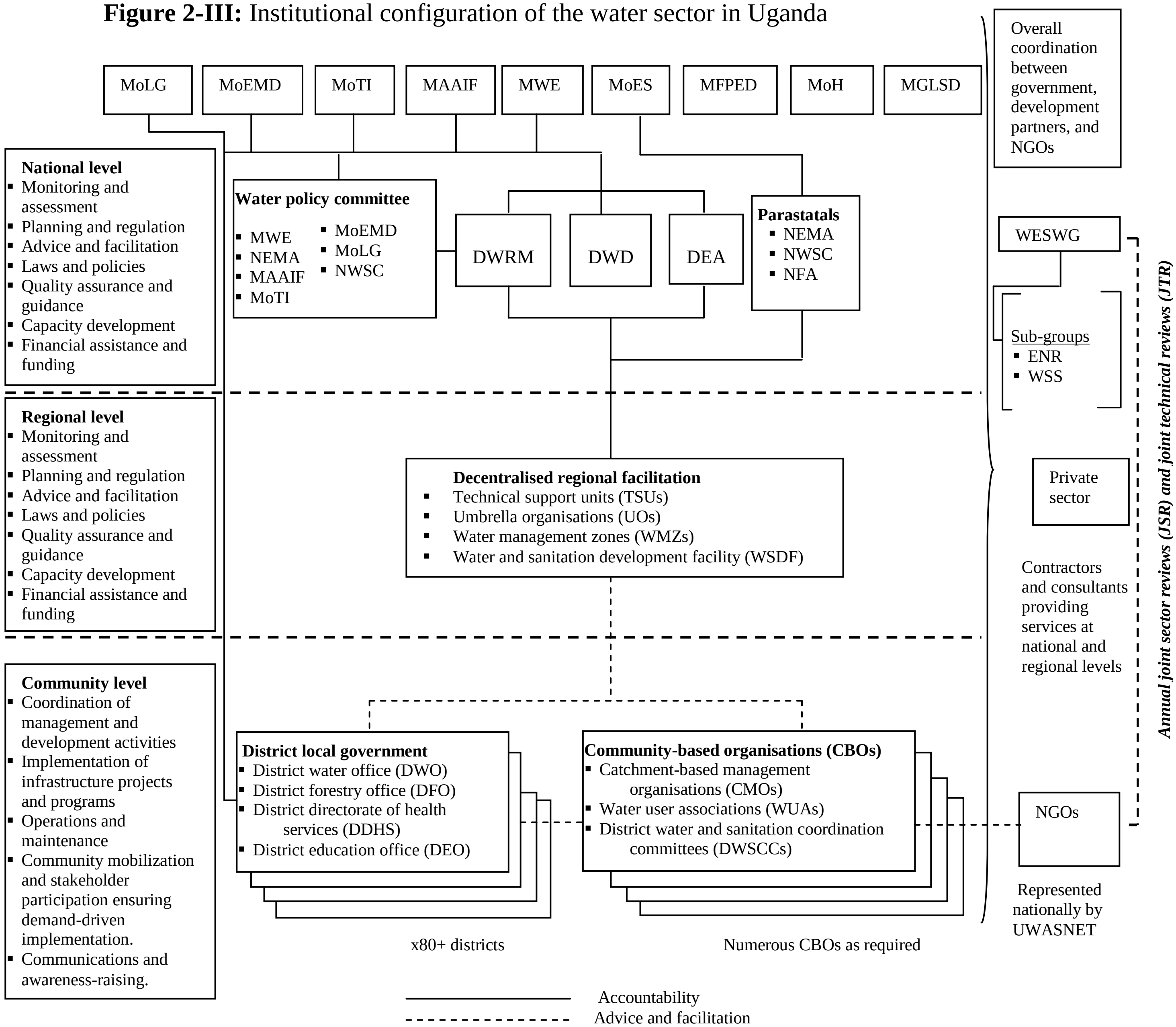
Overall sector coordination is through the Water and Environment Sector Working Group (WESWG). Under the water and sanitation sector, there exist the following components: water resources management (WRM); rural water supply (RWS); urban water supply and sewerage (UWSS); water for production (WfP); and sanitation (MWE, 2009). The institutional framework for the water and sanitation sector comprises a number of organisations and stakeholders at national, district, and community levels as illustrated in Figure 2-III.

3.1 Policy, legal, and strategic framework

The management and development of water resources in Uganda is governed by the (1995) Constitution of the Republic of Uganda. This is further supported by the Uganda Water Action Plan (1995) and the National Water Policy (1999) which sets out the overall policy framework. The National Water Policy seeks to facilitate an integrated approach to the management of water resources in a manner that is sustainable and optimal for the country. The approach is informed by the recognition of the social value of water, while at the same time giving adequate attention to its economic value. There are other policies designed to play an auxiliary role, such as the National Environment Management Policy (1994); the Wetlands Policy (1995); the National Land Use Policy; the National Health

Policy and Health Sector Strategic Plan (1999); the National Environmental Health Policy (2005); the School Health Policy (2006); and the National Gender Policy (1997).

Figure 2-III: Institutional configuration of the water sector in Uganda



Source: MWE (2009).

Notes: MoLG: Ministry of local government; MoEMD: Ministry of energy and mineral development; MoTI: Ministry of trade and industry; MAAIF: Ministry of agriculture, animal industry and fisheries; MWE: Ministry of water and environment; MFPED: Ministry of finance, planning and economic development; MoH: Ministry of health; DWRM: Directorate of water resources management; DWD: Directorate of water development; DEA: Directorate of environmental affairs; NEMA: National environment management authority; MGLSD: Ministry of gender, labour and social development; NWSC: National water and sewerage corporation; NFA: National forestry authority; WESWG: Water and environment sector working group; ENR: Environment and natural resources; WSS: Water supply and sanitation; UWASNET: Uganda water and sanitation NGO network.

The key legal frameworks that guide the management of the sector include the:

a) Constitution of the Republic of Uganda (1995);
b) Water Act, Cap 152;
c) Environment Act, Cap 153;
d) National Water and Sewerage Corporation Act, Cap 317;
e) Local Governments Act, Cap 243;
f) Land Act, Cap 227;
g) Public Health Act (1964);
h) Children Statute (1996);

Furthermore, the regulations and standards that are in place to guide users include the:

a) Water Resources Regulations (1998);
b) Water Supply Regulations (1998);
c) Water (Waste Discharge) Regulations (1998);
d) Sewerage Regulations (1999);
e) Waste Management Regulations (1999);
f) Environmental Impact Assessment Regulations (1998);
g) National Environment (Standards for Discharge of Effluent into Water or on Land) Regulations (1999); and
h) National Environment (Waste Management) Regulations (1999).

Strategies and guidelines

The water sector also includes a number of guidelines and strategies such as:

- The Water Sector Pro-poor Strategy (2006), Directorate of Water Development (DWD);
- District Water and Sanitation Conditional Grant Guidelines, December (2001);
- Rural Water Supply and Sanitation Handbook for Extension Workers (2002);
- Framework for Technical Support Units, November (2001);
- Community Based Maintenance System, DWD.
- National Water Quality Management Strategy (2006);
- The Plan for Modernization of Agriculture (2000);
- The country's Strategic Interventions Programme for Export Promotion;
- The School Health Minimum Requirements (2000);
- The Infant and Maternal Mortality Strategy;

- The Water and Sanitation Gender Strategy (2003);
- The Strategy for 'Water and Sanitation for Emergency Response';
- The Community Empowerment Strategy, Ministry of Gender, Labour and Social Development (MGLSD);
- The National Sanitation Guidelines, 2001, Ministry of Health (MoH);
- The Kampala Declaration on Sanitation (KDS) (1997);
- The Sanitation Memorandum of Understanding (2001) between Ministry of Water Lands and Environment (MWLE), Ministry of Health (MoH), and Ministry of Education and Sports (MoES);
- Long-term Strategy for Water Supply and Sanitation Services in Small Towns (2003);
- Long-term Strategy for Water Supply and Sanitation Services in Rural Growth Centres (2003);
- National Water Quality Management Strategy (2006).

3.2 Reform measures in the water and sanitation sector

Since 1998, the Government of Uganda, with the support of the Development Partners, has taken steps to reform four different sub-sectors, namely: rural water and sanitation (RWS); urban water supply and sewerage (UWSS); water for production (WfP); and water resources management (WRM) (MWE, 2009). In line with the developed sector investment plans, a geographical information system (GIS)-based water and sanitation sector integrated investment tool was developed in 2007. This tool was intended to provide better insight into current and planned sector investments through enhanced monitoring and evaluation, identification of priorities and the determination of areas with development deficits, as well as detect areas where investments would have the highest impact.

The system was also designed to help visualize the spatial disparities across the country in order to ensure transparent and equitable resource allocation and performance. The reforms have been put in place with a view to minimising duplication and contradictions in mandates of the different institutions; to address current issues such as population growth, shifting priorities towards water for production in order to contribute to prosperity for all;

increased incidence of climatic variability; the impact of water resources management on the economy; and the operationalisation of decentralised integrated water resources management (IWRM) strategies at catchment level.

4 Water resource accounting

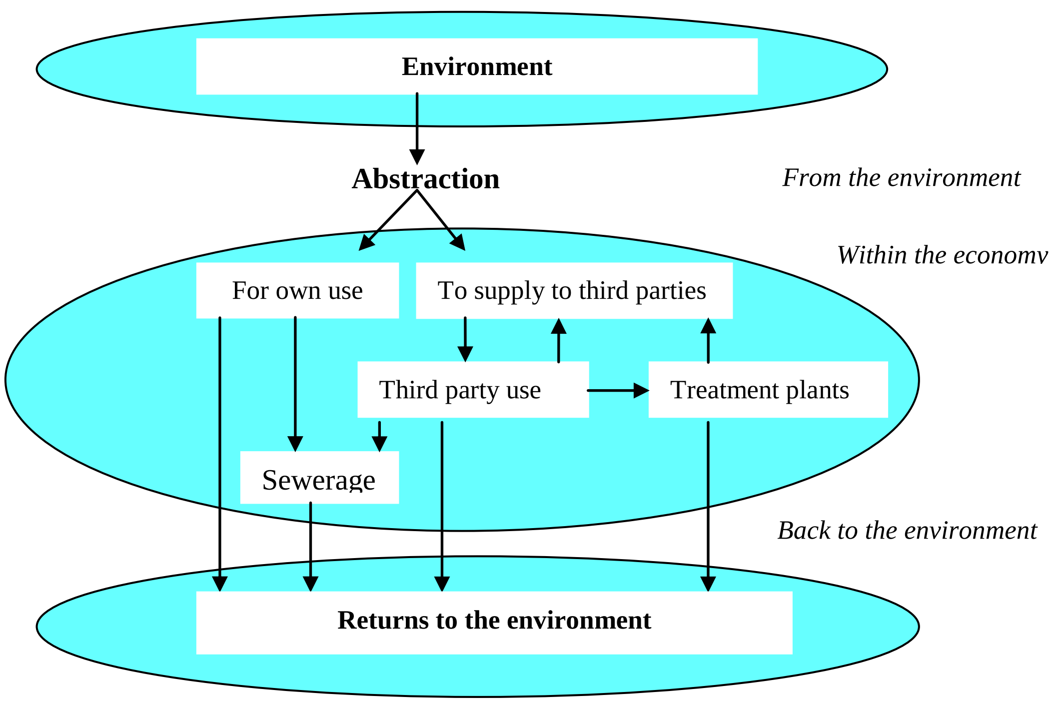
This Chapter uses the SEEAW to account for the available supply and use of water resources. The SEEAW framework makes possible the link between water resources and the economy because the water supply and use tables (SUTs) have the same structure as the SAM. This suggests that economic policy analysis through integrated natural resource modelling is possible. The SEEAW[6] is a comprehensive water accounting system that has been developed with the objective of standardizing concepts and methods in water accounting (UN, 1993; UNSD, 2012). It provides a conceptual framework for organising economic and hydrological data thereby permitting a consistent analysis of the contribution of water to the economy and the impact of the economy on water resources (FAO, 2012). In fact, Dost et al. (2013) have developed an augmented integrated water accounting framework where they employ remote sensing data to build on a combination of existing systems and approaches. They argue that their approach to water resource accounting is easily applicable even in ungauged and poorly gauged basins. This is particularly the case for most developing regions of the world.

These accounts are vital to furnish information to policy-makers about the impact of current economic policies and growth patterns on the environment's resources. In this way, judgment can be made as to whether or not such policies are sustainable. In addition, information from these accounts helps to gauge the impact on the economy of policies taken for environmental reasons. Finally, one of the fundamental aims of this accounting framework is to assess how much economic 'growth' as it is conventionally measured, is

[6] See www.emwis.net/thematicdirs/glossaries/system-environmental-economic-accounting-water.

actually capital consumption due to resource depletion (World Bank, 2006, cited in FAO, 2012). When water is abstracted and processed, it is considered a product, as it enters into the economic sphere. This product can be delivered to other industries or to final consumers. Once water is no longer useful in its current state, it is considered to be a residual. Some flows of residuals are recorded within the economy (for example, the routing of waste water to treatment plants) but, ultimately, all residuals are returned to the environment (see Figure 3-III). These flows do enter the economy; hence the return of water to the environment is recorded as a residual flow. In the case of Uganda, water used for hydro-electricity generation and the water extracted by agriculture for irrigation is considered as water returned to the hydrological system.

Figure 3-III: Schematic flow of water resources



Source: Adopted from UN, IMF, IBRD and OECD (2003).

4.1 Data

Macroeconomic data was obtained from the Ministry of Finance Planning and Economic Development and the Uganda Bureau of Statistics. Water data was obtained from the Directorate of Water Resources Management (DWRM, 2012) and the Small Towns Water and Sanitation Programme under the Ministry of Water and Environment. Other data was obtained from the National Water and Sewerage Corporation (NWSC, 2012) as well as the AQUASTAT database published by the Food and Agricultural Organisation (FAO).

4.2 Development of the water accounts

In this section, the water accounts are developed using the SEEAW. The procedure entails partitioning the physical supply and use tables (PSUT) by their key components. In this Chapter, the accounts are adapted to integrate the environment and the economy[7]. The following components are included in order to reflect the key elements which are at the core of water resources management in Uganda:

- *From the environment:* This is the source of all water resources and the ultimate repository to which all used and non-used water resources return.
- *Mean annual run-off (MAR)*: This receives water from the environment and redistributes to surface water and groundwater and back to the environment. This component is presented as part of surface water and groundwater yield by the DWRM.
- *Surface water yield:* collects from *MAR* and redistributes to available yield;
- *Groundwater:* sources are replenished by *MAR* and contribute to available yield;
- *Soil water:* collects precipitation from *MAR* to support evapotranspiration activities through natural and cultivated agriculture. This is accounted for under groundwater;

[7] See Eurostat (2014), subsection 2.1.2, for an exposition of the framework for developing the physical supply and use tables (PSUT).

- *Consumption*: measured as water that is not returned to water bodies because it has either been absorbed by plants (crop water), livestock, humans (households) or industry. This component is presented accordingly in the accounts.

4.3 Results, analysis and discussion

The resource flow matrix is an input-output table that describes supply and use transactions in one table. Water users are aggregated in the water statistics in order to correspond to particular categories according to how water is supplied to these users. From the flow matrix, the main source of irrigation water to agriculture is from surface water while water supply to households, crops and fisheries is from the distribution agencies as well as other ground and surface water. The industrial sector is taken to be mainly supplied by the distribution agencies since there is no official data on abstraction for own use (see Tables 3-III–5-III).

Table 3-III: Water supply table (Millions of cubic meters)[8]

			Agriculture							DWR Total						Total supply
			Livestock	Irrigation[l]	Crops[l]	Fisheries	**Energy**[l]	**Industry**	Total[**]	**NWSC**	**STWSP**	**Govt**	**HHold**	**RoW**		
	Total Abstractions														**43,201**	**43,201**[a]
From the environment	From surface water (internal)														13,000	13,000
	From ground water (internal)														9,500	9,500
S1	RoW (in transfers)	From surface water (M)													8,700	8,700
		From surface water (X)													12,001	12,001
		From ground water (M)														
		From ground water (X)														
		For own use					80									
		For delivery							83.4	79.7	3.7					
Within the economy	**Total supply of water**		**174.1**[l]	**151**[k]	**389**[j]	**105**[i]	**80**[h]	**46**[g]	83.4[f]	**79.7**[e]	**3.7**[d]		**264.1**[c]	**3,301**[b]		**4,594**
	Water supplied to users								83.4	79.7	3.7		264.1			348
S2	Recycled water															
	Waste water to sewerage															
To the environment																
S3	Total residuals															
	Waste water															
	Returns from Irrigation			151												
	Water supply for HEP generation						80									
	Leakages															
	Other returns to the environment					105										
	To the sea															
Consumption																**4,174**
Total supply			**174.1**	**151**	**389**	**105**	**80**	**46**	**83.4**	**79.7**	**3.7**		**264.1**	**3,301**	**43,201**	**43,201**

Source: Author's compilations.

[8] See Appendix 1 for explanatory notes on the data sources and table presentation.

Table 4-III: Water use table (Millions of cubic meters)[9]

			Agriculture							DWR (Total)					
			Livestock	Irrigation	Crops	Fisheries	**Energy**	**Industry**	Total	**NWSC**	**STWSP**	**Govt**	**Hhold**	**RoW**	**Total use**
	Total abstractions														
From the environment	**From surface water (internal)**		**174**	**151**		**105**	**80**	46	83.4	79.7	3.7		181.9		**821**
U1	From ground water (internal)				**389**								82.10[b]		82.1
	RoW (X-M)													**3,301**	**3,301**
		From surface water (M)												8,700	8,700
		From surface water (X)												12,001	12,001
		From ground water (M)													
		From ground water (X)													
		For own use					80								
		For delivery													
Within economy	**Total use of water**		**174**	**151**	**389**	**105**	**80**	**46**	**83.4**	**79.7**	**3.7**		**264.1[a]**	**3,301**	**4,594**
	Water supplied to users									79.7	3.7		264.1		348
U2	Recycled water														
	Waste water to sewerage														
To the environment															
U3	Total residuals														
	Waste water														
	Returns from irrigation														
	Water used for HEP generation														
	Leakages														
	Other returns to the environment														
	To the sea														
Consumption															**4,174**
Total use			**174**	**151**	**389**	**105**	**80**	**46**	**83.4**	**79.7**	**3.7**		**264.1**	**3,301**	**4,594**

Source: Author's compilations.

[9] See Appendix 1 for explanatory notes on the data sources and table presentation.

Table 5-III: Water flow matrix within the economy (Millions of cubic meters)

Origin	Destination	From surface water (internal)	From groundwater (internal)	From other water (rain harvesting)	RoW (in Transfers) From surface water (M)	From surface water (X)	From groundwater (M)	From groundwater (X)	For own use	For delivery	Agriculture				Energy	Industry	DWR (Total)	DW R (tota l)			Hholds	RoW	Consumption	Total supply
											Livestock	Irrigation	Crops	Fisheries		Industry	Total **	NWSC	STWSP	Govt				
From surface water (internal)											174	151		105	80		83.4	79.7			144.5			13,000
From groundwater (internal)													389						3.7		82			9,500
	RoW (X-M)																					3301		3,301
RoW (in transfers)	From surface water (M)																							8,700
	From surface water (X)																							12,001
	From groundwater (M)																							
	From groundwater (X)																							
	For own use														80									
	For delivery																							
Agriculture	Livestock																							
	Irrigation																							
	Crops																							
	Fisheries																							
Energy																								
Industrial																								
DWR																								
	NWSC															46					33.70			80
	STWSP																				3.7			3.7
Govt																								
Hholds																								
RoW																						3,301		
Consumption																							**4,174**	**4,174**
Total supply																								**43,201**
Total use of water		**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**174**	**151**	**389**	**105**	**80**	**46**	**83.4**	**79.7**	**3.7**	**0**	**264**	**3,301**		**4,594**
Surplus																								**38,524**

Source: Author's compilations.

From the accounts, the key indicators (in millions of cubic meters) are obtained from the developed water accounts from which a water balance model is derived. These key indicators follow the rules of the SEEAW. The balance between water flows is expressed as:

Total abstraction **(4,511)** + Use of water received from other economic units **(83.4)** = Supply of water to other economic units (**83.4)** + Total returns **(336)** + Water consumption **(4,175).**

Since total water supply to other economic units equals the total water use received from other economic units, the identity can be rewritten as:

Total abstraction **(4,511)** = Total returns **(336)** + Water consumption **(4,175).**

4.4 Summary of findings from the resource accounting

Flows from the environment to the economy are estimated at 43.2 billion m^3. Agriculture accounts for 63 percent of total water use with 21.2 percent going to livestock, 18.4 percent to irrigation, 47.5 percent for crops, and 13 percent to fisheries. Industry accounts for 4 percent of total water use in the economy while households consume 20.4 percent. Flows within the economy consist of supply water to other economic units via distribution (approximately 83.4 million m^3) which accounts for a small part of total water use (6.5 percent). This is evidence of the limited distribution of water in the country through the piped network. For instance, the NWSC and Small Towns Water and Sanitation Programme distribution network is limited to a few districts in the country and is confined largely to urban areas. Consequently, a large proportion of water use by economic agents is obtained from other sources such as rainwater harvesting, springs, deep wells, and boreholes.

The results show an estimated 38.6 billion m^3 in water supply surplus. This suggests that there are available water resources that can be exploited for productive use. Subject to availability of more detailed data, future analysis will provide for a more accurate picture of the exact amount of surplus water resources in the economy. This is because there is a need to net-out the threshold requirements for water that cannot be withdrawn from the environment as it is required for the ecosystems to function, for example, riverine habitat (in-stream flow requirements (IFR))[10] thresholds vary from one country to another. Furthermore, depending on the technical hydrological assessments and recommendations, the existing water resources can be harnessed and utilised. In addition, it is necessary to account for other possible losses of water into the environment through deep seepage, river losses and evapo-transpiration. These are technical hydrological issues which are outside the scope of this Chapter. However, it is clear from the results that the current level of water resources is adequate to address the existing economic challenges that emanate from water scarcity.

5 Policy analysis and relevance of water resource accounting

The existing institutional and policy framework in Section 3 clearly shows that there are multiple institutions charged with the management of water resources in Uganda. However, there is a need for an explicit connection between water sector policies and those of the socioeconomic sectors, since water resources are a key input into the country's economic and social sectors. This is even more pronounced for developing agro-based economies such as Uganda. Fortunately, the institutional framework provides for a key component such as water for production. Therefore, institutions which are charged with managing the productive sectors of the economy, i.e., the Ministry of Finance Planning and Economic Development (MFPED), the Ministry of Transport, the Ministry of Agriculture Animal Industry and Fisheries (MAAIF), and the Ministry of Tourism Trade

[10] In their study of the South African economy, King and Crafford (2001) cite an estimate of 30 percent of the mean annual run-off (MAR) as the in-stream flow requirement.

and Industry (MTTI) need to link their development plans and policies with those of the water sector.

According to WCED (1987), achieving sustainable development is a goal worth pursuing for any economy. In this context, sustainable development is defined as a process in which the economy, environment and ecosystem of a region change in harmony such that there are improvements over time. Consequently, the development of a sound national water policy should relate the different development plans of the socioeconomic sectors in an explicit manner (see Simonovic and Fahmy, 1999). In this Chapter, we propose a framework for policy analysis as a blueprint for explicitly relating development plans for the different socioeconomic sectors to those of the water sector (see e.g., Meadows et al., 1992). This framework can easily be adapted for similar studies on other countries.

This framework is designed to provide policy analysis of IWRM in a typical economy. The idea is to explicitly link a nation's development plans in the different socioeconomic sectors with the water resources. For example, agriculture, industry, households, hydro-electricity and navigation are key sectors that primarily depend on water. Development plans in these sectors involve a number of policy variables and inputs. Therefore, the interaction between the policy variables and their impacts are monitored through multiple indicators in the socioeconomic and ecological domains. Due to the multiplicity of variables, the SEEAW framework used in the water resource accounting in Section 4 uses aggregated water data as do the existing approaches for analysing the associated policy impacts. For instance, CGE models also use aggregation and hierarchical decomposition in order to simplify model development and data compression to a manageable size. While the aggregation hides some of the temporal and spatial variability, it still preserves the fundamental trends and helps to provide answers which are often demanded by policy-makers. However, some CGE models are developed with a regional and spatial dimension. The TERM-H2O is one example of such models (see Horridge et al., 2005).

5.1 Structure of the proposed framework

The objective of this framework is to provide a mechanism for evaluation of both water policies and socioeconomic policies with a view to achieving the long-term socioeconomic development path for the country. In the framework, evaluation of policies can be undertaken using several indicators with respect to water availability, ecosystem quality, and economic growth (Simonovic and Fahmy, 1999). The modeling approach utilises hierarchical decomposition procedures to analyse interactions between a given sector and the water resources sector. For instance, agriculture can be decomposed into different sub-sectors. This is due to the very nature of its diversity with respect to cropping patterns, scale, and type of water used. The analytical framework is illustrated as follows:

$$MS_i = (Ipw, Ipo, Inp, t) \rightarrow O_t(O_{env}, O_{wat}, O_{econ}, O_{soc}, t) \qquad (1)$$

Where MS = sector model; i = sector model identifier; Ipw = policy input variable controlled by the Ministry of Water and Environment; Ipo = policy input variable controlled by other institutions; Inp = non-policy input variable, t = time; O = output vector; O_{env} = environmental indicators; O_{wat}= water availability indicators; O_{econ} = economic indicator; O_{soc} = social indicators.

There are many policy variables involved in a given sector, determined by a given development plan. Furthermore, the water supply variables are controlled by the Ministry of Water and Environment (MWE), while the demand side policy variables and inputs are controlled by other institutions in other sectors. In most cases, all policy variables are dynamic in nature. Conversely, non-policy variables are deterministic with given values over the planning period. Table 6-III proposes a series of possible variables that can be considered in policy analysis under the different sectors. It is worth noting that the choice of which variables are policy or non-policy depends on the structure of the economy, the existing development plan and the prevailing institutional, legal, and policy framework.

Table 6-III: Input variables

Sector	Ipw[a]	Ipo[b]	Inp[c]
Agriculture	• Development of water for production infrastructure	• Irrigation development and expansion (hectares/p.a.) • Valley dam infrastructure development • Population growth • Economic growth • Agricultural patterns and practices	• Unit consumption rates • Unit employment rates • Unit production • Fertilizer use • Pesticide use • Water saving due to irrigation use (m^3) • Crop productivity
Households	• Sewerage treatment • Domestic water supply	• Net distribution efficiency • Population growth rate • Daily household demands	• Water treatment cost (m^3) • Sewerage treatment (m^3)
Industry	• Treatment of industrial effluent	• Industrial growth rate • Location of industries • Scale of industrial operations. • Type of industrial activity	• Net return/ m^3 • Water requirement/unit of output • Level of industrialization • Pollution/unit of output • Employment/unit of output
Hydro-electricity	• Water release for electricity	• Capacity of hydro-power facility • Dam size • Cost of electricity generated	• Technology • Demand for electricity • Employment • Net return/ per unit of power
Navigation	• Navigable waterways	• Navigation growth • Cost of navigation	• Pollution by vessels • Employment/vessel • Net return/ vessel
Water	• Precipitation harvesting • Desalination • Groundwater exploitation • Surface water exploitation • Treated waste treatment	• Proportion of return flow from agriculture • Proportion of return from households • Proportion of returns from industrial water use	• Desalination cost/unit • Precipitation harvesting cost/unit • Cost of groundwater exploitation/unit • Cost of surface water exploitation/unit • Cost of wastewater treatment/unit

[a] Policy input variables controlled by the Ministry of Water and Environment (MWE).
[b] Policy input variables outside the control of MWE.
[c] Non-policy input variables.

The interaction between policy variables and their impacts are monitored through multiple indicators in the social, economic, and ecological domains. Due to the aggregation procedures, the model outputs should be taken as indicators and not precise measures of impacts of different scenarios. Nonetheless, these procedures have been scientifically considered as satisfactory for policy analysis. The proposed indicators for policy evaluation are highlighted in Table7-III. Evaluation is based on multiple criteria and this is reflected in the proposed indicators.

Table 7-III: Output indicators

Sector	O_{econ} [d]	O_{soc} [e]	O_{env} [f]	O_{wat} [g]
Agriculture	• Sectoral output • Employment • Sectoral income	• Food security • Employment • Health	• Fertilizer use • Pesticide use	• Sectoral water consumption
Households	• Water time saved due to water availability	• Employment • Health • Education outcomes	• Pollution from households • Water quality index	• Household water consumption
Industry	• Sectoral output • Employment • Sectoral income	• Employment • Health • Social amenities created	• Pollution from industry • Technologies for abatement	• Industrial water consumption • Water use efficiency
Hydro-electricity	• Sectoral output • Employment • Sectoral income	• Employment • Clean energy consumption • Health outcomes	• Pollution impacts (positive & negative)	• Sectoral water requirement
Navigation	• Employment • Contribution to mobility • Time savings	• Employment • Ease of mobility	• Sectoral pollution	• Congestion of waterways
Water	• Cost of abstraction and supply	•	• Water resource exploitation	• Water balance

[d] Economic indicators.
[e] Social indicators.
[f] Environmental indicators.
[g] Water availability indicators.

Once the policy variables and outputs have been identified, the final step is to undertake simulation of policy alternatives. Analysis can be undertaken using dynamic mathematical programming models, computable general equilibrium models (see Kilimani et al., 2015)[11], partial equilibrium models or qualitative analytical approaches. Irrespective of the modeling technique chosen, the aim is to investigate the effect of a policy variable on other variables away from the baseline.

6 Conclusion

In this Chapter, national water accounts were developed to establish the amount of water available as well as flow into the different sectors of the economy. In order to link the relevance of water resource accounting to socio-economic policy analysis, the Chapter proposes a framework which can be used to analyse the link between water policies and the policies of the different sectors. The framework involves the creation of a model structure, identification of the relevant policy variables, the selection of policy evaluation indicators and, finally, undertaking policy simulation. The proposed framework provides an input into policy analysis not only for Uganda but for other developing countries as well, whose social and economic activity is highly dependent on water resources availability and management.

The framework is envisaged to provide a useful tool for analysing the different policy alternatives which have implications for water resources utilisation. It allows for active inter-institutional interaction as well as providing feedback regarding the outcomes of different socioeconomic activities. The main objective is to identify priority actions in line with a country's development plans. Finally, it is critical to note that the proposed framework has been developed as a basis for the analysis of inter- and intra-sectoral linkages between water resource policies and the policies of the other sectors of the

[11] Kilimani et al. (2015) apply a water-CGE model (UgAGE) to provide a meticulous application of a water tax policy using the proposed framework developed in this paper.

economy. It is therefore envisaged that empirical testing based on country or regional-specific studies should contextualize this framework. This should be guided by the structure of the economy in question, water resources availability and use, the institutional and policy framework, and the choice of empirical modeling technique. The key aim of this Chapter is to demonstrate the fact that sound integrated water resources management requires robust understanding of the social, economic, and institutional linkages and the water resources.

7 Emerging policy issues

The Ugandan economy is currently experiencing water-related challenges emanating from the volatile changes in climate as well as changes in population and economic activity. These changes are increasingly putting a strain on the availability of water resources. This Chapter demonstrates the multiplicity of links between water resources and the economy with a view to highlighting the fact that water as an economic resource needs effective allocation and management. The results from the water accounts show that water consumption within the economy is 4.2 billion m^3, with the agricultural sector accounting for an estimated 63 percent of consumption. Total water demand stands at approximately 11 percent of total water availability. Whereas this figure seems to be low, projections indicate that the country is poised to experience severe water scarcity in the near future. This calls for the need to actively link the water policies with the policies of the other sectors, guided by their development plans. This will be the only sure way of achieving efficient and sustainable use of the existing water resources.

Annex B: Explanatory notes on the Supply and Use tables

Notes on Table 3-III: The Supply table

From surface water (M): Imports of surface water.

From surface water (X): Exports of surface water.

From groundwater (M): Import of groundwater.

From groundwater (X): Export of groundwater.

RoW (in transfers): Water supply to and from the rest of the world.

Water supply for HEP generation: Water supplied to hydro-electricity generation.

DWR: Water under jurisdiction of the Directorate of Water Resources. Both commercial and non-commercial supply.

NWSC (National Water and Sewerage Corporation): This is commercially supplied water by the National Water and Sewerage Corporation.

STWSP (Small Towns Water and Sanitation Programme): This is commercial water supplied in other smaller urban centers in the country outside the NWSC supply territory by the Directorate of Water Development (DWD).

S1, S2, S3: These are the sources water supply.

** This is a sum of water supplied by NWSC and STWSP under the Department of Water Resource development.

a) Source (DWRM, 2011), National Water Resources Assessment Draft Report. This value is given as a lump sum volume. The disaggregating by source was done using the FAO (2005) AQUASTAT database. The values by source from FAO (2005) scaled down to yield the lump sum total supply volume provided the DWRM (2011) study.

b) RoW is given by (X-M) of surface water flows.

e) Commercial water supply data from National Water and Sewerage Corporation (2011).

d) Data from the Small Towns Water and Sanitation Programme under the Department of Water Development, Ministry of Water and Environment (2011).

c) Source (Government of Uganda. Ministry of Water and Environment, Department of Water Resources Management (2011) Report page 14).

f) This is the sum of commercially distributed water by the NWSC and the SWSP.

g) Food and Agriculture Organisation of the United Nations. (2005)Global Information System on Water and Agriculture [Online] Available from: www.fao.org/nr/aquastat/. (Accessed: 22nd Feb 2013).

h) Food and Agriculture Organisation of the United Nations. (2005). Global Information System on Water and Agriculture [Online] Available from: www.fao.org/nr/aquastat/ [Accessed: 22nd Feb 2013].

i) Ministry of Water and Environment (2009): Sector Investment Report -Table 1-1 (2015 projections were taken), Page 3.

j) Ministry of Water and Environment. (2009): Sector Investment Report -Table 1-1 (2015 projections were taken), Page 3.

k) UN-Water & Directorate of Water Development. (2006).

National Water Development Report Table 7.1, Page 118.

l) UN-Water, & WWAP. (2006). National Water Development Report-Table 7.2 (2015 projections were taken), Page 121

m) Water used for irrigation and, crops as well as one used for electricity generation is taken as water returned to the environment.

Notes on Table 4-III: The Use table

From surface water (M): Imports of surface water.

From surface water (X): Exports of surface water.

From groundwater (M): Import of groundwater.

From groundwater (X): Export of groundwater.

RoW (in transfers): Water use by and from the rest of the world.

Water used for HEP generation: Water used for hydro-electricity generation.

DWR: Total distributed water both for NWSC and the Small Towns Water and Sanitation Programme.

NWSC (National Water and Sewerage Corporation): This is commercially supplied water by the National Water and Sewerage Corporation.

STWSP (Small Towns Water and Sanitation Programme): This is commercial water supplied in other smaller urban centers in the country outside the NWSC supply territory.

U1, U2, U3: These are the uses of water supply.

a) Total = surface water (90%) and groundwater (10%) based on the design consumption rates in Table 4.8 (Government of Uganda. Ministry of Water and Environment, Department of Water Resources Management (2011), National Water Resources Assessment Draft Report-page 96.

b) Government of Uganda. Ministry of Water and Environment, Department of Water Resources Management (2011), National Water Resources Assessment Draft Report-page 98.

Chapter Four

Counting the Cost of Drought induced Productivity losses in an Agro-based Economy: The Case of Uganda

Abstract

Climate variability affects economies directly through its impact on agricultural output and indirectly through its effect on the activities of down-stream industries and household welfare. We use a computable general equilibrium model with a highly disaggregated agricultural sector to analyse the costs of a drought on the Ugandan economy. The case of Uganda is interesting because its economy is largely agro-based with a heavily rain-fed agricultural sector. In this Chapter, we assess the resulting losses with respect to GDP, employment, the trade balance and household welfare. The results show that the effects vary substantially by sector from moderate to severe. There are macro level losses in terms of reduced exports while at a household level; the terms of trade gains mitigate part of the potential welfare losses with respect to consumption. At a sectoral level, the fall in employment within the agricultural industries is less compared to the output losses. Overall, we see that even a short-term drought can cause substantial losses to the economy, hence the need for targeted interventions to mitigate such drought impacts. Given the multi-dimensional nature of drought impacts, a combination of findings from this study with other qualitative surveys can give a much wider picture of the full cost of a drought.

Key words: Computable General Equilibrium modelling; Drought; Economic activity; Uganda

JEL Classification code: D58, Q25, Q54

1 Introduction

NEMA (2010) notes that the severe droughts registered in recent years have had significant negative effects on water resources, agricultural sector performance and the overall economy of Uganda.[12] Moreover, climate models predict that extreme weather events will become more frequent in the 21st Century (see e.g., Hertel et al., 2010). This Chapter seeks to investigate the economy-wide impacts of a typical drought on the Ugandan economy with the view to highlight some policy interventions to cushion the economy against the associated effects. This is critical given the fact that most of the existing policies to deal with droughts are largely focused on short-term responsive actions such as food aid, rather than proactive planning and mitigation strategies. Whereas responsive actions are critical for smoothing short-term disturbances, they are incapable of providing long-term socioeconomic resilience to future drought impacts (Ding et al., 2011). There is a general consensus that mitigation and preparedness are fundamental for mitigating future drought risks. However, public policy managers seldom allocate resources to mitigation because of limited information on the costs and benefits of drought mitigation programs.

The adverse effects of a drought pose the risk of exacerbating future water scarcity in addition to other stressors such as population growth, rapid urbanisation, and economic activity. The impact of droughts is most likely to be bigger on the developing countries than the developed. In sub-Saharan Africa for example, the agricultural sector employs approximately 70-80 percent of the population and contributes nearly 30 percent of GDP, with not less than 40 percent in export composition (Commission for Africa, 2005). However, drought occurrences coupled with the low investment in water supply infrastructure, i.e., irrigation systems, limits the economic performance of, especially the agro-based economies (Faurès and Santini, 2008). Approximately 97 percent of total cropland in sub-Saharan Africa is dependent on rain-fed subsistence agriculture. This has

[12] The El Niño and La Niña phenomena are thought to have been the principal causes.

adverse implications for agricultural production whenever there are episodes of high seasonal rainfall variability (Calzadilla et al., 2013).

An analysis of the effects of droughts on the agricultural sector in Uganda shows that during periods of drought, all crops in the nine farming systems experience a moisture deficit ranging from 128 mm to 251mm for perennial crops and 128–242 mm for non-perennial crops (DWRM, 2011). Therefore, changes in rainfall and temperature directly affect crop production. Furthermore, rainfall as the primary source of all fresh water resources determines the recharge of both surface and ground water sources as well as the level of soil moisture, which is central to crop growth. Rainfall is also the primary contributor to crop yield variability since it exhibits more volatility than potential crop evapo-transpiration— a key determinant of crop water requirements (Calzadilla et al., 2014). For instance in the United States, the period 2009-2011 saw swaths of west Texas and neighbouring states go through a severe drought. Another prolonged drought which started in 2012 is still being experienced in the same region and California. The consequence of which has been a depletion of water storage reservoirs hence affecting all forms of socioeconomic activity in the region (see Galbraith, 2012).

Horridge et al. (2005) used a multi-regional computable general equilibrium (CGE) model and found that the severity of the 2002-03 drought cost 1.6 percent of Australia's GDP. Similarly, an econometric analysis on the US agriculture by Reilly et al. (2003) found that higher levels of rainfall were associated with reduced variability in crop yield. This implies that episodes of higher rainfall intensity reduce the yield gap between rain-fed and irrigated agriculture. Hence, the absence of irrigation systems amidst droughts can adversely affect the performance of the agricultural sector.

Whereas the cost of setting up irrigation infrastructure has generally been on the decline, coupled with improvements in the performance of such infrastructure, sub-Saharan Africa has not benefited in this regard for the most part (see Inocencio et al., 2007; Calzadilla et al., 2013). The region still faces higher costs for developing irrigation infrastructure compared to other regions of the world. Inocencio et al. (2007) in their study of 314 irrigation projects implemented between 1967 and 2003 in 50 countries in Africa, Asia, and Latin America using simple regional averages found that the unit costs of irrigation infrastructure in sub-Saharan Africa (SSA) appear higher than those for other regions. The only caveat was that a detailed assessment revealed that under certain conditions, unit costs of irrigation projects in SSA are not statistically different from those in non-SSA regions. They further note that SSA irrigation infrastructure is not inherently more costly than in other regions. In the study, several factors were cited as the drivers of the observed costs. Project size was identified as the most important factor determining both unit investment cost and performance of irrigation projects. Specifically, the larger is the 'project size', the lower is the unit cost and the higher is the project performance. In sub-Saharan Africa, land fragmentation in part, accounts for this high cost.

As a consequence, approximately only 6 percent of the cultivated land area is equipped for irrigation compared to 33.6 percent in Asia and 17.7 percent for the world. In Uganda, less than 1 percent of potential arable land is under irrigation (Svendsen et al., 2009). The state of irrigation infrastructure has therefore contributed to the region's inability to mitigate the adverse effects of climatic shocks. From a household welfare perspective, rural poverty accounts for 90 percent of total poverty in sub-Saharan Africa. This is equally the case with Uganda where previous reductions in poverty rates arising from over two decades of sustained economic growth face a likelihood of reversal. The increased prevalence of droughts is posing a threat to the welfare of especially the rural households. Studies by Dorosh et al. (2002; 2003) to analyse the impact of agricultural productivity shocks in Uganda found that broader increases in agricultural productivity have the potential to raise household incomes, with the largest gains going to regions where household consumption is the lowest.

> *"Because agriculture accounts for a large share of incomes for these households, policies and external shocks that affect agriculture, including shifts in world prices, changes in agricultural productivity, and reductions in marketing costs, may have significant effects on rural poverty"* (Dorosh et al., 2002 p.1).

Miguel et al. (2004) found that variability in rainfall seasons is highly correlated with household income shocks in Uganda.[13] This implies that droughts impede production and income at a household level, which in turn affect aggregate output and welfare (see Asiimwe and Mpuga, 2007). In fact, Ligon and Sadoulet (2007) show that a percentage point increase in agricultural growth in developing countries, has been associated with a four to six percentage points increase in consumption by the poorest third of the population.

Moula (2009) in a study of the impact of climate change in Cameroon used the Ricardian method and found that a 7 percent decrease in precipitation would result in a net decline in crop revenue by US$2.86 billion Similarly, Björkman-Nyqvist (2013) showed that rainfall deviations from their historical mean were linked to deviations in agricultural output in Uganda. The agricultural sector in Uganda is a key foreign exchange earner and supplier of inputs to other sectors of the economy. In addition, it is a vital source of livelihood since over 76 percent of household income is related to agricultural production. More importantly, 42 percent of households report agriculture as vital source of income while 26 percent cite it as the only source of income (MFPED, 2014). Therefore, any disruptions in agricultural activity can lead to economic instability at a micro and macro-level (see OPM, 2012).

Within the foregoing context, the key objective of this study is to analyse the susceptibility of agricultural output to drought, and the extent to which these effects are propagated within the economy. In our analysis, a drought is analysed from the perspective of a short-term climate anomaly. Specifically, the study seeks to: analyse the cost of a drought on the key sectors and

[13] Note that Miguel et al. (2004) found a close relationship between rainfall and GDP at a cross-country level. Similarly, Levine and Yang (2006) found that deviations in rainfall from the district level mean were positively associated with agricultural output in Indonesia in the 1990s.

macroeconomic variables; suggest possible measures to mitigate these adverse impacts; and highlight key policy options arising from the analysis.

1.1 Contribution

This study differs from most of those in the literature on drought impacts in four ways. First, we use a general equilibrium framework in which data from climate and economic models are integrated for evaluating the socioeconomic impacts of a drought. Most studies employ partial equilibrium analysis to estimate the effects of drought on agricultural productivity on specific sectors or crops within a limited geographical area (see Schlenker and Lobell, 2010; Jones and Thornton, 2003). However, partial equilibrium models investigate the effects of drought on specific regions or sectors, holding the potential effects on other sectors constant. The preference for general equilibrium model analysis is in their ability to investigate the economy-wide impacts of shocks. Within a general equilibrium framework, it is possible to trace the consequence on other sectors of an expansion or contraction in any given sector.

Second, even for studies that employ a general equilibrium framework, many use global or multi-regional models e.g., the GTAP-W (see Hertel, 1997; Burniaux and Truong, 2002; Calzadilla et al., 2011; Calzadilla et al., 2014; Berrittella et al., 2007; Rosegrant et al., 2008; Zhu et al., 2008 (IMPACT), and Giesecke, 2011 (IMPLAN). The aggregation and assumptions which are made when developing global models, limits the detailed inclusion of differences between countries. As such, country specific details tend to be averaged out.

Third, most of these studies have been undertaken in different contexts and for different motivations. For instance, most studies have been undertaken for developed or upper-middle income countries (see e.g., Calzadilla et al., 2014; Calzadilla et al., 2011; for South Africa; Reilly et al., 2003, for the USA, Falloon and Betts, 2009 for Europe). Some studies focus on virtual water trade in specific sectors (Hoekstra and Hung, 2005); while others focus on specific crops within the agricultural sector (see Pauw et al., 2011; Hertel et al., 2010;

Skjeflo, 2013). Even for studies that employ single-country general equilibrium models to analyse the impacts of droughts beyond agriculture i.e., the inclusion of other downstream sectors like manufacturing, some tend to limit their analysis to specific components of the agricultural sector. In addition, the shocks which are imposed on the productivity of primary factors are not informed by actual estimates derived from climate, and econometric models on yield productivity losses (see e.g., Horridge et al., 2005).[14] Therefore, the resulting analysis may present a less than accurate picture of the potential economy-wide effects of drought.

Fourth, isolating drought effects can be analytically challenging especially in instances where data are incomplete or unavailable. Consequently, it may not always be possible to analyse the direct and indirect effects of a drought. Cognisant of such challenges, empirical studies have favoured the use of CGE models in undertaking disaster impact assessments (see, Horridge et al., 2005; Al-Riffai and Breisinger, 2012). Within the CGE literature, most studies have either adopted an ex ante approach to assess the impacts of hypothetical events (see Boyd and Ibarraran, 2009; Skjeflo, 2013), or ex post approaches, in order to evaluate the impacts of historical events (Horridge et al., 2005; Al-Riffai and Breisinger, 2012).

This Chapter uses a specially developed water-CGE model which has been modified from the official Uganda Applied General Equilibrium (UgAGE) model to analyse the impact of drought on the economy in the short-run. In this Chapter, the methodology used allows the focus of analysis to highlight the costs of a drought using actual productivity losses from the literature on crop yields. This approach is informed by the fact that the benefits of any intervention can easily be approximated using the estimated costs that would otherwise be avoided by drought mitigation programs. Therefore, in order to establish the benefits of drought mitigation programs, a quantification of the economic impacts of drought needs to be

[14] The study by Horridge et al. (2005) is among the few that provide a meticulous approach to measuring productivity losses based on climate related data.

available (Ding et al., 2011). In spite of the importance of accessing the economic impacts of a drought, most studies tend to mix production losses, indemnity payments, and relief costs. In addition, studies focus on agricultural losses only and do not capture the broad range of impacts resulting from drought.

In this Chapter a highly disaggregated agricultural sector is used to assess the primary effects of a typical drought on the economy. Furthermore, we trace the resultant effects on the economy via the downstream industries, by modelling the drought effects on the agro-processing component of the manufacturing sector. In addition, unlike most studies whose analysis is based on simulating 'what if' scenarios, the modelling procedure in this Chapter is based on analysis of the impact of productivity losses which have already been measured using rigorous econometric and crop yield models under different climate shock scenarios. As such, the magnitude of productivity losses used in the model is not hypothetical, and can therefore approximate the true would be economy-wide effects of a typical drought within the model limitations. This modelling approach is therefore aimed at providing lessons not only for Uganda, but other developing countries. This is vital because developing countries tend to have similar socioeconomic structures. As a result, a drought is bound to present somewhat similar challenges.

The rest of the Chapter is organised as follows: Section 2 highlights Uganda's socioeconomic situation and the prevalence of climate related shocks, a brief synthesis of the literature on the issues under investigation is presented in Section 3, while Section 4 describes the UgAGE model and the modelling framework. Section 5 focuses on the analysis and discussion of the results, while the conclusion and emerging policy issues are presented in Section 6.

2 Situational analysis of drought prevalence in Uganda

Understanding the impact of climatic shocks depends both on the biophysical and socioeconomic factors, with the latter being the key determinants for a community or household's ability to cope with the shock (Akerlof et al., 2013). In this section, we highlight the socioeconomic characteristics of the different regions of Uganda vis-à-vis the occurrence of climate related shocks. The impacts of climate variability create challenges and impose severe losses and hardships especially on the poorest communities. This is largely the case because their livelihoods are often very sensitive to adverse climate change. Mubiru (2010) notes that the most dominant and widespread climate related disasters are due to drought, whose frequency has been observed to be on the increase over the past two decades (GOU et al., 2007).

Drought affects the recharge of ground and surface water sources, as well as soil moisture which is vital for crop production. The impacts of drought are further exacerbated by the fact that although the country is endowed with water resources, their distribution is uneven. For example, the semi-arid areas of the country stretching from Southwest through Central to the Northeast regions of the country (the 'cattle corridor') experience chronic water stress. As a consequence, prolonged droughts always cause severe water shortage, leading to loss of livestock, decline in milk production, food insecurity, increased food prices, and a negative effect on the overall micro and macroeconomy. At a micro level, MFPED (2014) showed that poverty has been on the decline. Table 8-IV presents a poverty profile of population through time. It is clear that there has been a decline in poverty across the different sections of the population. However, despite this decline, the number of people living in poverty is still high.

Table 8-IV: Trends in household poverty in Uganda

Year	Population (millions)	Poor (%)	Insecure non-poor (%)	Middle class (%)
1992/93	17.4	56.4	33.4	10.2
1999/00	21.4	33.8	43.9	22.4
2002/03	25.3	38.8	39.9	21.2
2005/06	27.2	31.1	40.2	28.7
2009/10	30.7	24.5	42.9	32.6
2012/13	34.1	19.7	43.3	37.0

Source: MFPED (2014).

In Table 9-IV, we present a dichotomy of poverty trends between the rural and urban areas of the country. It is clear that the incidence of poverty remains higher in the rural areas than in urban areas. It is also important to note that in the rural areas, the primary sources of livelihood are rooted in climate sensitive economic activity. Therefore, droughts not only have macro level effects since a considerable proportion of the economy is agro-based but also micro level effects from a household welfare perspective. A decomposition of national poverty by region shows that the incidence of income poverty varies significantly (see UBOS, 2012). Results show that the incidence of poverty remains highest in the Northern region, but lowest in the Central region. A regional analysis of the poverty trends shows a decline in poverty since 2009/10, for all the four regions except the Eastern region (see MFPED, 2014 p.10).

Poverty levels for the Western and Central regions are below the national average, with the Western region registering the largest decline from 52.7 percent in 1992/93 to 8.7 percent in 2012/13. During the same period, absolute poverty in the Eastern region declined from 58.8 percent to 24.1 percent. However, the Eastern and Northern regions continue to register lower reductions in poverty rates compared to other regions, with levels that are above the national average. In fact, there was a slight increase of 0.2 percentage points in the Eastern region between 2009/10 and 2012/13, on account of an increase in rural poverty. Although the Northern region also recorded a significant reduction in its poverty level from 73.5 percent in 1992/93 to 43.7 percent in 2012/13, its poverty level remains more than twice the national average. Unlike the Eastern region, the rapid reduction in poverty in the Northern region was attributed to a decline in rural poverty. This has largely been a result of the end of the two decade long armed conflict in the region and a return of the population to their land from the Internally Displaced Peoples' (IDP) camps. The end of the conflict spurred a restart in rural economic activity, hence a decline in rural poverty. However, the increased volatility in climate trends might jeopardise these marginal welfare improvements.

Table 9-IV: Rural-urban dichotomy of household poverty in Uganda

	Rural			Urban		
Year	Poor	Insecure non-poor	Middle class	Poor	Insecure non-poor	Middle class
1992/93	60.4	32.5	7.2	28.8	40	31.2
1999/00	37.4	45.5	17.1	9.6	33.1	57.3
2002/03	42.7	41.1	16.6	14.4	32.8	52.9
2005/06	34.2	42.3	23.4	13.7	28.6	57.7
2009/09	27.2	45.9	26.9	9.1	26.4	64.5
2012/13	22.8	47.4	29.8	9.3	29.2	61.4

Source: MFPED (2014).

Bekele et al. (2014) contend that the impact of a climate hazard to a community e.g., drought depends on factors such as population, social behaviour, water use, and level of economic development. From the results in Table 9-IV, it is clear that the largest proportion of the country's poor lives in rural areas where the main economic activity is smallholder rain-fed agriculture. Furthermore, the poverty data shows that these rural households have the largest prevalence of poverty in the country. Esikuri (2005) notes that due to the heavy dependence on rain-fed agriculture, about 60 percent of sub-Saharan Africa agriculture is vulnerable to frequent and severe droughts. This increases the susceptibility of agriculture in case of frequent and severe droughts, as current trends seem to indicate (see Table 10-IV). In fact, Miguel et al. (2004) found that rainfall shocks constitute a good proxy for household income shocks in Uganda. Since agricultural activity in Uganda is primarily rain-fed, changes in climatic conditions have important implications for the households' total agricultural production; income and wellbeing (see Asiimwe and Mpuga, 2007). Similarly, Björkman-Nyqvist (2013, p.243) shows that rainfall deviations from the historical mean are associated with deviations in crop yields in Uganda. In Table 10-IV, we see that the largest percentage of climate related shocks reported by households are droughts which have been on the rise.

Table 10-IV: Households' exposure to climate shocks and stresses (percentages)

Climatic shocks and stresses	2005/06	2009/10	2010/11	2011/12
Droughts	39.8	45.8	45.9	43.3
Floods	13.8	2.1	6.5	11.3
Landslides	N/A	0.8	0.5	1.3
Crop pests and diseases	9.5	4.6	2.6	4.7
Livestock diseases	5.9	2.8	2.4	2.4

Source: UBOS (2012): Uganda National Panel Survey data.

The findings in Table 10-IV have implications for the economy and the welfare of households. This is because a technical study by the Ministry of Water and Environment (see DWRM, 2011) notes that during drought events; both perennial and non-perennial crops register moisture deficits. This implies that periods of long droughts have the potential to severely disrupt agricultural economic activity in the country.

3 Literature review

The increasing volatility in climate trends with its associated effects has raised the attention of researchers and policy makers especially in the developing countries (Dong et al., 2015). This attention is largely being driven by the fact that empirical evidence cites developing countries as the most susceptible to these changes in climate. Their susceptibility is attributed to their inability to cope with frequent and severe droughts, floods, as well as shifts in temperature and rainfall patterns (IPCC, 2007; Hepworth and Goulden, 2008). In fact, IPCC (2007) in its fourth assessment report warns that by 2100, parts of sub-Saharan Africa are likely to emerge as the most vulnerable, with likely agricultural losses of between 2 and 7 percent of GDP per annum at a national level. These impacts have been projected to occur along with a high population growth which is estimated to reach approximately 2 billion in the region by 2050 (UNDP, 2007). This is will present a strain on the resources of many countries in the region.

Current trends in climate are severe in most regions of the developing world, coupled with the fact that technological change has been dismal. For instance, the Eastern and Southern Africa regions are characterised mainly by semi-arid and sub-humid climates with long dry seasons (Shiferaw et al., 2014). This is in contrast with West Africa where the variability in precipitation is concentrated on relatively short annual timescales and it is directly influenced by the El Niño and La Niña-Southern Oscillation (ENSO) (Nicholson, 2001).[15] ENSO events have a strong bearing on the inter-tropical convergence zone (ITCZ), regional monsoon wind circulation, and patterns of rainfall anomalies over many parts of sub-Saharan Africa (see Jury, 2000; Singh, 2006). These climatic changes present a major risk to agriculture which the majority of the world's population especially those in developing countries, highly depend upon (World Bank, 2007; Lobell and Field, 2007; Seo et al., 2009). Bhavnani et al. (2008) note that in sub-Saharan Africa, droughts and floods account for approximately 70-80 percent of losses caused by climate related shocks. Frequent droughts have been observed to reduce the economic growth of many African countries and threaten their long-term development prospects (see Jury, 2000; World Bank, 2005; Hellmuth et al., 2007; Brown et al., 2011).

Kurukulasuriya and Rosenthal (2003) argue that the socioeconomic impact of climate shocks is influenced by a given economy's ability to respond to such shocks. Therefore, the low adaptation capacity in many developing countries implies that households, especially those which depend on agriculture risk being stuck in the vicious cycle of poverty. The consequences of such shocks usually manifest in significant reductions in consumption, and asset depletion (Macours, 2013). It can also hamper household productivity and upward mobility, with inter-generational consequences. For instance, Hoddinott (2006) in their study of climate shocks and their consequences in Zimbabwe shows that women's Body Mass Index (BMI) fell as a result of drought. This has implications for their reproductive health. In

[15] El Niño and La Niña, respectively refer to the warming and cooling of surface temperatures (SST) in the equatorial Pacific Ocean. These influence atmospheric circulation and hence rainfall and temperature in specific regions around the globe. Since the changes in the Pacific Ocean (El Niño and La Niña) and changes in the atmosphere (Southern Oscillation) are inseparable, the acronym ENSO is used to describe the resulting atmospheric changes (Singh, 2006).

addition, households with fewer opportunities for engaging in non-agricultural activity were found to have been severely affected by the drought as there was little scope for mitigation through engagement in other income generating activities.

As studies on susceptibility to climate shocks continue to emerge, it is vital to take stock of the key findings on the impacts of such shocks on economies in regions which have been cited as the most vulnerable. The outcomes from such investigations can serve as lessons for current and future assessments with respect to vulnerability. These investigations provide essential insights into the processes and actions needed to be taken in order to enhance our understanding of the links between climate shocks and socioeconomic activity especially in the developing world. For agro-based economies like Uganda, temperature and rainfall are the climate variables that directly affect the economy through their primary effects on agricultural production (see Ziervogel et al., 2006). Empirical evidence suggests that an increase in average temperatures can shift the duration of a growing season, thereby affecting crop growth in regions where heat already limits production.

A number of studies have investigated the extent of economic losses induced by droughts. These studies vary both in scope and methodology. The scope differs with respect to the determination of liability, assessment, comparison of different drought mitigation strategies, or exploring the vulnerability and resilience to a drought. Similarly, the methodologies range from linear programming models, surveys, econometric models, input–output (I–O) models, CGE models, through to hybrid models (see Cochrane, 1997). The I–O and CGE models have been favoured as most suitable for macroeconomic assessments of drought losses. However, the former does not account for behavioural changes and input substitutions. Thus, their results tend to yield upper bound estimates of the losses. Static CGE models on the other hand assume perfect adjustment to equilibrium which may over estimate the resilience of the responses towards the shock (Rose, 2004; Rose and Liao, 2005).

To ensure robustness, CGE models have got several validation mechanisms for their results. Validity is a key issue in that it ensures that the modelling process: (i) is computationally sound, (ii) uses accurate up-to-date data, (iii) adequately captures behavioral and institutional characteristics of the relevant parts of the economy, (iv) is consistent with history and (v) is based on a model that has forecasting credentials. Among the most favoured validation mechanisms is the back-of-the-envelope (BOTE) technique used to explain results from a particular application of a full-scale model (see Dixon and Rimmer, 2013). Since CGE models are large scale in nature, a BOTE construction provides a mechanism for demonstrating that the computations have been performed correctly, i.e., that the results do in fact follow from the theoretical structure and model database. In addition, BOTE computations help CGE modellers to ensure that the model: is "understood"; isolates those assumptions which "drive" particular results; and can be used to assess the plausibility of particular results by seeing which real world phenomena have been considered, and which ones have been ignored. Finally, by modifying and extending the BOTE calculations, the reader is able to obtain a reasonably accurate idea of how some of the projections would the underlying assumptions and data (Dixon et al., 1977, pp.194-195). Therefore, their limitations notwithstanding, CGE models are better at investigating issues that require an economy-wide scope.

Finally, the impacts of drought can be both direct and indirect. Identifying an adequate definition for direct and indirect impacts is crucial for economic impact assessments because the bounds set by such definitions dictate the scope of impacts that may or may not be included (Ding et al., 2011). However, consistent classification of the two types of impacts is often lacking. Van der Veen (2004) reviews the different cost concepts used in the economic literature on climate related disasters. For instance, Shiferaw et al., (2014) define the direct impacts as mostly on production, health, livelihoods, household assets, and infrastructure. The indirect impacts cause backward and forward multiplier effects in the economy resulting in a decline in household welfare through their impact on commodity prices (Zimmerman and Carter, 2003; Holden and Shiferaw, 2004). In this Chapter, the effects of a drought e.g., on output across industries are categorized as the direct economic impacts of drought; while indirect economic impacts stem from the interactions and transactions among industries and sectors. A detailed description of the methodology employed follows in the next section.

4 Methodology

4.1 UgAGE theory and database

We use the Uganda Applied General Equilibrium Model (UgAGE) to simulate and measure the potential effects of a typical drought on the Ugandan economy. The UgAGE model is an ORANI-style CGE model (Dixon et al., 1982; Horridge, 2001) built on a database for Uganda that distinguishes 37 industries and commodities; including 25 within the broader agriculture sector (see Roos et al., 2014). UgAGE also features theory and data linked to the demand and supply of taxable water in the economy, similar to that used in the UPGEM[16] model (Blignaut et al., 2008). The detailed agricultural sector in the model, in combination with the model's treatment of water, allows for more accurate analysis of affected industries and commodities due to a drought.

The model's core theoretical structure is typical of most comparative-static CGE models and consists of blocks of equations that describe: i) industry demand for produced inputs and primary factors; ii) industry supply of goods and services; iii) investor demand for inputs to capital formation; iv) household demand; v) export demand; vi) government demand; vii) the composition of final purchasers prices that detail the relationship between basic costs, trade and transport margin costs and taxes; viii) market clearing conditions for commodities and primary factors; and ix) numerous other macro-economic variables and price indices.The neoclassical assumptions drive the behavior of all private agents in the model. Each industry minimises cost subject to given input prices and constant returns to scale production function. Zero pure profits are assumed for all industries. Optimising equations determining the

[16] University of Pretoria General Equilibrium Model.

commodity composition of industry output are derived subject to a CET function, while functions determining industry inputs are determined by a series of nests. At the top level of this nesting structure intermediate commodity composites and a primary-factor composite are combined using a Leontief production function. Each commodity composite is a CES function of a domestic good and its imported equivalent, incorporating Armington's assumption of imperfect substitutability for goods by place of production (Armington, 1969). The primary-factor composite is a CES aggregate of composite labour, capital and, in the case of primary sector industries, land. Household demand is modelled as a linear expenditure system that differentiates between necessities and luxury goods, while also incorporating the Armington CES nest for choices between imported and domestic versions of each commodity.

The UgAGE database is based on the 2009 SAM for Uganda published by UBOS. From the SAM, the data is transformed to be compatible with the detail and structure of the UgAGE model. This is then aggregated into 37 industries and commodities and a single representative household. The model is implemented and solved using the GEMPACK® suite of software programs. GEMPACK® eliminates linearisation errors that may occur in ORANI-style models by implementing shocks in a series of small steps and updating the database between steps.[17] Simulation results are reported as percentage change deviations away from an unperturbed baseline represented by the structure of the base year data (Harrison and Pearson, 1996).

[17] In this particular application, we use Euler's multi-step solution technique to eliminate linearisation errors.

4.2 Model closure

In simulating the impact of a typical drought on Uganda, we set up the UgAGE model's policy closure to reflect a short-run time horizon. This choice of closure is a modified version of the standard Dixon-Parmenter-Sutton-Vincent (DPSV) closure (see Dixon et al., 1982 Chp.19) as it is designed to reflect our interest in the near term impacts of a drought given that such an event is typically restricted to only a couple of years. In line with typical short-run economic theory, the assumptions of our short-run policy closure restricts any change in capital stock levels and real wages, but allow endogenous movements in employment, and the rate of return on capital by industry relative to the baseline.

On the expenditure side, we set aggregate real investment to be exogenous while the investment slack variable is endogenous in order to shift the supply curve for capital. Keeping investment as exogenous is informed by the expectation that a typical drought does not drag on long enough to alter aggregate investment decisions over a short-run period. Aggregate real consumption and trade balance (in real terms) are endogenous while the ratio of household consumption to GDP is exogenous. In this regard, aggregate real consumption can hence be interpreted as the aggregate index of welfare. In addition, all tax rates, preference variables and technical change variables are held exogenous in the policy closure, that is, we do not allow them to change relative to their baseline projections as a result of the particular shock under investigation. The nominal exchange rate is set as the numeraire.

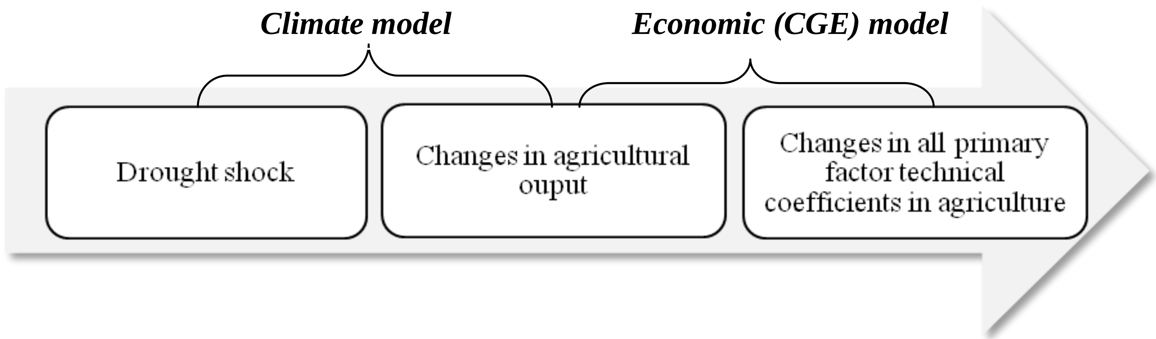
4.3 Simulation design

CGE modelling simulations typically analyse the impact of a particular exogenous shock or policy change on the economy, relative to a business-as-usual baseline picture of the economy. In this Chapter, we impose exogenous shocks on the Ugandan economy that are representative of the direct impacts of a typical drought. The literature identifies two main types of exogenous shocks associated with a drought scenario: the first is a reduction in primary factor productivity of agricultural industries dependent on rainfall, and the second is a partial and temporary closure of downstream manufacturing industries, such as agro-processing.

In calibrating the size of the exogenous shocks on the Ugandan economy, we use a 'quasi sequential' modelling process (see Figure 4-IV). The model is calibrated first, to obtain the primary factor productivity shocks from the agriculture industries' output data. The benchmark losses in output are based on a summary of crop productivity scenarios derived from a synthesis of studies from different regions of the world, using a variety of models (see Hertel et al., 2010, p.584). The process is quasi because we circumvent the process of having to estimate a profit model for Uganda's agricultural output which would have yielded the primary factor productivity shocks to be used. The approach we use has the potential to yield more robust results (Burke et al., 2011).

Second, we use the results from stage one which have been transformed into technological shocks for the primary factors in the agricultural sector's production function as shocks for our CGE model. Note that the primary factor productivity change has been calibrated for each agricultural industry. As such, we avoid the common approach used in many studies of imposing uniform shocks across all industries. This is vital as each industry is affected differently by a drought. Furthermore, productivity losses in the agricultural sector cause supply constraints to the other sectors of the economy. In our model, the sector of interest is the agro-processing component of the manufacturing sector. In this study, the impact of the productivity shocks is conveyed through factor returns, employment and commodity prices, among other critical macroeconomic variables. Regarding the issue of household welfare, although the model has no micro simulation component, we can still provide some intuitive answers with respect to how it might be affected based on what is known about the nature of households that directly derive their livelihood from the agricultural sector.

Figure 4-IV: Sequential modelling framework



Source: Adapted from Haddad et al. (2012).

The drought shocks are implemented in the UgAGE model by:

i) Reducing primary-factor productivity for each agriculture industry by an appropriate amount to reflect the impact of a typical drought. In general, this implies that more primary factors in the form of capital, labour or land would be required to produce the same amount of output as before the drought, thereby raising input costs and ultimately reducing output. The sizes of the productivity shocks are calibrated and reverse-engineered for each individual industry to reduce its output by 10 per cent.

ii) Reducing operational capital stock in the downstream manufacturing sector, specifically agro-processing, by an appropriately weighted amount to reflect the impact of a typical drought. This shock recognizes that a large-scale reduction in the inputs to the agro-processing sector will temporarily cause a shutdown of unused capital. The size of the shock is calibrated and weighted to reflect a temporary shutdown of 10 per cent of the capital stock in the agro-processing industry, within the broader manufacturing industry. This shock also carries the benefit of mitigating any unrealistic benefits which the industry might receive through a terms of trade change, following the losses in the agricultural sector.

5 Simulation results and discussion

5.1 Macro results

Table 11-IV presents results for the macroeconomic effects of a drought simulated using the UgAGE model. As noted earlier, the intensity of the drought being simulated can be considered as ‘typical’. The results of the simulation reported here may then be used as a benchmark to evaluate the economy-wide effects of more or less severe droughts.

Table 11-IV: Results of main macro variables (Percentage change deviation)

Variable description	Percentage change
Contribution of the Balance of Trade to GDP	-1.14
Aggregate employment	-5.13
Ratio, consumption/GDP	0
Average nominal wage	1.31
GDP price index	1.83
Terms of trade	2.67
Aggregate investment price index	0.24
Aggregate capital stock	-0.96
Consumer price index	1.31
Exports price index	2.67
Export volume index	-5.20
Import volume index	-0.24
Real GDP	-5.01
Aggregate primary factor use	-2.86
Real household consumption	-4.61
Aggregate real government expenditure	-4.61

Source: Author’s computations.

As expected, the drought causes GDP to decline. The exogenous shocks imposed due to the drought directly lower productivity across various agriculture industries, thereby reducing the level of agricultural output leading to the temporary shut-down of capital in the downstream manufacturing industries. We find that with the relatively ‘typical’ severity level of the drought simulated via the imposed exogenous shocks, GDP declines by 5 percent in the short-run relative to a business-as-usual baseline. As a comparison, OPM (2012, p.10) in a study of impact of the 2010/2011 drought in Uganda reported losses of 7.5 percent of GDP, equivalent to US$1.2 billion. With sticky real wages and fixed capital stocks (outside of the exogenous temporary closure of some capital in the manufacturing industry) assumed in the short-run, the loss in GDP from the supply side stems from reduced employment, lower effective capital stock weighted for the shock to the manufacturing industry and the deterioration in primary factor productivity as a result of the drought. Aggregate employment weighted by the wage bill declines by 5.1 percent. Given the relatively low wages which characterise employment in many sectors, such a decline in employment implies higher job losses induced by the simulated agricultural sector productivity losses.

Real household consumption recorded a decline of 4.6 percent, underscoring the welfare impact of a typical drought on household welfare. The decline in household consumption is slightly less than that of real GDP because the potential decline in household consumption was ameliorated by the gains in the terms of trade of 2.7 percent. The terms of trade improved on account of domestic price increases, resulting in a decline in exports by 5.2 percent.

Ultimately, the lesser decline in household consumption compared to that of real GDP is because of the ability for households to substitute between the now expensive domestically produced output with the relatively cheaper imported versions of the same. The interaction of this income and substitution effect is highlighted by the result for aggregate import volumes, which declines by only 0.24 percent relative to the baseline. In the absence of any other information, with real GDP and consumption falling by between 5 percent and 4.6 percent respectively, our first guess may have been that imports should also fall by approximately that amount in order to reflect the impact of the drought in dampening domestic demand.

However, the net result of imports falling by only 0.24 percent is mainly due to household and industry demands switching away from expensive domestic goods to relatively cheaper imported versions, as predicted by the Armington nests in the theoretical structure of industry and household demand.[18] Among the key export commodities, Maize registered the largest decline in output of 11.9 percent followed by Beans (11.5%). Output in the manufacturing sector as a whole declined by 13.2 percent, on account of the partial shutdown of capital in the industry in the model and the resulting rise in input costs due to the drought. Not surprisingly, imports of tradedables such as Beans and Manufactured goods increased relative to the baseline following the Armington substitution effect, thereby registering increases of 11.2 percent and 1.3 percent, respectively.

5.2 Losses in industry output

In Table 12-IV, we present results for the impact of a drought on output for the selected industries. Outputs for the agricultural industries decline dramatically with Coffee being the worst affected. The negative down-stream effects are seen in the manufacturing sector via the decline in agro-processing activities within the sector.

Table 12-IV: Results for the impact of drought on industry output (Percentage changes)

		Category		
Commodity	Percentage change	Export	Staple	Agro-processing
Maize	-11.90	*	*	*
Millet	-11.88		*	
Beans	-11.35	*	*	
Wheat	-7.04			*
Matoke	-10.62		*	
Simsim	-10.35	*	*	*
Sorghum	-6.93		*	
Cassava	-6.93		*	
Potato	-7.07		*	
Groundnuts	-8.08		*	*
Coffee	-13.25	*		*
Manufacturing	-13.25			

Source: Author's computations.

It is worth noting that the large negative effects on output are not matched with similar reductions in employment except for Coffee farming which registered a decline in labour

[18] See Armington (1969) for a thorough exposition.

input of 17 percent. Indeed employment, especially in the agriculture industries declined due to the drought but not to the same degree as the decline in output. This is due to the fact that a considerable proportion of the decline in output emanates from reduced productivity of both inputs. With fixed capital, as per the short-run closure rules, the loss in employment defined by effective labour input is minimal.

Horridge et al. (2005) in their study of drought in Australia similarly found minimal job losses in the farm sector. This was attributed to the fact that the agricultural sector in Australia is characterized by owner-operators. In Uganda, changes in employment have a direct impact on household welfare via its effect on households' earning potential. The effect of a drought on household welfare can also be linked to changes in the consumer price index. Indeed, as the results in Table 12-IV indicate, household consumption is compromised, the fact that employment is relatively less affected, notwithstanding. This can be attributed to the low earnings associated with agricultural sector employment. As such, the rise in prices has implications for household welfare as most agricultural households often have lower incomes, with equally lower possibilities of compensating through non-farm income generating activities.

Finally, it is fascinating to note that the impact of a typical drought on industry output is driven mainly by the direct effect of a drought on the productivity losses than the short-run elasticity. For example, a commodity like Groundnuts with a higher short-run supply elasticity of 0.32 registered a lower decline in output of 8.1 percent compared to Maize with a lower short-run elasticity of 0.25, but with output losses of 11.9 percent. This is due to the capital-labour ratio requirements for each of these industries. Results show that industries with higher capital-labour ratios were more severely affected by this productivity shock than those with lower ratios. The sectoral impact of a shock depends on the extent to which industries can substitute their inputs. In particular, the impact of a shock on a given industry hinges on the capital-labour intensity and how elastically each industry can substitute between its inputs and also vary their quantities. For instance, capital is fixed in the short-run.

In this instance, a drought shock alters the relative prices of each good which causes each industry's input cost share to vary. In addition, studies on crop yields showed different crops are affected differently by drought even when it is of the same magnitude (see Hertel et al., 2010). These differences were accounted for in the implementation of the shock as described in sub-section 4.3 and also partly explain the observed differences.

5.3 Decomposition analysis of the changes in industry output

Table 13-IV presents results of the Fan decomposition[19] analysis of the results of the impact of a drought on industry output. If we take Maize for example, we see that the predicted changes in domestic output are derived from three effects:

i) The local market effect. i.e., changes in domestic demand for maize, whether domestically-produced or imported;
ii) The domestic share effect. i.e., a shift in local usage of agricultural maize, from the imported to the domestically produced; or
iii) The export effect. i.e., an increase in the export demand for maize.

In most cases, these effects tend to work in different directions. However, the results show that the effects of a drought adversely affect output thereby reducing all the components of the decomposition. The essence of the Fan decomposition is to show the relative magnitudes of these three contributions to output change. Table 13-IV gives a breakdown of the changes in shares in total industry output for some selected industries.

[19] Named after Fan Ming-Tai of the Academy of Social Sciences, Beijing Institute of Quantitative and Technical Economics.

Table 13-IV: Effect of a drought on the shares of industry output

Industry	Local Market	Domestic share	Export	Total
Maize	-5.16	-1.83	-4.91	-11.90
Rice	-13.05	0.01	0*	-13.05
Wheat	-11.99	4.42	0.53*	-7.04
Cassava	-6.96	0	0.03*	-6.93
Potato	-7.07	-0.01	0.001*	-7.07
Tobacco farming	-0.16	-0.003	-0.03	-0.20
Groundnuts	-8.52	-0.05	0.48*	-8.08
Millet	-5.25	0	-6.64	-11.89
Sorghum	-3.00	-0.89	-3.05	-6.93
Beans	-4.75	-0.06	-6.55	-11.35
Coffee farming	-13.26	0.01	0*	-13.24
Tea farming	-2.25	-0.01	-5.05	-7.31
Vanilla	-0.004	0	-0.16	-0.16
Matoke	-10.80	0	0.18	-10.62
Forestry	-2.15	0.03	0.01*	-2.11
Manufacturing	-3.30	-6.65	-3.08	-13.03

Note: * denotes industries whose output is classified as non-tradable in the model.
Source: Author's computations.

In Table 13-IV, we select a few strategic industries for our analysis. For the selected industries, the local market contribution largely explains the reduction in overall output for all the industries. This highlights the effect of a drought in depressing overall demand for agricultural related commodities. This is largely driven by the effect of drought on output prices. Among the key export commodities, Beans registered the largest decline in exports demand of 16.9 percent, contributing 6.6 percent to the fall in overall industry output of 11.3 percent. Similarly, Maize had a drop in export demand of 9.5 percent, contributing 4.9 percent to its overall drop in industry output of 11.9 percent.

In terms of a shift from the usage of local output from domestic to imported, we see that a typical drought induces a decline in the usage of relatively expensive local output, thereby increasing the amount of imported versions of the good, except for Wheat. This could be explained by the fact that domestic Wheat production is limited coupled with a slight decline in aggregate imports which were not bolstered by the terms of trade gains. The demand for locally produced output declines, with the largest decline being for the manufactured output. This is explained by the cost of the intermediate agro-inputs as well as output declines which the manufacturing sector has to contend with in the production of its final outputs. In this case, the drought only compounds the constraints to the performance of the manufacturing industry. An outstanding feature of the results is the fact that the drought causes a reduction in demand for staple commodities, with Matoke, registering the highest decline (10.8%), followed by Potatoes (7.1%), Cassava (6.9%), Maize (5.2%), with Millet registering the lowest decline (5.1%). The results underscore the adverse effects which a drought causes to the domestic and external sectors of the economy. Domestically, and at a micro level, it is clear that household welfare gets compromised from output declines and the rising prices, especially of staple commodities. At a macro level, higher prices hamper exports which affect foreign exchange earnings. This is critical, given the fact that the bulk of Uganda's exports are agro-based.

In the foregoing analysis, it is also important to be mindful of the model limitations. Specifically, the UgAGE model assumes that producers are profit maximising price takers and that households have access to well-functioning markets. The reality in Uganda, as is indeed in most developing countries, is that there are high transaction costs in the agricultural sector, and limited access to credit markets. In practice, these are factors which can compound the impact of a drought on the economy. Such factors in turn curtail the adaptive capacity of an economy at micro level. In instances where multiple markets for goods which are produced and consumed by especially the agricultural households fail, production decisions become intertwined with consumption decisions (see De Janvry et al., 1991; Skjeflo, 2013). Cognisant of this reality, Löfgren and Robinson (1999) and Holden et al. (1999) have attempted to account for this inter-linkage in computable general equilibrium models of developing countries[20].

[20] These studies add a micro-simulation component which captures detailed welfare measures in their CGE models.

Given the increasing frequency and severity of drought, future studies should account for market imperfections, and risk within a dynamic framework. This is critical given the fact that microeconometric studies on adaptation to climate anomalies in sub-Saharan Africa have found that farmers are already using a wide range of coping strategies to deal with such shocks. Coping mechanisms include the use of drought resistant crop varieties, livestock, tree planting; soil conservation methods and diversification of their economic activities (see Below et al., 2010). However, empirical evidence still shows that adaptation is still constrained by certain factors, such as access to credit, property rights with respect to land, and irrigation (Deressa et al., 2009). In Uganda, less than 1 percent of the arable land is under irrigation.

Critical issues such as household adaptation through adjusting to changes in market prices are considered endogenous in computable general equilibrium modelling. Similarly, adaptation strategies such as adoption of drought resistant crop varieties, improved infrastructure and investment in irrigation, are not included in our model. A number of institutional and social structures which are critical to highlighting the true cost of a drought are not easily modelled using economy-wide techniques. Adger (2006) suggests that quantitative assessments such as the ones employed in this Chapter should be combined with qualitative studies that take into account much more complex social and institutional contexts in order to have a more comprehensive picture that more closely captures the actual cost of such shocks.

6 Conclusion and emerging policy issues

The UgAGE model used allows for the disaggregation of the impacts of drought through agricultural sector productivity losses. In this Chapter, we focused on the short-run economy-wide costs of a typical drought. However, it is possible that the costs of a drought can easily persist into the medium to long-term. In fact, as current climate trends suggest, the frequency and severity of drought is on the increase (IPCC, 2007). This implies that whereas a single drought episode might be short-lived, the increasing frequency can result in the effects of individual drought episodes overlapping, thereby presenting costs to the economy are both persistent and amplified.

The results from this study present critical lessons especially for developing countries that are dependent on agriculture as a source of food security, and export earnings, and still consider it as a base for industrialisation through agro-processing. As the findings indicate, this sector is sensitive to climate variability. Furthermore, as it is always the case, demand for staple crops is often inelastic, and agriculture still contributes to a large share of household income both directly and indirectly. In Uganda, a survey by the Uganda Bureau of Statistics (see MFPED, 2014) shows that 42 percent of the population derives part of their income from agriculture related activities, while 26 percent depend on agriculture as the only source of income. Our results are a further confirmation of the importance of this link.

Given the fact that the agriculture sector in Uganda is heavily dependent on smallholder rain-fed agriculture, it is vital to explore avenues for tapping into alternative sources of water for production. However, it is critical to note that the majority of households which heavily depend on agriculture are mostly poor. Therefore, interventions such as irrigation should focus on areas that are highly drought prone. In such areas, efficient water use practices such as small-scale irrigation have a high potential to alleviate the cost of a drought both at a micro and macro level.

In addition, irrigation should be adopted together with other land management practices that promote soil moisture conservation. This will help in converting more evaporation into transpiration thereby greatly increasing agricultural output without necessarily placing additional pressure on the existing water sources. The rural economy— the backbone of the agricultural sector needs further adaptation mechanisms in the face of more volatile climatic trends. Measures in addition to irrigation such as improvements in the financial, and risk-management infrastructure need exploration. These can be achieved by promoting education of rural households through climate information dissemination, and increasing non-farm income opportunities through access to credit. Current efforts towards reviving farmer Savings and Cooperative Societies (SACCOs) need deeper support and enrichment. Such measures among others would be fundamental for the development and uptake of new farming technologies that are risky, but productive.

Chapter Five

Water Taxation and the Double Dividend Hypothesis

Abstract

The double dividend hypothesis contends that tax policies which are aimed at protecting the environment can potentially yield other benefits for the economy. However, empirical evidence of the potential impacts of environmental taxation in developing countries is still limited. This may be partly due to the limited use of environmental tax policies in economic and environmental management in many of these countries. This Chapter seeks to contribute to the literature by exploring the impact of a water tax in a developing country context, with Uganda as a case study. Policy makers in Uganda are exploring ways of raising revenue by taxing environmental goods such as water. Whereas their primary focus is to raise revenue, this study is aimed at demonstrating how taxes on environmental goods can potentially yield other benefits beyond addressing a country's fiscal needs.

This study employs a computable general equilibrium model to shed light on the impact of a water tax policy when a tax is accompanied by a plough-back scheme of the same magnitude. We seek to establish whether a water tax policy that is accompanied by a revenue plough-back scheme can induce more growth, employment and industry output. Whatever the degree of regressivity resulting from the tax, it is possible to design a policy that benefits the economy. The policy was also checked for sustainability using a long-run water demand scenario. The results show that water demand remains more or less on the same trajectory and in fact, a higher level of dividends is realized.

Key words: Environmental Tax; Revenue plough-back; Double dividend; Economic growth
JEL Classification code: C68; H23; E62; Q52

1 Introduction

A number of developing countries are experiencing both economic and environmental challenges. Similarly, the ability for these countries to pursue their development goals is often inhibited by a lack of resources. This research investigates the possibility of designing a tax policy that is capable of minimising the costs of environmental regulation while achieving the economic objectives such as raising tax revenue (Yusuf and Resosudarmo, 2007; Fullerton et al., 2008). In this regard, a specially developed water CGE model (UgAGE-Water) is used to investigate the economic impact of a water tax on the economy.

Policy-makers are increasingly paying attention to environmental regulation through the use of economic instruments because of their potential to generate government revenues e.g., environmental tax receipts or the proceeds of auctioned emissions trading allowances. This has led to the need to develop a closer link between environmental policy and tax policy (Fullerton et al., 2008). This need is borne out of the recognition that on the one hand, the new government revenues may provide an opportunity for tax reform. On another hand, the availability of environmental taxes alters the constraints and costs of a prevailing tax policy. Specifically, the new taxes in addition to the existing ones may have a distortionary impact on the labour and capital markets.

In Uganda, water resources are increasingly becoming stressed in terms of quantity and quality. These strains are emanating from increased economic activity, population growth as well as changes in climate (Bates et al., 2008). Unfortunately, the current water pricing policy in Uganda is largely market-based. As such, it does not seem to adequately capture the full cost the increasing water scarcity as well as cost of delivering water supply to communities and industries. In this regard, we contend that a well-designed tax can induce efficient water use and also harness resources for financing the development and expansion of an efficient water supply infrastructure.

In line with the developments in the economic and environmental policy arena, this Chapter analyses the impact of a tax on water in a developing country context with Uganda as a case study. During the 2013/14 fiscal year, the Ministry of Finance Planning and Economic Development (MFPED) proposed to apply a Value Added Tax (VAT) on water. This tax measure was aimed at improving tax administration and generating revenue (see MFPED, 2013, page 44). Since the use of environmental tax instruments has not been a common policy measure in Uganda, the proposed intervention constitutes an interesting policy research issue and has therefore partly motivated this study.

The study is aimed at investigating the benefits of environmental taxation beyond revenue generation. It is critical to undertake a study that assesses the impact of such an intervention from an economy-wide perspective. First, empirical evidence suggests that taxes on water resources can yield multiple benefits for the economy if implemented on the basis of equity (see e.g., Rosegrant et al., 2002; Van Heerden et al., 2006; Letsoalo et al., 2007; Blignaut et al., 2008). However, the economy-wide impacts are most likely to vary depending on the context and cannot therefore be known apriori (EEA, 2011). In this regard, policymakers need to understand these impacts in order to balance between the need to maximise the aggregate gains from these tax reforms and the rights to equitable sharing of the associated costs and benefits.

Second, water resources are increasingly becoming stressed in terms of quantity and quality across the globe. These strains are emanating from economic activity, demographic trends as well as severe changes in climate (Bates et al., 2008; Tol et al., 2008). Projections indicate increased rainfall in high altitudes, and decreased rainfall in the low lying areas (IPCC, 2001). In addition, the increase in temperatures implies larger water demand and higher rates of evaporation, all of which combine to aggravate the problem. In Uganda, changes in climatic conditions are being experienced through increased rainfall volatility across seasons and rising temperatures (FEWSNET, 2012). These changes in climate have implications for future water resources availability with ramifications for poverty reduction, employment and food security (Rosegrant et al., 2007).

Whereas the adverse effects of these climatic changes have become central to the debate on issues of long-term global, social and economic stability, the policy interventions in Uganda do not seem to be paying adequate attention to the long-term impact of water resource availability from an economic point view. In fact, most of the existing studies on water resources in Uganda have focused mostly on hydrological aspects. This is despite the fact some of the country's economic challenges seem to be emanating from developments in the water sector (see MFPED, 2011, p.80). Amidst these challenges, Uganda has a substantial volume of water resources that could be utilised to mitigate the water related challenges in the economy. For instance, approximately 25 percent of the country's surface area is covered by fresh water lakes and rivers (DWRM, 2011). However, critical sectors such as agriculture are still rainfall dependent. This is largely because the existing infrastructure to ensure optimal water use is limited. It is therefore critical that measures are put into place to harness resources that can be used to finance the development and expansion of water infrastructure. In this regard, a tax on water may therefore be one of the options.

The framework for analysing interventions which are aimed at efficient management of water resources through taxation has its foundations in Pigou (1920). Proponents of the use of environmental taxes argue that they are efficient instruments not only for protecting the environment but for generating other benefits for the economy. This is referred to as "double dividends" in the literature. This study therefore seeks to add to the existing empirical evidence by assessing the possibility of the existence of "double dividends" in the case of Uganda. The hypothesis asserts that economies stand to gain from the imposition of environmental taxes through environmental conservation, revenue generation, employment, poverty reduction, and overall economic growth via the "revenue plough-back" effects. Pearce (1991) and Oates (1995) argue that an environmental tax has the likelihood of conserving the environment as well as generate revenue that can be used to reduce other distortionary taxes on employment, investment and consumption. In fact Schöb (2009) argues that tax related policy interventions are superior to other environmental policy instruments, such as command and control. In addition, there are other benefits that accrue if some of the realised tax revenue is invested in the provision of safe water. For example, the expansion of piped water infrastructure in Argentina during the 1990s reduced child mortality by 8 percent (Galiani et al., 2005). Other studies find that access to safe water reduces childhood exposure to pathogens in drinking water which may improve long-run health and educational outcomes (Venkataramani, 2009).

This Chapter therefore seeks to investigate the impact of a tax on water on the Ugandan economy because there is the need to investigate whether environmental taxes can generate positive impacts in a developing country. Whereas related studies exist, these are limited and have been undertaken in different contexts and motivations. Some studies have been undertaken for developed or upper-middle income countries (see e.g., Van Heerden et al., 2006; Letsoalo et al., 2007; Blignaut et al., 2008) for South Africa; Diao and Roe, 2003 for Morocco; Brouwer et al., 2008, and Pulido-Velázquez et al., 2008 for Europe). Other studies have focused their investigation on a global scale (see Berrittella et al., 2007; Tol et al., 2008) in their analysis of the impact of tax on water on production, consumption, and international trade patterns). Some focus on optimal water use in specific sectors (see Heerden et al., 2006; Blignaut et al., 2008; Wittwer, 2011) while others have been carried out under situations of water scarcity (see Letsoalo et al., 2007; Calzadilla et al., 2008; Calzadilla et al., 2010; Qin et al., 2012).

This study seeks to analyse the impact of an environmental tax first, with the view to assess its feasibility as a revenue generation tool. This is aimed at forming a basis for the future use of related policy instruments to generate revenue for the economy. Second, the study is aimed at investigating whether a tax is an effective instrument for environmental regulation to the extent that it can induce efficient water use. This is borne from the fact that while the country has sufficient water in the immediate term, projections show that it might not be the case in the long-term (see MWE, 2009). As water becomes scarce, interventions are needed to economize on its use. In most developing countries, the mechanisms for efficient utilisation of water are largely absent. These range from small scale and obsolete irrigation infrastructure to the low levels of water charges. These do not encourage efficient water use (Seckler et al., 1998; Tol et al., 2008). It is therefore argued that a tax would increase the price of water which in turn, would lead to the adoption of efficient ways of utilising it (see e.g., Dinar and Yaron (1992). Besides addressing the issues of distortionary taxes, the realized revenue would be used to meet the country‘s fiscal needs which among others, would allow for investment in developing the country’s water sector infrastructure. Currently, the sector’s infrastructural needs are financed from central government grants and external sources.

Third, some studies use partial equilibrium models in order to assess the impact of water resource policies on the economy see Rosegrant et al., 2002; Sahibzada , 2002; De Fraiture et al., 2004). These do not provide adequate analysis of issues whose impacts are bound to be economy-wide (Faust et al., 2012). Some studies use Input–Output models to analyse the impact of water resource policies on the economy (Delgado, et al., 1998; Hassan and Olbrich, 1999; Rose et al., 2000; Bautista et al., 2002; Juana and Mabugu, 2005). Whereas I–O models provide for a general equilibrium environment in which one can trace the multiplier effects in order to perform distributional impact analysis, these models lack the standard statistical properties (see Leontaritis and Billings, 1985; Duchin, 1992; Miller and Blair, 2009). In addition, the linearity assumption of basic input-output models and the absence of market and price considerations make them to be less favourable. Some studies assess the impact of policies using virtual water (Allan and Olmstead, 2003). Others use global models to assess the impact water resource policies on the economy (see Seckler et al., 1998; Alcamo et al., 2000; Yang et al., 2003; Berrittella et al., 2007). Given the aggregation and assumptions which are made when developing such models, their accuracy may be questionable. Those that use CGE models mostly focus on the impact of water resource policies on specific sectors of the economy (Decaluwé et al., 1999; Diao and Roe, 2003; Van

Heerden et al., 2006) or regions of the economy in some cases (see e.g., Goodman, 2000; Gómez et al., 2004).

In this Chapter, we use a CGE model that has been specially developed using Ugandan data to analyse the impact of a tax on water on the Ugandan economy. A specially developed computable general equilibrium model is used to investigate the economy-wide feedbacks and the welfare implications of the proposed tax intervention. The rest of the Chapter is organised as follows: Section 2 provides an over view of the developments in water sector in Uganda and the associated socioeconomic trends, Section 3 highlights the key issues in the literature with respect to the double dividend hypothesis, while the analytical framework and data issues are discussed in Section 4. Section 5 presents the setting of our policy scenario and model closure conditions while the results and discussion are presented in Section 6. Section 7 presents the conclusion and emerging issues arising from the study.

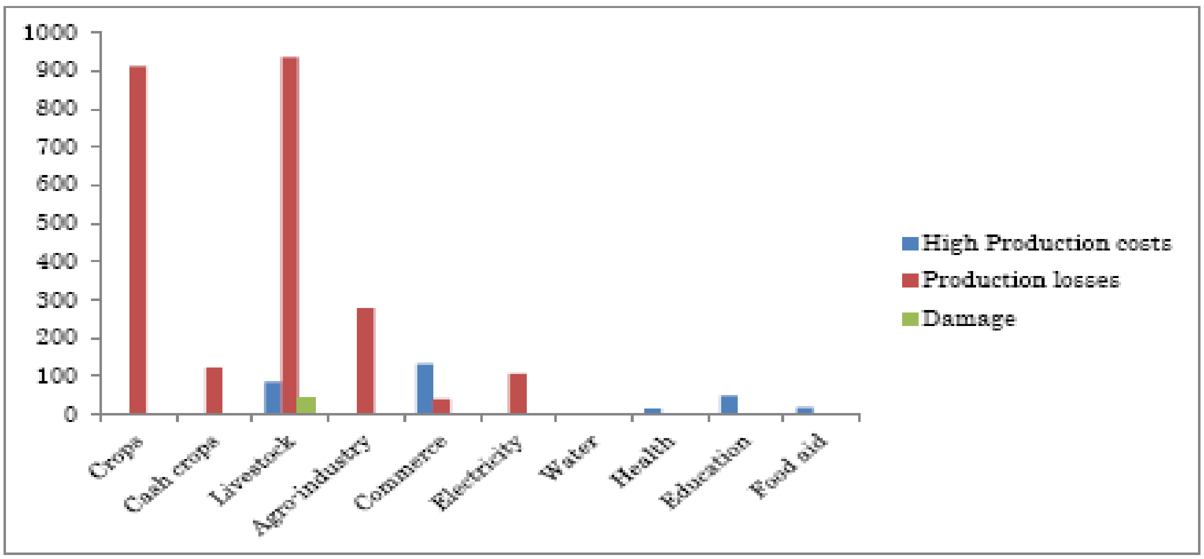
2 The water sector and Uganda's economy

Discussions of water issues regularly highlight the importance of water for food security and public health as well as its contribution to the transformation of agro-based developing economies. Water related policies have therefore become central on the agenda of the international community (Chumi and Dudu, 2008). For instance, among the targets for the Millennium Development Goals is MDG 7 which seeks to ensure environmental sustainability (United Nations, 2007). The target is to ensure "reduction by half, the proportion of people without sustainable access to safe drinking water and basic sanitation by 2015". Haller et al. (2007) in their study of the economic returns on investments in water supply and sanitation indicate that every US$1 spent on water supply and sanitation services yields an economic return of approximately 5 to 46US$, with the highest returns going to the least-developed areas. Much of this additional income accrues from the time saved by having reliable water supply close to the household (Hunter et al., 2010). Studies show that inadequate water supply is a contributor to many deaths in children under 5 years (Prüss and Havelaar, 2001; Fewtrell et al., 2005).

Studies also show that investment in water can induce a reduction in poverty (Hanjra and Gichuki, 2008). It can therefore be argued that adequate water and sanitation is an essential prerequisite for economic development. Poor countries with access to improved water have been cited to experience an average annual growth of 3.7 percent. On the other hand, countries with the same per capita income but without such access have an annual growth rate of only 0.1 percent (SIWI, 2005). In Uganda, water is central to supporting production across different sectors of the economy (MWE, 2009). In developing countries, constraints to water supply, whether for productive or domestic uses, are shown to have direct and adverse impacts on livelihoods (Grey and Sadoff, 2007; Hunter et al., 2010). This relationship between water resources and the economy is demonstrated by the Ministry of Water and Environment in an analysis of the effects of droughts on the agricultural sector (DWRM, 2011). In periods of drought, all crops in the nine distinct farming systems in the country experience a moisture deficit ranging from 128 to 251m^3 for perennial crops and 128–242 m^3 for non-perennial crops. Hence, any sustained period of drought can have adverse effects on the economy.

Several studies urge the need for investment in low-cost water harvesting techniques, irrigation, and clean water provision as a means of increasing food production and reducing the infectious disease burden (Rosegrant and Miejer, 2002; Sanchez and Swaminathan, 2005). In sub-Saharan Africa and south Asia for instance, access to a small amount of irrigated land has transformed food security for the highly vulnerable households (Mathew, 2005). In Uganda, consequences of the absence of low cost water harvesting techniques and irrigation are demonstrated by an assessment by the Office of the Prime Minister (OPM) which cites how rainfall deficits severely affect food security in the country. The decline in agricultural output presents a knock-on effect on food prices leading to further macroeconomic instability. The study by the OPM (2012) estimated that the value of damage and losses caused by the rainfall deficit was approximately US$ 1.2 billion equivalent to 7.5 percent of GDP in 2010. Figure 5-V highlights the losses which accrued from this shock. The adverse effects of the shock were highly felt in the productive sectors of the economy. A breakdown of the sectoral effects shows that the livestock sub-sector lost UGX1.1 trillion while the production of food and cash crops registered UGX1.0 trillion in damages and losses. There were losses in agro-industry of UGX278.0 billion; commerce lost sales of approximately UGX169.9 billion; while electricity production losses amounted to UGX106.3 billion. In addition, there were effects on other sectors such as sanitation, health care provision and nutrition assistance, education as well as food aid to the severely affected regions.

Figure 5-V: Sectoral damages and losses from the rainfall deficit (UGX Billions)



Source: OPM (2012).

Amidst these water related challenges, the country is endowed with a substantial amount of fresh water from the different sources which can be utilised to address some of the challenges. The total volume of renewable resources is estimated at approximately 43.3 billion m^3 (DWRM, 2011). With regard to surface water, there are eight major catchment areas which drain into other water bodies within and outside the country. According to DWRM

(2011), the estimated renewable groundwater resources exceed current projections of demand for domestic water supply by a substantial margin. This is with respect to areas which are not served under the piped water distribution network. Projections indicate that the sustainable utilisation rate for the year 2030 is below 15 percent for most areas (DWRM, 2011). However, these water resources experience both seasonal and spatial variability, a situation which is further being exacerbated by the volatile changes in temperature and precipitation. In fact, Carter and Parker (2009) note that groundwater resources are dependent on rainfall for replenishment and this makes them to be susceptible to climatic variability. Hence uncontrolled abstraction of water can present a danger of causing a fall in water levels and exhaustion of resources (Foster and Chilton, 2003).

Whereas Uganda receives a mean annual rainfall of 1200 m^3, the positive effects of this rainfall are eroded by the high rates of potential evaporation which is approximately 75 percent within the range of 1350–1750 m^3. This implies that in the absence of sustained rainfall, the ground water recharge capacity in most areas of the country is greatly affected. This is exacerbated by increasing temperature which adversely affects regions where rainfall intensity is less than potential evapo-transpiration. Worse still, effective utilisation of the existing water resources is curtailed by a mismatch between the location of the water resources and the regions where demand is high, notably the arid and semi-arid areas of the country (MWE, 2009). MacDonald et al. (2005) suggest that areas which, in addition to prolonged droughts and sparse populations have no reliable water supply, development of groundwater through natural reservoirs is the only realistic option for significantly improving water coverage. Once such instances of lop-sided availability of water resources are put into account, Kemp et al. (2005) argue that statistics on national water resources prove not to be a good indicator of water scarcity. Their view is that it is critical to have water resources (usually groundwater) close to the point of need. This calls for the need to develop the necessary infrastructure. MacDonald and Calow (2009) conclude that inadequate attention to the variability in the nature and occurrence of water resources is a key reason for having expensive and unreliable water supply. This implies that in the absence of the necessary infrastructure, such regions continue to suffer.

In Uganda, current per capita water consumption is still low. However, it is projected to rise gradually from the current 21 m^3 to approximately 30 m^3 per capita per annum by 2035. This implies that policies and infrastructure have to be put into place to ensure efficient utilisation of water resources. This is related to the fact that water sources across the globe are under threat from pollution through intensive agriculture, industry, and poor sanitation. The ramifications for developing economies are that since expensive water treatment is not affordable, the only option is for people to use contaminated water (Hunter et al., 2010). Table 14-V highlights Uganda's water demand projections by sector.

Table 14-V: Water demand estimates and projections (Millions m^3)

Sector	**2009**	**2015**	**2020**	**2035**
Domestic: NWSC	56	85	116	284
Domestic: Small Towns	24	35	47	111
Domestic: Rural	127	210	306	588
Livestock	107	151	164	211
Crops	335	489	452	676
Fisheries	52	105	157	210
Rural Industries	5	19	23	33
Total water demand	**707**	**994**	**1,266**	**2,113**
Available water Percapita (m^3)	2,171	1,740	1,480	896

Note: NWSC stands for National Water and Sewerage Corporation. This is a Government Parastatal charged with the supply of commercial water in the country.
Source: MWE (2009).

The role of water as a vital economic resource is not in doubt. However the debate is on the best policy to ensure its efficient use. There are two schools of thought on the economic value of water (Perry et al., 1997). One school argues that water should be allocated to its best uses by being priced at its economic value. In addition, it should be allocated through competitive markets. Using the market theory, the value of a commodity is the maximum amount which users are willing to pay for it such that in equilibrium, the marginal cost and marginal benefit are equal (Briscoe, 1996; Perry et al., 1997). Another school of thought maintains that water should not be left to market forces because it is a basic human need.

However, the current challenges faced by water resources underscore the need to ensure their efficient utilisation. In this regard, the current study is motivated by the challenges faced by water resources to argue that water should be utilised in a framework that accounts for its economic value, while still ensuring that it is being equitably accessed.

2.1 Tariff levels and pricing policy

Water pricing policies are important instruments to achieve national and regional goals. In this regard, users should pay a fair price for water in order to reflect its value to society as a scarce resource. For the case of Uganda, the legal framework for the provision of commercially distributed water provides for such measures. According to Statutory Instrument 2002 No. 23,

> *"NWSC Water and Sewerage rates shall be subject to annual indexation against the domestic price index, exchange rate, foreign price index and electricity tariff so as to maintain real value of the tariff".*

However, the tariff structure in the country has largely been based on affordability and uniformity across the country while ensuring cost recovery (DWD and WWAP, 2006). As a consequence, the tariff levels and structure have not been adequate for system expansion as they only cover operational and maintenance costs. Major investments in the sector's infrastructural improvement and extension are currently being financed by direct transfers from government and support from development partners. This trend is likely to continue until revenue mobilization reforms are undertaken within the water sector in order to generate revenue and ensure efficient water resource utilisation. The realization of cost recovery in terms of operation and maintenance, depreciation as well as investment would require an increase in tariffs. Table 15-V shows the evolution of the tariff structure for commercially supplied water in Uganda.

Table 15-V: National Water and Sewerage Corporation tariff structure (UGX/m^3)

Customer category	Old Tariff 2004/05	Adjustment 2005/06	Adjustment FY2006/ 07	Adjustment 2007/08	Adjustment 2012 to date
Public Standpipe	521	568	688	784	1,236
Domestic	806	879	1,064	1,213	1,912
Institutions / Government	993	1,082	1,310	1,493	2,353
Commercial <500m^3/m	1,379	1,4622	1,716	1,931	2,887
Commercial 500 – 1500m^3/m	1,421	1,462	1,716	1,931	2,887
Commercial >1500m^3/m	1,324	1,324	1,496	1,601	2,307

Source: NWSC (2014).

Due to the rising operational costs, the NWSC increased the tariff rates based on the policy of tariff indexation in response to a 69 percent increase in the electricity tariffs in 2012. From Table 15-V, it is evident that there was a significant increase in the tariff level compared to the previous years. In addition, the NWSC uses a rising block tariff structure for commercial consumers to ensure efficient water use. However, the tariff level still needs adjustment in order to ensure efficient water use and revenue generation for infrastructural expansion. Structurally, the tariff is higher for the commercial consumers and lower for the domestic consumers with the lowest being for bulk sale at stand taps. However the poorer households which inevitably use these stand taps generally end up paying more for the water collected due to their high operational costs.

2.2 Institutional framework for water resources management in Uganda

The management of water resources is under the Ministry of Water and Environment (MWE). This function is enshrined in the Water Act (Cap 152) of the Constitution of the Republic of Uganda (MWE, 2009). The MWE is charged with the planning and coordination of all sector activities with the overall mission of “promoting and ensuring the rational and sustainable utilisation, development and effective management of water and environmental resources for the socio-economic development of the country”. The MWE is therefore tasked with setting national policies and standards, managing and regulating water resources and determining priorities for water development and management. It also monitors and evaluates sector development programmes to keep track of their performance, efficiency and effectiveness in service delivery (MWE, 2009).

The Ministry has the following directorates: Directorate of Water Resources Management, Directorate of Water Development (DWD) and the Directorate of Environmental Affairs (DEA). In addition, there are agencies such as the NWSC whose role is to supply commercial water. The agency derives its legal mandate from Decree No. 34 of 1972 and later from the National Water and Sewerage Act enshrined in the (1995) Constitution of Uganda. This agency is charged with improving water and sanitation services in the country on a commercially viable basis (NWSC, 2011). Accordingly:

> *Using the New Economic Order Model (NEO) which was introduced in 2011 as a planning tool premised on the principle of demand and supply of water, the agency seeks to achieve equilibrium between effective demand for our services by ensuring that the customer is adequately and efficiently served, while ensuring optimization of resources.*

It is clear that the NWSC's model is geared towards ensuring efficiency in the commercial provision of water. In fact, the approach is in line with the existing evidence on the estimated potential welfare gains from improvements in the quality of water service such as reducing variability or interruptions in the water delivery schedule (Olmstead, 2010). This has been established to be the case for both developing (Baisa et al., 2010) and industrialized countries (Hensher et al., 2005). It is therefore vital that one of the interventions of the NWSC should be to ensure that water pricing is based on supply cost recovery and full economic cost (Letsoalo et al., 2007).

3 Literature review

Measures to introduce environmental taxes may face opposition as these taxes could potentially have adverse affects on employment and the competitiveness of national industries. However, the rationale behind environmental taxation is to increase welfare. The benefits may be hard to quantify and are often realized over a long period. It is against this background that the double dividend theory has become central to investigating the impact of environmental taxes on the economy. According to this theory, the revenues from the realized taxes can be used to lower other (distortionary) taxes. In that case, an environmental tax may not result in an extra tax burden following its imposition. In fact, a tax my yield positive effects on output and employment as a results of lowering other taxes.

In this section, we highlight the existing literature on the double dividend hypothesis. The review is not exhaustive as it is only aimed at indicating the nature of the debate surrounding the double dividend hypothesis (see Shackleton et al., 1993; Goulder, 1995; Bosquet, 2000; Ekins and Barker, 2001; Tol et al., 2008; Schöb, 2009; Fullerton et al., 2010; Katri, 2012 among others, for extensive reviews on the subject). In addition, it is aimed at providing a context for this Chapter. In the literature, some authors suggest that measures to address changes in the environment should be designed to use policy instruments that raise revenues. This is because the resulting revenues can be used to generate other benefits for the economy.

Since Pigou (1920), it has been widely accepted that environmental taxes are efficient instruments for environmental protection. In addition, they are found to be superior to other policy instruments like command and control. The arguments in favour of taxes on environmental goods have their foundations in the double dividend theory. According to the theory, revenue generated from the imposition of environmental taxes can be used to lower other would be distortionary taxes. In so doing, the economic cost of the environmental tax is lowered thereby resulting into benefits for the economy (see Tullock, 1967; Nichols, 1984;Terkla, 1984; Lee and Misiolek, 1986; Van Heerden et al., 2006; Letsoalo et al., 2007;

Brouwer et al., 2008; Tol et al., 2008; Katri, 2012, and Zhou and Segerson, 2012 among others). The major implication of the double-dividend theory is that if there is consensus about an environmental target, revenue-raising instruments are preferred to other policy instruments which, although cost-efficient in regulating the environment, do not raise public revenues (Schöb, 2009). Realization of the double dividend is in terms of the environment (first dividend) and the economy (second dividend) which are envisaged to improve following the imposition of the tax (Letsoalo et al., 2007).

Goulder (1995) develops two versions of the double dividend hypothesis: the strong and the weak form of the double dividend. The weak form requires a revenue-neutral environmental tax reform to plough-back the additional revenues in order to reduce the economic costs of the tax compared to the case where those revenues are ploughed-back as a lump-sum. On the other hand, the strong form version requires that environmental tax reform to not only yield environmental gains but also non-environmental welfare (Rausch and Reilly, 2012). Economic analysis demonstrates the potential benefits of ploughing back revenue from an environmental tax. Specifically, such a tax can be used to offset other taxes thereby reducing the potential cost of the policy. Under certain circumstances, it can boost economic welfare (Goulder, 1995). However, Zhou and Segerson (2012) demonstrate that depending on the size of the tax base, environmental taxes may be efficient instruments for improving environmental quality, but not necessarily a better way to raise revenue.

Several studies use different approaches to check for the existence of the double dividend hypothesis in many different contexts. Bovenberg and De Mooij (1994) use a simple one factor model which assumes competitive markets and find that environmental taxes exacerbate, rather than alleviate the pre-existing tax distortions. Fullerton and Metcalf (1997) and Goulder et al. (1997) show that increasing a narrow-based green tax and reducing a broad-based tax say on labour income would be distortionary. This implies that the revenue-plough-back effect may not fully offset the negative effect of the environmental tax on employment. This would be the case even when the revenue is used to reduce the tax rate on labour income.

The literature highlights the fact that whereas a strong double dividend is possible, it not may not always be guaranteed. In fact, it depends on a number of factors which among others include the existing tax rates; elasticities as well as the level of inefficiency of the tax system (see Goulder 1995; Van Heerden et al., 2006; Bento and Jacobsen, 2007; Katri, 2012; Zhou and Segerson, 2012). In the case of an environmental tax that targets water as a factor of production, substitution elasticities between factors are critical. The fixed factor, capital should be a poor substitute for the water, while labour should be a good substitute. With an elastic supply of capital, the converse is true (see De Mooij and Bovenberg, 1998). This efficiency gain has to be large enough in order to offset the negative impacts that are inherent in environmental taxes. The broader is the tax base, the lower is the distortion. Goulder (1994) asserts that environmental taxes are usually narrow because they are meant to change specific behaviour.

Goulder (1995) and Bovenberg and Goulder (1997) use a general equilibrium model and fail to find evidence of a double dividend. In all their scenarios the environmental tax is found to be more distortionary than the substitute taxes and they attribute this finding to the relative narrowness of the environmental tax. For instance, Goulder (1995) finds that the economic cost of environmental taxes would be in excess of 35 percent if the revenues are ploughed-back across the board rather than in a targeted manner to reduce other distortionary taxes. On the other hand, Jorgenson and Wilcoxen (1993) do find a double dividend under certain conditions. Irrespective of the end result, the costs or benefits of the tax reform were found to vary with the scenario chosen. However, they were in line with the expectations of Goulder (1994). That is, the lower are the costs, the larger are the differences in Marginal Excess Burden (MEB) and the more the tax burden was shifted from the overtaxed to the under-taxed factor.[21] Zhou and Segerson (2012) utilise the framework by Bovenberg and de Mooij (1994) to assess the viability of using environmental taxes to finance budget deficits in the US state of Connecticut. They find that due to the narrowness of the tax base, environmental taxes have limited potential to raise revenue to finance the fiscal deficits and/or reduce other distortionary taxes. Nonetheless, they note that such taxes can still generate significant gains for the economy if they lead to significant improvements in environmental quality.

The analysis of the double dividend hypothesis besides revenue mobilization involves the redistribution of income in the economy. Worth noting is the fact that the process results in the deviation of the tax mechanism from its optimal level.[22] Therefore, the distributive impacts of environmental tax reform need to be studied in much detail. There are studies which have looked at the distributive component of environmental taxation (see Blignaut et al., 2008; Chiroleu-Assouline and Fodha, 2006; Chiroleu-Assouline and Fodha, 2009; Letsoalo et al., 2007; Tol et al., 2008; Van Heerden et al., 2006). The findings suggest that the distributional impact of the tax depends on the specific form of the tax reform and how it is implemented. The suggestion of shifting the tax burden to the unemployed or those working in the informal sector to increase employment as is in Bovenberg and Vander Ploeg (1998) has the potential to adversely affect income for the lowest income groups.

From the existing literature, it is clear that the double dividend hypothesis has been analysed using different methodologies, assumptions, and measures. It is therefore not surprising that these studies yield mixed results. For instance, studies in the developed countries tend to find a positive second dividend when employment is used as a benchmark and modest positive or negative effects on output (see e.g., Ekins et al., 2011; Ekins and Barker, 2001; Bosquet, 2000; Patuelli et al., 2005; Lutz and Meyer, 2010; Moe, 2010). However Schöb (2009) fails to find evidence of the strong form of the hypothesis in his study of the United Kingdom.

[21] See Goulder (1994) for a thorough exposition on the adjustment mechanism.
[22] In the absence of externalities it would be optimal to have a lump sum tax.

Empirical studies in the U.S have found that when revenue from environmental taxes is used to reduce pre-existing taxes, the gross cost of the tax system increases, i.e., the strong form of the double dividend hypothesis does not hold (Zhou and Segerson, 2012). Goulder (1992) finds that welfare is reduced by 0.48 percent when the environmental tax is used to reduce the corporate income tax and by 0.53 percent when used to reduce the personal income tax. Furthermore, Goulder (1995) reviewed some empirical studies based on different models and found that a tax swap resulted in a welfare loss for most models except the Jorgenson-Wilcoxen model (see Zhou and Segerson, 2012).

For the developing countries, some studies find evidence of the hypothesis in its strong form, but add a caveat that the design and implementation of such interventions is critical. For instance, Van Heerden et al. (2006) use a CGE model to investigate of the plausibility of achieving a double dividend through a tax on water and energy and plough-back the revenue back into the economy. They find that it is possible for such interventions to yield double dividends. Other studies with closely similar findings include Decaluwé et al. (1999); Diao and Roe (2003); Bluffstone (2003); Letsoalo et al. (2007) and Blignaut et al. (2008). In fact Sartzetakis and Tsigaris (2009) note that environmental tax reform may reduce involuntary unemployment. With regard to equity, such reforms can adversely affect the income distribution, thereby reducing the possibility of achieving a second dividend.

From the literature, it can be concluded that achieving a double dividend from an environmental tax is possible but it is not obvious. The initial conditions in terms of the existing taxes, possible distortions in the labour market, together with the specific nature of the tax intervention are key determinants of the outcome of any such policy measure. Therefore, the design of the tax intervention should clearly be well thought out, with attention being paid to the pre-existing distortions (Letsoalo et al., 2007). In fact, interventions that are designed to yield multiple benefits i.e., additional dividends (say poverty reduction) require more detail with respect to their policy design. Spratt (2012) in a scoping study of environment taxation in developing countries concludes that limits to the effectiveness of environmental taxes become more severe as the number of policy goals increase. He asserts that achieving "double dividends" may be hard and triple dividends even much harder.

4 Methodology

This study employs the Uganda Applied General Equilibrium (UgAGE) model to evaluate the economy-wide impact of potential water tax scenarios in Uganda. The theoretical structure of UgAGE is based on the ORANI-G model documented in Horridge (2001) with various add-ins to facilitate the detailed modelling of water accounts in the country. In this version of UgAGE, we use an aggregated 13-sector database. The model is implemented in GEMPACK and solved using Euler's multi-step solution technique.

Applied or computable general equilibrium models provide industry-level disaggregation in a quantitative description of the whole economy and typically postulate neo-classical production functions and price-responsive demand functions, linked around an input-output matrix in a general equilibrium model that endogenously determines prices and quantities. As required by GEMPACK®, an initial levels solution of the model is represented by the base year data. The theory of the model is then, essentially, a set of equations that describe how the values in the model's database move through time and move in response to any given policy shock. For any given exogenous policy shock, the results produced by the model represent changes or percentage changes away from an unperturbed projection of the economy and its structure, represented by the base year data.

Following the ORANI-style of implementing a CGE model, the general equilibrium core of UgAGE is made up of a linearized system of equations describing the theory underlying the behaviour of participants in the economy. It contains equations describing, amongst others: the nature of markets; intermediate demands for inputs to be used in the production of commodities; final demands for goods and services by households; demands for inputs to capital creation and the determination of investment; government demands for commodities; and foreign demand for exported goods.

The specifications in UgAGE recognize each industry as producing one or more commodities, using as inputs combinations of domestic and imported commodities, different types of labour, capital and land. The multi-input, multi-output production specification is kept manageable by a series of separability assumptions. This nested production structure reduces the number of estimated parameters required by the model. Optimising equations determining the commodity composition of industry output are derived subject to a CET function, while functions determining industry inputs are determined by a series of nests. At the top level, intermediate commodity composites and a primary-factor composite are combined using a Leontief or fixed-proportions production function. Consequently, they are all demanded in direct proportion to industry output or activity. Each commodity composite is a CES function of a domestic good and its imported equivalent. This incorporates Armington's assumption of imperfect substitutability for goods by place of production (Armington, 1969).

The primary-factor composite is a CES aggregate of composite labour, capital and, in the case of primary sector industries, land. Composite labour demand is itself a CES aggregate of the different types of labour distinguished in the model's database. In UgAGE, all industries share this common production structure, but input proportions and behavioural parameters vary between industries based on available base year data and econometric estimates, respectively. In this regard, the model parameters used in our analysis are derived from the IFPRI model for Uganda (see Dimaranan et al., 2006), in addition to other relevant studies in the literature (see Hertel et al., 2007; Boysen and Mathews, 2012; Boysen, 2012; Roos et al., 2014) and informed by the author's knowledge of the Ugandan economy. Those sets of parameters include: (1) The Armington elasticity between domestic and imported commodities; (2) Export elasticities; (3) Elasticity of substitution among labour types (or skills); (4) Elasticity of substitution among primary factors; (5) CET transformation for industries with multiple commodities; (6) Expenditure elasticity for the LES household demand system; (7) The Frisch parameter (elasticity of marginal utility of income) and (8) The Armington elasticity for investment.

The demand and supply equations in UgAGE are derived from the solutions to the optimisation problems which are assumed to underlie the behaviour of private sector agents in conventional neo-classical microeconomics. Each industry minimises cost subject to given input prices and a constant returns to scale production function. Households maximise a Klein–Rubin utility function subject to their budget constraint. Units of new industry-specific capital are constructed as cost minimising combinations of domestic and imported commodities. The export demand for any locally produced commodity is inversely related to its foreign-currency price. Government consumption, typically set exogenously or linked to changes in household consumption, and the details of direct and indirect taxation are also recognised in the model. Zero pure profits are assumed for all industries.

The model's database is based on the 2009 SAM for Uganda published by UBOS. In the SAM, households are categorized into 4 regional groups by rural-urban and by income quintiles. In all, there are 39 industries and commodities. However, these were aggregated into 13 sectors to facilitate our analysis. This is in addition to splitting electricity and water into two industries. Water data (DWRM, 2012; FAO, 2005) are drawn from the relevant departments under the Ministry of Water and Environment in order to create a vector of taxable water for each industry in the SAM as well as a vector of extra water charges that may be charged on volumes of water. All taxable water is derived from ground and surface water data.

Next, we add a water revenue equation into the UgAGE model to enable us to calculate changes in total revenue raised and changes in water demand. It is derived from the identity that total revenue raised R is equal to the tax rate T per volume times the quantity of water X. That is:

$$R = T.X \tag{1}$$

All model equations are expressed in percentage change form. The model is linearised in order to allow for solving. From equation (1), the change in revenue dR is approximately equal to the tax rate T times the change in the base dX plus the base X times the change in the rate dT. Formally:

$$dR = T.dX + X.dT = T.X.x/100 + X.dT = R.x/100 + X.dT \tag{2}$$

with x being the percentage change in X If x is the percentage change in X, then we know that $x = 100 * dX / X$, such that $dX = x.X/100$. Equation (2) is used in our model to calculate the changes in revenue received from charges on water consumption by all industries. The changes in the tax rates are exogenous. In addition, they are shocked according to various scenarios outlined in Section 5. All the other variables are either entered into or they are computed by the model. Note that the variable x is the percentage change in water consumption by industries and it is endogenous. Put differently, x is computed by the model. We expect that an additional charge on water will lead to a decrease in water consumption. Total revenue from the extra water charges will be added to total government revenue.

5 Policy scenarios

In this section, we employ different taxation and plough-back scenarios to assess the distributional effects of a water tax. This involves levying a tax and establishing the appropriate channels through which the realized tax revenue can be utilised in order to yield dividends for the economy. The simulation scenarios employed are in line with the policies of the Ministry of Finance Planning and Economic Development of revenue mobilization. Similarly, they are related to the vision of the Ministry of Water and Environment and the water distribution agency (NWSC) of improving water and sanitation services in the country on a commercially viable basis. Whereas the critical policy issues include revenue generation and provision of water at market rates we use simulation scenarios which reflect the fact that issues of access and affordability are equally important.[23] The charges for some sectors of the economy particularly the households majority of which are poor, should not be at a level where they are left without access to safe water (Spratt, 2012).

Cognizant of the issues of affordability and access, the following scenarios were simulated using the UgAGE model. A tax of UGX500 (US$20cents per m^3) on water used by the following industries: i) Mining; ii) Manufacturing; iii) Construction; iv) Agriculture; v) Business; vi) Hotels and restaurants; vii) Other services.[24] The choice of sectors was informed by their ability to pay as well as the degree of water use in their production activities. Industries with less water use in their activities were left out. In terms of plough-back, three simulations were performed: a) a decrease in production taxes on capital and labour; b) a decrease in sales taxes, and a decrease in taxes on exports.[25] The choice of the plough-back schemes was informed by the fact that the reduction in the level of taxation to factors of production would induce economic activity via production while a sales tax break would drive economic activity via consumption. The third policy option was chosen because Uganda is a small open economy and taxes on water could be harmful on the traded sectors.

5.1 Policy variables

Four variables of interest are analysed in the model. These include changes in: a) water use; b) GDP; c) employment; d) industry output. The variables are expressed in "per unit of government revenue" so that the different policy scenarios are comparable. These variables presented in the next section as changes in water consumption per billion shillings in

[23] See e.g., Gowlland-Gualtieri (2007) for a contextualized exposition of how issues of sustainability and equity in the provision of water are implemented in South Africa.
[24] Includes water used by households.
[25] We would like to thank one of the referees of this paper for this suggestion.

government revenue; Percentage change in real GDP per billion shillings of revenue collected or ploughed-back; Percentage change in aggregate employment per billion shillings of revenue collected or ploughed-back; and changes in industry output.

5.2 Model closure

In order to analyse the impact of a water tax on water use and the economy as a whole, the effectiveness of such a policy measure has to be assessed on how sustainable it would be with respect to the use of water resources. In this regard, the model closure rules have been set to account for policy sustainability using the long-run time horizon.[26] Results from the policy measures for both long-run and short-run closures are presented in Section 6. Under the short-run closure conditions, capital stock in each sector is exogenous, while the rates of return on capital, aggregate employment and trade balance are endogenous. The trade balance is set to be endogenous because it is possible for the economy to run a deficit on the external sector in the short-run. In addition, aggregate investment, the composites of GDP from the expenditure side (private and public consumption), real wage rate, all technological change variables and all tax rates inventories are exogenous. Furthermore, the reader is invited to note that the both closure conditions set all technological change variables and all tax rates and inventories are exogenous in both closures.

Under the long-run closure rules, the income side of GDP is set such that labour supply (aggregate employment) is exogenous at its full employment level (i.e., not to be driven by policy but by demographic factors). This is in line with the fixed non-accelerating inflation rate of unemployment (NAIRU) in the long-run (Bohlmann, 2011). The real wage rates are endogenous as they are considered to be flexible in the long-run since wage contracts are periodically renegotiated. By absorbing any demand-side pressure via changes in real wages, the labour market is allowed to clear. Similarly, capital stock is endogenous in order to reflect

[26] See Dixon et al. (1982) and Bohlmann (2011) for a thorough description of the technical details behind the structure of CGE models.

changes in net investment in the long-run while the rate of return on capital is exogenous. This is because the factors which influence long-run rates of return such as interest rates and risk premiums are relatively stable and unlikely to be affected by policy interventions. Using the DPSV rule, sectoral investment is constrained to follow capital.

From the expenditure side of the economy, household consumption is set to closely follow GDP in the long-run. Similarly, government consumption and imports are expected to follow household consumption and they are endogenous. This implies that both the average propensity to consume and the ratio of private to public consumption are exogenous. Exports are determined as a residual to balance GDP from the expenditure side with GDP from the income side. In order to cater for the macro-environment in the closure i.e., the relationship between the domestic economy and the rest of the world, the dynamics of a small open economy are employed. In this regard, changes in the domestic demand and supply conditions have no effect on the rest of the world prices. Therefore, exports and imports prices are exogenous. Under the short-run closure, we set the trade balance to be endogenous on the belief that, it is possible for the economy to run on deficit on the trade account in the short-run. However, since no country can run on a trade deficit indefinitely, it is only natural to fix the trade balance over time. Hence, the trade balance is set to be exogenous under the long-run closure. Finally, our numeraire is the nominal exchange rate.

6 Results and discussion

6.1 Macroeconomic level results

In this Chapter, three sets of simulations are carried out using the using the modified UgAGE model. The first set of simulations is an imposition of a UGX500 (US$20 cents per m^3) tax on commercially supplied water (Pearce, 1991). The imposition of a tax is expected to generate government revenue. In our modelling framework, the imposition of a tax is accompanied by three revenue plough back schemes on sales, production taxes and export taxes such that the overall policy change is revenue neutral. This is done for both long-run and short-run closure conditions for the selected industries. Table 16-IV presents macro level results from the tax simulations and revenue plough back schemes of the proposed policy interventions. The modelling framework is applied to show results from the different policy mixes. The linearity property of the model allows the percentage changes for particular shocks to be summed up in order to yield the total effect.

The analytical process evolves as follows: when a tax is levied, (i) taxes increase the cost of production and therefore decrease the supply of most commodities (the "price interaction effect"), while (ii) the increase in government revenue without a concomitant increase in government expenditure decreases aggregate demand. Since both capital and skilled labour face inelastic supply in the short-run, the fall in aggregate demand causes a significant reduction in price levels and a decline in real GDP. This leads to a decline in the volume of taxable water used. The increase in domestic prices leads to a decline in exports of most commodities and an increase in imports. The plough-back schemes work in the opposite direction.

Table 16-V: Results of main macro variables (Percentage changes)

	Environmental tax		**Revenue plough-back scheme**					
	Water tax		*Sales tax*		*Production tax*		*Export tax*	
Variables	S-R	L-R	S-R	L-R	S-R	L-R	S-R	L-R
Agg revenue ploughed-back	5.04	-2.49	-219.3	-219.6	-219.7	-219.4	-219.4	-219.7
Aggregate revenue generated	219.74	219.65	0	0	0	0	0	0
Aggregate employment	-0.36	0	0.25	0	0.35	0	0.66	0
Terms of trade	0.35	0.09	-0.41	-0.51	-0.36	-0.22	-2.07	-2.88
Consumer price index	0.33	0.11	-0.43	-0.47	-0.29	-0.14	0.48	0.44
Exports prices	0.35	0.09	-0.41	-0.51	-0.36	-0.22	-2.07	-2.88
Nominal exchange rate	0	0	0	0	0	0	0	0
Real wage	0	-1.13	0	1.06	0	2.74	0	2.76
Real GDP	-0.15	-0.14	0.11	0.23	0.16	0.61	0.29	0.52
Export volume index	-0.51	-0.24	0.53	0.65	0.45	0.10	2.14	2.78
Imports	0.11	-0.13	0.04	0.002	-0.18	0.04	0.62	-0.01
BOT contribution to real GDP	-0.15	-0.01	0.11	0.15	0.16	0.01	0.29	0.63
Capital stock	0	-0.34	0	0.48	0	1.22	0	1.03
Aggregate primary factor use	-0.17	-0.16	0.12	0.22	0.16	0.56	0.30	0.48
Aggregate real investment	0	-0.33	0	0.51	0	1.26	0	1.17
Real household consumption	0	-0.06	0	-0.04	0	0.36	0	-0.41
Real government demands	0	-0.06	0	-0.04	0	0.36	0	-0.41
Aggregate real inventories	0	0	0	0	0	0	0	0
Volume of Taxable Water	-12.37	-12.36	0.11	0.13	0.141	0.24	0.22	0.17

Notes: S-R: Short-run; L-R: Long-run.

Source: Author's computations.

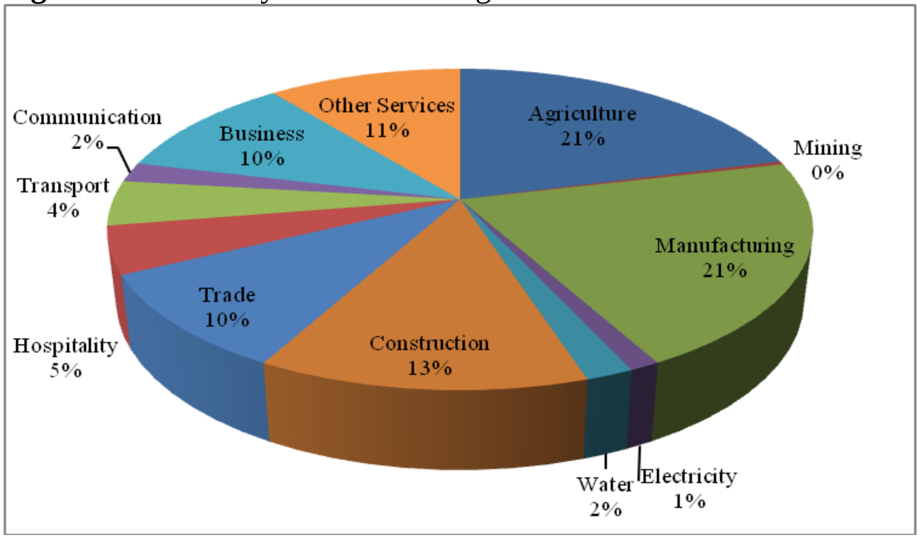
The focus of the analysis is mainly on the sustainability of the proposed intervention with regard to economic performance as well as water resource use. In this regard, the interpretation and discussion of results pays more attention to the results from the long-run closure. On the issue of sustainability, the policy is sustainable with regard to its water use. From Table 16-V, the reduction in water use following the imposition of the tax is larger than the increase in water use following the revenue plough-back process. In fact, the trajectory of water consumption is more less the same in both closures.

With the imposition of a tax, prices rise, leading to a decline in exports and an improvement in terms of trade in the long-run. Furthermore, real wages decline by 1.13 percent, investment, imports decline as well due to the reduction in domestic demand. This leads to a decline in real GDP. Conversely the plough back of the generated revenues leads to a decline in prices. With aggregate employment fixed, the increase in demand following a tax plough-back scheme raises real wages. However, the increase is real wages is higher under the export tax plough back scenario (2.76 percent) compared to the 1.1 and 2.64 percent under the sales tax scenario and production tax scenarios. Aggregate investment increases and as well as factor use. A fixed rate of return allows capital stock to increase by 0.48, 1.22 and 1.03 percent under sales tax, production tax and export tax schemes respectively. Private and public consumption increases under the production tax scenario but not under the sales tax.

The increase in components of aggregate expenditure leads to different levels of increase in real GDP for the three revenue plough back schemes. The production tax scheme represents a more optimal policy intervention for the macroeconomy in the long-run with a desirable increase in real GDP of 0.6 percent compared to the 0.22 and 0.52 percent under the sales tax and export tax breaks, respectively. This difference in performance could be attributed to the channels though with the three taxes affect the components of aggregate demand. For instance, the sales tax is more thinly spread across intermediate inputs, investment, households, individual and collective exports and on sales to government. This is in stuck contrast with the production tax which is only directed towards production activities, thereby having a higher positive impact. Despite the increase in real wages, the plough back schemes result in decline in export prices and an increase in export volumes. The price reduction induces a decline in terms of trade. However, the contribution of the trade balance to real GDP is positive in all the three plough-back scenarios.

A critical analysis of the three plough-back schemes shows that sales tax produces fewer gains with percentages in the key macroeconomic aggregates being lower or negative than the production tax. For instance, private and public consumption declines marginally by 0.04 percent compared to a gain of 0.38 under the production tax scheme. Investment increases by 0.51 percent compared to 1.3 percent under production taxes. Overall, the effect on the economy of the imposition of a tax and plough-back of the resulting revenue is sustainable. From the macro level, the tax induces a reduction in water use under both short-run and long-run time horizons. The resulting increase in water consumption following the revenue plough-back is less than the initial decline and yet the effect of the plough-back on the economy is positive in terms of increasing real GDP. In order to put the subsequent analysis into perspective, Figure 6-V highlights the industry shares in the UgAGE model used. From the figure, agriculture and manufacturing constitute the largest shares according to the industry break down in our model. It is important to note that whereas agriculture is a larger industry relative to the rest, the combined effect of the rest of the industries outweighs that of agriculture depending on the scenario under consideration.

Figure 6-V: Industry shares in the UgAGE model



Source: Authors.

6.2 Environmental effects

In analysing the environmental effects of the tax (first dividend), changes in water use are divided by changes per unit of tax revenues in real terms. The results are presented in Table 17-V where a tax reduces water use, implying that for all the simulations, changes in water use following a tax yield the first dividend for the different industries. In addition, all three plough-back schemes yield an environmental dividend. This implies that the environmental benefits associated with the reduction in water use are realized irrespective of the channel through which the collected revenue is ploughed back into the economy. Essentially, the first dividend is confirmed to exist under the plough-back schemes only if there is a net reduction in the amount of water used per unit of real government revenue ploughed back. From the results, we see that a tax on water consumption always leads to a decrease in water use under the two time horizons (Table 17-V, column 2 and 3). Whereas water consumption increases following the revenue plough-back process, this increase is less than the initial decrease in water use following the tax (column 4–9) hence an environmental dividend.

From the table, a tax on agriculture results in a decrease in water consumption by the sector of 0.0201 percent per UGX1 billion of realized tax revenue. All changes in water consumption are expressed in terms of percentage changes per UGX1 billion of revenue collected. On the other hand, a sales, production tax or export break through plough-back increases economic activity. As a result, more water is consumed. For example, a sales tax break increases water consumption by 0.002667 percent on average per industry for each UGX1 billion in ploughed-back tax revenue. A combination of a tax on agriculture and a sales tax break involving the same amount of revenue, results in a net decrease in water demand. A comparison of the three plough back schemes shows that an export tax break results in a higher decline in water consumption.[27] From a sustainability point of view, the policy shows the presence of dividends under both time horizons.

Table 17-V: Marginal changes in water consumption from a tax and plough-back

	Water tax		*Sales tax break*		*Production tax break*		*Export tax break*	
Reduction in water consumption			**Increase in water consumption**					
	Short-run	Long-run	Short-run	Long-run	Short-run	Long-run	Short-run	Long-run
Industry			0.001406	0.002667	0.001885	0.005697	-0.116794	0.00957
Agriculture	-0.02011	-0.02016	+	+	+	+	+	+
Mining	-0.02139	-0.02273	+	+	+	+	+	+
Manufacturing	-0.02034	-0.02005	+	+	+	+	+	+
Construction	-0.02068	-0.02093	+	+	+	+	+	+
Hospitality	-0.01097	-0.01053	+	+	+	+	+	+
Business	-0.00957	-0.00965	+	+	+	+	+	+
Other Services	-0.01339	-0.01327	+	+	+	+	+	+

Notes: The results in column 2 and 3 are percentage decreases in water use per UGX1 billion in tax revenue raised. Under the plough-back schemes (columns 4-9), the result 0.00141, 0.00189, and -0.116794 are the short-run average increases in water use for the respective schemes. If the increase in water use which follows the plough-back is less than the initial decrease following the tax, the net effect is a decline in water use and hence a plus (+) sign to signify an environmental dividend.

Source: Author's computations.

[27] Due consideration was taken in the choice of water demand semi-elasticities used as they are fundamental in influencing the results. Different elasticities were tested over a wide range and there was no significant change in results for the variables of interest.

6.3 Economic effects

GDP and employment effects

In order to assess the economic impact of the tax on the economy, we compute the Marginal excess burden (MEB). The marginal excess burden (MEB) is the change in real GDP divided by the change in real government revenue. In this case, we analyse how GDP declines as a result of an increase in total tax revenue. On the other hand we also assess the impact on GDP of a tax break through the three plough-back schemes. In this case, the MEB measures the increase in GDP per decrease in total tax revenues. Formally:

MEB = change in real GDP/change in real government income

The MEB is a proxy for the distortion which arises from the imposition of a tax. Given that the numerator and denominator are measured in monetary terms, comparing the MEBs for the different scenarios gives combinations of scenarios which produce a second dividend, i.e., an increase in GDP while maintaining total government revenue constant.

Table 18-V: Marginal excess burden from the imposition and plough-back of a tax

	Water tax		**Increase in GDP**					
	Marginal Excess Burden		*Sales tax*		*Production tax*		*Export tax*	
	Short-run	Long-run	Short-run	Long-run	Short-run	Long-run	Short-run	Long-run
Industry			0.0011	0.0023	0.0016	0.0061	0.00294	0.00519
Agriculture	-0.00655	-0.00652	-	-	-	-	-	-
Mining	-0.00018	-0.00017	+	+	+	+	+	+
Manufacturing	-0.00034	-0.00034	+	+	+	+	+	+
Construction	-0.00076	-0.00075	+	+	+	+	+	+
Hospitality	-0.00130	-0.00136	-	+	+	+	+	+
Business	-0.00098	-0.00097	+	+	+	+	+	+
Other Services	-0.00284	-0.00287	-	-	-	+	+	+

Notes: The results in column 2 and 3 are percentage decreases in real GDP per UGX1 billion in tax revenue collected. Under the plough-back schemes (columns 4-9), the result 0.0011 and 0.0016 are the average increases in real GDP for the respective schemes. If the increase in real GDP following plough-back is more than the initial decrease which follows the tax, the net effect is an increase in real GDP and hence a plus sign to signify an economic dividend.

Source: Author's computations.

The MEBs for all water tax policy measures as well as the three plough-back measures are compared in Table 18-V Column 3 and 4 presents the losses in GDP that accrue to the different industries following the imposition of a tax for the respective time horizons. A double dividend is indicated by a plus (+) sign. This implies that the increase in real GDP per unit of real government revenue lost as a result of a tax break is larger than the decrease in real GDP per unit of real government revenue collected from the tax for the respective industries. Otherwise, a minus (–) sign is indicated.

From our computation, the results in Table 18-IV are interpreted as follows: When a water tax is levied on the agriculture industry and UGX1 billion is realized in tax revenue, real GDP decreases by UGX6.5 million. Similarly, the MEBs are computed for the plough-back schemes producing values of 0.0011, 0.0023 for the sales break tax, 0.0016 and 0.0061 for the production tax break, and 0.00294, 0.00519 for the export break during the short-run and long-run time horizons respectively. From the results, a combination of a water tax on agriculture and the three tax breaks result in a decrease in real GDP. The results show that a tax on water for agriculture would be distortionary to the economy in the short and long-run because the net effect on GDP is negative despite the plough-back schemes. Similarly, taxing other services and ploughing back using a sales tax break would not yield a dividend in the short-run However, for the rest of the industries; a tax followed by plough-back yields a double dividend for the economy for both time horizons and for all the three plough-back schemes. In Table 19-V, we present results of the percentage changes in aggregate employment per unit of government revenue for the short-run time horizon since aggregate employment is endogenous in this case.

Table 19-V: Marginal changes in employment from a tax and plough-back scheme

Water tax		Plough-back scheme		
Marginal change in employment		*Sales tax break*	*Production tax break*	*Export tax break*
Industry		0.000237	0.00033	0.000655
Agriculture	-0.00087	-	-	-
Mining	-0.00187	-	-	-
Manufacturing	-0.00019	+	+	+
Construction	-0.000012	+	+	+
Hospitality	-0.00073	+	-	-
Business	-0.00017	+	+	+
Other Services	-0.00037	+	-	+

Notes: The results in column 2 are percentage decreases in employment per UGX1 billion in tax revenue collected. Under the plough-back schemes (columns 3 and 4), the result 0.000237 and 0.00033 are the average increases in employment for the respective schemes. If the increase in employment following plough-back is more than its initial decrease following the tax, the net effect is an increase in employment and hence a plus sign to signify an economic dividend.

Source: Author's computations.

Generally, employment is closely linked to GDP. In this study however, the results of the percentage changes in employment per one billion of tax revenue follow a slightly different trend from that of the MEB results in Table 18-V for the mining, hospitality and other services industries. From Table 19-V, a double dividend is realized for taxes to certain industries as well as for certain plough-back schemes. For instance, a water tax on the agriculture and mining industries would be distortionary, even when the taxes are ploughed-back using any of the schemes. The declines in employment for the largest sectors have implications for household welfare as the agricultural sector alone employs over 75 percent of the population. The export tax break performs better in correcting the distortion with respect to GDP performance compared to the sales and production tax breaks. However, the converse is true with respect to employment. Note however that the differences in performance of the tax and plough-back schemes emanate from utmost two industries in both cases. The analysis of changes in employment and output follow in sub-section 6.4.

6.4 Decomposition of the changes in industry output

Table 21-IV presents results of the Fan decomposition[28] analysis of the impact of the tax on industry output. If we take agriculture as an illustration, we show that the predicted changes in domestic output are derived from three effects:

i) The local market effect. i.e., an increase in domestic demand for agricultural output, whether domestically-produced or imported;
ii) The domestic share effect. i.e., a shift in local usage of agricultural output, from the imported to the domestically produced; or
iii) The export effect. i.e., an increase in the export of agricultural output.

In most cases, these effects tend to work in different directions. For instance, a water tax increases the cost of production which induces a decrease in foreign demand. As a result, local producers cut down on the level of supply thereby increasing the domestic price and facilitating import penetration. The essence of the Fan decomposition is to show the relative magnitudes of these three contributions to output change. Table 21-V presents the results of changes in total industry output following a tax and plough-back schemes for all industries analysed in the model. In order to provide a more detailed analysis of the decomposition, Table 21-V gives a breakdown of the changes in shares in total industry output for some selected industries.

[28] Named after Fan Ming-Tai of the Academy of Social Sciences, Beijing Institute of Quantitative and Technical Economics

Table 20-V: Impact of the imposition and plough-back of a tax on industry output

	Environmental tax		Revenue plough-back scheme					
Industry	*Water tax*		*Sales tax*		*Production tax*		*Export tax*	
Category: ***Taxed***	Short-run	Long-run	Short-run	Long-run	Short-run	Long-run	Short-run	Long-run
Agriculture	-0.289	-0.372	0.127	0.205	0.162	0.272	0.014	-0.223
Mining	-0.377	-1.945	0.085	0.533	0.114	0.616	0.366	2.103
Manufacture	-0.081	0.268	0.196	0.695	0.435	2.196	1.057	4.030
Construction	-0.006	-0.304	0.008	0.471	0.013	1.179	0.008	1.034
Trade	-0.061	-0.018	0.099	0.28	0.147	0.934	0.447	1.262
Hospitality	-0.546	-0.089	0.45	0.175	0.5	-0.891	2.391	2.521
Business	-0.037	-0.113	0.044	0.292	0.072	0.932	0.041	-0.128
OthServices	-0.262	-0.15	0.128	-0.151	0.209	0.092	0.076	-1.136
Category: ***Non-taxed***								
Electricity	-0.051	0.168	0.062	0.162	0.054	-0.022	0.689	-2.566
Water	0.001	0.118	-0.002	-0.144	0.001	0.058	0.011	-0.706
Transport	-0.088	-0.039	0.079	0.124	0.077	0.267	0.052	-0.242
PostTelCom	-0.088	-0.135	0.05	0.023	0.049	0.083	-0.007	-0.835
General Government	-0.086	-0.143	0.059	0.023	0.04	0.254	-0.080	-0.616

Note: The results are percentage changes in total industry output following the taxation and plough-back process.
Source: Author's computations.

From Table 20-V, a tax induces a larger reduction in output for the taxed industries than the non-taxed. Nonetheless, the effects of the policy are felt across the economy. Similarly, the plough-back schemes show an improvement in output for most of the industries with the export tax break, recording the largest impact. However, for the taxed industries, mining, manufacturing and the business sector registered a much more increase in output from the plough-back scheme than the initial decline that followed the tax in the long-run. This is the case for general government and transport among those in the non-taxed industries category. The breakdown of changes in shares of industry output following the policy intervention as analysed in Table 21-V.

Table 21-V: Effect of a water tax and plough-back on the shares of industry output

	Local market		**Domestic share**		**Exports**		**Total**	
Industry	Short-run	Long-run	Short-run	Long-run	Short-run	Long-run	Short-run	Long-run
Scenario 1: *Water tax*								
Agriculture	-0.085	-0.133	-0.029	-0.052	-0.175	-0.188	-0.289	-0.372
Mining	0.005	-0.043	-0.157	-0.773	-0.225	-1.129	-0.377	-1.945
Manufacture	0.026	-0.011	-0.063	0.193	-0.044	0.087	-0.081	0.268
Scenario 2: *Sales tax break*								
Agriculture	0.021	0.113	-0.011	-0.02	0.117	0.112	0.127	0.205
Mining	0.019	0.153	-0.062	0.079	0.128	0.301	0.085	0.533
Manufacture	0.029	0.153	0.014	0.254	0.153	0.289	0.196	0.695
Scenario 3: *Production tax break*								
Agriculture	0.084	0.532	0.002	-0.062	0.076	-0.198	0.162	0.272
Mining	0.032	0.476	0.049	0.125	0.034	0.015	0.114	0.616
Manufacture	0.03	0.625	0.266	1.043	0.139	0.528	0.435	2.196
Scenario 4: *Export tax break*								
Agriculture	0.249	0.496	-0.042	-0.159	-0.193	-0.560	0.014	-0.223
Mining	0.112	0.579	-0.801	-0.181	1.055	1.706	0.366	2.103
Manufacture	0.155	0.601	0.367	1.303	1.269	2.126	1.057	4.030

Notes: The percentage change in local sales is derived from both foreign and domestic sources. The local market component of the percentage change in domestic production is weighted by the value of local domestic sales. The domestic share component is calculated as a residual (see Horridge, 2000).[29]

Source: Author's computations.

In Table 21-V, we select a few strategic industries for analysing the effects of the policy intervention on the industry output as well as changes in shares of output for the two time horizons. For the selected industries, the local market contribution explains only part of the proportional reduction in output. For agriculture, the long-run decline in local market share is 0.052 percent out of the total decrease in output of 0.372 percent. For mining, the local market share decreases by 0.043 percent out of 1.95 per cent while for manufacturing, it decreases by 0.011 percent. However, the decline in local market share is over compensated by the increase in domestic share and exports.

In terms of a shift from the usage of local output from imported to domestic, we see that the tax induces a decline in the usage of local output, thereby increasing the amount of imported output for agriculture and mining sector output. However, the manufacturing sector recorded an increase in both share of demand for domestic outputs and exports thereby leading to an

[29] No interactive term is concealed in the residual. Because these decompositions are specified in small change terms, the changes due to each part add up to the change in the whole.

overall increase in total output despite the tax. Mining recorded the largest decline in industry output following the tax with exports being the source of this decline. The sales tax plough-back scheme shows an increase in the local market share of output for all industries, with exports accounting for the largest share of changes in industry output. On the other hand, the production tax plough-back scheme recorded an increase in industry output with the local market share contributing to the proportion of this increase. A comparison of the three plough-back schemes indicates that with the exception of the agricultural sector, an export tax break induces a higher increase in industry output than the sales and production tax. We see that the increase in the local market share contributes greatly to the overall increase in industry output in the long-run.

Table 22-V presents results of the impact of the policy intervention on employment in the economy. Note that although aggregate employment is fixed under the long-run closure, there are changes in employment within the various industries. Under the short-run scenario, employment is endogenous. From the table, the imposition of the tax results in a decline in employment across taxed sectors as well as the non-taxed. The reverse is true for the plough-back schemes. In the long-run however, some industries register gains in employment from the imposition of tax, specifically, manufacturing, trade, and hospitality. This could be attributed to improvements in water use efficiency. On the other hand, it is clear that industries for which water is a major input in their production such as mining, agriculture and construction register a decline in employment.

The plough back schemes result in an increase in employment for all the schemes for most industries, with manufacturing being the major gainer in employment with 1.12 and 1.59 and 3.5 percent for sales tax, production tax and export tax plough-back schemes respectively. However, the sectoral losses in employment are varied under different plough-back schemes. It is probable that the reduction in taxes and the resulting increase in real wages induce substitutability away from labour in favour of capital for these labour intensive industries.

Furthermore, since employment is fixed on the aggregate, increases in employment in some industries result in declines in employment in others.

Table 22-V: Impact of the imposition and plough-back of a tax on employment

Industry	**Environmental tax**		**Revenue plough-back scheme**					
	Water tax		*Sales tax*		*Production tax*		*Export tax*	
*Category: **Taxed***	Short-run	Long-run	Short-run	Long-run	Short-run	Long-run	Short-run	Long-run
Agriculture	-0.853	-0.283	0.376	0.031	0.48	-0.232	-0.853	-0.863
Mining	-1.814	-2.035	0.37	0.253	0.462	-0.224	-1.814	1.506
Manufacturing	-0.184	0.539	0.497	0.441	1.12	1.59	-0.814	3.543
Construction	-0.012	-0.1	0.014	0.24	0.021	0.612	-0.012	0.498
Trade	-0.09	0.192	0.186	0.074	0.248	0.417	-0.09	0.822
Hospitality	-0.786	0.026	0.652	0.067	0.723	-1.304	-0.786	2.496
Business	-0.178	0.243	0.245	-0.089	0.438	0.019	-0.178	-1.033
Other Services	-0.393	-0.085	0.176	-0.304	0.304	-0.242	-0.393	-1.592
*Category: **Non-taxed***								
Electricity	-0.167	0.462	0.205	-0.156	0.177	-0.79	-0.167	1.845
Water	0.004	0.411	-0.004	-0.461	0.003	-0.707	0.004	-1.404
Transport	-0.198	0.195	0.176	-0.134	0.171	-0.37	-0.198	-0.857
PostTelCom	-0.224	0.131	0.135	-0.271	0.119	-0.647	-0.224	-1.485
General Gov't	-0.091	-0.098	0.065	-0.02	0.041	0.145	-0.393	-0.711

Notes: The results are percentage changes in total industry output following the taxation and plough-back process.

Source: Author's computations.

7 Conclusion and emerging policy issues

The study set out to explore the possibility of using a water tax to generate positive effects for the environment and the economy using a modified version of the UgAGE model was used. In this study, a weak double dividend is found to hold. This is in line with a large volume of literature where environmental taxation and revenue recycling policies often result in the price interaction effects outweighing the revenue recycling effects. As a result, it is not possible to realise a strong dividend from such taxation policies. Given the limited use of taxes in environmental regulation and fiscal policy, the results highlight issues that are vital for policy decision making.

Environmental resources are experiencing challenges, most of which emanate from economic and human activity. This calls for the need to institute measures to regulate such activities in a sustainable manner. Similarly, as policy makers seek new ways of widening the tax base, it is vital to investigate the viability of using environmental taxes for purposes of domestic resource mobilization which this study has undertaken in part. Specifically, a tax of US$20 cents was used in this study because the objective was to assess whether or not a water tax can yield dividends in a developing country context. Different tax rates were tested and the results proved to be highly sensitive to the tax rates used. Overall, the results show that it is actually possible to generate positive dividends for the economy.

In addition, the results show that the policy is sustainable when assessed from the persistence of both environmental and economic dividends using the long-run time horizon. From the results, water demand remains more or less on the same trajectory in the long-run and in fact, a higher level of dividends is realized. However, the realization of any dividends depends upon the sectors on which the tax is imposed, the tax rate and the choice of plough-back scheme. For instance, some studies impose taxes on specific sectors as is the case with this study. However, the plough-back is usually done across the board. In this study, simulations which involved revenue plough-back across the board did not yield any dividends. This implies that only a deeper understanding of a given economy and careful policy design can lead to the realization of dividends from environmental taxation. Whereas the dividend hypothesis asserts that there are gains that accrue from environmental taxation, there is no guarantee that this bound to occur. Therefore, results cannot be generalized across economies.

The relevance of the study goes beyond environmental taxation in Uganda in that it can be extended to other developing economies whose use of environmental tax instruments is still limited and yet these economies stand to suffer from the adverse effects that may arise from environmental resources mismanagement. Given the fact that water resources constitute only one of the multiple environmental problems being faced globally, the need to utilise environmental tax instruments for purposes of economic and environmental management especially in the developing countries cannot be over emphasized. Finally, the potential for the generation of dividends can only be realized under certain conditions. This implies that a different analytical set up may yield dividends from a different choice of industries and tax policies from the ones which have been tested in our model. The results from the analysis of a specific policy intervention will depend on the existing conditions for the economy in question. In this study, we mainly focused on establishing whether it is possible to generate revenue, reduce water consumption and increase economic growth, and employment all at the same time. The findings show that depending on the set up, it actually is.

Chapter Six

Overall Conclusions and Issues for Future Research

The thesis set out to investigate the role of water resources in the economy. In this regard, water resource accounts were developed, and combined with the official UgAGE model to develop a single-country water CGE model— UgAGE-Water. In the model, water is used as an explicit factor of production. Specifically, changes were made to the basic structure of the model in order to include the separation of water from the intermediate inputs as well as primary factors. This modification serves as a contribution to the limited literature on single-country economy-wide modelling of water resources and the economy. Previous investigations had not found it as feasible due to the lack of sectoral data on water use that is amenable to the structure of a conventional CGE model. This challenge is driven largely by the fact that water which is normally taken as a non-market good is largely not reported in the national economic accounts of most countries. The modified UgAGE now has features that are crucial for the assessment of water resources and the other sectors of the economy.

From the water resource accounts in Chapter 3, the results show an estimated 38.6 billion m^3 in water surplus. This suggests that there are available water resources which can be exploited for productive use. Subject to availability of more detailed sectoral data, future analysis should provide a more accurate picture of the exact amount of surplus water resources in the economy. Tentatively, it is clear that if it is used efficiently, the current level of water resources is adequate to address the existing economic challenges that emanate from water scarcity. Furthermore, the policy analysis framework which was developed provides a useful tool for analysing the different policy alternatives which have implications for water resources utilisation in an economy. It allows for active institutional interaction as well as feedback regarding the outcomes of different socioeconomic activities. The main objective of the framework is to identify priority actions in line with a country's development plans. The key aim of Chapter 3 was to demonstrate the fact that sound integrated water resources management requires a robust understanding of the social, economic, and institutional linkages and the water resources.

Using UgAGE-Water, different water related policies were analysed in the thesis. In Chapter 4 titled, we explored the impact of water scarcity brought about by a ‘typical’ drought on the different aspects of the economy. Specific interest was paid to the welfare losses at a household level, GDP, employment, the performance of the external sector, as well as the inter-sectoral effects between a disaggregated agricultural sector and the other down-stream industries which mainly rely on the agricultural sector for their inputs. The results show that the effects vary substantially by sector from moderate to severe. There are macro level losses in terms of reduced exports while at a household level; the terms of trade gains mitigate part of the potential welfare losses with respect to consumption. At a sectoral level, the fall in employment within the agricultural industries is less compared to the output losses. Overall, it was concluded that even a short-term drought can cause substantial losses to the economy. There is therefore the need for targeted interventions in order to mitigate the impact of drought occurrences. Given the multi-dimensional nature of drought impacts, a combination of findings from this study with other qualitative surveys should give a much wider picture of the full cost of a drought and a wide range of possible mitigation measures.

In Chapter 5 which focused on the possibility for a water tax to yield positive benefits for the economy was investigated. This was motivated by the fact that water resources in Uganda, are increasingly becoming stressed in terms of quantity and quality. Unfortunately, the current water pricing policy in Uganda is largely market-based. As such, it does not seem to adequately capture the full cost the increasing water scarcity as well as cost of delivering water supply to households and industries. The analysis was underpinned by a proposed policy by the Government of Uganda to levy a tax on commercially distributed water where we investigated the benefits of environmental taxation beyond revenue generation. The results showed that the potential for generation of dividends can only be realised under certain conditions. In other words, a different analytical set up may yield different dividends given the choice of industries, and tax policies. Furthermore, the study established that results from the analysis of a specific policy intervention mostly depend on the existing conditions for the economy in question. In this part of the thesis, our main focus was on establishing whether it is possible to generate revenue, reduce water consumption, increase economic growth, and employment all at the same time. The findings show that is possible to realise these benefits in varying degrees, depending on the policy set up.

This thesis contributes to the existing literature on the economic modelling of water resources in a way that adds more insight into a better understanding of the role of water resources in the economy. For instance, the UgAGE-Water model used in the empirical analysis provides insights into economy-environmental modelling, using single-country economy-wide models which are limited in the literature. However, the research also has some limitations in terms of the approaches used. The first limitation is with respect to the water resource accounts. The limited details on water supply, use, and returns for some sectors implied that we could not get a detailed breakdown of sectoral water consumption and use especially with respect to the return flows back into the environment. Nonetheless, this is of less concern as the major interest was on flows from the environment into the economy. Therefore, greater efforts were undertaken to get detailed sectoral data for sectors which are key drivers of the economy. Furthermore, the estimate of the current water supply surplus position of the country still indicates that the country water resource accounting position is largely healthy in the short to medium term. Given these limitations, future studies should consider updating the water accounts using more disaggregated sectoral data across the water resource flow cycle.

On establishing the impact of drought on the economy, we acknowledged in Chapter 3 that although economy-wide modelling provided results with respect to losses across sectors at an aggregate level, we noted that given the multi-dimensional nature of drought impacts, future studies should employ a combination of findings from these macro models with other qualitative and quantitative microeconometric surveys in order to give a much wider picture of the full cost of a drought. Furthermore, future research on the analysis of water resources in an economy-wide setting should consider accounting for the potential increase in the price of water in a disaggregated agricultural sector. In addition, the resulting potential for substitution within the primary factor nest should be investigated across sectors with respect to output and employment at a sectoral level. Such an investigation is critical considering that the expected impacts of climate variability on water resources might inevitably deem it necessary for substitution to occur among primary factor inputs as an adaptation strategy.

Given the fact that irrigation is among the key mitigating mechanisms against drought, but is also a large consumer of capital, future studies should investigate the impact of investment in irrigation infrastructure on agricultural sector output, employment and overall GDP growth. Finally, considering the spatial distribution of water resources and the central role of water in agricultural sector performance, future studies should include a regional dimension in the model, each with its own water endowment. This should in turn be used investigate the role of initial water endowment on regional agricultural sector output and employment. Furthermore, the model should be linked to the regional poverty profiles, in order to assess how differences in water resource endowments influence poverty trends. This is critical since over 70 percent of population lives off agricultural sector activities.

The limitations notwithstanding, the overall findings of the thesis have been presented to point towards critical analytical and policy interventions to ensure sustainable management and use of water resources not only in Uganda, but for other developing countries as well as they tend to have similar structures, and challenges.

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