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An Integrated Computable General Equilibrium Model Including Multiple Types and Uses of Water

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by

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Declaration

I hereby declare that I have completed this dissertation independently and on my own. I have not been supported by a commercial agent in writing this dissertation. Additionally, no aids other than the indicated sources and resources have been used. Futhermore, I assure that all quotations and statements that have been inferred literally or in a general manner from published or unpublished writings are marked as such. This work has not been previously used neither fully nor partially to achieve any other academic degree.

Stuttgart-Hohenheim, January 2015

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Brief Contents

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List of Abbreviations

CER	Comission for Energy Regulation
DFG	Deutsche Forschungsgemeinschaft
FAO	Food and Agriculture Organization of the United Nations
GDP	Gross Domestic Product
GTAP	Global Trade Analysis Project
NA	National Accounts
OECD	Organisation for Economic Co-operation and Development
SAM	Social Accounting Matrix
SEEA	System of Environmental-Economic Accounting
UNESCO	United Nations Educational, Scientific and Cultural Organization
WMO	World Meteorological Organization
WWP	United Nations World Water Assessment Programme

Zusammenfassung

In vielen Regionen der Erde ist Wasser eine knappe Ressource die einer zunehmenden Nutzungskonkurrenz unterliegt. Es wird erwartet, dass sich dieses Problem aufgrund des Klimawandels sowie des Bevölkerungs- und Wirtschaftswachstums in Zukunft noch verschärfen wird.

Um diesem Trend entgegenzuwirken und die begrenzten Wasserressourcen ganzheitlicher, gerechter und nachhaltiger zu nutzen, sind politische Maßnahmen nötig, die die Versorgung mit, wie auch die Nachfrage nach, Wasser regeln. Wasser ist essentiell für das menschliche Überleben, wird aber überdies auch in vielen Produktionsprozessen benötigt, daher haben wassermanagementbezogene Entscheidungen zumeist sehr komplexe Auswirkungen. Ökonomische Simulationsmodelle haben sich allgemein als geeignet erwiesen, um Konsequenzen von Politikänderungen vorab abzuschätzen. Insbesondere Allgemeine Gleichgewichtsmodelle ermöglichen es, die Verknüpfungen zwischen unterschiedlichen Wirtschaftssektoren und -subjekten innerhalb eines Wirtschaftsraumes zu berücksichtigen. Daher eignet sich diese Klasse von Modellen sehr gut, um die Konsequenzen von Wassernutzungsentscheidungen zu analysieren. Obwohl besonders seit den 1990er Jahren mehrere Allgemeine Gleichgewichtsmodelle speziell zur Analyse von Wassernutzungsfragen entwickelt wurden, gibt es bisher kein Modell, das den Wassersektor ganzheitlich darstellt und alle Aspekte der Wasserversorgung, der Nachfrage und der Bewirtschaftung berücksichtigt sind.

Vor diesem Hintergrund wird in der vorliegenden Dissertation ein auf den Wassersektor fokussiertes Allgemeines Gleichgewichtsmodell (STAGE_W) entwickelt, welches eine allgemeine, ganzheitliche und flexible Grundstruktur bietet. Diese ermöglicht es, unterschiedliche Wasserbezugsquellen, aus denen mittels verschiedener Wasseraufbereitungsprozesse Wassergüter von unterschiedlicher Qualität hergestellt werden, abzubilden. Diese Wassergüter werden entweder in der Produktion von anderen Wirtschaftsgütern als Vorleistungen oder von Haushalten als Endverbrauchern verwendet.

Die dieser Dissertation zugrunde liegenden Fallstudien sind nach bestem Wissen des Autors die ersten Allgemeinen Gleichgewichtsansätze, die die Wiederaufbereitung von Abwasser und die Versorgung mit brackigem Grundwasser als unabhängige Produktionsprozesse mit spezifischen Kostenstrukturen darstellen. Eine weitere Neuheit des in dieser Dissertation entwickelten Ansatzes ist die Darstellung von mehrstufiger Wassernutzung. Die Menge des zur Wiederverwertung verfügbaren Abwassers ist dabei an den Wasserverbrauch von an ein Abwasserentsorgungssystem angeschlossenen Verbrauchern gekoppelt. Die Einführung von mehreren impliziten wasserspezifischen Steuern ermöglicht darüber hinaus die Simulation einer großen Spanne von Wasserpolitik-Szenarien, darunter beispielsweise auch die Simulation von Preisdiskriminierung.

Um die Funktionalität von STAGE_W und sein Potential zu demonstrieren, wird das Modell in dieser Dissertation auf eine Social Accounting Matrix von Israel angewandt. Basierend auf dieser Datengrundlage werden mehrere Fallstudien durchgeführt, die im Rahmen von drei wissenschaftlichen Artikeln präsentiert werden. Israel ist dabei ein ideales Beispiel, da das Land einerseits stark von Wasserknappheit betroffen ist und andererseits zu den weltweit führenden Nationen im Bereich der Erschließung von unkonventionellen Wasserquellen und der Entwicklung von Wassertechnologien, wie der Meerwasserentsalzung und der Nutzung von wiederaufbereitetem Abwasser gehört.

Der erste Artikel bietet eine Literaturübersicht über die bisher existierenden Ansätze der Darstellung von Wasser in Allgemeinen Gleichgewichtsmodellen und beschreibt STAGE_W und dessen wasserspezifische Erweiterungen im Detail. Das Modell wird angewandt um eine 50%ige Reduktion der für die Israelische Wirtschaft verfügbaren Frischwasserressourcen zu simulieren. Die Auswirkungen dieses Schocks werden mit und ohne die Möglichkeit, in zusätzliche Entsalzungskapazitäten zu investieren, analysiert. Dabei zeigt sich, dass die ökonomischen Auswirkungen in beiden Fällen leicht negativ sind. Anders als erwartet, verbessert die Bereitstellung von Trinkwasser aus zusätzlichen Entsalzungsanlagen die Situation nicht wesentlich. Dies liegt hauptsächlich an den hohen Entsalzungskosten, die gegenwärtig in Israel subventioniert werden. Dabei beeinflusst die Finanzierung dieser Subventionen die Verteilungswirkung des negativen Wohlfahrtseffekts auf die unterschiedlichen Haushaltsgruppen.

Im zweiten Artikel wird eine Abschaffung des derzeit in Israel existierenden diskriminierenden Preissystems für Trinkwasser simuliert, bei dem Trinkwasser an Gemeinden zu Preisen, die über den Bereitstellungskosten liegen, abgegeben wird, während der Landwirtschaftssektor und industrielle Verbraucher das Wasser zu subventionierten Preisen erhalten. Zwei alternative, in Israel diskutierte, Preissysteme werden stattdessen eingeführt: Einerseits die Preisliberalisierung, bei der die Trinkwasserpreise für alle Verbraucher an die Bereitstellungskosten angeglichen werden, und andererseits die Bepreisung zu Grenzkosten, die den Trinkwasserpreis für alle Verbraucher auf das Kostenniveau von Meerwasserentsalzung anhebt. Beide Preissysteme bringen eine doppelte Dividende durch gleichzeitige Reduktion des Wasserverbrauchs und Wirtschaftswachstum. Dabei erlaubt die Bepreisung zu Grenzkosten größere Wassereinsparungen, während die Preisliberalisierung ein größeres Wirtschaftswachstum bewirkt.

Im dritten Artikel wird das Modell bezüglich der Nutzung von aufbereitetem Abwasser erweitert. Dabei wird die Menge des zur Wiederaufbereitung zur Verfügung stehenden Abwassers vom Wasserverbrauch der an ein Abwassersystem angeschlossenen Konsumenten abhängig gemacht. Dies erlaubt die Darstellung gekoppelter Wassernutzung. Außerdem kann mit Hilfe dieses Ansatzes der Schattenpreis von Abwasser endogen bestimmt werden; dies kann zur Schaffung eines effizienteren Wasserpreissystems dienen. Es wird gezeigt, dass die Berücksichtigung dieser Koppelung in Ländern wie in Israel, in denen ein hoher Anteil des zur Verfügung stehenden

Abwassers wiederaufbereitet und genutzt wird, äußerst wichtig ist. In solchen Fällen führt die Verminderung des kommunalen Wasserverbrauchs zu einer Reduktion des zur Verfügung stehenden aufbereiteten Wassers, was dessen Potential als Substitut für Trinkwasser reduziert.

Die beschriebenen Fallstudien zeigen die Nützlichkeit des Modells und belegen die Aussagekraft der mit Hilfe von STAGE_W getroffenen Schlussfolgerungen. Die Modellergebnisse können nicht unbedingt antizipiert werden, da sie das Resultat komplexer Interaktionen innerhalb des Modells sind. Zudem ist keines der bisher entwickelten Modelle in der Lage in ähnlichem Umfang alle relevanten Aspekte die diese Ergebnisse beeinflussen, darzustellen. Daher wird gefolgert, dass STAGE_W ein geeignetes Instrument ist um Optionen für eine nachhaltige Nutzung von Wasserressourcen zu analysieren. Auch Politikern in anderen Ländern ermöglicht es, vorab die gesamtwirtschaftlichen Folgen von Wassernutzungsentscheidungen abzuschätzen, falls eine geeignete Datengrundlage zur Verfügung steht. Einer der größten Vorteile von STAGE_W ist dabei die Möglichkeit, eine unbeschränkte Anzahl unterschiedlicher Wasserqualitäten sowie - mit Hilfe der integrierten Wassernebenkonten - maximale jährliche Entnahmemengen aus verschiedenen Quellen zu berücksichtigen. Die Wassernebenkonten vereinfachen auch die Interpretation der Ergebnisse, da sie ermöglichen, dass die Modellresultate direkt in Mengen und Preisen dargestellt werden, was weitere ex-post Berechnungen unnötig macht.

Zusammengefasst ist festzustellen, dass das entwickelte Modell zur Analyse vieler verschiedener Szenarien genutzt werden kann, die auf Wasserpolitik, aber auch auf Ressourcenverfügbarkeit und neuen Technologien im Wassersektor basieren. Da STAGE_W die Gesamtökonomie abbildet, kann dabei - anders als bei Einzelsektormodellen und Kosten-Nutzenanalysen - ein ganzheitliches Bild der Auswirkungen von Änderungen im Wassersektor gezeichnet werden.

Summary

Water is a scarce resource in many regions of the world and competition for water is an increasing problem. With climate change and population as well as economic growth, water scarcity is expected to increase even further in the future.

To countervail this trend and to achieve a more integrated, equitable and sustainable management of water resources, policies are needed to regulate the supply of as well as the demand for water. Besides being essential for human survival, water is used in many economic activities, thus, water related management decisions usually have complex implications. Economic simulation models in general have been proven useful to ex-ante assess the consequences of policy changes. Specifically, Computable General Equilibrium (CGE) models are capable to consider the interlinkages between different sectors and economic agents within an economy. Therefore, this class of models is very suitable to analyze the consequences of water-related management decisions. Although especially since the 1990s several CGE models have been developed for the analysis of water-related questions, so far no model provides a holistic picture of the water sector including all aspects of water provision, demand and management.

Against this background, in this thesis a CGE model (STAGE_W) is developed which is especially focused on the water sector and provides a generic, integrated and flexible framework to incorporate various water sources from which several water activities produce water commodities of differing quality. These are consumed by other activities as intermediate inputs or by households as final users.

The applications presented in this thesis are to the best knowledge of the author the first CGE approaches to depict the recycling of wastewater and the provision of brackish groundwater as independent activities with specific cost structures. Another novelty of the model is that it allows for the depiction of cascading water use, whereby the quantity of sewage available for reclamation is linked to the water consumption of economic agents connected to a sewer system. Furthermore, the inclusion of several water specific taxation instruments allows for a wide range of water policy simulations including price discrimination.

To demonstrate the functionality of the model and its capabilities, STAGE_W is applied to a Social Accounting Matrix for Israel. Based on this database several case studies are conducted which are presented in three scientific articles. Israel provides an ideal example as the country is strongly affected by water scarcity on one side, and also among the world leaders when it comes to the development of new water sources and technologies such as desalination of seawater and recycling of wastewater on the other side.

In the first article, a literature review on previously existing approaches of water depiction in CGE models is provided along with a detailed description of STAGE_W and its water-related

extensions. The model is applied to simulate a reduction of freshwater resources available to the Israeli economy by 50%. The effects of this shock are analyzed with and without allowing for further investments to increase the desalination capacity. The results show that the economic effects are slightly negative under both scenarios. Counterintuitively, the provision of additional potable water through desalination does not substantively reduce the negative outcomes. This is mainly due to the high costs of desalination, which are currently subsidized in Israel. Thereby, the financing of these subsidies influences the distribution of the negative welfare effect over household groups.

The second article simulates an abolishment of the discriminatory water pricing system currently established in Israel and under which potable water is provided to municipalities at fees above the supply costs, whereas water delivered to the agricultural and the manufacturing sectors is supplied at subsidized rates. Instead, two alternative pricing schemes being discussed in Israel are introduced: price liberalization, which unifies the prices for all potable water consumers at cost recovery rates, and marginal pricing, lifting the potable water price to the cost of desalination. It is found that both schemes yield a double dividend by simultaneously saving water and increasing economic growth. Thereby, marginal pricing allows for larger water savings and, in the long run independence from freshwater resources, while price liberalization results in higher economic growth.

In the third article, the model is further refined with respect to the recycling of wastewater. The quantity of sewage available for reclamation is linked to the water consumption of economic entities connected to a sewer system, which allows for a better depiction of cascading water use and to endogenously estimate the marginal value of unpurified sewage which can be used to inform the pricing decision in this sector. It is shown that a consideration of this link is crucial, if a high share of potable water is reclaimed and used further, such as in Israel. In this case, reducing the potable water consumption of municipalities also negatively affects the availability of reclaimed wastewater and thereby reduces its potential as a substitute for potable water.

These case studies provide evidence of the validity and usefulness of the model developed. The model results cannot necessarily be anticipated, as they are the outcome of complex interrelations within the model and none of the previously developed models has the capacity to capture all the relevant aspects of the water sector which influence these outcomes. Therefore, it is concluded that STAGE_W constitutes a helpful tool to implement a more sustainable management of water resources, allowing policy makers also in other countries, given the availability of an appropriate database, to ex-ante estimate the economy-wide effects of water related decisions. One of the major advantages of STAGE_W in this respect is its capability to include an unlimited range of different water qualities as well as maximal annual withdrawal quantities from various water resources, through the integrated water satellite accounts which also allow for a direct interpretation of results in terms of quantities and prices without the requirement for further ex-post calculations.

Summing up, the model can be applied to analyze a wide range of scenarios addressing water policy-related questions, but also regarding resource endowments or new technologies within the water sector. As the economy as a whole is depicted, a more holistic picture of effects resulting from changes in the water sector can be drawn in comparison to single sector models or cost-benefit analyzes.

1 Introduction

Water is the driving force of all nature.

Leonardo da Vinci

According to the United Nations, water is the most precious resource in the world (UNESCO-WWP, 2006). Yet, water scarcity is an increasing problem in many regions. Already in the year 2000, 1.6 billion people were living under severe water-stressed conditions, a figure which is expected to reach 3.9 billion by 2050 which would be more than 40% of the world's population (OECD, 2012). The main factors contributing to this problem are a growing global population and growing wealth, leading to higher demand for water as well as water-intensive products. It is estimated that global freshwater demand will increase by 55% in the period from 2000 to 2050 (OECD, 2012). The quantity of water available for usage, in contrast, is mostly determined by precipitation. However, with continuing climate change rainfall patterns are predicted to become more erratic whereas due to rising temperatures, evaporation rates are expected to increase in many regions of the world, resulting in a reduced and more unsteady supply of freshwater predominantly in regions which already suffer from water scarcity today (Collins et al., 2013). By now, these factors have led to an increasing competition for water on the demand side, between countries as well as between sectors and users within sectors. Therefore, in many countries water availability already poses a limit to sustainable economic growth (Dinar, 2014) and extraction rates exceed replenishment rates in many watersheds and, thus, water resources diminish.

To countervail this trend and to manage water resources in a more integrated, equitable and sustainable way, institutions and policies are needed which control the supply and demand of water. On the demand side, basically two economic mechanisms can be applied: Consumption of single water users can be restricted by allocating quotas or a pricing system can be established which ideally reflects the scarcity of the resource. On the supply side, the situation could be eased by fostering the usage of alternative water sources such as desalination of seawater or reclamation of wastewater. This, however, requires investments in processing facilities and usually results in higher provision costs compared to the supply of water from freshwater sources.

Although the agricultural sector globally accounts for the lion's share of water usage with 70% of the total water withdrawal (FAO, 2011), water is used in the production process of many different economic activities besides its consumption being essential for human survival. Therefore, restricting water supply has many implications (Dinar, 2014). In addition, improving water use efficiency and developing alternative water resources is costly and often requires public funding which has to be financed by redistributing money from other areas. All this contributes to the complexity of water management decisions.

Economic models have been proven useful as decision support tools for policy makers, as they provide estimates of the consequences of management decisions in complex environments. Given the fact that water is an important input in many economic activities as well as a final consumption good, changes in the water sector [1] usually have economy-wide implications. Especially Computable General Equilibrium (CGE) models are capable to incorporate these manifold direct and indirect interlinkages between water and economic activities and actors and, thus, can be very useful to analyze the economy-wide outcomes of changes in the water sector.

CGE models which explicitly integrate water have been developed since the early 1990s; however, so far most of them depict only specific aspects of the water sector, rather than considering the whole water sector. In many models water is integrated as a resource which is often relevant for the agricultural sector, only (e.g. the TERM-H2O model by Dixon et al., 2010 or the CGE-W model by Robinson & Gueneau, 2013 as recent examples). This ignores the fact that water usually needs to be processed (at least pumped and transported) before it is available for usage. Thus, some models include a water activity which provides this service (e.g. Decaluwé et al., 1999) and might also supply water to other sectors (e.g. Gómez et al., 2004 or the GTAP-W model by Berrittella et al., 2007). A few models even consider different water activities such as Gómez et al. (2004) who added a desalination activity or qualities. For instance, Rivers & Groves, (2013) allow for internal recycling of cooling water in power plants alternative to freshwater abstraction. However, so far no model provides a comprehensive framework which integrates all dimensions of the water system including supply, consumption and management aspects.

Against this background, the main objective of this thesis is to develop such a CGE model which is flexible to include a wide variety of water resources and qualities and depicts all dimensions of the water sector in such detail as to allow for a wide range of water-related simulations. The model presented in this thesis (STAGE_W) is based on the STAGE model (McDonald, 2007) which is extended to include more detail regarding the water sector: Several water activities with different cost structures are introduced, which exploit water resources, process water and produce water commodities, which are delivered to and consumed by other activities as intermediate inputs or households as final users. In this context, this thesis provides to the best knowledge of the author the first approaches to depict the recycling of wastewater and the provision of brackish groundwater as independent activities with specific cost structures. The same applies to the depiction of cascading water use, whereby wastewater available for reclamation is linked to the water consumption of economic agents connected to a sewer system.

In addition, several water-related tax instruments are introduced to STAGE_W, allowing for a wide range of policy scenarios, including price discrimination. The inclusion of water satellite accounts allows for quantity restrictions and a direct interpretation of model results in price and quantity terms

[1] Water sector in this thesis refers to all water-related activities, commodities and resources.

without further ex-post calculations. A detailed description of STAGE_W with all its extensions and including all the equations and the relevant model code can be found in Luckmann & McDonald (2014) which is added to this thesis in the annex.

STAGE_W is a single country model, flexible to be applied to any country or region of interest. To demonstrate its capabilities, it is calibrated to a Social Accounting Matrix (SAM) of Israel which constitutes the database for the analyses. Israel provides a good example to demonstrate the capabilities of the model, as the Israeli economy is strongly affected by water scarcity, which is why a complex water management system has been put in place and Israel is among the world leaders in the utilization of alternative water sources (OECD, 2011). All this is complemented by good availability of water-related data, as by law all water resources are public property governed by the state and, therefore, consumption is generally recorded (Kislev, 2011).

The employed SAM has been compiled by the author in collaboration with colleagues in the framework of the trilateral project on '*The Economic Integration of Agriculture in Israel and Palestine'* funded by Deutsche Forschungsgemeinschaft (DFG). The compilation process of the original SAM is described elaborately in Siddig et al. (2011) and has been further extended by the author to capture the water sector more detailed. Specifically four water resources have been included (freshwater, seawater, brackish groundwater and wastewater) from which four activities (freshwater purification, desalination, pumping of brackish groundwater and wastewater reclamation) with specific cost structures produce three different water qualities (potable water, brackish water and reclaimed wastewater). These water commodities are used as intermediate inputs in activities and are consumed by households. Moreover, two specific water-related tax accounts have been added to the SAM. An aggregated version of the final SAM can be found in Luckmann & McDonald (2014) in the annex.

This thesis is based on three articles which form a cumulative dissertation and which constitute the following three chapters: The first article *"An Integrated Economic Model of Multiple Types and Uses of Water"* (chapter 2), which has been published in *Water Resources Research*, gives an overview of previously existing water-focused CGE approaches and describes STAGE_W as well as its extensions in detail. A case study of Israel is presented, showing the economic effects of a reduced availability of freshwater resources, with and without an increase in desalination capacity.

The third chapter, which consists of the article *"Modelling sectorally differentiated water prices: An application to the Israeli water economy"* submitted to *Water Resources Management*, provides an application in which STAGE_W is used to assess the impacts of changes in water policies. Two alternative water pricing schemes are introduced and the effects of this policy change on the Israeli economy and the welfare of households are examined in detail.

In the fourth chapter, *"When water saving limits recycling: modeling economy-wide linkages of wastewater use"* submitted to *Water Research*, a further refinement of the model is presented regarding the reclamation of wastewater: the quantity of wastewater available for reclamation is linked to the potable water consumption of municipalities, to better depict the cascading water use. It is shown, that a consideration of this link is crucial, if a high share of potable water is reclaimed and used further, such as in Israel. In this case, reducing the potable water consumption of municipalities affects the availability of reclaimed wastewater negatively and, thereby, reduces the potential for using it as a substitute for potable water.

Finally, chapter five draws some general conclusions on the modeling approach presented in this thesis and gives an outlook on how STAGE_W could be further extended. Also, some suggestions are provided for additional simulations which could be conducted with the help of this model, but would go beyond the scope of this PhD thesis.

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2 An Integrated Economic Model of Multiple Types and Uses of Water

This chapter consists of the correspondent article, published 2014 in *Water Resources Research* Vol. 50, Issue 2, pp. 3875-3892, doi: 10.1002/2013WR014750

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Key Points:

1. Various water types and uses are integrated in a general equilibrium model
2. A complex water policy and pricing structure is developed
3. Water scarcity causes low welfare loss in Israel due to substitution

Abstract: Water scarcity is an increasing problem in many parts of the world and the management of water has become an important issue on the political economy agenda in many countries. As water is used in most economic activities and the allocation of water is often a complex problem involving different economic agents and sectors, Computable General Equilibrium (CGE) models have been proven useful to analyze water allocation problems, although their adaptation to include water is still relatively undeveloped. This paper provides a description of an integrated water-focused CGE model (STAGE_W) that includes multiple types and uses of water, and for the first time, the reclamation of wastewater as well as the provision of brackish groundwater as separate, independent activities with specific cost structures. The insights provided by the model are illustrated with an application to the Israeli water sector assuming that fresh water resources available to the economy are cut by 50%. We analyze how the Israeli economy copes with this shock if it reduces potable water supply compared with further investments in the desalination sector. The results demonstrate that the effects on the economy are slightly negative under both scenarios. Counter intuitively, the provision of additional potable water to the economy through desalination does not substantively reduce the negative outcomes. This is mainly due to the high costs of desalination, which are currently subsidized, with the distribution of the negative welfare effect over household groups dependent on how these subsidies are financed.

Index Terms: 1880 Hydrology: Water management; 1884 Hydrology: Water supply; 6304 Policy Sciences: Benefit-cost analysis; 6339 Policy Sciences: System design; 6344 Policy Sciences: System operation and management;

Keywords: CES-nesting, wastewater reclamation, brackish water, desalination, Israel, CGE

2.1 Introduction

Water scarcity is an increasing problem in many parts of the world and, since the Dublin Statement of 1992 (WMO, 1992), water has been internationally recognized as a scarce resource. Globally agriculture accounts for about 70% of total fresh water withdrawals, mainly for irrigation. The industrial and energy sectors use about 19%, which is mostly cooling water, and 11% are used within municipalities, including domestic usage (FAO, 2013). Considering that irrigated agriculture accounts for about 40% of global crop production (WWAP, 2012), it is evident that the availability of irrigation water is a key determinant of food security. Thus changes in the water sector affect peoples' welfare directly but also indirectly through food supply. With a growing global population, climate change and increasing competition from other economic sectors, water scarcity problems are expected to worsen in the future. Consequently, the management of water has become an important issue on the political agenda in many countries (Dinar, 2012) and thus there has been an increase in water related economic models and research.

Analysis of the economic implications of water allocation choices is needed to support the political decision making process. Since water is used in most economic activities and the allocation of water resources involves many economic agents and sectors with complex interactions, Computable General Equilibrium (CGE) models have proven useful to analyze the economic effects of water policies (Dinar, 2012). However, the adaptation of these models to include the utilization of water resources is still relatively undeveloped. A major reason for this is the limited availability of databases that include the economic flows related to water and thereby provide the basis for calibrating a CGE model. The UN system of environmental-economic accounting for water (SEEA-Water) provides a well-articulated method for embedding water accounts within national accounts data as satellite accounts to a social accounting matrix (SAM): while it was adopted as an interim international statistical standard in 2007, it awaits revaluation after revision (UNSTATS, 2013).

This paper reports on the development of an integrated water focused CGE model that includes multiple types and uses of water, and illustrates the insights from such a model. A brief review of the development of the behavioral relationships used in water focused CGE models, in section 2.2, provides the context within which this model has been developed. The model incorporates different aspects of previously developed models and extends them to form an integrated model capable of analyzing a wide range of scenarios within the water sector (section 2.3). In the fourth section, an application of the model to the Israeli water economy is presented and the results are evaluated. The fifth section discusses the features of our modeling approach as well as the possible extensions and further applications.

2.2 Water in General Equilibrium Models

Water has regularly been included as an input to production in CGE models, and since the 1990s successive studies have introduced new approaches to water focused CGE models. However, while these studies, and their associated CGE models, have emphasized specific aspects of water use, they have not addressed the water system as an integrated system that includes different types of water and consideres all dimensions of water supply and demand in an economy. The model reported in this paper addresses this gap in the literature. This section reviews the range of features included in different water-focused CGE models, and specifies the features required in an integrated model. The empirical literature is not reviewed. A recent review can be found in Fadali et al. (2012).

Early water-focused CGE models concentrated on the economic effects of curtailing water use in the agricultural sector, either transferring it to other economic sectors or the environment. Since water rights in agriculture are mostly attached to land titles, such that land owners also own a certain quantity of water, water was either only indirectly included in the model equations as a fixed share of the value of land, e.g., Seung et al. (1997) or as a factor of production that is used in a fixed ratio together with land in irrigated agriculture, e.g., Berck et al. (1991); Seung et al. (1998). These early studies treated the water sector as a passive rather than active agent responsible for the provision of usable water. A very recent extension taking up this approach is to integrate such a CGE model, in which water consumption is included indirectly by linking it to GDP, household income, and crop productivity, with a water-management model, which allows for a finer depiction of the water distribution within irrigated agriculture and within one season (Robinson & Gueneau, 2013).

An active water sector can be represented as an activity which builds dams and pumps groundwater to supply irrigation water to the agricultural sector (Decaluwé et al., 1999), in contrast to an irrigated agricultural sector supplying itself by pumping untreated raw-water. Such water related activities can also produce potable water that is delivered for use by other activities as an intermediate input commodity and for consumption by households (Gómez et al., 2004). The integration of a water related activity transforming a raw water resource into a water commodity has subsequently been used in other models, e.g., Tirado et al. (2006); Juana et al. (2011); Watson & Davies (2011), and it has become standard to treat the water sector as a productive activity that produces inputs.

Water focused CGE models typically assume that water can be substituted, to a greater or lesser extent, by other inputs, usually in a nested CES production system. A range of different substitution possibilities have been explored: in arable farming water has been a substitute for fertilizer (Decaluwé et al., 1999); pumped water has been a substitute for a capital-land aggregate (Gómez et al., 2004); and farmers have been able to substitute water with capital to simulate a more efficient irrigation system, and thereby decrease water intensity, in response to the imposition of a tax on irrigation water (van Heerden et al., 2008). Substitution possibilities between irrigated, irrigable and dry land have also been modeled: irrigable land can become irrigated land, using fixed amounts of water per unit area, or be substituted with dry land or irrigable land without water (Dixon et al., 2010), alternatively the quantity of irrigation water applied can be varied (not fully irrigated land) (Calzadilla et al., 2011). In models that include water consumption of non-agricultural sectors, water can often be substituted by capital, e.g., Gómez et al. (2004), or a capital and labor aggregate, e.g., Qin et al. (2012).

Other models include alternative water sources or different water qualities. Seawater can be an input to a desalination activity that produces potable water, comparable to the traditional water treatment activity, but with a different cost structure, e.g., Gómez et al. (2004). Recycling of water can be introduced by differentiating between consumptive and non-consumptive uses of water, whereby the latter returns back to the system and can be used by other activities (Watson & Davies, 2011). This increases total water supply, if water is transferred from activities with high consumptive usage, e.g., irrigated agriculture, to activities with lower consumptive usage, e.g., municipalities. Similarly, the electricity generation sector can internally recycle used (cooling) water and thereby save on abstraction and discharge fees (Rivers & Groves, 2013).

Water is not only important as an input but also as an environmental resource. For instance, specifying an ecological sector that absorbs the difference between total water endowment and water use by consumers and producers enables an evaluation of the environmental implications of different supply and demand side water policies, e.g., Llop & Ponce-Alifonso (2012).

In many countries water prices charged differ between consumers. This has produced a number of models that assess the impact of different pricing policies. Differences in (potable) water prices paid by different user groups, e.g., agriculture versus municipalities, can be captured by a water price distortion factor, (Watson & Davies, 2011), or by applying different water tax rates to different sectors (Qin et al., 2012). Differences in water prices inevitably have welfare and distributional implications. In most water focused CGE models the welfare effects are not immediately evident because they have a single household; multi household CGE models can be used to provide more information on the distributional effects and investigate poverty issues, e.g., Boccanfuso et al. (2005) and Letsoalo et al. (2007).

While most water focused CGE-models are applied at the country scale or even at the watershed level some have used augmented data from GTAP to calibrate global models. Water can be introduced as a factor used for agricultural production or delivered by the service sector to the rest of the economy, e.g., Berrittella et al. (2007), and crop water demand is calculated based on evapotranspirational needs, assuming no losses due to irrigation inefficiencies. Moreover, rainfed- and irrigated agriculture can be differentiated, e.g., Calzadilla et al. (2011). In these studies, the water-factor is introduced with a value of zero, assuming that supply exceeds demand globally in the base situation; only after a water supply shock is introduced does water get a value. To date these studies have not been extended to non-agricultural activities owing to a lack of data.

While water focused CGE models have been developed to address specific aspects of water, none provided an integrated framework to depict the production and use of different water qualities that allows for substitution and price differentiation at different levels. The model developed for this study permits the inclusion of multiple (active) water related production activities that supply water to other activities and consumers, using a range of user defined production technologies and different types of water resources. These activities can be subjected to various constraints, including quotas. As far as is known, this is the first model to include the recycling of wastewater and the provision of brackish groundwater as independent activities with specific cost structures. The model also includes a range of tax instruments that can be easily extended to match the characteristics of individual economies. These developments enable the model to simulate a wide range of water, related policy options. By embedding the modeling of water within a CGE model that has a rich specification of domestic institutions – multiple households, incorporated business enterprises and government – as well as a wide spectrum of tax instruments the analyses of the results can provide insights relating to income distribution and welfare as well as fiscal policy options.

2.3 An Integrated Approach to Modeling the Provision and Use of Multiple Water Qualities

The STAGE_W model (Luckmann & McDonald, 2014) presented here encompasses multiple water related activities and allows for the production of water of the same quality (homogenous) by multiple activities. The various qualities of water are included as inputs in the production functions of the other sectors and can be consumed by households. Typically, only potable water is consumed as a final product by households. Several water-related tax elements are included. Water quotas can be imposed on the total (economy wide) quantity of water used or on the quantities of water used in production or consumption. This allows for a wide range of water policy simulations.

2.3.1 Model Structure

The STAGE_W model is an extension of the STAGE CGE model described in McDonald (2007), which is a descendant of the USDA ERS model of the early 90s (Robinson et al., 1990). The STAGE model is coded in General Algebraic Modeling System (GAMS). The code for the basic STAGE model is available from www.cgemod.org.uk. It is a SAM based CGE model that has a mix of non-linear and linear relationships governing the behavior of the model's agents. The model can be implemented in either comparative static or recursive dynamic mode.

Domestic agents – activities, households, (incorporated business) enterprises, government and investment – consume composite aggregates of domestic and imported commodities that exhibit constant elasticity of substitution (CES), following Armington (1969). The distribution of domestically produced commodities among domestic demand and exports is governed by relative prices on these markets, using constant elasticity of transformation (CET) functions, which reflects imperfect product transformation. In the base version, domestic production is modeled as a two stage production process with either constant elasticity of substitution (CES) or Leontief technologies applied. At the first stage, intermediate input and value added generate the output of each activity based on CES technology. At the second stage, the use of intermediate inputs is in fixed proportions applying Leontief technology, while the CES technology is used to form value added by primary production factors where the optimal ratio of factors is determined by relative prices. Households maximize utility subject to Stone-Geary utility functions over disposable incomes, while enterprises, government and investment demand commodities in fixed proportions. The base version also includes multiple tax instruments and allows for a wide range of factor market clearing conditions and macroeconomic closures.

The extension of the model to encompass multiple water qualities and production activities requires developing the production system to accommodate differences in the production technologies used to produce and use different types of water. The chosen production system involves a series of nested CES and/or Leontief technologies. The production system must also be modified to allow for the production of homogeneous commodities by multiple activities that have different cost structures. To implement this in a CGE model some constraints and/or policy instruments have to be imposed on the model; STAGE_W contains policy instruments – taxes/subsidies – in addition to resource/input constraints, which allow for more than one activity producing the same homogenous good. The generic production system in the model is illustrated in Figure 2.1. In this example seven types of water are included. Three of these are natural resources: fresh water, which is comprised ideally of surface water and groundwater, (Diao et al., 2008), seawater and brackish groundwater, which usually stems from deep aquifers and has a lower salinity level compared to seawater. Additionally there is wastewater from sewage or other wastewater systems, which is a by-product of potable water consumption. On the right, three water commodities are depicted, which are produced from the natural resources and by-products on the left. Potable water is produced from either fresh water or seawater, brackish water is brackish groundwater pumped up from aquifers and delivered to users, and reclaimed water is treated wastewater.

The production system illustrated in Figure 2.1 requires the development of a database that gives empirical content to the model. Depending on the database the model can easily be adjusted to include further water qualities, e.g., different purity levels of reclaimed water or exclude irrelevant ones for the country of interest.

The SAM (transactions) defines the inputs and outputs used in the base period while water satellite accounts provide data on the physical quantities of water used by each activity and by domestic institutions, e.g., households. The user specifies the substitution possibilities at each level of the production nest by defining the substitution elasticities (σ_i) where i defines the level of the nest at which the elasticity operates; for any elasticity set to zero the technology at that level of the nest is

Leontief. Given this information, the selection of the precise production system by each activity is automatically defined by the model code.

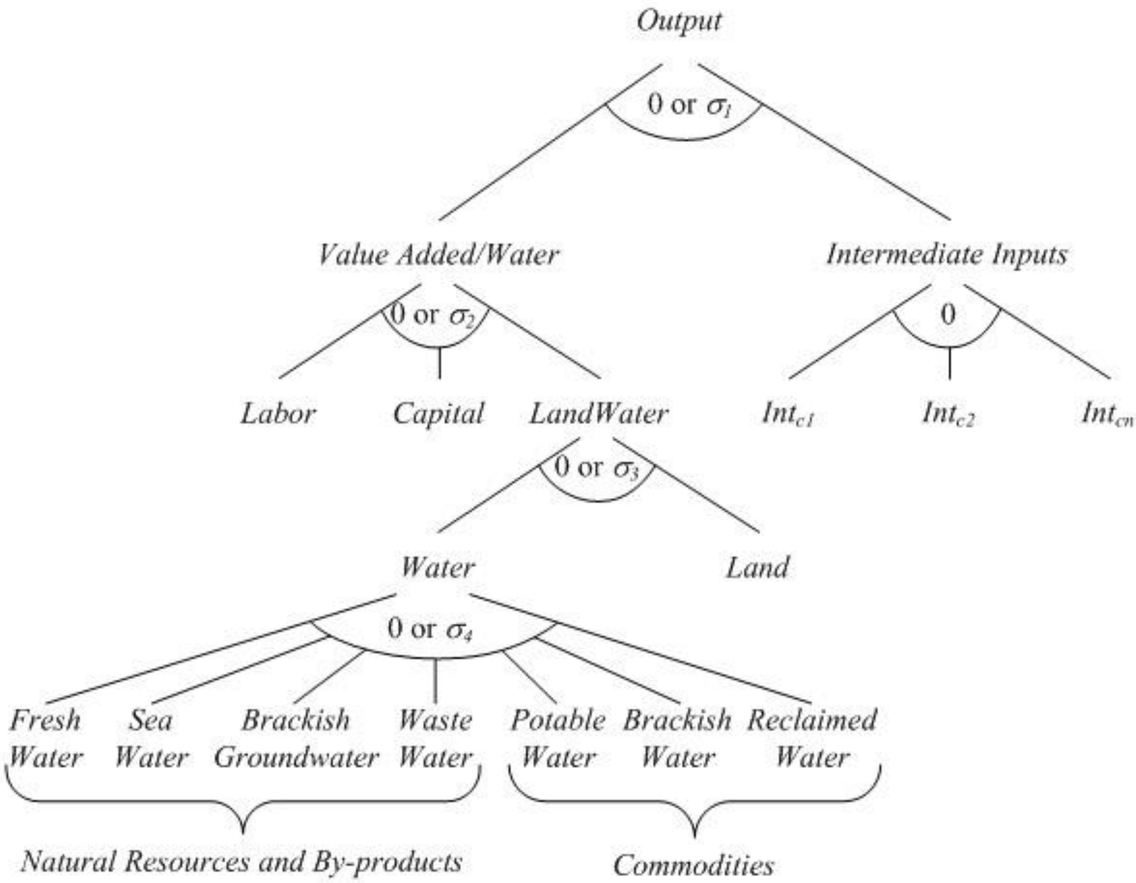


Figure 2.1. Production system for activities in STAGE_W. σ1-4: substitution elasticities.

Consider first water production activities. There is one activity for each water resource or by-product. Utilizing additional production factors (capital, labor) and intermediate inputs (such as energy and consumables), it converts the resource or by-product to a water commodity, which is then used as an input in other activities or, in case of potable water, is consumed by households. On the other hand, one water commodity can be produced by several activities. In the example depicted in Figure 2.1, there are four natural resources and by-products from which three water commodities are produced, as the fresh water activity and the desalination activity both produce potable water. The fresh water activity produces potable water from fresh water without using any other water resources, by-products or commodities or land. Hence the value added/water aggregate collapses to an aggregation of labor, capital and fresh water. Applying Leontief production technology on all levels ensures that the quantity of potable water produced is equal to the quantity of fresh water entering the process. Desalination, by definition, requires the use of seawater as an input and, given the high cost of desalination, only produces potable water. Thus two activities with, typically, different cost structures produce a homogenous product. The basic STAGE model assumes that if the "same" commodity is produced by different activities it is heterogeneous – a CES aggregate. This variant is adjusted so that the option exists to define such commodities as homogenous. Given differences in cost structures it is necessary for the model to include instruments that ensure the supply price for the homogeneous commodities is the same from each activity; this is described in section 2.3.2.

In case potable water is lost before it reaches consumers, due to leakage, potable water would be an input to its own production. If (aggregate) water is produced with Leontief technologies the implied rates of the loss of potable water in production and losses in transmission are fixed, while if potable water is produced with CES technologies, it implies the rate of leakage is a function of the price of potable water. Thus CES technologies imply a long run scenario where the water authorities respond to changes in prices by “adjusting” the rate of losses; this differs from the approach suggested by Faust et al. (2012).

Similarly the production of brackish and reclaimed water depend on the use of brackish groundwater and wastewater, respectively, plus other inputs that may or may not include other types of water. By defining policy inspired (exogenous) extraction rates for the different water resources it is possible to condition the model so that the outputs of water producing activities are limited to output levels determined by the extraction rates. This can be used to calibrate the model to the current situation.

For water consuming activities, the various types of water commodities are used according to the input structure contained in the database. Irrigated agricultural activities use (agricultural) land and one, or more, types of water commodities. It is useful to segment these activities and commodities so as to distinguish between activities that can use the different types of water, e.g., to single out crops that are salt resistant and thus can use either brackish or potable water for irrigation or non-food crops that can be irrigated with reclaimed water. Generally, non-agricultural activities do not use agricultural land but do use water of different types. In such cases the Land/Water aggregate collapses to the Water aggregate.

The model is flexible and adjusts to the usage of different water commodities and factors, e.g., land, by different activities. For example, service activities, e.g., trade, transport and communication, typically do not use marginal water (reclaimed water and brackish water) or land. Thus, their production structure collapses to two stages, such that potable water is combined with labor and capital in one value added nest.

Finally stocks of water resources that are reserved for environmental or other reasons, e.g., to guarantee a certain level of river flow, are not usually accorded a monetary value and are not given monetary values in this model. If decisions are made to preserve stocks of water resources, these decisions will reduce the flow of water resources available to the economy.

2.3.2 Water Costs and Pricing

The price system in the STAGE model is also adjusted by introducing new tax instruments in the water sector. In the model tax instruments are taxes if their values are positive and subsidies if their values are negative; the terms taxes and subsidies are therefore interchangeable and the choice of term is context specific. Potable water, irrespective of how it is produced, is usually supplied via only one water network and therefore is functionally homogenous. However, if water-producing activities face different production structures and costs then multiple activities can only produce the same type of water simultaneously if there are instruments in the price system that equalize the production costs. To allow for the simultaneous production of potable water by multiple activities, we introduce a (implicit) production subsidy (*TX*(*a*)) for the desalination activity, which allows the production of potable water for the same supply price (*PQS*(*c*)) despite different costs (Figure 2.2). This reflects the fact that most desalination plants are either operated by governmental organizations or the government guarantees prices to the private operators so they recover the costs of desalination. Typically desalinated water is supplied to the final user at a price below its production costs, and hence subsidized. Nevertheless, the model allows for equalizing prices through a mix of taxes and/or subsidies.

Furthermore, we introduce two water tax instruments to provide additional flexibility in terms of water price policies, such as differential pricing. First, we introduce an implicit commodity tax on water commodities (*TWAT*(*c*)) that is added on top of the existing sales tax (*TS*(*c*)) and increases the price of water commodities to the highest water tariff charged in the country under consideration (*PQD*(*c*)). This is usually the price charged to municipalities (households and service sector). Second, all water consumers, which pay a lower tariff (e.g. the agricultural sector), receive an implicit subsidy (*TWATA*(*c*,*a*)) that can be adjusted individually to the *a* water using activities, allowing for many different final price levels (Figure 2.2).

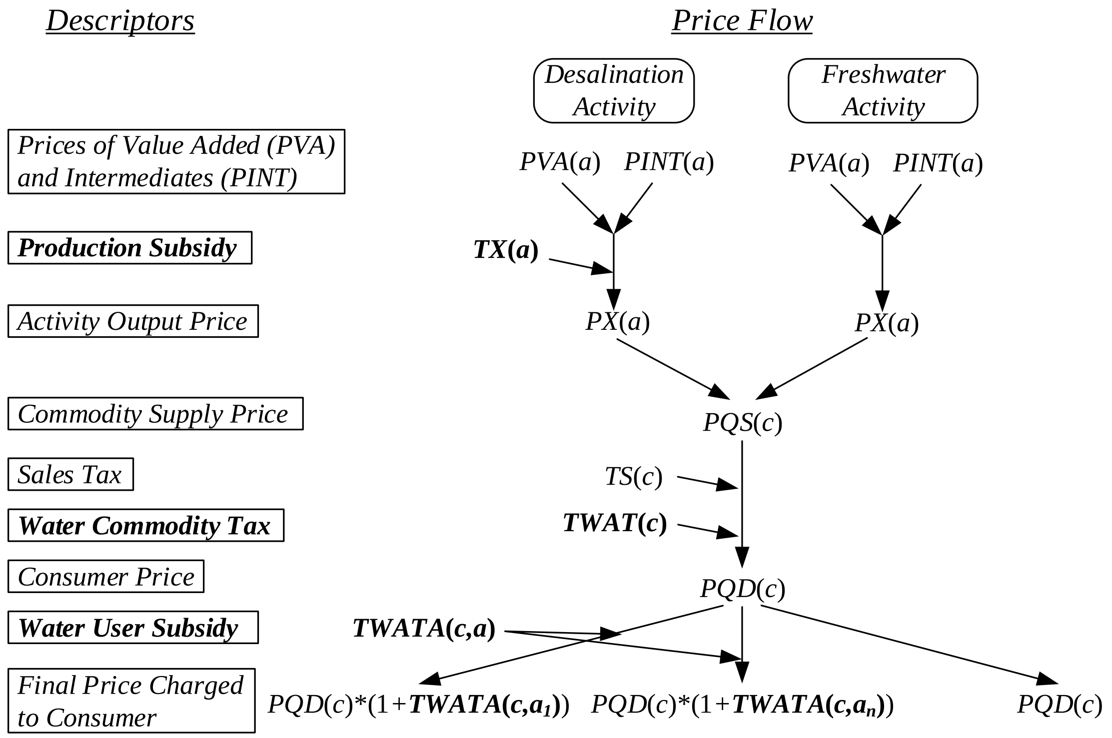


Figure 2.2. Differentiation of potable water prices.

The model allows for the use of satellite accounts for water that record physical quantities. Consequently the model can be calibrated with real quantities and prices and hence the model can isolate price and quantity results for the water commodities without further post simulation calculations. Where water satellite accounts are absent, the model can be calibrated using implied relative prices and (value based) quantities. In this case the model is calibrated using normalised prices, typically calculated as one plus any price wedge, and the quantity units are defined as the value of water divided by this price. In such cases shocks to the model need to be adjusted in line with the quantity units in the model; typically these are expressed as percentage changes in the base quantity units.

2.4 A Case Study

The model is applied to the water sector in Israel because of its complex water management and price system. Water management is a crucial issue in Israel due to its location in the dry-summer subtropical zone, its few inland water bodies and its relatively large population and level of water demand. Therefore, a managed water sector, with metered water supplies to all consumers including agriculture and a distinct pricing scheme for potable water have been put in place, whereby potable water prices charged are highest for municipalities (including households and the service sector), lower for the manufacturing sector and the lowest in the agricultural sector. In addition, Israel is among the world leaders in the use of alternative water sources (seawater, brackish groundwater and wastewater).

Therefore, in this implementation of the model there are four water production activities that produce three water commodities. The four activities are fresh water, desalination, wastewater reclamation and pumping of brackish water activities, which produce three qualities of water – potable, brackish and reclaimed water. As described above, potable water can be produced either by the fresh water activity or by the seawater desalination activity. As potable water prices are distinct between municipalities, manufacturing and agriculture in Israel, manufacturing and agricultural activities receive different levels of water user subsidies, while the price charged to municipalities is adjusted with the help of the water tax only. The two marginal water commodities, brackish water and reclaimed water, are produced by respective activities and are used solely for irrigation.

The time path over which Israel implements changes in water policies is not deemed critical in this analysis since the time sequence of the establishment of new desalination plants does not substantively impact on the long term results. Hence for this case study the model is operated using its comparative static mode.

2.4.1 Database and Parameters

The starting database for our application is a SAM for Israel in 2004 (Siddig et al., 2011). The year 2004 can be considered a normal year for the Israeli economy, in a period of growth after a recession in 2000 and 2001 due to the Second Intifada and before the worldwide economic crisis in 2009 (CBS, 2013). Therefore the results obtained by simulations based on this SAM can be considered representative and allow for extrapolation to more recent years.

The SAM provides data on 45 commodities and activities, 38 production factor accounts, and 18 tax categories. The SAM furthermore includes 10 household types, first grouped according to ethnic background (Jewish and Non-jewish) and second according to income (5 quintiles), which allows for the analysis of distributional effects.

Water in the original SAM is represented by one sector. We use additional data on the Israeli water sector in 2004 provided by the National Water Authority (NWA) (in Zaide, 2009), FAO (2009) and the Israeli Statistical Office (CBS) (2009) to provide the technology data needed to disaggregate this account. Costs of water supply and fees charged are calculated based on the Satellite Account of Water in Israel 2006 (CBS, 2011). Although the Israeli Water Authority has raised water prices between 2004 and 2006 by more than the inflation rate due to the severe water shortage in Israel, the policy of differentiating prices did not change. Thus, water prices used in this study are already closer to cost recovery rates than they were in 2004 and therefore the magnitude of simulated changes is smaller than if 2004 data were used. Therefore, using updated prices depicts the current situation more realistically.

After introducing additional production factors, activities, commodities and tax instruments, the adjusted SAM is subjected to a balancing procedure that assures that if the (transaction) values for water in the SAM are divided by the appropriate prices they are consistent with the water quantities produced and consumed as reported by the NWA and CBS.

Furthermore, desalination of seawater has been introduced in Israel on a considerable scale only in 2007. Therefore, to be able to run simulations considering this important source of potable water, a presimulation is required. The presimulation adjusts the structure of the SAM, and its water accounts, to represent the situation in 2007 when 123 million m^3 of potable water were derived from desalination and the production of potable water by purifying fresh water decreased by about the same amount (CBS, 2010). The new SAM accounts for these changes and forms the database for this case study.

All water producing activities use different shares of inputs and thus have different cost structures. Table 2.1 reports these cost structures for the case of Israel. The lowest row of the table shows the total production costs for each activity. For all activities, energy is the most important input since all activities require pumping water either from the ground at depths up to 1000 m in case of brackish water (Brimberg et al., 1994) or through micro-membranes for desalination, which is a very energy-intensive process (Garb, 2010). Capital shares are the highest for wastewater reclamation and desalination due to high investment requirements. The same holds true for consumables, which are mainly chemicals for wastewater reclamation and materials, such as membrane replacements, for desalination. Only the purification of fresh water relies on fresh water resources and thus has to pay an extraction levy that reflects the scarcity of the resource (Kislev, 2001). Finally, other inputs mainly include construction and other services, which are consumed by all water producing activities to a minor extent.

Table 2.1. Cost structure and total production cost of water producing activities in 2006.

Inputs [%]	Fresh water	Wastewater reclamation	Pumping of brackish water	Desalination
Energy	30.2	30.0	34.8	40.0
Labor	30.1	22.8	34.2	10.0
Capital	14.6	20.0	17.2	20.0
Consumables	8.3	20.0	5.0	14.5
Fresh water	7.2	0.0	0.0	0.0
Machinery	6.2	4.6	5.0	10.0
Taxes	1.1	0.9	1.3	1.8
Other	2.3	1.7	2.6	3.7
Total production cost [2006 USD/m³]	**0.56**	**0.16**	**0.08**	**0.91**

Source: own compilation based on Feinerman & Rosenthal (2002), Beltran & Koo-Oshima (2006), Stevens et al. (2008), CBS (2011) and Siddig et al. (2011).

In this analysis the effects of further increasing the desalination capacity are investigated. New desalination plants are built according to current technologies. After that no major changes in production technology are possible, while the plants might produce potable water for decades. The same holds true for other infrastructure in the water sector, e.g., reclamation plants. Therefore, we decide to exclude technological progress in this simulation and hence keep the cost structure for the activities that produce water commodities fixed by setting the substitution elasticities on all levels to zero; thus Leontief-technology is applied.

In non-water activities, the following elasticities of substitution are applied. For the combination of the three water commodities we use a medium to low substitution elasticity (σ_4 in Figure 2.1) of 0.8 (Sadoulet & de Janvry, 1995). This is mainly because the SAM used for this analysis includes aggregated activities of which not all components can use marginal water qualities. Also, although there is an extensive supply network for reclaimed water in Israel the option to use marginal water does not exist in all localities. Lastly, farmers might decide not to switch to marginal water usage because of fears with respect to soil degradation caused by soil contamination or salinization. For the combination of land and water, the substitution is governed by an elasticity (σ_3 in Figure 2.1) of 0.3 in accordance with Faust et al. (2012). For the value added-water nest we apply an elasticity (σ_2 in Figure 2.1) of 0.8, which is slightly lower than the elasticity used by Berck et al. (1991) for a high elasticity scenario. At the top-level we choose an elasticity (σ_1 in Figure 2.1) of 0.5.

Figure 2.3 depicts the water use in the Israeli agricultural sector according to the agricultural activities identified in the SAM. Agriculture is the biggest user of water in Israel, whereby, based on total consumption, vegetable and fruit plantations are by far the largest water users, followed by the production of other crops, which include cotton, sunflowers, and other field crops. Also the usage of marginal water is restricted to some of the irrigated agricultural activities only.

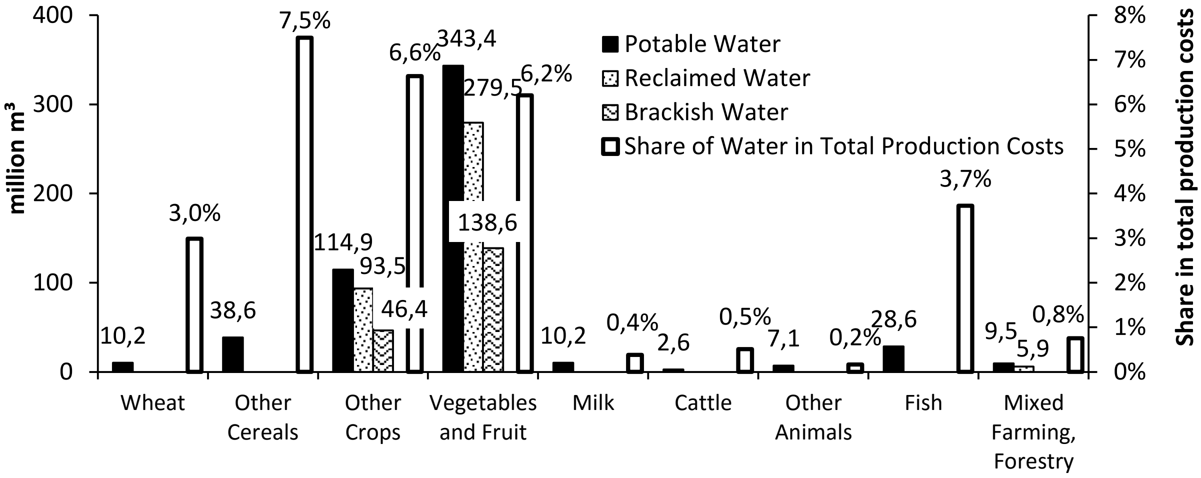


Figure 2.3. Water use in the Israeli agricultural sector in 2004 in million m³ and share of water in total production costs.
Source: own compilation based on FAO (2009), Zaide (2009) and Siddig et al. (2011).

The usage of brackish water is limited to two activities ("vegetables and fruit" and "other crops"), since only these activities include some plants that are tolerant toward increased salinity levels, e.g., tomatoes, melons, and cotton. Because of sanitary restrictions, the usage of reclaimed water is limited to these two, above mentioned activities as well as the "mixed farming and forestry" activity. Only these activities either produce some non-food outputs, e.g., cotton and timber products or crops for which lower sanitary restrictions apply, since they can be irrigated without the water being in direct contact with the harvested parts, e.g., olive and citrus trees. Due to data limitations however, these aggregates also include crops which do not allow for the usage of marginal water. This is considered by adjusting the water commodity substitution elasticities of these activities. No data on the use of marginal water in the different agricultural sectors is available. Therefore, brackish and reclaimed water commodities are split between activities which allow for their usage according to the total water consumption of their respective activities in the SAM.

2.4.2 Closures and Market Clearing

Given the small share of the Israeli economy in the world market we assume world market prices to be fixed (small country assumption). The other closure rules are selected so that adjustments are all achieved within the solution period, e.g., there are no changes in future capital stocks or investment unfunded in the current period. The external balance also remains fixed, whereas the exchange rate is flexible. Moreover, we assume that savings are investment-driven. Regarding the government, we assume consumption of fixed quantities of all commodities and no changes in the savings rate as well as government transfers. A constant balance of the government account is achieved by adjusting the income tax rate households pay in a multiplicative way, whereas all other tax rates remain constant with the exception of water related taxes described in the scenario section hereafter. In addition, the volumes of enterprise demand and enterprise transfers to households remain unchanged.

Factor markets are cleared under the assumption that all factors of production are fully employed and mobile between activities, such that the model results reflect the long-term perspective after adjustments have taken place. The only exception to this is the fresh water resource, which has a fixed unit value whereas the quantity used is flexible. This allows for reduced usage of renewable water resources in the simulations.

2.4.3 Scenarios

We examine two scenarios to show different aspects of our model. Current water policy debates in Israel are concerned with the practicality of further increasing desalination capacity in spite of its high production costs and whether it would be more efficient to invest in water saving technology or improve water recycling. We investigate the implications of expanding desalination capacity in case of a strong decrease of available fresh water resources, which could be caused by political negotiations giving more water rights to the Palestinian Authorities or a potential Palestinian state that would most likely overlay Israel's most important ground water aquifer. Moreover, there is pressure to reduce the off take of water from the Jordan River to prevent the sea level of the Dead Sea from further falling. In addition to this, Israel is facing a lasting drought for almost a decade. This has led to a decrease in replenishment rates of fresh water aquifers to 63% of the multiannual average by 2008 (Shachar, 2009). All these factors reduce the quantity of fresh water resources which will be available to the Israeli economy in the long run. This reduction of fresh water supply is examined under two different scenarios regarding the development of the desalination activity: a fixed desalination capacity (Scenario Fix-dsal) and an expansion of the desalination capacity (Scenario Exp-dsal). Results of both scenarios are compared with the current situation (Base). For both scenarios a range of reductions in the output of the fresh water activity were analyzed: output was reduced in 10% steps between 10% and 80%, after which the model came up against binding constraints. Between 10% and 70% reductions in the output of the fresh water activity the patterns and signs on the results were consistent. Therefore only the results for 50% reduction output are reported in detail. The choice of a 50% reduction in output was also influenced by estimates that this is the level of reduction required to achieve sustainable replenishment rates considering the above described causes of pressure on the Israeli fresh water resources. The full set of results is available upon request from the corresponding author.

2.4.3.1 Fixed Desalination Capacity (Fix-dsal)

In the first scenario (Fix-dsal) we fix the output of the desalination activity to its current level. This means that total supply of potable water is strongly reduced, as the output reduction of the fresh water activity cannot be compensated by the desalination activity. To manage demand, the water authority therefore will be required to either allocate quotas to water users or increase prices. We opt here for the second option and therefore let the implicit water tax (*TWAT*) adjust so that the consumer price (*PQD*) for potable water adjusts to clear the market. We keep the implicit water consumer subsidy rates (*TWATA*) unchanged, such that prices change at the same rate for all water users. The implicit subsidy to the desalination activity (*TX*) is left flexible, such that its activity price received by the desalination activity (*PX*) is the same as the price of the freshwater purification activity, even if price changes resulting from this simulation might affect the two potable water producing activities differently.

2.4.3.2 Increased Investment in Desalination Capacity (Exp-dsal)

In the second scenario (Exp-dsal) we let the desalination sector expand and keep the rest of the settings as in the Fix-dsal scenario. Only the subsidy to the desalination sector is kept constant, as in this case the model can adjust production quantities of the desalination sector by taking up production factors from the fresh water activity. We compare the results of this simulation to the Fix-dsal scenario to see whether water saving and substitution of potable water with marginal water commodities only, or the additional substitution possibility with desalinated water is more beneficial in terms of welfare and other economic indicators.

2.4.4 Results

2.4.4.1 Water Quantities

Due to the shock in fresh water resources of the two simulations, the output of the fresh water purification activity is halved (Table 2.2). In the first scenario (Fix-dsal) this leads to large reductions of potable water volumes available to the economy. For the three different economic sectors (agriculture, manufacturing and services) the cuts in potable water supply occur at almost the same rate, as the price ratio between sectors does not change and we assume similar elasticities of substitution. However, reduction rates in the manufacturing and service sectors are slightly higher compared to agriculture. This is due to the relatively low shares of water in total production costs of these activities (below 0.6%), and hence potable water can be substituted more easily with capital and other inputs, compared to agriculture, where the share of water can be more than 7% (Figure 2.3).

In the initial situation half of the water requirements of the agricultural sector are fulfilled by marginal water commodities. In the Fix-dsal scenario, the supply of marginal water to the agricultural sector increases by a further 6%. Therefore, although in this sector the highest absolute reduction in potable water consumption occurs (-332 million m^3), total water consumption only drops by about 27%. Households, on the other hand, cut potable water consumption only by about 19% on average, with poorer households cutting their consumption by less. This reflects the properties of the utility function (Stone-Geary) where poorer households are characterized by a lower own price elasticity of demand for water and a higher share of subsistence consumption. In the Exp-dsal scenario the reduced utilization of the fresh water resource is almost entirely balanced by an increase in desalination (Table 2.2). Therefore, only minor reductions of potable water usage occur in the different economic activities and with households. In addition, there is less need for substitution with marginal water qualities and thus the use of these water types only increases by 0.2%.

Table 2.2. Changes in water demand and supply.

		Water quantity [million m³]			Change compared to base [%]	
Sector	Water quality	Base	Fix-dsal	Exp-dsal	Fix-dsal	Exp-dsal
Agriculture	Potable	565	233	553	-58.7	-2.1
	Reclaimed	379	401	380	5.7	0.2
	Brackish	185	195	185	5.6	0.2
	Sum	1129	829	1118	-26.6	-1.0
Manufacturing	Potable	113	44	111	-61.5	-2.2
Services	Potable	228	89	223	-61.2	-2.3
Households	Potable	483	391	479	-19.1	-0.9
Total		**1954**	**1352**	**1931**	**-30.8**	**-1.2**
thereof	*Fresh water*	*1267*	*633*	*633*	*-50.0*	*-50.0*
	Desalinated	*123*	*123*	*732*	*0.0*	*495.4*

Source: model results.

2.4.4.2 Prices and Taxes

The curbing of the fresh water activity results in less demand for inputs by this activity. The same holds true for all other activities, which reduce production owing to the reduced availability of potable water. This reduces demand for production factors and hence their prices (Table 2.3), which means that the production costs of potable water decline by about 5% in the Fix-dsal scenario. The reduction in costs is slightly smaller for the desalination activity compared to the fresh water activity, which means that the subsidy to the desalination activity needs to increase slightly (1.8%).

Table 2.3. Changes of factor prices (in %)

	Fix-dsal	Exp-dsal
Labor (weighted average)	-6.0	-0.1
Capital	-5.9	0.0
Land	-60.1	-1.8

Source: model results.

As the total available quantity of potable water is reduced in the Fix-dsal scenario, the government needs to also reduce the demand for this commodity. As described above, we therefore allow for adjustments in the consumer price of water. In this case, the government would need to raise the implicit tax on potable water (*TWAT*) from 0.35 USD/m³ to 2.39 USD/m³ to achieve the consumer prices shown in Figure 2.4, such that all water users experience the same percentage increase in water prices. For a sectorally differentiated price policy, additional adjustments in the implicit water consumer subsidy (*TWATA*) would be necessary. These changes in water taxes together with declining production prices result in government revenue from the water sector increasing from 10 million USD in the base to 1230 million USD under the Fix-dsal scenario, which is 2.7% of total government income. This is recycled to households through a reduction of income tax rates by 2.6%.

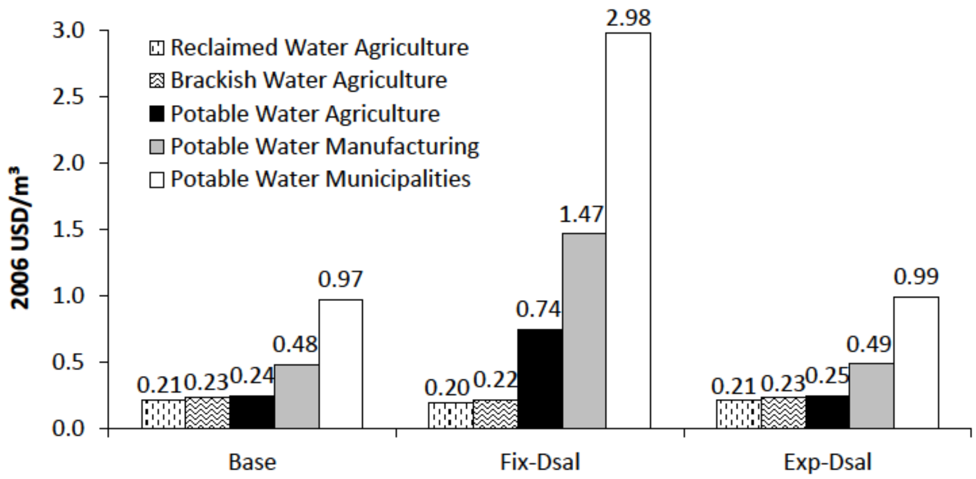


Figure 2.4. Changes in consumer prices of water commodities.
Source: model results.

Because of the fall in factor prices, the production of marginal water commodities also becomes cheaper in this scenario. As *TWAT* is kept constant for these water commodities, this directly translates into a reduction of consumer prices by about 6% (Figure 2.4).

In the Exp-dsal scenario the expansion of the desalination activity absorbs many of the production factors released by the fresh water activity. Also, as the total water quantity available does not change much in this scenario, the production by other activities only changes marginally, releasing very few additional production factors. Thus production prices of potable water as well as for marginal water commodities remain quite stable in this scenario (-0.1%). As the total volume of potable water supplied is reduced by 1.7%, only minor adjustments in consumer prices are required (Figure 2.4); these are achieved by increasing *TWAT* by less than 0.03 USD/m³. For marginal water, the prices remain almost constant.

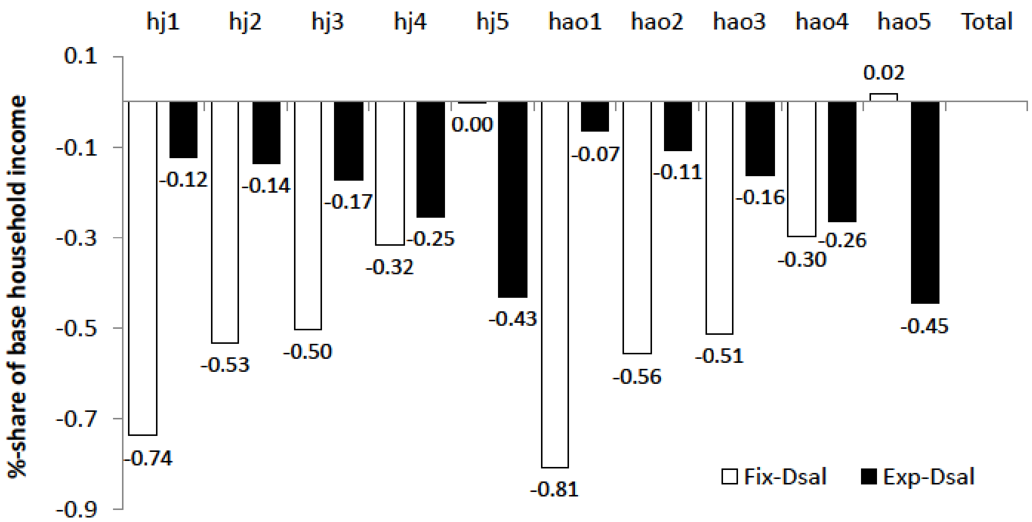
However, the expansion of the desalination capacity requires 216 million USD of additional subsidies, which is equivalent to 0.4% of total government expenditure and turns the government balance from the water sector to become negative (-180 million USD). To balance the government budget, household income tax rates are increased by 1.8% in this scenario.

2.4.4.3 Production

The output of most commodities is only slightly altered in both scenarios and total production is even slightly increasing in the Exp-dsal scenario. Especially in the manufacturing and service sectors, water represents only a very small share of input costs and hence the increased cost of water has only a small impact on total costs. Moreover, some of the activities in these sectors do not use water at all. However, in some agricultural activities, such as the production of non-wheat cereals, water constitutes to up to 7.5% of total production costs (Figure 2.3). Therefore, in the Fix-dsal scenario in which potable water prices increase drastically, domestic cereal production decreases by 17%, which is largely compensated by increased imports. Water intensive activities, which allow for the substitution with marginal water commodities such as the production of vegetables and fruit experience a smaller drop in production (3.2%). However, the production of other crops including cotton, sunflowers, and other field crops, shrinks by 14% in the Fix-dsal scenario, although potable water can be substituted with marginal water in this activity as well. This is due to the high world market dependency of this activity, as about half of the domestic output is exported and about the same quantity is imported, too. As the Israeli currency is appreciating in the Fix-dsal scenario by about 5.6%, imports become cheaper relative to domestic production and exports are less profitable. Therefore activities that export large shares of their output and activities producing goods with high import shares become less profitable.

2.4.4.4 Welfare and Macroeconomic Results

The share of the water sector in the total economy and the share of households' expenditures on water are small. Therefore, the effect of the two simulations on households' welfare, measured in terms of equivalent variation (EV), which identifies the changes in economic welfare for a household due to changes in both incomes and prices, are also small (Figure 2.5). Nevertheless, the increasing price of potable water affects households in several ways. Directly, due to the higher prices of potable water households have less dispensable income available to spend on other commodities and indirectly household income is further reduced as wages fall in both scenarios (Table 2.4).



EV in million 2006 USD

	hj1	hj2	hj3	hj4	hj5	hao1	hao2	hao3	hao4	hao5	Total
Fix-Dsal:	-46.0	-52.2	-75.5	-64.3	-0.9	-26.3	-16.7	-12.5	-4.7	0.2	**-299.1**
Exp-Dsal:	-7.7	-13.4	-25.9	-51.8	-144.1	-2.2	-3.2	-4.0	-4.2	5.3	**-261.7**

Figure 2.5. Household welfare measured in absolute equivalent variation (EV) and as percentage share of household income. hj: Jewish households; hao: Arab and other households; 1-5: Income-quintiles.
Source: model results.

In the Fix-dsal scenario this leads to a reduction in household income at rates between 4.4% and 5.2%, whereby poor household groups are less affected as, they receive up to 26% of their income from government transfers, which remain constant. On the other hand, households' factor income from which especially rich households derive more than 80% of their income, fall by around 6.0%. However, also consumer prices of non-water commodities fall by up to 5.9%, with the lowest reductions occurring in agricultural and food products. Additionally the direct household tax rate is reduced by 2.6%, as the government receives more income from the increased water taxes. However, this is not enough to offset the income losses, and welfare declines. Poor households are more negatively affected than rich ones, as they have a higher share of water and food in total expenses, and benefit less from the tax reduction. Therefore, the equivalent variation (EV) as a percentage share of total household income in the base becomes negative especially for poorer household groups (Figure 2.5). Only the richest non-Jewish households can profit very slightly from the new situation, as they spend the lowest income share on water and food (8.5% of their income, compared to more than 25% for poor households of both ethnic groups).

Table 2.4. Household income, from factors and total.[a]

	Average gross monthly income [2006 USD]		Change compared to base [%]			
	Base		Fix-dsal		Exp-dsal	
	Factor Income	**Total**	Factor Income	**Total**	Factor Income	**Total**
Jewish households, 1. quintile	1400	2021	-6.0	-4.4	-0.2	-0.1
Jewish households, 2. quintile	1999	2735	-6.0	-4.7	-0.1	-0.1
Jewish households, 3. quintile	2975	3722	-6.0	-5.0	-0.1	-0.1
Jewish households, 4. quintile	3907	4677	-6.0	-5.2	-0.1	-0.1
Jewish households, 5. quintile	6267	7405	-5.9	-5.2	-0.2	-0.1
Arab & other households, 1. quintile	1403	2025	-6.1	-4.4	-0.1	-0.1
Arab & other households, 2. quintile	2007	2747	-6.0	-4.7	-0.1	-0.1
Arab & other households, 3. quintile	3091	3847	-6.0	-5.0	-0.1	-0.1
Arab & other households, 4. quintile	3948	4731	-6.0	-5.1	-0.1	-0.1
Arab & other households, 5. quintile	6393	7571	-5.9	-5.1	-0.2	-0.2

[a] *Other incomes are derived from transfers from government, other households and remittances from abroad. Source: model results.*

In the Exp-dsal scenario, the total negative welfare effects on households are slightly smaller but richer households are more affected. This is due to the fact that households' incomes only decline marginally (Table 2.4). The main negative effect in this scenario comes from the increase in the direct tax on households by 1.8%, which is required to finance the increased subsidies due to the expansion of the desalination activity. This results in a transfer from tax payers to water users, which is positive for poor households. The slight drop in most non-water consumer prices (a maximum of 0.1%) is not enough to compensate the losses (Figure 2.5).

Similarly the small size of the water sector means that the macroeconomic effects are marginal. Real GDP, measured by expenditure, and total absorption drops by only 0.2% in both scenarios.

We also tested different ways to compensate gains or losses in water taxes in the simulations reported in this paper, e.g., through government transfers, additive adjustments of the household tax or adjustments of other tax instruments, and found that the macro results and the scale of welfare effects were quite similar. There were only small changes in the way the welfare reduction is distributed over different household groups.

2.4.5 Conclusions

The simulation results suggest that although the reduction of water resources is drastic, the extent to which it affects the national economy after adjustments is relatively minor. If the desalination capacity can expand, total potable water consumption is reduced by less than 2%, as fresh water resources, which are less available, are substituted by desalinated water, which is a perfect substitute.

However, even if we do not allow the desalination capacity to increase, the possibilities for substitution of potable water by other factors of production and intermediate inputs mean that the output of several industrial and service activities drops by no more than 1%, even though their water consumption declines by more than 60%. Therefore the final macroeconomic effect in this scenario is small, too. It might be argued that the substitution elasticities, selected from the literature for this analysis, are too high for the large shock presented in this paper. In fact, sensitivity analyses in which substitution elasticities in the production structure are reduced by 50% yields more significant results: output of irrigated agricultural is reduced by up to 14%, real GDP falls by 0.8% and the EV would be up to -2.3% of base household income (Table 2.A1 in the Appendix). However, the literature suggests that by investing in internal wastewater reclamation, industries can reduce their fresh water intake by up to 95% without reducing production (Levine & Asano, 2002). As this model reflects a medium to long term perspective it can be argued that the applied elasticities reflect such a shift of production technology by substituting potable water with capital and other inputs required for internal wastewater reclamation.

When comparing the two scenarios, we observe that the welfare and macroeconomic outcomes are quite similar, although one might expect that the expansion of the desalination capacity might have a more beneficial effect, as this activity produces a perfect substitute for potable water derived from fresh water resources. However, as desalination is far more costly than the provision of potable water from natural fresh water (Table 2.1), the Israeli water authority is subsidizing these additional costs. An expansion of the desalination sector therefore causes additional distortions. Poorer households are less negatively affected, compared to richer household groups, if desalination capacity is increased; this reflects the fact that these subsidies are financed by a multiplicative increase of the household income tax. To mitigate these effects and reduce distortions in the water sector, additional adjustments in the water pricing scheme would be required such that the water price paid by consumers covers the costs of provision.

Possible further simulations include technical change aspects in the desalination sector, as desalination costs have decreased substantially in recent decades, mainly due to energy saving technologies (Karagiannis & Soldatos, 2008). For the next decade it is even expected that desalination will become an energy producing process through forward osmosis (Spiritos & Lipchin, 2013). Additionally, a stricter standard for the quality of reclaimed water has been introduced in Israel in recent years, such that the enhanced quality of reclaimed water means it can be used for irrigation with fewer restrictions (Lavee & Ash, 2013). Reclaimed water of this quality may be suitable for many industrial purposes and thus it would be interesting to analyze the positive economic effects of the increased substitution possibilities versus the higher cost of upgrading reclaimed water.

2.5 Concluding Comments

Over and above being essential for life water enters physical, economic and social relationships in myriad ways that are deeply interconnected. This makes the evaluation of decisions about water use, water provision and water resource based investment projects highly complex. The standard methods for evaluating such decisions are all variants of cost benefit analyses that require detailed data on each decision's costs and benefits. In the case of water resource based decisions the interconnectedness of the water system makes it especially difficult to evaluate both, the opportunity costs of investments and the benefits. In such complex systems, CGE models have the potential to aid the evaluation of costs and benefits and hence improve the evaluation of competing projects. Of particular importance in this context are insights into how decisions on water use by human agents may be influenced by water pricing and quota policies and how the economic costs associated with different water management schemes and environmental decisions may change the patterns of water use and affect the economy as a whole.

At the same time simulation exercises using water-focused CGE models can be used to explore the economic costs of environmental policies and the economic implications of different technology choices. Furthermore, this type of model can be used to help in the identification of those improvements in water supply systems, which are likely to yield the greatest economic benefits and hence can influence the direction of applied water research.

The case study for Israel demonstrates that even quite radical restrictions on the use of water resources may have relatively limited impacts on welfare, although it is important to recognize that the results for Israel reflect the specific economic context. Israel is a relatively wealthy economy for whom water, although scarce, represents a relatively small share of economic activity and costs. In other economies the relative importance of agriculture and water may be appreciably different and hence the implications of changes in water supply may be orders of magnitude different. Moreover the results indicate the extent to which water policies may have non trivial impacts on households with differing levels of income. For instance while in the case of Israel the choice of direct/income taxes instrument to fund the policy shock ensure the poor were less adversely affected than the rich, other tax instruments have different implications.

In recent years, water has increasingly gained attention in CGE modeling. However, so far water related CGE models have been focused mostly on specific aspects of water, e.g., water in the agricultural sector, potable water, etc. The model presented in this paper depicts water in a more integrated way, which allows simulating a wide range of scenarios and detailed analyses. This approach shows that substitution and adjustment processes at various levels may significantly mitigate the effects of water scarcity. These include, among others, the substitution of water by other production factors (land, labor, capital), options to increase the share of reclaimed water, water saving technologies in private households as well as enterprises, changes in the composition of production, especially in agriculture, and investments in the desalination of water or upgrading of marginal water sources. Furthermore, the model presented in this paper allows investigating complex changes in the pricing policy as a tool to influence water consumption, as with the help of the implicit water user tax instrument (*TWATA*), prices for water using agents (activities and households) can be adjusted individually. Most importantly it is evident that not considering these options in water related CGE applications is likely to substantially affect simulation results.

There are manifold opportunities for enriching the insights provided by this model. As currently specified the model relies heavily on economic data and less heavily of engineering and scientific knowledge, which could be introduced into modelling exercises in at least four different ways. First, engineering and scientific information about the abilities of existing systems to substitute between different inputs could be incorporated into the model to provide more robust information about substitution possibilities across different time horizons. Second, engineering and scientific knowledge could be used to define the input requirements of new production technologies so that new investments were introduced in a more satisfactory manner. Third, environmental sciences could provide evidence about the environmental impacts of different water resource decisions and how these might feedback into the system, e.g., the implications of discharging and recharging aquifers for water quality. And fourth, hydrological science and models can be used to understand the physical interconnectedness of water systems and thereby ensure that the economic evaluations are consistent with scientific evidence, e.g., Robinson & Gueneau (2013). These opportunities represent a substantial and long term research agenda.

The STAGE_W model can be easily adapted to different situations and other countries or databases, although it is necessary to review carefully the substitution elasticities. Also, when applying the suggested approach to other countries, a careful evaluation of the water system is required to ensure that the model adequately represents the water system in that country. If there are features of the water system not adequately encompassed by the model then the model needs revising rather than perturbing the data so it conforms to the model structure.

There are a number studies using the model, and developments to the model, envisaged in the short term. While Israel is among the world leaders in the use of reclaimed water (Lavee & Ash, 2013), the availability of adequate quantities and qualities of wastewater is potentially critical if recycling of water is to expand. One option is to include behavioral relationships that ensure that the supply of the wastewater is consistent with other water types in the model, e.g., reductions in the domestic use of potable water are highly likely to result in reductions in the availability of wastewater. This will also provide an opportunity to seek engineering and scientific information about wastewater treatment and to incorporate such information into the model. On the other hand many poorer countries do not have adequate wastewater reclamation facilities, e.g., Weldesilassie et al. (2009), let alone the infrastructure to supply reclaimed water to farms. In such cases it is of interest to evaluate the potential benefits from wastewater reclamation in such economies, e.g., Egypt.

It is also planned to extend the model to evaluate the implications of different irrigation systems. There is increasing pressure on water for irrigation and hence less efficient irrigation systems, e.g., flood irrigation, are increasingly being challenged and users are being encouraged to adopt more efficient practices, e.g., drip irrigation. This analysis would provide an opportunity to incorporate hydrological information into the model.

2.6 Appendix

Table 2.A1. Changes in economic indicators, with halved production elasticities.

		Change compared to base [%]	
		Fix-dsal	Exp-dsal
Output	Agriculture	-9.86	-0.13
	irrigated	*-13.48*	*-0.15*
	Manufacturing	-0.46	0.14
	Services	0.00	-0.01
Equivalent variation	Jewish households, 1. quintile	-1.84	-0.13
	Jewish households, 2. quintile	-1.31	-0.15
	Jewish households, 3. quintile	-1.22	-0.19
	Jewish households, 4. quintile	-0.67	-0.27
	Jewish households, 5. quintile	0.34	-0.42
	Arab & other households, 1. quintile	-2.31	-0.06
	Arab & other households, 2. quintile	-1.58	-0.11
	Arab & other households, 3. quintile	-1.46	-0.18
	Arab & other households, 4. quintile	-0.78	-0.27
	Arab & other households, 5. quintile	0.38	-0.42
Real GDP		-0.06	-0.08

Source: model results.

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3 Modelling Sectorally Differentiated Water Prices - Water Preservation and Welfare Gains Through Price Reform?

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Abstract: This study simulates the economy-wide effects of introducing new water pricing systems in Israel. A Computable General Equilibrium (CGE) model, STAGE_W, is used, that includes multiple water commodities produced from different water resources. The current water pricing scheme supplies potable water to municipalities at fees above the supply costs and subsidizes water delivered to the agricultural and the manufacturing sectors. Due to limited freshwater resources, climate change and population growth, water scarcity is an increasing problem in Israel. Therefore, pricing systems which lead to a more efficient allocation of water are intensely debated. This study analyzes two alternative pricing schemes under discussion in Israel: price liberalization, which unifies the prices for all potable water consumers at cost recovery rates, and marginal pricing that lifts the potable water price to the cost of desalination. Both schemes reduce water demand with limited economic costs. Price liberalization is the more favourable option from a national welfare perspective, while marginal pricing allows for larger water savings and, in the long run, independence from fresh water resources.

Keywords: water policy; cost recovery price; marginal pricing; wastewater reclamation; desalination; Israel

3.1 Introduction

Water in Israel is a very scarce resource (Fleischer et al. 2008): the annual supply of less than 250 m^3 per capita is 50% below the threshold of severe water scarcity according to the Falkenmark indicator (Tal 2006). The long-term sustainable average annual renewable supply of freshwater from natural sources is estimated at about 1,800 million m^3 including aquifers shared with the Palestinian Territories (Weinberger et al. 2012), which matches only about 80% of the total Israeli water consumption. However, the actual supply is highly variable (Fleischer et al. 2008). In recent years, Israel faced almost seven consecutive years of drought (Lavee and Ash 2013) and replenishment rates of aquifers have been as low as 1,091 million m^3 in 2008 (Weinberger et al. 2012). This, together with an increasing demand for potable water, due to economic growth and immigration, has led to a situation of overexploitation of renewable water resources in the country.

To mitigate this problem and meet the annual demand of about 2,130 million m^3, alternative water sources have been explored in recent years. In 2010, about 450 million m^3 of reclaimed wastewater and 300 million m^3 of desalinated water were supplied in addition to natural sources. At the same time, 174 million m^3 of brackish groundwater were extracted. Agriculture is the main user of water at 1,044 million m^3 per year (more than 50% is recycled wastewater and brackish water), followed by municipalities[2] at 764 million m^3 and industry at 120 million m^3. 143 million m^3 are diverted to Jordan, as agreed in the 1994 peace treaty, and to the Palestinian Water Authority, while 60 million m^3 is reserved for the rehabilitation of natural habitats (IWA 2012).

The problem of water scarcity is expected to become more severe in the future (Kislev 2011): domestic water demand in Israel is predicted to rise with population growth, increases in temperature and changes in the amount and distribution of rainfall (Fleischer et al. 2008). Moreover, the supply of water to the Palestinian National Authorities is expected to increase in the future (Kislev 2011).

Water prices are set by a governmental agency, the Israeli Water Authority (IWA), which established an agreement with farmers in 2007 stipulating a gradual shift to cost recovery prices. However, in 2010 the agricultural sector still received potable water at subsidized prices (Kislev 2011). The same holds true for the manufacturing sector, though to a lesser extent, which contradicts the declared aim to restrain water consumption (NIC 2010). This situation continues till today: the IWA suggests that potable water prices in the agricultural sector still would need to be raised by close to 40% to achieve cost recovery rates (Reznik et al. 2015).

Because the current pricing system is heavily debated domestically, this study estimates the implications that different pricing regimes might have on water use, welfare and economic performance in Israel. As changes in the water policy have economy-wide effects, a water focussed

[2] Municipalities include the service sector and households.

Computable General Equilibrium (CGE) model, such as STAGE_W (Luckmann and McDonald 2014), which is used in this study is well suited to evaluate these effects. While CGE-models have been applied to analyse water policies in different contexts before (e.g. Briand 2006; Letsoalo et al. 2007; Solís and Zhu 2015), the novelty of our approach is that it considers different water qualities produced with different cost-structures linked to different water-resources and for which a differentiated pricing system applies.

3.2 The Israeli Water Economy

According to the Israeli law, all domestic water resources are state property. The IWA was established to implement the water law, govern water resources and determine water prices (Kislev 2011).

The exploration of new water sources has been encouraged by the effects of a lasting drought: by 2010 about 75% of all wastewater produced in Israel was reclaimed and used. Due to the growing municipal potable water consumption, the IWA aims to provide about 600 million m³ of reclaimed wastewater mainly to the agricultural sector by 2020 (IWA 2012; Lavee and Ash 2013). Further, several reverse osmosis seawater desalination plants have been constructed on the basis of Build-Operate-Transfer (BOT) contracts by private companies. The installed capacity is expected to reach 750 million m³ per year by 2020 (IWA 2012), to cover most of the municipal demand.

The IWA is also seeking to reduce potable water consumption, particularly in the agricultural sector, where it aims at a higher usage of reclaimed wastewater, which is made more attractive by a lower price (Kislev 2011). However, sanitary restrictions limit its irrigation use to non-food and tree crops. In addition, the use of brackish water, mainly for the irrigation of salt tolerant crops (e.g. cotton and tomatoes) has been fostered and reached 174 million m³ in 2010 (IWA 2012). These supplies are from fossil aquifers in the Negev in the south of Israel.

The IWA operates a pricing regime whereby prices are differentiated according to user-group (municipalities, industry, and agriculture) and water qualities (brackish, reclaimed, and fresh) (Figure 3.1). The taxes and subsidies in the water sector are not explicitly identified but can be calculated as the difference between the costs of water provision and the fee charged to each consumer group. The IWA guarantees prices to the operators of the desalination plants, but the costs of provision of potable water by seawater desalination are far higher than the costs of fresh water purification. Therefore, there is an implicit production subsidy for desalination. However, the IWA sets the final consumer price independent of the costs of supply. This results in an implicit consumer subsidy for potable water consumption in the agricultural and manufacturing sectors, and an additional tax levied on wastewater and brackish water consumption, as well as on potable water consumption of the municipal sector.

The National Investigation Committee report on the water economy in Israel recommended introducing a water pricing scheme, which reflects total average water supply costs including extraction, transportation, and environmental costs, to limit water extraction to a level below the average annual recharge (NIC 2010). Alternatively it has been argued that the water price should equal the marginal cost of potable water, i.e., the cost-level of desalination, since at this price, all water demands could be supplied (Kislev 2011). Marginal cost can be considered the benchmark price on efficiency grounds. These water pricing strategies are the basis for the analyses reported in this paper.

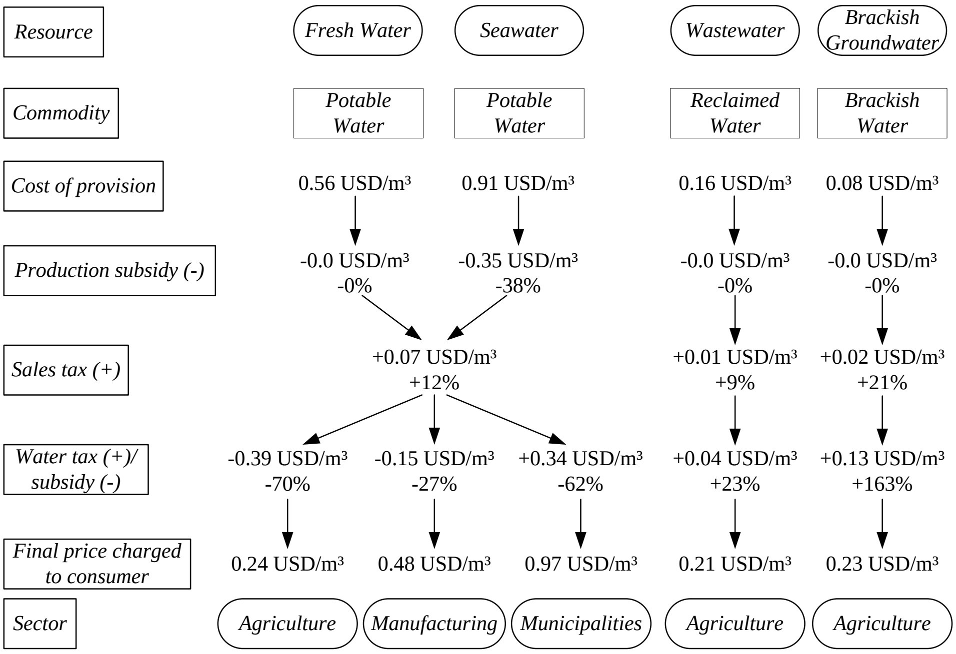


Figure 3.1. Israeli water pricing scheme (2006), prices and tax rates.
Source: own compilation based on CBS 2011 and Siddig et al. 2011.

3.3 Methodical Background

CGE models are often applied to study the economy-wide effects of changes in exogenous factors such as policy. The advantage of this class of models lies in their ability to capture feedbacks within the economy and thus allow for the assessment of second round effects (Logar and van den Bergh 2013). Especially for analyses regarding the water sector, CGE models are suitable because water is used across the economy in production and by households while the sector is often managed by the government and subject to complex policies. Thus, changes in the water sector affect many economic agents directly (e.g. if water prices increase) and indirectly (e.g. increasing prices of agricultural products if water prices increase). Therefore, this model class is well suited to analyse the potential effects of a change in water-related policies (Logar and van den Bergh 2013). CGE models require a large data-base, usually compiled in a Social Accounting Matrix (SAM), which captures all economic interactions within an economy, together with a set of assumptions regarding the behaviour of the different economic actors. A recent overview on water related CGE approaches is provided by Dinar (2014).

With respect to Israel, limited water related CGE studies have been conducted. Yerushalmi (2012) investigated the efficiency of the administrative water allocation in Israel. The database was highly aggregated and included three productive sectors, two factor accounts (labour and capital), and one representative household-government account. While analysing social welfare effects of the introduction of a water market, Yerushalmi (2012) did not consider distributional effects and consequences for different household groups or limited domestic water resources and the use of desalination to preserve those resources. The STAGE_W model has been used by Luckmann et al. (2014) to investigate effects of increasing the desalination capacity to alleviate water scarcity and to demonstrate the importance of considering the freshwater and reclaimed wastewater supply as an interlinked system They concluded that the social benefits of water supplied from additional desalination facilities may be negative due to the current pricing policy, which involves large subsidies. Their finding motivates further analysis of the current pricing system and provision of possible alternatives, which is addressed in the present study.

3.4 Data and Model

This study is based on a 2004 SAM by Siddig et al. (2011), which is the most recent and detailed available SAM for Israel. This SAM is further updated and expanded it to depict details of the Israeli water sector. Accounts for four water resources (groundwater, seawater, wastewater, and brackish groundwater), four related activities and three water commodities (potable water, reclaimed wastewater and brackish water) have been included using data from the IWA (in Zaide 2009), FAO (2009) and CBS (2009; 2011). Additional satellite accounts record the use of physical water quantities. Detailed information on costs of water supply and fees is sourced from the 2006 Satellite Account of Water in Israel (CBS 2011) and summarized in Figure 3.1. Moreover, a pre-simulation is implemented to update the water accounts of the SAM to the situation in 2007, such as to capture the increasing contribution of desalination after the opening of the Ashkelon desalination plant in 2005.

The final SAM has 46 activity accounts, 45 commodity accounts, 40 factor accounts, and 11 tax instruments. Distributional issues are addressed by 10 representative household groups, categorised by ethnic background (Jewish and non-Jewish) and income (5 quintiles).

Agriculture is the largest user of water in Israel; the use of water by the different agricultural activities identified in the SAM is reported in Figure 3.2. Within the cropping sector, vegetable and fruit plantations are by far the largest water users followed by “other crops”, including cotton, sunflowers, and other field crops. The usage of brackish water is limited to these two classes of crops as only these two groups include plants that are tolerant of elevated salinity levels. Similarly, recycled wastewater can only be used by these crops in addition to “mixed farming and forestry” due to sanitary regulations. Data on the use of marginal water[3] by different agricultural activities is limited and hence the use of brackish and reclaimed water is split between activities that allow their use according to their shares in total water consumption. Moreover Figure 3.2 reports the cost shares of water in total production costs.

The model, STAGE_W (Luckmann and McDonald 2014), is a water focused CGE model development of the STAGE model (McDonald 2009). Changes in the behavioural relationships are concentrated on production and consumption relations and water specific tax instruments. For this study the model is adapted to capture the particular structure of the water sectors in Israel, described above. The model encompasses four water (re-)sources which are linked to four related activities, each with different cost structures that produce three water commodities (Figure 3.1). Freshwater purification and desalination produce the same output: potable water that is distributed via a single network. Consequently a homogenous commodity is produced by two activities with different costs structures. Therefore, the desalination activity is implicitly subsidised, which reduces the output price of desalination to the one of freshwater purification.

The seven water resources, by-products and commodities, form the lowest level of the production system (see Appendix, Figure 3.A1), and constitute the potential components of water-aggregates that are specific to the activity that uses that aggregate. The composition of this aggregate is governed by each activity: each water activity[4] requires a specific resource, whereas for non-water activities the water-aggregate can be formed from up to three different water commodities.

The four water activities employ fixed proportions of capital, labour, and intermediates. All non-water activities are modelled with more flexibility. Agricultural activities, which allow for the consumption of all three different water commodities, can substitute these water commodities with a medium to low substitution elasticity (σ_4) of 0.8 (Sadoulet and de Janvry 1995). This rather low substitutability reflects the fact that not all components of the aggregated activities can use marginal water qualities and that the option to use marginal water does not exist in all localities, although there is an extended supply network for recycled wastewater in Israel. On the third level of the production function, water and land form a CES-aggregate, whereby the substitution elasticity (σ_3) is 0.3 following estimates of irrigation-land substitutability by Faust et al. (2015). The land-water aggregate is then combined with labour and capital at the second level of the production function. Given the prevalence of drip irrigation systems in Israel which increase the water use efficiency at the cost of the investment required, the substitution elasticity (σ_2) is set at 0.8 (Berck et al. 1991). The top-level combines the value added and water aggregate with aggregate intermediate inputs with an elasticity (σ_1) of 0.5.

[3] In this paper, the term marginal water refers to reclaimed wastewater and brackish water.
[4] This is an activity which produces a certain water commodity from a water resource or by-product with the help of labour, capital (value added) and intermediate inputs.

Two water specific tax/subsidy instruments allow differential pricing of water according to water type and user. The (implicit) commodity tax and a user specific subsidy result in three different prices for potable water according to user group: agriculture, manufacturing and municipalities. This is illustrated, with the applied rates for Israel, in Figure 3.1.

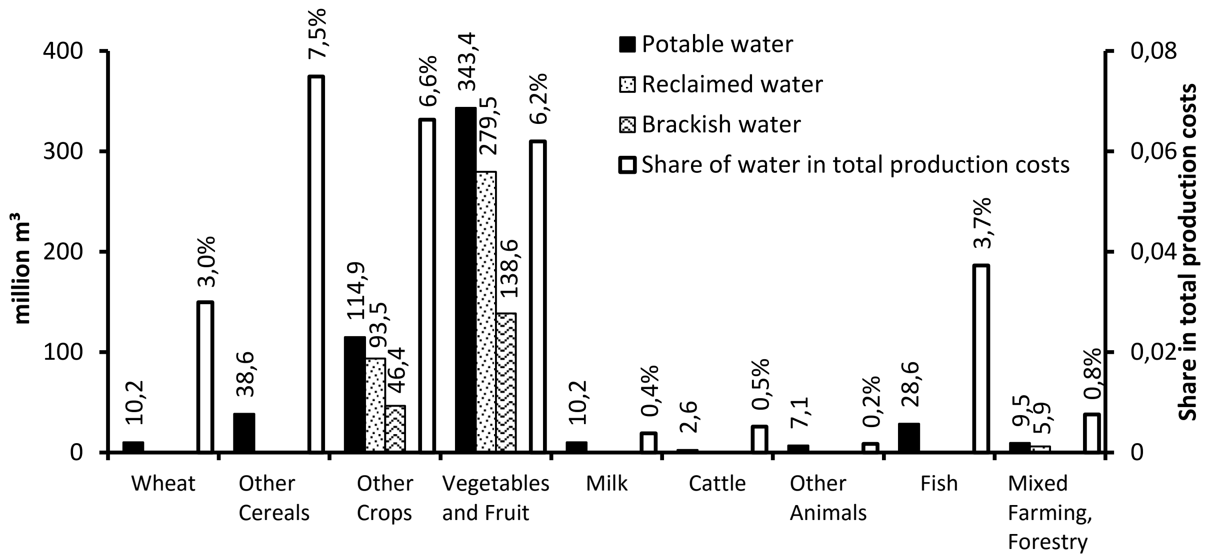


Figure 3.2. Water use in the Israeli agricultural sector in 2004.
Source: Luckmann et al. 2014.

3.5 Water Policy Scenarios

3.5.1 Scenarios

This study evaluates the implications of two alternative water pricing strategies on the Israeli economy with a focus on the different end users of water commodities: price liberalization for potable water and marginal cost pricing for potable water. These pricing regimes are depicted in three scenarios and the outcomes are presented against the current pricing system, which is a differentiated pricing structure for potable water where agricultural and manufacturing use are subsidized and municipalities are taxed.

3.5.1.1 Lib: liberalization of the potable water sector

This scenario estimates the economic costs of the current Israeli water policies relative to a free-market scenario, i.e., all taxes and subsidies on potable water are removed, so that the final price paid by all consumer groups is equal to the producer price plus the value added tax which is held constant. Thus consumers of water cover the full costs of provision, which is a major policy objective of the IWA (Rejwan 2011). Taxes on marginal water commodities are not altered in this simulation, since they are not under debate, which allows the simulation to capture the outcomes of a policy change solely in the potable water sector.

3.5.1.2 Marg-sav: marginal price scenario without redistribution of additional government revenue

This scenario simulates the declared objective of the IWA to reduce dependency on natural fresh water resources (Rejwan 2011). It imposes the marginal price for potable water in Israel on all consumers, which is the full cost of desalination inclusive of capital costs of building desalination plants and delivery (Kislev 2011). This increases all consumer prices. In the long-run, any quantity of potable water can be supplied at this price since it includes investment costs for further desalination plants. Therefore, this scenario allows for independence from natural fresh water resources in the long-run. Again, policies on marginal water commodities are not altered.

3.5.1.3 Marg-trans: marginal price scenario with redistribution of additional government revenue

The shock for this scenario is the same as in the previous scenario, but it further assumes that government savings are fixed and transfers to households are flexible. Due to the shock, government expenditures on water subsidies decline and the government's budget surplus is redistributed to households as transfers that change equiproportionally, which has different distributional implications.

Because simulation results in terms of quantity and price changes differ only very slightly between the two *marg-scenarios*, they are jointly reported, except for the welfare analysis.

3.5.2 Macroeconomic Closure and Factor Market Clearing

Israel is a small country, therefore in the model world market prices are fixed. It is also assumed that the external balance is fixed, reflecting the large current account transfers received by Israel. The external account is cleared by variations in the exchange rate. The real value (volume) of investment is fixed and government savings are flexible (except for the last scenario): the saving rates of domestic non-government institutions (households and enterprises) adjust to clear the capital account. Government account transfers to enterprises and tax rates remain constant with the exception of the subsidy to the desalination activity, which endogenously adjusts to balance changes in production price differences between the two potable water producing activities. The other water tax instruments are exogenously adjusted in the simulations. Transfers to households are fixed in the first two reported scenarios but are flexible in the third.

All factors of production are fully employed and mobile between activities, such that the model results reflect a long-term perspective. Exceptions are the water resources and by-products, which have fixed values per unit while the quantities used are flexible to allow for changes in water consumption.

The potable water price shifts in the simulations cause a reduction in demand. It is a political decision whether supply from natural fresh water or from desalination should be reduced. It was decided here to reduce primarily the desalination supply, due to the higher provision costs. As this is not sufficient, also the supply from natural fresh water resources is reduced. This approach has the additional advantage, that it removes the distortive subsidy on the desalination activity.

3.6 Simulation Results

3.6.1 Water Prices and Production Costs

In all simulations applied in this study, potable water prices are unified. In the *lib-scenario*, this results in a price reduction for municipalities and a price increase for agricultural and industrial users, whereas in the *marg-scenarios* this results in a price increase for all user groups. The largest changes occur to the agricultural sector, where the price of potable water increases by 159% in the *lib-scenario* and quadruples in the *marg-scenarios* (Table 3.1).

In all scenarios, price changes are predominantly caused by the abolishment of taxes and subsidies on potable water. Yet, part of the price changes stem from second round effects since water price changes also have economy-wide effects: due to unified pricing, water is shifted to activities in which it is used more efficiently. As potable water becomes cheaper for the services sector in the *lib-scenario*, this sector expands and uses additional production factors coming from reduced agricultural and industrial activities. Due to higher demand for factors and intermediate inputs motivated by the increased overall production, most factors of production and intermediary inputs become more expensive and, therefore production costs for potable water increase by 0.7% in the *lib-scenario*. In the *marg-scenarios*, water becomes more expensive for all sectors, hence, slightly affecting the whole economy negatively. Therefore, all factors of production and most non-agricultural intermediate inputs become cheaper and thus production costs of potable water decrease by -0.3%.

The production costs of both marginal water commodities are affected similarly in the different scenarios. Since the respective tax instruments are not altered in the simulations, these changes directly translate into consumer price changes (Table 3.1).

Table 3.1. Changes in consumer prices of water commodities and in water demand and supply.

	Scenario:	base	lib	marg	lib	marg
		Average water price charged				
Water quality	Sector	*2006 USD/m³*			*% change compared to base*	
Potable water	Agriculture	0.24	0.63	0.97	159.1	303.5
	Manufacturing	0.48			30.9	103.9
	Municipalities	0.97			-35.3	0.8
Reclaimed wastewater	Agriculture	0.21	0.21	0.21	0.8	-0.3
Brackish water	Agriculture	0.23	0.24	0.23	0.8	-0.3
		Water quantity				
		million m³			*% change compared to base*	
Potable water	Agriculture	565	280	198	-50.4	-65.0
	Manufacturing	113	91	63	-19.1	-43.9
	Municipalities	712	883	709	24.1	-0.5
	All	1390	1255	970	-9.7	-30.2
Reclaimed wastewater	Agriculture	379	398	403	5.0	6.4
Brackish water	Agriculture	185	194	197	4.8	6.3
All	Agriculture	1129	872	798	-22.8	-29.3
All	All	1954	1846	1570	-5.5	-19.7
Natural fresh water	All	1267	1255	970	-1.0	-23.5
Desalinated	All	123	0	0	-100.0	-100.0

3.6.2 Agricultural Sector

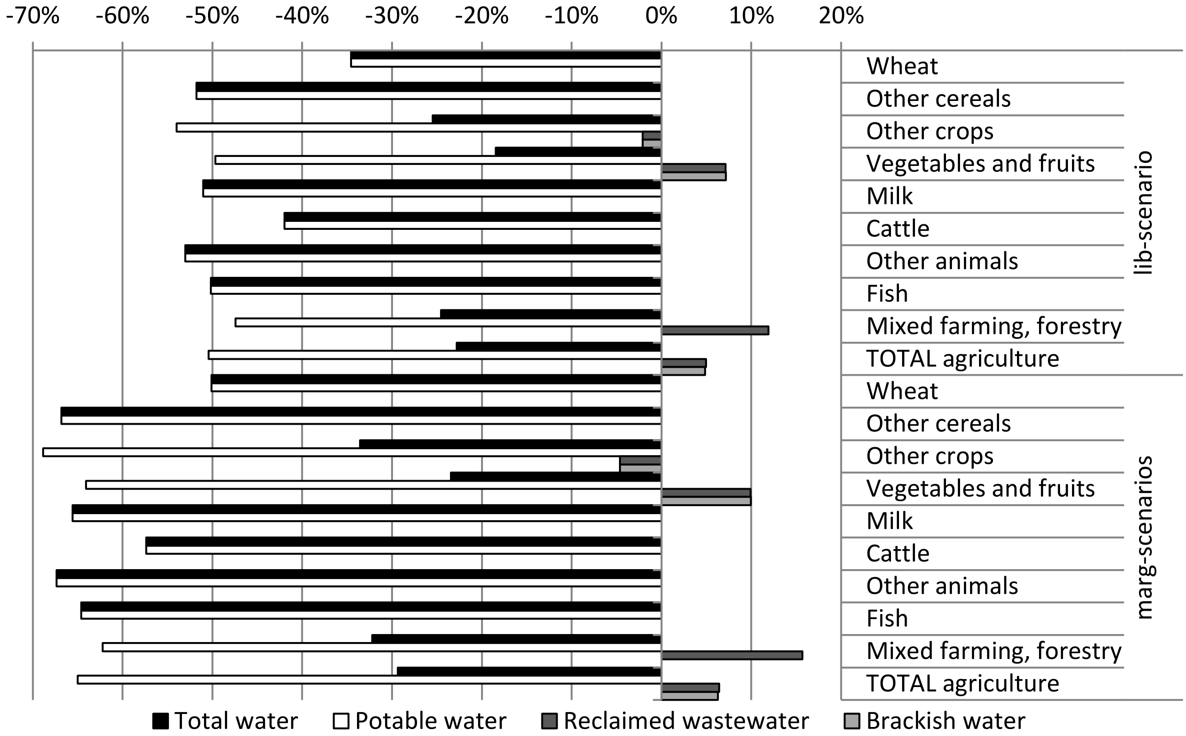
In all scenarios, the agricultural sector experiences the highest potable water price increase. Consequently, the use of potable water in agriculture declines sharply. As marginal water commodities become cheaper in relation to potable water in all scenarios (Table 3.1), the usage of these water types slightly increases, which mitigates the reduction in the overall consumption of water in agriculture (Table 3.1, lower section). The increase in demand for marginal water commodities is not larger because its use is limited to only a few agricultural activities and therefore, the substitution-elasticities are low. Furthermore, prices of marginal water commodities are influenced very little in view of the fact that the marginal water sector is small and reacts in a relatively unresponsive manner.

The changes in water use by the agricultural sector are shown in detail in Figure 3.3a. The consumption of potable water by agricultural activities declines by up to 54% in the *lib-scenario* and up to 69% in the *marg-scenarios*. On the other hand, the share of marginal water use increases in the production of "vegetables and fruits" and "other crops" by 17% and 24% in the *lib-* and *marg-scenarios*, respectively, as well as in "mixed farming" by 19% and 27%, respectively, since marginal water becomes relatively cheaper. The overall water-balance is negative for all activities, and especially the production of water intensive commodities declines (compare Figure 3.3a and 3.3b). Moreover, water is substituted by land and other factors of production which become cheaper. The absolute quantity of marginal water used in the production of "other crops" declines because of the comparatively strong decrease in the production of this activity (Figure 3.3b). This decline results from its high export dependency and the pronounced reductions in exports due to rising production costs in combination with constant export prices.

The increased prices of water inputs cause higher producer prices for all domestically produced agricultural commodities. The highest increase occurs for "other cereals" for which the producer price rises by 9% and 14% in the *lib-* and *marg-scenarios*, respectively. Due to higher production costs, it becomes less profitable to export agricultural commodities at fixed world prices in all scenarios, while imports become comparatively cheaper and thus slightly increase. Taken together, composite consumer prices do not increase as much as consumer prices for domestic supply of agricultural goods (Figure 3.3b). The magnitude by which the consumer prices for domestic supply of agricultural goods increase is mostly correlated with the water use intensity of the respective activity.

Domestic demand for all agricultural commodities decreases due to increasing prices. Most strongly affected are "other cereals", for which demand is reduced by 13% and 20% in the *lib-* and *marg-scenarios* respectively. Export quantities are reduced even more than supply to the domestic market. The total effect on domestic production can be seen in Figure 3.3b. Since in all scenarios potable water becomes more expensive while export prices remain stable, the output is particularly reduced for commodities which have a high share of water in their input costs (Figure 3.2) and which are to a large extent exported.

(a) Changes in water consumption



(b) Changes in production and prices

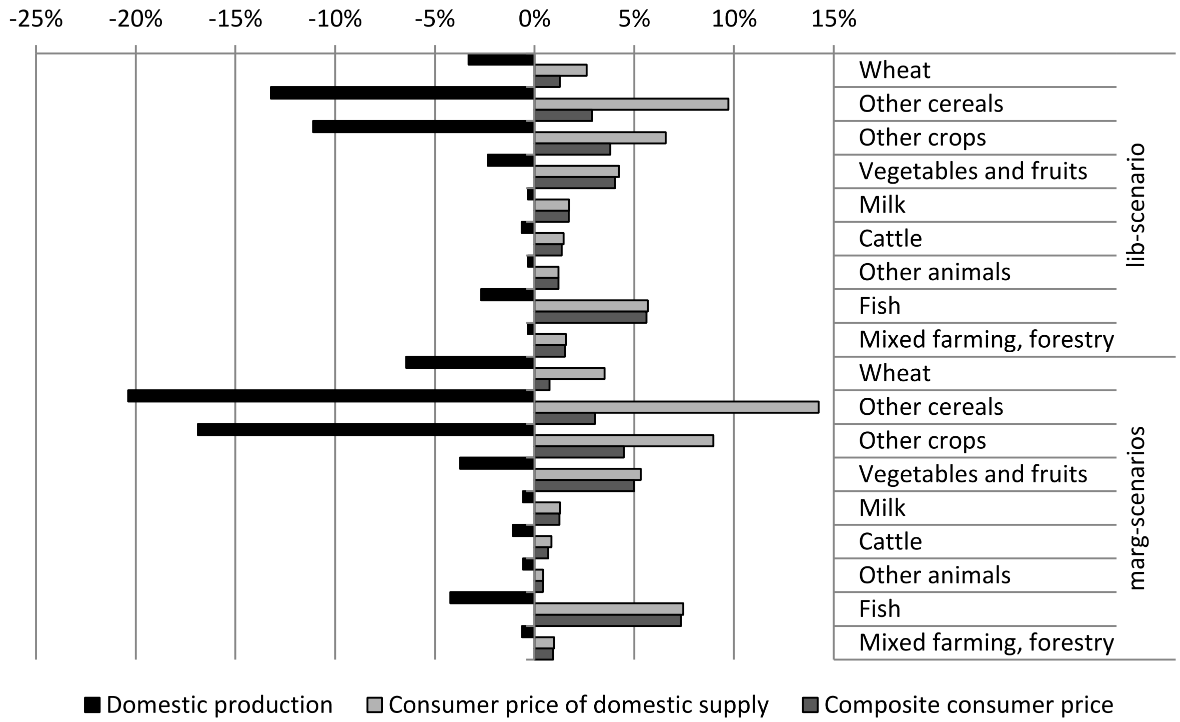


Figure 3.3. Changes in water consumption by the agricultural sector (a) and in production and prices of agricultural commodities (b).

3.6.3 Manufacturing and Municipalities

Because of the higher price in all scenarios, potable water consumption is reduced in the manufacturing sector by up to 45% in the *marg-scenarios*. Although this seems high, such a reduction could be achieved through internal water recycling, which allows for saving rates of up to 95% (Levine and Asano 2002). The magnitude of the reduction in individual activities is correlated with the increase in overall production costs, which are caused by the rise of the potable water price. The same holds true for service activities, though at a lower magnitude (0.9% on average), as the potable water price for municipalities increases by 0.8% only. Households also reduce potable water consumption slightly (-0.3% on average) By way of contrast, the *lib-scenario* causes potable water prices to decrease for municipalities and therefore consumption increases. However, total potable water consumption still decreases since this is outweighed by the reduction of potable water consumption of the other sectors (Table 3.1).

Producer and consumer prices of all non-agricultural commodities also rise in the *lib-scenario*. For the manufacturing sector, the price increase is mainly due to the higher potable water prices as well as the increase in agricultural commodity prices which raises the costs of inputs in food processing activities. However, because of the low share of water in the production costs and the moderate price increase of agricultural commodities, prices of manufactured goods increase by no more than 2%, with the largest increases in the output prices of food processing activities.

The decrease in the price of potable water for municipalities in the *lib-scenario* has two effects: first, it decreases household expenditures for water and second, it reduces water costs for the service sector. Nevertheless, output prices in the service sector rise by about 0.7% due to the price increase of industrial products. As intermediary inputs, these make up for a higher share in production costs in the service sector compared to water. Additionally, household demand for services increases since household expenditures on water declines, which allows for additional consumption of other goods.

In the *marg-scenarios*, on the other hand, prices of services and of most manufacturing goods drop slightly (by about -0.3%), only products of the food industry become more expensive (by about 0.7%) due to the increase in the prices of agricultural commodities. The reason for the general price decrease, despite even stronger price increases for potable water compared to the *lib-scenario*, is the reduced production of agricultural and most industrial goods, which frees up labour and thereby lowers the wage rate. The lower wage rate overcompensates for the effect of increasing water prices and thus results in a lower output price. Household income declines as a result of the decrease in wages, while consumer prices of water and foodstuff increase. The result is a lower domestic demand for these commodities. However, demand for other commodities increases slightly due to household substitution and the expanding production of marginal water which requires additional intermediary inputs.

Overall household demand increases by 0.21% in the *lib-scenario* and 0.07% in the *marg-scenarios*. In the *marg-scenarios* this additional demand is largely fulfilled by imports (+0.21%) which, due to a slight appreciation of the Israeli currency (0.3%) become cheaper.

3.6.4 Macro and Welfare-Effects

The effect on the total output of the Israeli economy in the *lib-scenario* is positive due to the removal of distortions in the water sector. In the *marg-scenarios* a price increase for all water users is added to this, which has an adverse effect. The overall welfare effects of the two simulations are small since the share of the water sector in the Israeli economy is small (about 0.7% of total domestic production in the base situation) and all household groups spend less than 1% of their income on water. Therefore, real GDP[5] increases by only 0.12% in the *lib-scenario.* Also, the effect of *marg-scenarios* on real GDP is still positive (+0.03%) driven by the slight increase in private consumption.

The effects on household welfare, measured as changes in equivalent variation (EV) relative to household consumption expenditure, are also small for similar reasons.[6] In the *lib-scenario*, the EV shows a clear trend in favour for richer households and it is negative for the two poorest quintiles of both ethnic groups. Changes in EV range from -0.2% for the poorest quintile of Jewish households to +0.8% for the richest non-Jewish households (Figure 3.4). The reasons for this are the opposing effects of decreasing water prices charged to municipalities. While the decreasing prices make water and service commodities cheaper, they also increase the price of agricultural commodities and decrease wages in the agricultural sector. The latter affects the poorer households disproportionately, as they derive a relatively high share of their income from employment in the agricultural sector and at the same time spend a comparatively high share of income on agricultural and food-commodities.

In the *marg-sav-scenario*, when the government saves its additional income, the welfare effects are exaggerated, whereby additional household groups are negatively affected (Figure 3.4). This is due to the rising prices of water and food-commodities. Only the top Jewish and the top two non-Jewish household quintiles still profit from this situation, mainly because of the high share of income from enterprises of these household-groups, which increases by 2.7% in this scenario. Moreover, prices for services fall, which especially benefits the richer quintiles. In the *marg-trans-scenario,* where additional water tax revenue is transferred to households, distribution is more equal and welfare effects are minimized. Thus welfare losses are mostly converted to gains, which reach a maximum of 0.2%. Only the third non-Jewish quintile still experiences a very small loss of 0.03% as the gains from the additional government transfers cannot completely compensate the losses caused by the price increases in this case.

[5] Measured from the expenditure side.

[6] It should be noted that welfare benefits resulting from positive externalities due to lower fresh water consumption (e.g. positive environmental effects or economic benefits for future generations) are not taken into account in the EV.

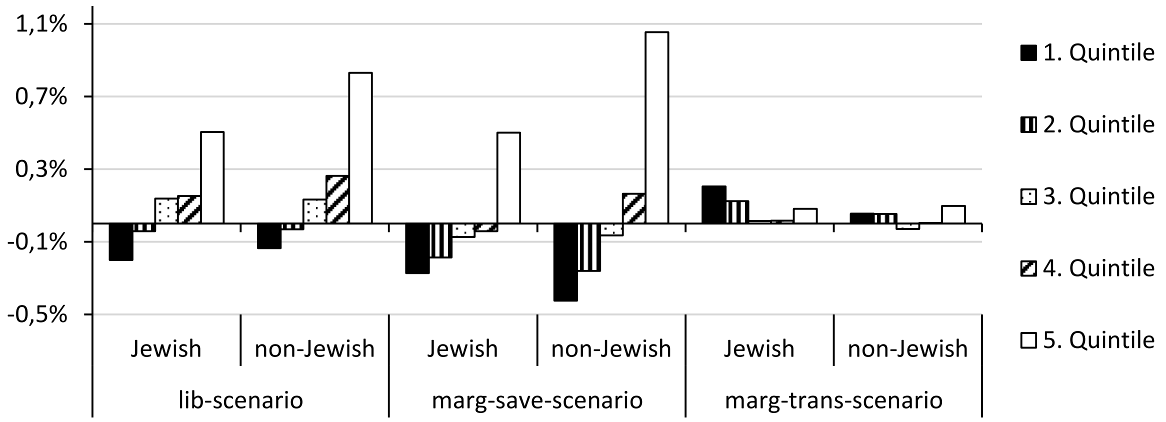


Figure 3.4. Changes in household welfare measured in equivalent variation as percentage share of household expenditure.

3.7 Discussion and Conclusions

The non-sustainability of the current water supply scheme in Israel is widely recognised and the current political debate has emphasised price-based policy reforms. This analysis assesses two core options for a more efficient water policy: price liberalization and marginal cost pricing for potable water.

Both pricing options reduce the demand for potable water to an extent that make desalination schemes unnecessary and at the same time relieve the pressure on aquifers. Therefore, instead of further extending desalination capacity, installed desalination capacity could be used flexibly as a buffer against shortages and droughts as suggested by Goldfarb and Kislev (2005).

The costs of the current water pricing scheme are harmful to the Israeli economy. They result in an annual GDP loss of 0.12% (equivalent to about 150 million USD) compared to a market based approach in which prices are unified and cover the full costs of water supply. If the water pricing schemes were reformed as envisaged by the *liberalization scenario*, demand for potable water would reduce to a level that makes desalination unnecessary and additionally saves 12 million m^3 of natural fresh water annually.

The analyses show that both pricing scenarios result in substantial reductions in the demand for potable water. These reductions in demand are noticeable for the liberalization scenario, but even more for the marginal cost pricing scenarios (297 million m^3). Under the marginal cost scenarios, the aquifers could be protected from overexploitation even at their low replenishment rates from recent droughts by providing some 100 million m^3 of potable water through desalination.

In both marginal pricing scenarios the economic costs are low. Caused by the reductions in taxes, real GDP, private consumption and welfare of many household groups actually increase. In all scenarios government funds increase, mainly due to the reduced expenditure, owed to the removal of the desalination subsidy and in the *lib-scenario*, because of the overall increase in economic activity generating additional tax revenue. The increase in government revenue could be used to fund investments in the development of alternative water facilities and technologies. These investments could include: improving access to the reclaimed water network and upgrading the quality of reclaimed wastewater so as to allow for a wider use in the agricultural sector and also in some industrial processes. Additionally, transfer payments could be made to those households that experience reductions in welfare as demonstrated by the marginal cost pricing scenario with compensating redistribution. This would mitigate the negative effects of a potable water price increase and further reduce the pressure on freshwater resources.

If the government of Israel aims at saving even more natural fresh water or providing additional potable water, e.g. to meet rising demand due to population growth, these requirements can be supplied by desalination, which would operate cost-neutral in the marginal pricing scenarios[7]. In the longer-term, the marginal cost pricing scenarios would allow the Israeli economy to be completely independent from natural fresh water resources. The water fee in these scenarios covers the costs of desalination, which include the capital costs for investing in new desalination plants. That way, any quantity of potable water could be provided independently from aquifer replenishment rates. This becomes even more feasible if technological progress is considered, which is expected to further reduce desalination costs (by up to 50% in the next 20 years) (Ziolkowska 2015). As a result, desalination in Israel would become competitive enough (compare Figure 3.1) to produce potable water without being subsidized. In this case economic indicators would be similar to the scenarios described in this paper and not be affected negatively (see footnote 7).

In general, this analysis shows that a more market oriented/liberal water policy improves welfare, a finding that is in line with other research (e.g. Solis and Zhu 2015). Further, it suggests that a smart water policy yields a double dividend by saving water on the one side and increasing economic growth on the other, which coincides with findings from South Africa (Letsoalo et al. 2007). Even a triple dividend (reduction of poverty) would be possible, depending on the redistribution policy of budgetary revenue from increased water fees. Thereby the increasing use of marginal water resources contributes to mitigate the negative outcome for the agricultural sector.

The substitution elasticities and market clearing conditions for this analysis are set up to report effects for a medium- to long-term time horizon. A sensitivity analysis shows that with halved production elasticities most economic indicators develop in the same direction, whereby most outcomes are more negative or less positive due to the lower flexibility in the short-term, which is expressed by the reduced substitution elasticities (Appendix, Table 3.A1).

[7] A simulation in which desalination capacity is fixed at the current level, such that the reduction occurs to the usage of fresh water resources, yields very similar results in terms of water usage and production. Due to the higher costs of desalination, which is subsidized, the change in real GDP turns negative (-0.01%). The equivalent variation is slightly more negative, but income distribution more balanced.

For a long-term analysis, in order to consider the growth of water demand due to economic and population growth and to depict the time path of adjustment, future research could apply a dynamic CGE model similar to the approach by Briand (2006). Another potential avenue would be to evaluate the implications of further treating the wastewater, which would increase the costs, but at the same time allow it to be used by a much wider range of activities. That way shocks in the potable water sector could be absorbed more easily. Further, it would be an option to link STAGE_W to an agent-based model in order to better capture the quota and block rate pricing system for potable water in Israel.

The model is formulated in a generic way and therefore can be expanded or adjusted to diverging conditions. Presuming the availability of an appropriate database, and carefully re-evaluating the assumed substitution elasticities, it can be applied to other countries in which a different set of water qualities and resources might be used and alternative pricing schemes might be applied.

3.8 Appendix

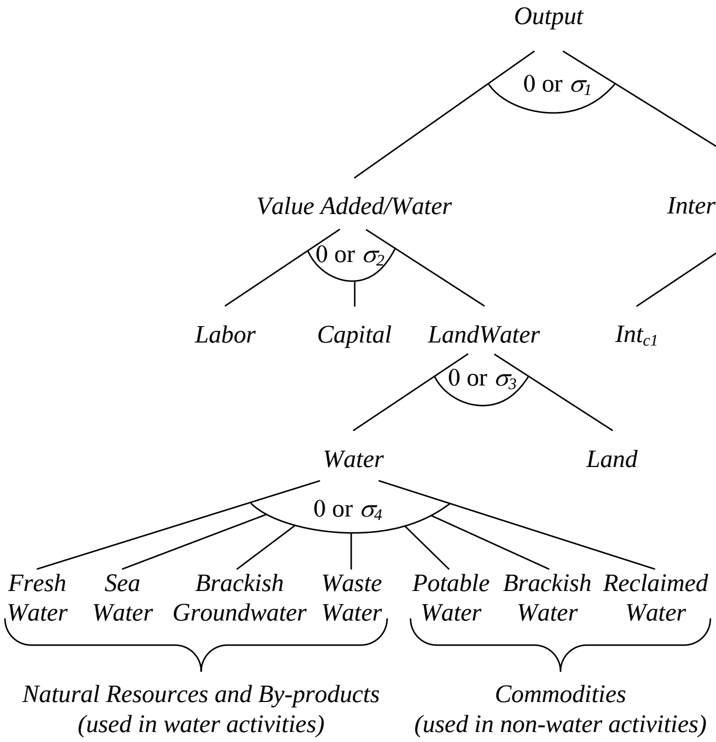


Figure 3.A1. Production System for Activities in STAGE_W.
Source: modified from Luckmann et al. 2014.

Table 3.A1. Changes in economic indicators with original (orig.) and halved (half) production elasticities.

		% change compared to base			
	Scenario:	lib-orig.	lib-half	marg-orig.	marg-half
Production	Agriculture	-3.09	-3.32	-4.81	-5.66
	irrigated	-4.23	-4.60	-6.58	-7.84
	Manufacturing	-0.21	-0.13	-0.35	-0.18
	Services	0.25	0.21	0.23	0.26
Real GDP		0.12	0.09	0.03	0.02
Eqivalent Variation	*Jewish households*				
	1. Quintile	-0.20	-0.24	-0.27	-0.36
	2. Quintile	-0.04	-0.08	-0.19	-0.25
	3. Quintile	0.14	0.12	-0.07	-0.08
	4. Quintile	0.15	0.15	-0.04	-0.02
	5. Quintile	0.51	0.49	0.50	0.66
	non-Jewish households				
	1. Quintile	-0.14	-0.24	-0.42	-0.65
	2. Quintile	-0.03	-0.13	-0.26	-0.44
	3. Quintile	0.13	0.04	-0.06	-0.20
	4. Quintile	0.26	0.18	0.16	0.11
	5. Quintile	0.83	0.75	1.06	1.28

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4 When water saving limits recycling: Modelling economy-wide linkages of wastewater use

This chapter consists of the correspondent article, published 2016 in *Water Research* Vol. 88, pp. 972-980, doi:10.1016/j.watres.2015.11.004

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Abstract:

The reclamation of wastewater is an increasingly important water source in parts of the world. It is claimed that wastewater recycling is a cheap and reliable form of water supply, which preserves water resources and is economically efficient. However, the quantity of reclaimed wastewater depends on water consumption by economic agents connected to a sewage system. This study uses a Computable General Equilibrium (CGE) model to analyse such a cascading water system. A case study of Israel shows that failing to include this linkage can lead to an overestimation of the potential of wastewater recycling, especially when economic agents engage in water saving.

Keywords: Cascading water use; Computable General Equilibrium model; STAGE_W; Wastewater recycling; Wastewater reclamation; Shadow price

4.1 Introduction

Water scarcity is an emerging global problem. Population and income growth are increasing demand appreciably. At the same time, the supply of water from traditional sources is failing to keep pace, and is being constrained by environmental and other concerns that are limiting the expansion of storage capacity and restricting extraction from aquifers. Moreover, the quality of freshwater resources is deteriorating as they are increasingly polluted, resulting in the spread of waterborne diseases (Jimenez and Asano, 2008) and limiting usefulness of the water. Consequently, societies have to recognise that water is an economic good that is costly.

There are multiple approaches to address water scarcity with all of them involving increased costs. The rate of demand growth can be limited by increases in efficiency, e.g. drip feed irrigation systems, reductions in transmission losses, etc., and/or by encouraging users to conserve water, e.g. using showers rather than baths. Supplies can be increased by using non-traditional sources (e.g. seawater desalination), increased purification of traditional sources, and/or by the recycling of wastewater, which includes the treatment of wastewater (reclamation) and its use in economic activities. The balance between the different approaches depends upon country-specific circumstances. This study is concerned with the economic implications of recycling wastewater: how its collection, (partial) purification and reuse interact with other sources of water in the system. Because of the complexity of water systems, and the extent to which water is integrated within economic systems, the analyses require the use of a framework (model) that captures these interactions.

Most wastewater, for reclamation, is collected through the sewage system. Given the origin of reclaimed wastewater and the costs of purification, most reclaimed wastewater is used for the irrigation of non-food crops and industrial processes, especially cooling, that do not require high levels of purification. Thus, wastewater recycling for irrigation is a potentially important as well as relatively low cost source of water and therefore is used in more than 40 countries (Jimenez and Asano, 2008). Typically, the ratio of recycled wastewater to total water extraction is low, although in countries facing severe water shortage it is already quite high, e.g. it is 35% in Kuwait and 18% in Israel (Jimenez and Asano, 2008). A major issue for water authorities contemplating recycling wastewater is that, as water becomes scarcer, programs are developed to increase the efficiency of water use and the price of water to consumers increases: both serve to lower the amount of wastewater available. For example, in Beijing rapidly increasing potable water prices have induced companies to invest in internal recycling facilities, lowering the potential for communal wastewater recycling (Yang and Abbaspour, 2007).

The analyses reported in this paper derive from a water-focused Computable General Equilibrium (CGE) model, STAGE_W (Luckmann and McDonald, 2014), which has been extended to encompass recycled wastewater by linking the supply of reclaimed wastewater to the quantity of wastewater available. The advantages of using a CGE model are that this class of models can capture the complex interactions within water systems and the demand for water, both as an input to production as well as consumption by households. Equally important is the fact that prices within a CGE model are variables. This means that any changes in water, and other, prices have direct impact on the decisions of agents in the model, whether these price changes are exogenously imposed, e.g. through government policies, or solved endogenously within the model. Hence, the model generates shadow prices for wastewater to inform governments and pricing decisions. The analyses are implemented using data for Israel, although the framework is generic and applicable in any country for which the requisite data are available.

The rest of the paper is structured as follows. Section 2 reports a review of existing approaches to model wastewater recycling from an economic perspective. Section 3 contains a description of the STAGE_W model and its extension. A description of the water system in the Israeli economy and the data used for the empirical application are provided in section 4. The simulations are reported and the results are analysed in section 5. While the final section 6 contains conclusions that are specific to the situation in Israel but also regarding the treatment of wastewater recycling in simulation models in general.

4.2 Literature Overview

Water models for economic policy analyses have developed greatly in the last 25 years (Booker et al., 2012), but the economics of the recycling of wastewater remains underdeveloped (Molinos-Senante et al, 2011).

A key issue is the economic viability of wastewater recycling, conditional upon different treatment levels and uses, e.g. irrigation vs. river disposal. Irrigation with reclaimed wastewater subject to secondary treatment can yield positive net economic benefits in Israel depending on the conveyance distance (Haruvy, 1997). Thus, there may be positive returns to increases in wastewater recycling. The key determinants will be the economic costs of wastewater recycling and the desalination of reclaimed water so that long-run chloride concentrations in the soil are stabilised (Haruvy et al., 2008). It has been argued that if reclaimed wastewater is treated to the highest sanitary and lowest salinity levels (including tertiary treatment), the net economic benefits exceed those from lower treatment levels; although the economically optimum levels of treatment will vary across regions (Lavee, 2013).

The distribution of reclaimed wastewater between producers of wastewater (municipalities) and consumers of reclaimed water (farmers) is problematic as reclamation of wastewater is a public good for the wastewater producers and a private good for the farmers: therefore, market failure exists and optimal allocations are not realised. If the polluter pays principle is applied and municipalities pay the full costs of wastewater reclamation, an (economically) efficient allocation of reclaimed wastewater is unlikely (Feinerman et al. 2001). Hence, there is a *prima facie* case for government intervention. In a game theoretic regional model total benefits are greatest if there is information symmetry, which supports cooperation and agreements between economic entities regarding the allocation and price of the reclaimed water (Axelrad and Feinerman, 2010).

Increases in the prices of potable water will induce firms to invest in water recycling and thereby reduce outflows of wastewater (Yang and Abbaspour 2007). Thus, dependent on the relative costs of internal water recycling compared with fresh water supply and discharge costs, it may be economically viable for firms to invest in such water-conserving technologies (Rivers and Groves, 2013). This may lead to considerable water savings, since investments in internal wastewater recycling by industries may reduce their freshwater intakes by up to 95% (Levine and Asano, 2002). Unsurprisingly CGE-based studies of water pricing conclude that if firms are charged for extracting water, e.g. from a river, that is returned to the source after use, then the rate of self-recycling will increase (Rivers and Groves, 2013). Such analyses do not encompass any users of the wastewater, which may make sense in countries that have abundant water supplies, e.g. Canada, but not in water scarce regions.

One approach to consider a cascading water use is to allow substitution possibilities between reclaimed wastewater and fresh water in a dynamic optimisation model. If the marginal provision cost for reclaimed wastewater is constant and potable water and reclaimed wastewater are perfect substitutes, then the use of reclaimed wastewater for irrigation becomes a backstop technology. Thus, if the unit price of potable water reaches the marginal cost of reclaimed wastewater farmers will choose to irrigate with reclaimed wastewater (Roumasset and Wada, 2011). If the marginal provision costs of reclaimed wastewater are increasing then it becomes a supplemental resource (Roumasset and Wada, 2011). However, in all previous studies, it has been assumed that the supply of wastewater is unlimited, which may be a misleading assumption when considering conditions of water scarcity (Park et al., 2008).

This study contributes to the literature by improving the modelling of wastewater recycling through endogenously connecting the provision of wastewater to the water consumption of economic entities in an economy-wide framework. The model presented in this paper builds on Luckmann et al. (2014), which is the first CGE model including a wastewater reclamation activity allowing for the transfer of reclaimed wastewater to other economic activities.

4.3 Model Description

The model used for this analysis makes the production of reclaimed wastewater dependent upon the endogenously determined supply of wastewater. This requires the simultaneous determination of the supply of sewage, which is a function of the demand for water by activities producing sewage, and the supply and demand for reclaimed wastewater. Consequently, the model must encompass the entire water system of an economy and how the economy reacts to changes in the water system or changes in water policies, which is what water-focused CGE models are designed to do.

The model is a development of the STAGE_W model, which is documented in Luckmann and McDonald (2014). Hence, the description of the base model here is limited. STAGE_W is a Social Accounting Matrix (SAM)-based single country CGE model, which includes non-linear and linear relationships governing the behaviour of the model's agents. The model is calibrated to replicate the economic transactions reported for the country in the SAM. Thus, the model encompasses all production, consumption, trade and policy relationships recorded in a SAM that is derived from National Accounts data. The SAM must contain a detailed water sector with different types of water activities producing different water commodities from water resources or by-products.

The demand for water in production is a nested production system (Figure 4.1). Different types of water, from natural or processed sources, are potential substitutes, which means, that the demand for each type of water is dependent upon its price and suitability for use in each activity, e.g. seawater cannot be used to irrigate crops but is a source of water for desalination. Similarly, the final demand for different types of water, e.g. by households, depends upon prices and its suitability, e.g. potable water can be used for all purposes by households but, in general, reclaimed water cannot.

In this class of models the production of water is costly, which reflects the fact that the extraction, distribution and treatment of all types of water requires the use of resources, even if the natural resource, e.g. seawater, rainwater, etc., is free. Since the costs of water from different sources differ, e.g. potable water derived from seawater or rivers and reservoirs, the model needs instruments that define the available supplies of water types from different sources and the implications of different policies. The former are represented by constraints on the availability of the natural resources, while a range of government policy instruments represents the latter. If the supply of potable water from rivers and reservoirs is unlimited, there will be no supply of desalinated water, because of its higher cost. If there is a supply of desalinated water and the price of potable water is the same across all sources then there must be policy instruments that ensure prices are the same. The subsidy and tax instruments in STAGE_W are: producer-activity (a) specific production tax/subsidy rates (TX_a); commodity (c) specific tax/subsidy rates (TW_c); and consumer-activity and commodity specific user tax/subsidy rates ($TWA_{c,a}$).

The supply of wastewater is endogenised by making it a function of the use of potable water in the model, as suggested by Feinerman et al. (2001). As the demand for potable water increases/decreases, so the supply of wastewater increases/decreases, and hence, the maximum quantity of reclaimed wastewater increases/decreases.

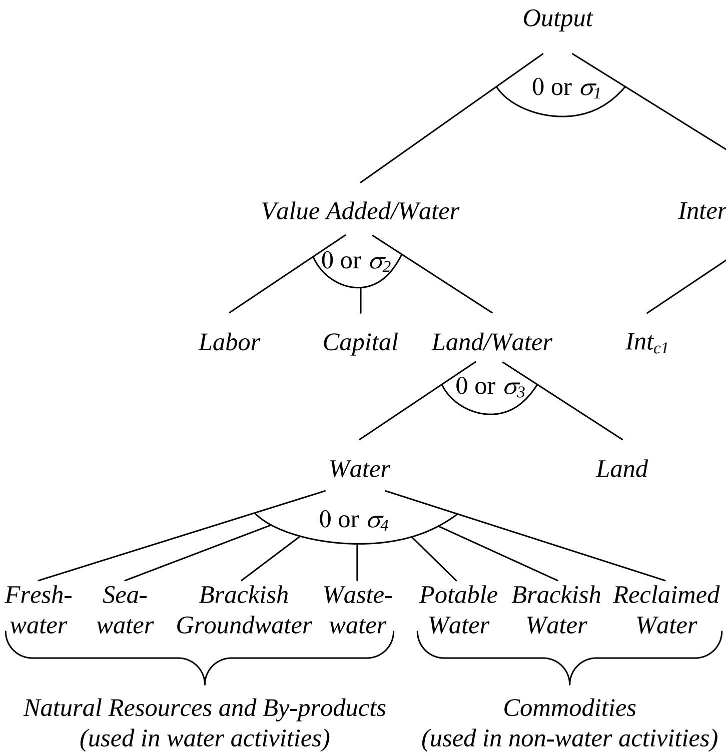

Figure 4.1. Production System for Activities in STAGE_W.

Accordingly, STAGE_W is extended by adding an equation that defines the availability of sewage (FS_{sew}) as dependent upon the quantities of water consumed by households ($QCD_{cwat,h}$) and activities connected to a sewer system ($QWAT_{cwat,asew}$)

$$FS_{sew} = E = shsews * (1 - shsewl) * \left(\begin{array}{l} \sum_{cwat,asew} QWAT2_{cwat,asew} * shsewmun_{cwat,asew} \\ + \sum_{cwat,h} QCD_{cwat,h} * shsewmun_{cwat,h} \end{array} \right) \quad (1)$$

where the coefficients *shsewmun* define the shares of water consumed that are realised as sewage, *shsews* defines the share of sewage collected and *shsewl* defines the share of the collected sewage lost. The supply of sewage defines the maximum quantity available for recycling but the actual quantity used depends upon the demand for reclaimed wastewater conditional upon the demand and supply of all water types in the system. Wastewater that is not recycled leaves the system. There may be environmental reasons for ensuring a minimum level of discharge, e.g. for natural conservation and the improvement of river quality: for convenience, in the model, these discharges are part of government consumption (*QGD*). The government consumption of wastewater has a lower bound (*comgovconst*), the quantity consumed in the base period, and no upper limit. Formally, this is a mixed complementary problem (2), with a lower bound being the base quantity (3). The government can adjust the lower bounds for different types of water individually or multiplicatively (*QGDWADJ*), e.g. in response to environmental concerns about inadequate river flows, etc.

$$QGD_{cwatrec} = G = QGDWADJ * comgovconst_{cwatrec} \qquad (2)$$

$$QGD.LO_{cwatrec} = comgovconst_{cwatrec} \qquad (3)$$

4.4 The Case of Israel

4.4.1 Wastewater Recycling in Israel

The annual freshwater supply in Israel is less than 250 m³ per capita, which is 50% below the threshold of severe water scarcity according to the Falkenmark indicator (Tal, 2006). All water in Israel, including sewage and wastewater, belongs to the state under the 1959 water law (Kislev, 2011). The Israeli Water Authority (IWA) manages the water sector and supervises all companies that are involved in the provision of water. Water authorities must treat municipal sewage (Inbar, 2010), such that 94% of the sewage is collected in a central sewer system and 91% is treated (Lavee, 2013). Some 75% (355 million m³) of the sewage is recycled, which is among the highest recycling rates in the world[8]. The remainder of the treated water is discharged into rivers to improve water quality and river flow (Inbar, 2010; Lavee and Ash, 2013). Reclaimed wastewater is distributed via a separate network; in many localities, farmers can use potable water or reclaimed wastewater for irrigation. Irrigation with recycled wastewater is limited to crops not for human consumption, e.g. cotton, fodder crops, or for crops whose consumed parts do not have direct contact with the water, e.g. orchards and other tree crops (Inbar, 2010).

Israel plans to increase the share of wastewater reuse to 95% over the next few years (Lavee and Ash, 2013). An extension of the sewage system, further development of reclamation facilities and an assumed doubling of urban potable water consumption, means that by 2050 as much as 900 million m³ of reclaimed wastewater will be supplied annually (IWA, 2012). Furthermore, it is planned to upgrade the quality of reclaimed wastewater to allow for a wider use in agriculture (IWA, 2012).

The Israeli government heavily subsidises the recycling of wastewater. The IWA has invested 4.6 billion New Israeli Shekel (NIS) (~1.34 billion USD) in the last decade for wastewater recycling projects. There is financial assistance for farmers who switch to reclaimed wastewater, and for raising the quality of reclaimed wastewater. 15-60% of the construction costs for private recycling facilities are subsidised, while inter-facility infrastructure is fully government funded. The annual subsidy is about 170 million NIS (~50 million USD) and is financed by domestic consumers through potable water prices and sewage fees (Lavee and Ash, 2013). At the same time, quotas for the use of potable water for irrigation have been cut drastically since the 1980s (Zhou, 2006).

[8] The wastewater-recycling rate is the share of recycled wastewater over total wastewater produced.

These policies result in a situation where demand for reclaimed water by agriculture exceeds supply. Demand will grow as reclamation facilities are upgraded to allow for unrestricted irrigation with reclaimed wastewater (Inbar, 2010). However, supply is limited in the short-run by the infrastructure, while in the long-run the available quantity is constrained by the quantity of wastewater entering the sewage-systems.

4.4.2 Model Database and Setup

The model for this study uses an Israeli SAM for 2004, which was a 'normal year' after the Second Intifada and before the world financial crisis in 2009 (CBS, 2013). The SAM, which is based on Siddig et al. (2011), includes satellite accounts for all water types and was extended for this study by adding effective sewage as a production factor.

The SAM has 46 economic activities that produce 45 commodities, including four water activities (freshwater purification, desalination, reclamation of wastewater, pumping of brackish groundwater), three water resources (freshwater, seawater and brackish groundwater) and one by-product (wastewater) to produce three water commodities (potable water, reclaimed wastewater, brackish water). Potable water is produced by a freshwater purification activity and a desalination activity. There are 41 production factors and 25 tax categories (two of which are implemented especially for the water pricing regime). Finally, there are 10 household groups, classified according to ethnic background (Jewish and non-Jewish) and income (five quintiles), that facilitate the analysis of welfare implications and distributional effects. An aggregated version of the SAM is reported in Luckmann and McDonald (2014).

Sewage is owned, *de facto*, by the government that runs the sewage system. Since it has no price, it is not an economic good with transactions values. The quantities of sewage are recorded in the satellite accounts. Only the wastewater reclamation activity uses sewage as an input, which, by virtue of the production functions and data, guarantees that sewage cannot be substituted by or for other inputs or production factors.

In this study the sewage produced by households, utilities and the service sector, except for construction, is quantified. The costs of the wastewater treatment activity include primary and secondary treatments; the latter is the most widespread treatment level in Israel. The reclaimed water can be used to irrigate non-food crops and crops for which lower sanitary restrictions apply.

The calibration of the model assumes that water activities use capital, labour, intermediates and water inputs in fixed proportions[9]; holding the cost structures constant as suggested by Tirado et al. (2006). This is a short-run assumption under which the technologies of the water system activities are fixed.

[9] This is achieved by setting the substitution elasticities to zero for water activities. For a long-run solution the substitution elasticities can be set to values greater than zero.

Substitution possibilities are imposed for non-water activities. Agricultural activities can substitute water commodities with a medium to low substitution elasticity (σ_4) of 0.8 (Sadoulet and de Janvry, 1995), which reflects the fact that not all components of the aggregated activities can use marginal[10] water qualities and that the option to use marginal water does not exist in all localities. On the third level of the production function, aggregate water and land have a substitution elasticity (σ_3) of 0.3 following Faust et al.'s, (2015) estimates of irrigation-land substitutability for Switzerland. The land-water aggregate then combines with labour and capital at the second level of the production function: given the prevalence of drip irrigation systems in Israel (Saleth and Dinar, 1999), the substitution elasticity (σ_2) is 0.8 (Berck et al., 1991). The top-level combines the value added and water aggregate with aggregate intermediate inputs with an elasticity (σ_1) of 0.5.

4.4.3 Scenarios and Closures

4.4.3.1 Scenarios

Israel has sought to reduce freshwater uptake from aquifers, mainly due to a series of drought years, in which aquifer replenishment rates fell to as little as 63% of the multi-annual average (Shachar, 2009). This required a reduction in freshwater consumption, at a time of growing population and economy and thus, increasing demand for water. Consequently, Israel is seeking to replace potable water with reclaimed wastewater for irrigation.

The scenarios assume a reduction of 50% in freshwater resources, which may appear drastic. Yet climate models indicate that drought conditions will be more likely in the future and that precipitation rates may decline by up to 50% in the region (Hertig and Jacobeit, 2008). Moreover, there is pressure for a more equitable allocation of water resource between Israel and Palestine, which may be necessary for a comprehensive peace agreement. Estimates indicate that water reallocation would reduce Israel's renewable freshwater resources by 32% with loss of another 22% due to climate change (Chenoweth, 2011). Thus, a 50% reduction is not unrealistic even if it is on the high side.[11]

The analyses assume that the quantity of desalinated water is constant. Thus, the reduced output of the freshwater activity reduces the quantity of potable water available to the economy.[12]

Two scenarios demonstrate the implications of a 50% reduction in freshwater resources. The distinction between the two scenarios is whether the link between freshwater consumption and sewage supply (equation 1) is included or not.

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[10] In this paper, the term marginal water refers to reclaimed wastewater and brackish water.

[11] In exploratory simulations, the decrease of aquifer offtake was simulated by reductions in the output of the freshwater activity in 10% steps up to 80%; beyond which solutions became infeasible. Between 10% and 70%, the patterns of the results were consistent. A full set of these results is available from the authors.

[12] Increasing the quantity of desalinated water would require investment in new desalination plants, i.e., an increase in the capital stock of the desalination activity. The interaction between new investment in potable water supplies and recycled water is beyond the scope of this study.

1) *Scenario "no-link": Reduced freshwater resources with unlimited sewage availability.* In this scenario, the supply of sewage (FS_{sew}) is unlimited at a constant very low price. The quantity of reclaimed wastewater then depends on the demand for and prices of other production factors and intermediate inputs, with the implicit tax rate on reclaimed water (TW_c) fixed.
2) *Scenario "link": Reduced freshwater resources with limited sewage availability.* In this scenario, any reduction in water consumption by municipalities reduces the quantity of reclaimed wastewater available to agriculture, which results in excess demand for reclaimed wastewater. The government can regulate demand by quotas or by a tax that raises the consumer price. The latter is an estimate of the marginal value of the sewage; thus, in this scenario the implicit tax rate on reclaimed water (TW_c) is made flexible such that its level indicates the marginal value of sewage.

The technical coefficients determining the shares of water collected in the sewage system (*shsews*), losses during the reclamation process (*shsewl*), and the ratio by which municipal entities convert water into sewage (*shsew*) are fixed to facilitate comparison between the two scenarios.[13] This setup makes the quantity of wastewater available dependent on the cost of potable water. A comparison of the scenarios' results highlights the relevance of modelling the link between potable water consumption and wastewater recycling.

4.4.3.2 Market Clearing and Macroeconomic Closure

The reduction of the freshwater resource and a fixed desalination capacity reduce the availability of potable water. The equilibriating variable for the potable water market is supply of sewage in scenario 1 ("*no-link*") and the commodity tax rate for potable water (TW_c) in scenario 2 ("*link*"). The production subsidy (TX_a) to the desalination activity is flexible to maintain a constant quantity of desalinated water[14]. The household income tax rates are (multiplicative) variables that clear the government account by compensating for endogenous changes in water taxes. All other tax rates remain constant.

Full employment and factor mobility are assumed for capital, land and labour. Since water factors are only used by one respective water activity they are not mobile, with fixed prices that are politically determined. Therefore, the quantity used of these factors is flexible, which allows the output of water activities to vary.

Israel is a small country so world market prices are fixed. The current account balance is fixed so that the external account is cleared by a variable exchange rate. For the government, consumption quantities and real transfers to households are fixed. Investment volumes and government savings are

[13] If the technical variables are adjusted to simulate that additional households are connected to the sewage system and less sewage is lost within the system, the values of all result-variables lie in between the two described scenarios.
[14] This mirrors the long-term contracts of the Israeli government with the private operators of desalination plants, which guarantees the take-up of a fixed quantity of water for a certain period and at a particular price.

fixed with the savings rates of households and enterprises flexible to clear the capital account. Thus, all welfare changes in the solution period impact directly on households with no inter-generational utility trade-offs.

4.4.4 Results

4.4.4.1 Water Prices

Under both scenarios the prices charged for potable water triple as the implicit water commodity tax ($TW_{cwatpot}$) increases until demand is brought into balance with the reduced supply of potable water (see Figure 4.2). The prices of potable water for agriculture increase accordingly from 0.24 USD/m³ to about 0.74 USD/m³ and for manufacturing from 0.48 USD/m³ to about 1.47 USD/m³, under the no-link scenario. Under the link scenario the prices rise by an additional 0.01 USD/m³. The uniform proportionate price increases reflect the assumption that the water user subsidy rate ($TWA_{cwatpot,a}$) is constant in relative terms.

The reduction in the availability of freshwater cannot be fully compensated by substitution with other inputs; the economy therefore contracts which results in falling factor and intermediate input prices (production prices of all industrial commodities decrease by between 5% and 6%, see further below). Brackish water becomes slightly cheaper, as the implicit commodity tax on this water quality is constant while costs of provision decrease. But brackish water can only be used by two agricultural activities; hence, there is little scope to increase demand (Table 4.1) despite the decline in the supply price.

With unlimited supplies of sewage, the no-link scenario, the price of reclaimed wastewater declines because costs fall with economic contraction. However, with limited sewage supply, the link scenario, the consumer price of reclaimed wastewater doubles with the increase in the implicit tax rate for reclaimed wastewater. In the link scenario, the total quantity of water available to the economy is lower than under the no-link scenario (Table 4.1); thus, the increase in the implicit water commodity tax is greater under the link scenario. Moreover, the impacts of the economic contraction on costs are greater in the link scenario, which explains the slightly larger decrease in the price of brackish water. In contrast, the slightly larger increase in the price of potable water under the link scenario reflects the fact that reclaimed wastewater increases in price due to the limited availability of sewage.

4.4.4.2 Water Consumption

The reduction in the availability of fresh water causes sharp reductions in the demand for potable water by all consumers. Except for households these are in the order of 60% under both scenarios, whereas household demand declines by less than 20% (see Table 4.1). These changes are in line with expectations given the 208% - 210% increases in consumer prices. The smaller reduction in demand by households reflects the greater substitution possibilities available to non-household users of potable water, the small shares of household expenditure on water and fixed shares of subsistence consumption, between 38% and 5% (decreasing with increasing income), in the household demand functions.

The importance of the link between potable water use and recycling of wastewater emerges in the results for water use by agriculture. Total water consumption by agriculture falls by 27% in the no-link scenario and by 43% in the link scenario. With no link and unlimited sewage, agriculture offsets the reduction in potable water availability by a small increase (5.7%) in consumption of reclaimed water. However, to do this the rate at which potable water used by municipalities is converted into reclaimed wastewater must increase from 72% to 111%, which is unrealistic, if the supply to the environment is to be kept constant. With the supply of reclaimed wastewater linked to the availability of sewage and fixed technical parameters of wastewater reclamation, the consumption falls sharply (43%) with consequent reductions in the output of crops irrigated with reclaimed wastewater.

These consumption results highlight the importance of including the link between the availability of sewage and wastewater recycling. Neglecting this linkage is likely to bias the results.

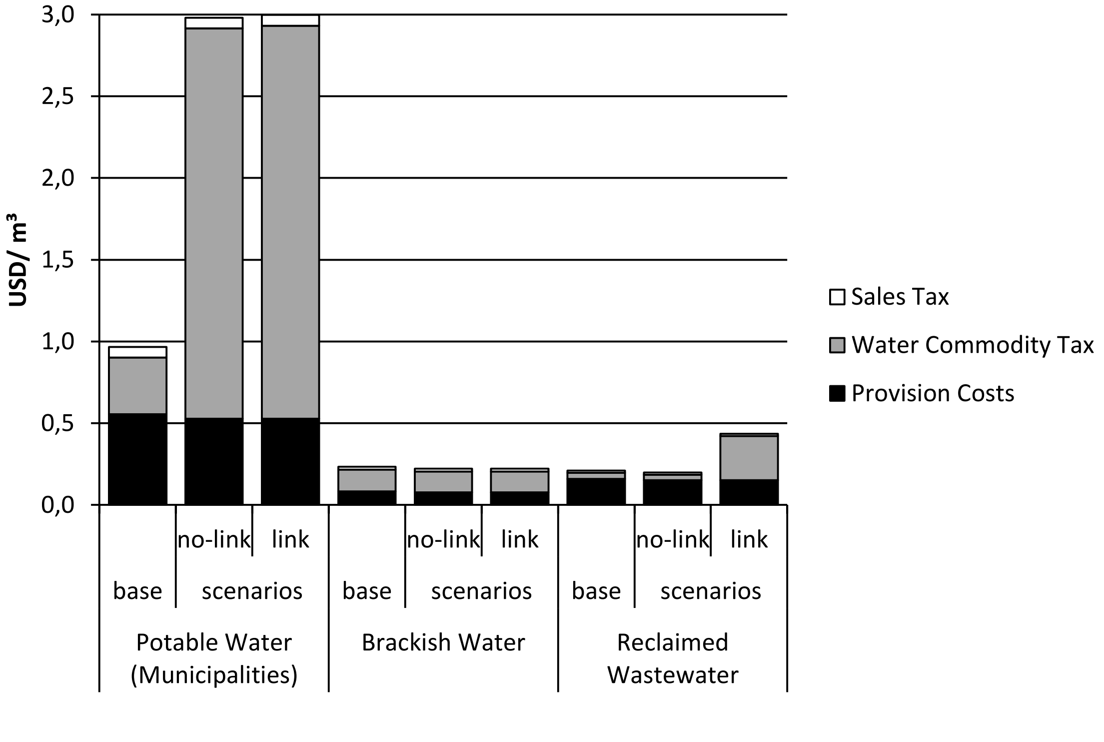

Figure 4.2. Provision costs and taxation of water commodities.

Table 4.1. Changes in water quantities consumed.

		Water quantity [million m³]			Change compared to base [%]	
Water quality	Sector	base	no-link	link	no-link	link
Potable	Agriculture	565	233	234	-58.7	-58.6
	Manufacturing	123	48	47	-61.5	-61.7
	Municipalities	702	476	475	-32.2	-32.3
	Services	218	84	84	-61.3	-61.5
	Households	483	391	391	-19.1	-19.1
Brackish	Agriculture	185	195	197	5.6	6.7
Reclaimed	Agriculture	379	401	216	5.7	-43.0
	Environment	126	126	126	0.0	0.0
	Total	**1954**	**1352**	**1170**	**-30.8**	**-40.1**
Reclamation rate [% of municipal water consumption]		72.0	110.8	72.0		

4.4.4.3 Domestic Production and Prices

The output of most activities is reduced in both scenarios since non-water factors and intermediate inputs can only partially compensate for increases in the price of potable water. The agricultural sector is the most affected because in agriculture water has the highest share of production costs, especially in the production of “other cereals”, “other crops” and “vegetables and fruit”, in which the share is 7.5%, 6.6% and 6.2%, respectively. The output of the former two activities is reduced the most (Figure 4.3), while the production of “vegetables and fruit” falls less due to the relatively lower integration in the international market and thus, the lower dependence on the fixed world market prices.

The economic contraction decreases the demand for labour and other factors of production: wages fall by about 6.1% and 6.3% in the no-link and link scenarios, respectively, which reduces production costs. The only exception is “other cereals”, for which costs rise by about 4.5% in both scenarios. This is due to the high water intensity of this activity, and the inability to substitute with marginal water commodities. The corollary is that where the water intensity of an activity is low and/or substitution possibilities are strong an activity’s output will decline less, as the decrease in wages and costs of other inputs compensates increasing water prices to a higher extent.

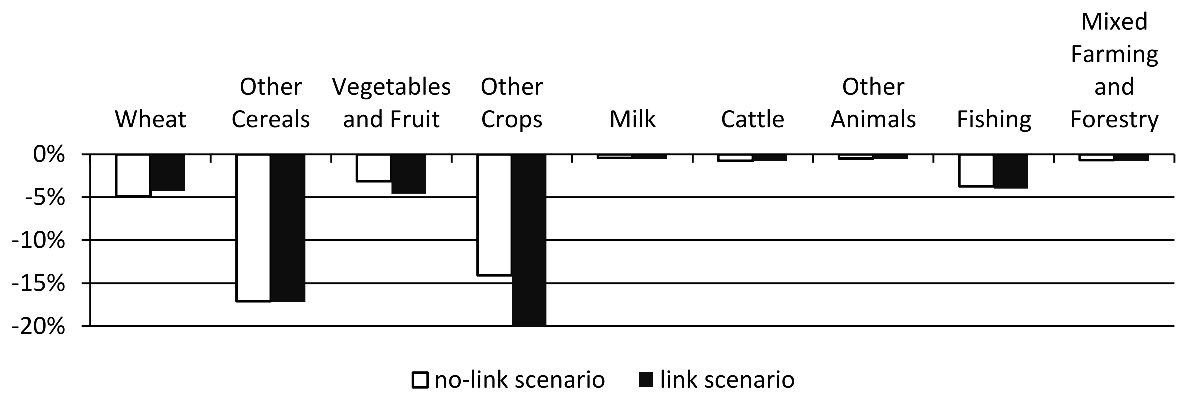

Figure 4.3. Changes in domestic production of agricultural activities.

4.4.4.4 Trade

The appreciation of the Israeli currency by 5.6% and 5.8% in the no-link and link scenarios, respectively, reflects the reduction in domestic production costs. Importantly, the composition of trade changes with increases in imports and reduced exports of (domestically) water-intensive products. Thus, there is a net gain in Israel's virtual water trade balance that contributes to water saving.

4.4.4.5 Government, Welfare and Macroeconomic Effects

The government income from the water sector increases due to the increases in the water commodity tax rates on potable water (from 0.35 USD/m³ to 2.39 USD/m³ and 2.40 USD/m³ in the no-link and link scenarios) and the tax on reclaimed wastewater (from 0.04 USD/m³ to 0.27 USD/m³ under the link scenario). Overall, the government's budget position allows the household income tax rates to fall by 2.6% and 2.8% in the no-link andn link scenarios.

Household welfare declines (Figure 4.4) because of the reductions in wage rates and returns on capital that reduce household income by between 3.2% and 5.6%. The reductions in income tax rates reduce the adverse impacts on welfare, while the welfare gains for the poorest Jewish households (hj1) are attributable to the constant real transfers from the government. This indicates that targeted government transfers can offset the welfare implications of reductions in the availability of water resources.

The real GDP[15] of Israel contracts by 0.21% in the no-link scenario and by 0.24% in the link scenario. This translates into a difference of 31 million USD, by which the effects of the reduction in freshwater availability would be underestimated annually if the linkage between water consumption and wastewater recycling is not considered.

[15] Measured by expenditure.

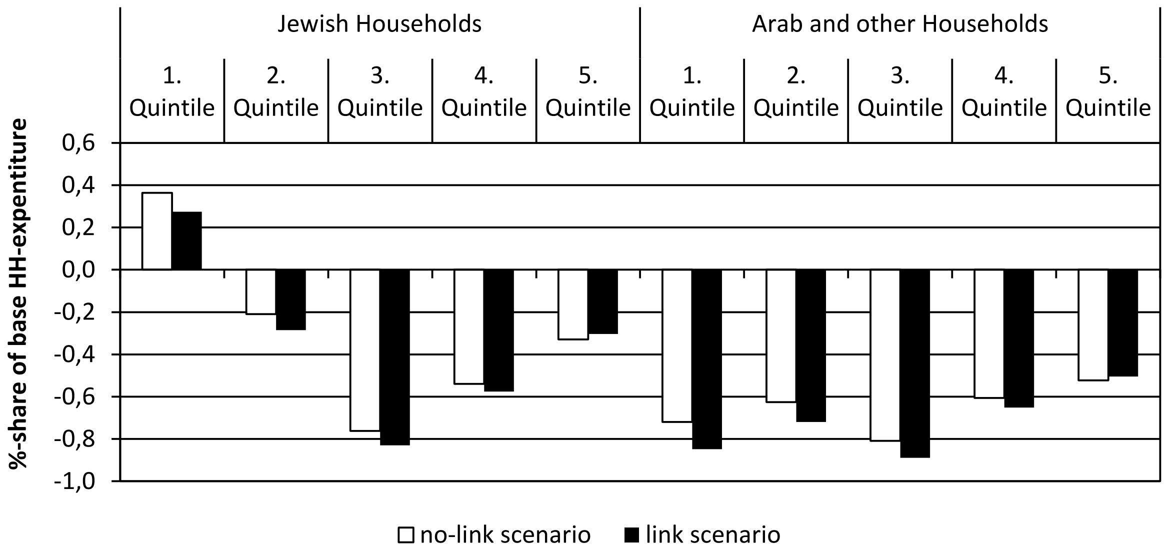

Figure 4.4. Household welfare measured in equivalent variation as percentage share of household expenditure.

4.4.4.6 Uncertainty

The prediction of future water resources involves several sources of uncertainty, e.g. the uncertainty about future greenhouse gas emissions and how they translate into hydrological effects in a given area (Chenoweth, 2011). The same holds for the allocation of water resources between the different political entities within the region. In order to see how much this uncertainty affects the model outcomes, the trends of the main parameters are investigated with respect to less and more severe shocks (Table 4.A1).

A reduction in freshwater availability in 10% steps from 0% to -70% causes approximately linear changes in water consumption. This leads to near linear increases in reclaimed water prices. However, due to limited substitution possibilities, increases in the output of reclaimed water lag behind reductions of potable water consumption. Thus, the potable water price rises exponentially, secondary effects become more severe, and GDP falls at an increasing rate. Similarly, the welfare of household groups decreases at an increasing rate. For most households the effects become more pronounced for reductions of above 40%.

4.5 Discussion

For Israel, reductions in freshwater resources lead to increased demand for reclaimed wastewater, and thus, higher willingness to pay. The implicit water tax, which is endogenously adjusted in the link scenario to balance the limited supply with the increasing demand, is an estimate of the marginal value of unpurified sewage. This has three benefits. First, it can be used as an estimate of the losses to activities that use reclaimed wastewater if wastewater producing entities engage in water saving. Second, this shadow price could be added to the reclaimed wastewater fee in case supply is reduced, so as to efficiently clear the market. And third, it can be used to evaluate the economic costs for expanding the infrastructure for water reclamation.[16]

Another option for the IWA to mitigate a reduction in usable freshwater resources is to increase desalination capacity, as discussed in Luckmann et al. (2014). But due to the higher costs of desalination compared to freshwater purification, the economy-wide effects would still be negative (-0.21 % of GDP, for the link-scenario).

This study develops an approach to link the reclamation of wastewater to the consumption of potable water by economic entities. The case study shows that not considering this linkage can substantially bias the results due to an underestimation of the negative economic effects of a reduction in freshwater resources. Although the usage of reclaimed wastewater is restricted to a few agricultural activities, the losses to the Israeli economy are markedly lower when the link is not considered. If reclaimed wastewater can be used in a wider range of activities (such as industrial cooling) and in more locations (expressed by a larger substitution elasticity), which is intended by the Israeli government (IWA, 2012), the losses would be lower.

Moreover, the dependence of wastewater recycling on sewage-input makes water saving in the municipal sector less efficient the higher the reclamation rates are, as it reduces the reclaimed water availability. Due to this, increasing potable water fees in the municipal sector could lead to unintended outcomes such as rising potable water demand from the agricultural sector resulting from less sewage and thus reclaimed wastewater supply. Therefore, other options to save water, e.g. more efficient irrigation systems, may be more favourable.

Finally, this study shows that wastewater recycling does not necessarily serve as a backstop technology as claimed by Roumasset and Wada (2011) and, thus, the aim of the Israeli government to make the agricultural sector more independent from potable water supply, might not be easily achieved under the conditions described.

This model is the first CGE approach that captures cascading water use by interdependent economic agents. The generic formulation of the model means that it can be applied to a wide range of situations, countries and simulations. There are also manifold options for further extensions. One aspect would be to incorporate the spatial dimension of (reclaimed) water supply, since the provision costs of reclaimed wastewater increase considerably with the distance from the source (Haruvy, 1997). This is less relevant in the context of this study, as effects on the demand side depend on water fees, which independent from the location in Israel. However, considering increasing marginal provision costs would allow the optimal quantity of wastewater recycling to be estimated. The integration of

[16] This possibility was tested in an additional scenario. However, even if all sewage was centrally collected (*shsews* = 1) and losses from the system (*shsewl*) would be reduced by 50%, only an additional 27 million m³ of reclaimed wastewater would be available, as the Israeli wastewater recycling network already has a quite high coverage. Therefore, the overall effects would be quite similar to the link-scenario.

different quality levels for reclaimed wastewater (with different cost structures) would add further to such an optimisation analysis.

4.6 Conclusions

This paper allows some conclusions to be made with respect to Israel, and, just as important, regarding the treatment of wastewater recycling in simulation models:

- For Israel, a reduction in potable water availability results in an excess demand for reclaimed wastewater, which can be balanced by increasing reclaimed water fees. The model can quantify both the excess demand and the reclaimed water fees.
- The study shows that indirect effects of changes in the water sector can be substantial, which demonstrates the advantages of economy-wide models.
- The case study on Israel demonstrates the relevance of the model to countries in which a cascade usage of water is extensive. In such cases, it is advisable to apply an integrated model that considers water activities as interdependent.
- The model provides a method for estimating the shadow price of wastewater, which can be used to inform the water pricing decisions.
- The study demonstrates that wastewater recycling cannot be regarded as a backstop technology for the usage of potable water in case of reduced water availability if a high share of water is recycled already.

4.7 Appendix

Table 4.A1. Sensitivity analysis: changes in economic indicators in the link scenario with different natural freshwater shocks (-50% = central scenario).

		Natural Freshwater Reduction [%]						
		-10	-20	-30	-40	-50	-60	-70
		Water Prices						
	Potable	17.74	41.64	75.37	126.07	209.67	369.58	772.51
	Brackish	-0.51	-1.19	-2.13	-3.52	-5.78	-10.03	-20.55
	Reclaimed	14.36	31.52	52.18	77.09	106.85	140.28	164.38
		Water Quantities [%]						
Potable	Agriculture	-11.15	-22.58	-34.29	-46.28	-58.55	-71.10	-83.93
	Manufacturing	-12.68	-25.18	-37.51	-49.67	-61.71	-73.66	-85.59
	Municipalities	-6.76	-13.33	-19.70	-25.88	-31.84	-37.61	-43.13
Reclaimed	Agriculture	-9.14	-18.01	-26.62	-34.97	-43.05	-50.85	-58.35
Brackish	Agriculture	1.54	3.00	4.36	5.59	6.69	7.67	8.78
		Production Quantities [%]						
	Agriculture	-0.76	-1.65	-2.69	-3.95	-5.53	-7.65	-10.88
	Manufacturing	-0.04	-0.09	-0.16	-0.26	-0.42	-0.67	-1.14
	Services	-0.01	-0.03	-0.04	-0.06	-0.08	-0.11	-0.17
		Equivalent Variation [% of base household expenditure]						
Jewish Households	1. Quintile	-0.01	-0.01	0.02	0.09	0.28	0.78	2.71
	2. Quintile	-0.05	-0.10	-0.16	-0.23	-0.28	-0.28	0.12
	3. Quintile	-0.08	-0.19	-0.34	-0.54	-0.83	-1.32	-2.35
	4. Quintile	-0.04	-0.10	-0.19	-0.34	-0.58	-0.99	-1.90
	5. Quintile	0.05	0.06	0.03	-0.08	-0.30	-0.79	-2.05
Arab and other Households	1. Quintile	-0.11	-0.24	-0.40	-0.59	-0.85	-1.21	-1.77
	2. Quintile	-0.09	-0.19	-0.32	-0.49	-0.72	-1.04	-1.58
	3. Quintile	-0.09	-0.20	-0.36	-0.57	-0.89	-1.41	-2.54
	4. Quintile	-0.04	-0.11	-0.22	-0.39	-0.65	-1.12	-2.18
	5. Quintile	0.03	0.02	-0.05	-0.20	-0.50	-1.14	-2.78
		Real GDP [%]						
		-0.02	-0.04	-0.08	-0.14	-0.24	-0.39	-0.71

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5 Synthesis, General Conclusions and Outlook

5.1 Background and Achievements

The 1992 Dublin Statement of the United Nations (WMO, 1992) officially recognizes that global freshwater resources are limited. At least since then it is generally understood that a more efficient management of these resources is required. Water management decisions usually have complex implications, as besides being vital for human survival water is used for various purposes in many different activities. To forecast potential consequences from water management decisions in advance economic models generally have been proven useful. Often applied approaches, however, such as cost-benefit analyses and programming as well as partial equilibrium and other single sector models, are unable to endogenously capture indirect effects from changes in the water sector. As an example for such indirect effects, an increase in irrigation fees results in increasing production costs of agricultural commodities. This leads to a reduction in farm income, which in turn results in a reduced demand for all non-inferior commodities. In contrast, the additional irrigation fee increases government income, which can be spent for different purposes. As competition for water between different sectors is increasing (OECD, 2012), it has been understood that more integrated approaches are needed to sustainably manage this precious resource (UNESCO-WWP, 2006).

Being capable to consider economy-wide linkages as well as the behavior of economic agents and welfare implications, which are especially relevant in the analysis of water-related questions, is the advantage of general equilibrium models. The strongly growing number of water-related CGE publications especially since the beginning of this century (Figure 5.1) provides an exemplary proof of their usefulness in this respect.

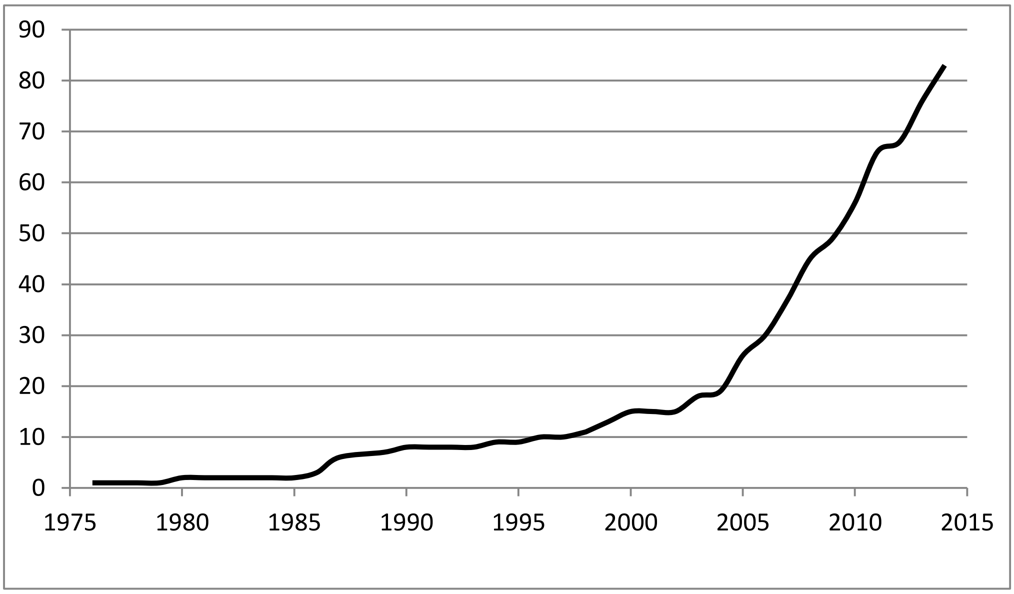

Figure 5.1. Number of SCOPUS listed water-related general equilibrium publications.
Source: own compilation based on SCOPUS (2014).

So far, however, these studies were mostly focused on certain aspects of the water sector often considering water for irrigated agriculture only (e.g. Calzadilla et al., 2011; Wittwer & Griffith, 2011). No water CGE model has yet been developed which provides a flexible and comprehensive framework to capture different water resources and qualities as well as treatment activities, such that it can be applied in many different circumstances to analyze a wide range of scenarios.

The aim of this thesis is to fill this research gap by developing a water-focused CGE model which depicts water in an integrated way and incorporates all dimensions of the water sector (supply, demand, management), including substitution possibilities for water on different levels. The model allows for cascading water use and the analysis of the effects on the welfare of different household groups. The different applications presented in the previous chapters provide a proof for the wide range of simulations the model can be applied to. Yet, the model is flexible to be calibrated to other databases and a different set of water qualities.

5.2 Main Findings

The findings from the analyses in the previous chapters underline the usefulness of the STAGE_W model developed in this thesis. The results of the first article (chapter 2), for instance, demonstrate that for Israel a tripling of potable water prices does not lead to very strong effects on the economy (GDP loss of 0.2%). This is mainly caused by the relatively low share potable water accounts for in the total consumption expenditure of Israeli households but also to a large extent due to the flexible adjustment possibilities depicted in the model. In activities which allow for the usage of marginal water, potable water is substituted with other water qualities. Other activities invest in more water-efficient systems and in general, the composition of domestic production as well as consumption shifts to less water-intensive commodities. This could free 50% of the currently used freshwater resources, without the need of further desalination plants.

The second article (chapter 3) shows that in the current situation an abolishment of water use subsidies in Israel would lead to a situation in which desalination would not be required anymore in normal years in terms of precipitation and the installed capacity could be used to provide additional supply in drought years. Yet, with increasing population and economic growth, the water demand is expected to rise in the future, which will require additional supply from desalination plants in order to achieve a more sustainable water management.

For Israel it can be said in general that substantial pressure can be taken from aquifers at relatively low economic costs, due to a small share of water and water-intensive products in total consumption expenditure and a high technological level in the water sector, which allows for the provision of a range of alternative water sources. As shown in chapter 3 the price of potable water could even be increased to the cost of desalination (marginal pricing) at relatively modest costs to the economy and potentially would make Israel completely independent from natural freshwater resources in the long-run.

Of course, one needs to be careful when generalizing the outcomes found with the help of a complex model like the one applied, as results might differ considerably for a country with a different economical structure but the advantage of STAGE_W is that it is generic and can be easily applied to other economies and based on their respective databases might deliver quite different results.

An extension to the model is presented in the third article (chapter 4). The introduced link between the water consumption of economic entities connected to a sewer system and the sewage available for reclamation is especially relevant in countries which already use a considerable share of reclaimed wastewater such as Israel. As shown, simulations might lead to an overestimation of the remaining potential for increasing the use of reclaimed wastewater if the consumption of water from which sewage is generated is not considered. This would result in an underestimation of the negative effects caused by a cut in water supply. This extension, considering the cascading use of water, shows that the reclamation of wastewater cannot be considered a backstop technology in situations in which already a large share of the sewage collected is used. Moreover, accounting for the cascading water use yields that per m³ of water additional value added is created if it is used by economic agents connected to the sewer system, which influences the optimal water allocation. To this effect, the model also provides a measure to estimate the shadow price of sewage, which can be useful for the creation of an efficient water pricing system including sewage fees and reclaimed wastewater prices. This extension would be easily applicable for other cascading water use systems, too, e.g., water which is used for cooling of industrial processes or in hydropower plants and afterwards for irrigation.

The case studies presented also showed, that the model provides results, which cannot necessarily be anticipated, as they are the outcome of the complex interrelations within the model. For example, the distribution of welfare effects results from the interplay of prices for potable water and other goods consumed on one side and factor wages and other household income on the other side. Thus, this model constitutes a helpful tool to implement a more sustainable management of water resources, allowing policy makers in any country, given the availability of an applicable database, to ex-ante estimate the economy-wide effects of water-related decisions. One of the major advantages of STAGE_W in this respect is its capability to include an unlimited range of various water qualities and maximal annual withdrawal quantities from different water resources, through the integrated water satellite accounts which also allow for a direct interpretation of results in terms of quantities and prices without the requirement for further ex-post calculations. This allows the model to be applied for a wide range of scenarios addressing water policy-related questions, but also regarding resource endowments or new technologies in the water sector. As the economy as a whole is depicted a more holistic picture of effects resulting from changes in the water sector can be drawn in comparison to single sector models or cost-benefit analyses.

5.3 Limitations

The quality of the model results depends to a large extent on the underlying database, which needs to depict the production and consumption structure of the economy under investigation in a sufficiently detailed and correct manner. Especially with respect to water, it is often difficult to compile the required data, as the water sector is not integrated in the national accounts statistics of many countries in enough detail. This is the case even though in 2007 the System of Environmental-Economic Accounting (SEEA) for Water was adopted by the United Nations Statistical Commission as an interim international standard and its usage has been encouraged (United Nations, 2012). The SEEA-Water provides an accounting framework for physical and also economic water accounts. A reason why it has so far been largely neglected might lie in the fact that in most cases the water sector does not function like other economic activities: There is no free market for the trade of water but typically only one supplier, due to the dependence on the infrastructure for water provision. Moreover, this supplier is mostly state-controlled, as the provision of water is so vital for human survival and since the United Nations acknowledge that water should be considered as an economic good, the access to clean water is also considered a basic right of all humans (WMO, 1992). Thus, water fees charged from consumers in many countries neither reflect the scarcity of the resource nor the costs of water provision. Additionally, this would require that water consumption of each user is measured; however, the installation of water meters is costly and not always possible. Therefore, in many countries flat rate pricing schemes exist (OECD, 2012) or water abstraction is not charged at all (OECD, 2010). The Indian government even provides subsidies which reduce the marginal costs for water supply significantly (Poddar et al., 2014). Even in Ireland, being an OECD-member country, there are no water fees for domestic consumers. Although it is planned to introduce such fees in 2015, not all water will be metered due to lacking infrastructure (CER, 2014).

Such water pricing schemes which are not based on the quantity of consumption and do not follow economic principles make it difficult to estimate the consumption quantities and the value of water in different economic activities. Thus, for many countries there still is insufficient data on water available on the national level to allow for a straightforward integration in a CGE-framework. A partial work-around to this problem for the agricultural sector has been presented by Calzadilla et al. (2011), who split the value of irrigation water from the land rent according to the yield difference between irrigated and rainfed land in each region.

Some countries also apply block rate pricing schemes especially for households. In most cases these schemes allow for a certain consumption quantity at a reduced rate and charge a higher fee beyond a certain threshold. An OECD study found that this is the case in about half of the utilities investigated (OECD, 2009). Although it would be useful to give policy advice with respect to household pricing, such a scheme has not yet been incorporated in the model. Technically it could be easily integrated with the help of another tax instrument. Practically, however, it would require water consumption data at the household level, which is hardly available. Therefore, till now average prices are used.

Furthermore, the econometric foundation for the estimation of the different elasticity parameters in STAGE_W can be further improved. Thereby, the model could benefit from findings in other research disciplines for example from agricultural engineering studies on how much water can be saved at which expenditure by employing a more efficient irrigation system. As these parameters vary depending on the time horizon and the production system, findings from case studies cannot be generalized easily. This is a common problem for many CGE models, however (Mitra-Kahn, 2008; Dixon & Jorgenson, 2013). Therefore, a carefully carried out sensitivity analysis should be included in any study providing policy advice in order to see in how far results are influenced by certain elasticity parameters.

In general it needs to be said, that results obtained from the model presented in this thesis (as from CGE models in general) should not be considered as forecasts or predictions of the future. The results are always the outcome of one (or more) exogenous shock(s) to which the model reacts. All other aspects changing continuously and simultaneously in the real world remain unaltered within the model (ceteris paribus condition). Therefore, the model results should rather be used to assess the consequences and implications which can be traced back to the induced shock independent from other factors. The final section of this thesis gives an outlook on how the model could be further used and developed in this sense.

5.4 Further Applications and Possible Extensions to the Model

As shown in the previous chapters, the model developed in the course of this dissertation can be used to analyze a variety of simulations focusing on the water sector. Still, the capabilities of STAGE_W can be further exploited as it could be applied to a much wider range of further simulations. Thereby, the model can be easily adjusted to the specific conditions of any country of interest. As, for example, further water sources or commodities can easily be added.

With respect to Israel, it would be interesting to look into the implications of the pursued upgrade of the wastewater quality. This causes higher costs for wastewater reclamation on the one side but also gives more flexibility regarding the application on the use side, as fewer restrictions apply.

An application which may also be relevant in other country contexts is the estimation of the economy-wide effects from building desalination plants or other investments in the water sector. In this respect it is advantageous that the model allows for several activities to simultaneously produce the same (homogenous) water commodity, despite of different cost structures. This is shown in the case studies of Israel for the purification of natural freshwater and desalination activities which concurrently produce potable water. Thereby, differences in total supply costs are captured by an endogenously adjusted subsidy-instrument.

On the global scale, the OECD (2012) found that till 2050 the water sector in most countries will mostly be influenced by socio-economic developments such as population growth, urbanization and economic growth. To depict such developments within the model it could be run in a (recursive) dynamic way. In the simplest form this means that, for example, estimated population and economic growth rates are exogenously enforced on the model, it is solved and the equilibrium presents the situation after one year with such growth rates. The resulting SAM is then used as the base for a second simulation in which the model is shocked by the growth rates again. In such a way many simulations can be run consecutively and the development-path e.g. with respect to water resources can be depicted.

Especially in the long-run, climate change and variability have been found to have substantial impacts on water resources as well (OECD, 2012). Also climate-related scenarios could be easily investigated using STAGE_W. For example, droughts result in a reduced productivity of rainfed irrigation. This could be simulated by adjustments of the production coefficient of the respective activities. Additionally, a lasting drought might lead to a reduced recharge rate of aquifers which could be simulated in STAGE_W by a reduction of the supply of certain water factors or a reduced output of certain water activities as simulated in chapters 2 and 4.

For such an analysis, it would be beneficial to separate rainfed cropping activities from irrigated agriculture, which is purely a matter of data work. This would ease the determination of more precise land-water-substitution elasticities for the individual activities. For rainfed activities the land water nest does not apply. For irrigated activities one could determine whether these crops can be grown with varying water intensity (e.g. deficit irrigation) or need a fixed quantity of water. In the latter case the elasticity σ_3 would simply be set to zero. Independent of that, these activities still could be supplied with an adjusted composition of water qualities, which is governed by the lowest nest in the production function.

If climate effects, water supply or water policy differ regionally within one economy, it would be beneficial to also regionalize the model and the database. A first step towards this would be to split up all activities which require land into activities of a certain region and allow for land and water commodities produced from local resources to be allocated within that region only, similar to the approach presented by Diao et al. (2005).

STAGE_W could also be further developed to consider seasonality, since water supply lows often coincide with demand peaks, resulting in temporal water shortages and sometimes the imposition of short-term water use restrictions. One approach, similar to the one for regional variability described above, has been presented by Ferrari et al. (2014), who disaggregate agricultural production activities according to seasons. A more complex approach in this direction is the CGE-W model developed by Robinson and Gueneau (2013). This model links a CGE model with a water system model and includes a water stress module. The CGE model is solved at the beginning of the cropping season, introducing an exogenous shock. This yields projections on the land being allocated to specific crops and together with the water stress module harvest expectations. Based on this first model run the total water demand is calculated. With the help of the water system model the available water is distributed on a monthly basis. From this, using the water stress module, yield shocks are calculated. These are fed into the CGE model, which is solved a second time with fixed allocation of land to crops simulating the economy-wide effects of the yield shocks at the end of the cropping season. The variables obtained from this run provide the starting parameters for the next year. Also STAGE_W could be linked to other (non-economic) water-related models in such a way. This would allow the analyses to directly benefit from the often more precise and detailed projections which can be made based on specialized water-focused models developed in other scientific disciplines e.g., regarding the development of the hydraulic cycle in a certain region or the reactions of crops towards water stress, which would deliver more realistic and detailed simulation results.

Another interesting aspect towards which the STAGE_W model could be further extended would be the integration of environmental externalities, such as pollution effects arising from the discharge of untreated wastewater or consideration of greenhouse gas emissions, due to increased desalination, which is still a quite energy-intensive process (Siddiqi & Anadon, 2011). With respect to the latter the database of the Global Trade Analysis Project which includes a CO_2 emissions dataset (GTAP, 2014) can provide a starting point. Also, the before mentioned SEEA for water allows to account for water pollution and emissions (United Nations, 2012). The pollution of water bodies could be considered by linking the production costs of water-purifying activities to the quantity of untreated wastewater discharge. This is because the provision costs of potable water would increase, if water bodies get more polluted, as the water either needs to be treated more, or the polluted water body cannot be used at all anymore, such that another (further away) source needs to be developed. In the current setup of STAGE_W, environmental aspects can be considered in an ex-post analysis, but the advantage to include externalities in the model itself would be the possibility to also integrate measures to internalize such negative externalities (e.g. a tax linked to CO_2 emissions).

Summing up, this thesis presents a novel CGE model which incorporates the water sector in a more holistic way compared to previous approaches. This, together with the flexibility of the model, allows for an in-depth analysis of a wide range of water-related simulations and scenarios.

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ANNEX

A.1 STAGE_W: An Applied General Equilibrium Model with Multiple Types of Water

The content of this chapter is identical with Luckmann, J. & S. McDonald, 2014. *STAGE_W: an applied general equilibrium model with multiple types of water; technical documentation*. Institute of Agricultural Policy and Markets, University of Hohenheim, Germany.

A.1.1 Introduction

This document provides a description of the STAGE_W computable general equilibrium (CGE) model, which is a development of the STAGE model and allows for the depiction of diverse water resources and qualities as well as the simulation of detailed water policy scenarios. STAGE_W is a member of the STAGE suite of single country computable general equilibrium models. At the core of the suite is the basic STAGE model, but the basic STAGE model is not often used in practical work rather it is customised to the setting/economic environment being explored. The guiding principle is that the basic STAGE model provides a template that can support multiple variants; indeed the expectation is that for most studies it will be necessary/desirable to make changes and/or addition to the basic STAGE model.

The basic STAGE model is characterised by several distinctive features. First, the model allows for a generalised treatment of trade relationships by incorporating provisions for non-traded exports and imports, i.e., commodities that are neither imported nor exported, competitive imports, i.e., commodities that are imported and domestically produced, non-competitive imports, i.e., commodities that are imported but not domestically produced, commodities that are exported and consumed domestically and commodities that are exported but not consumed domestically. Second, the model allows the relaxation of the small country assumption for exported commodities that do not face perfectly elastic demand on the world market. Third, the model allows for (simple) modelling of multiple product activities through an assumption of fixed proportions of commodity outputs by activities with commodities differentiated by the activities that produce them. Hence the numbers of commodity and activity accounts are not necessarily the same. Fourth, (value added) production technologies are specified as nested Constant Elasticity of Substitution (CES). And fifth, household consumption expenditure is modelled using Stone-Geary utility functions.

The main additional feature added for the STAGE_W version is the detailed description of the water sector, by allowing for the integration of various water resources as factors (e.g. groundwater, seawater, wastewater), from which specific activities (water activities e.g. pumping and purification of groundwater, desalination, water reclamation) produce water commodities (e.g. potable water, treated wastewater of different qualities). These commodities are used as inputs in the production process of other activities or are consumed by households and other agents (e.g. nature) as final users. The number and specification of water factors, activities and commodities are flexible and can be adjusted to the local conditions of the country analyzed. Also the model allows for the substitution of water commodities by water consuming activities. Besides this, the addition of two water specific tax instruments, allows for various pricing schemes, including price differentiation according to water user. All other features of the STAGE model are carried over directly to STAGE_W.

The model is designed for calibration using a reduced form of a Social Accounting Matrix (SAM) that broadly conforms to the UN System of National Accounts (SNA). Table A 1.1 contains a macro SAM in which the active sub matrices are identified by *X* and the inactive sub matrices are identified by 0. In general the model will run for any SAM that does not contain information in the inactive sub matrices and conforms to the rules of a SAM.[17] In some cases a SAM might contain payments from and to both transacting parties, in which case recording the transactions as net payments between the parties will render the SAM consistent with the structure laid out in Table A 1.1.

Table A 5.1. Macro SAM for the Standard Model.

	Commodities	**Activities**	**Factors**	**Households**	**Enterprises**	**Government**	**Capital Accounts**	**RoW**
Commodities	(X)	X	0	X	X	X	X	X
Activities	X	0	0	0	0	0	0	0
Factors	0	X	0	0	0	0	0	X
Households	0	0	X	0	X	X	0	X
Enterprises	0	0	X	0	0	X	0	X
Government	X	X	X	X	X	0	0	X
Capital Accounts	0	0	X	X	X	X	0	X
RoW	X	0	X	X	X	X	X	0
Total	X	X	X	X	X	X	X	X

The most notable differences between this SAM and one consistent with the SNA are:

1) The SAM is assumed to contain only a single 'stage' of income distribution. However, fixed proportions are used in the functional distribution of income within the model and therefore a reduced form of a SNA SAM using apportionment (see Pyatt, 1989) will not violate the model's behavioural assumptions.

2) The trade and transport margins, referred to collectively as marketing margins, are subsumed into the values of commodities supplied to the economy.

[17] If users have a SAM that does not run with no information in inactive sub matrices the author would appreciate a copy of the SAM so as to further generalise the model.

3) A series of tax accounts are identified (see below for details), each of which relates to specific tax instruments. Thereafter a consolidated government account is used to bring together the different forms of tax revenue and to record government expenditures. These adjustments do not change the information content of the SAM, but they do simplify the modelling process. However, they do have the consequence of creating a series of reserved names that are required for the operation of the model.[18]

The model contains a section of code, immediately after the data have been read in, that resolves a number of common 'problems' encountered with SAM databases by transforming the SAM so that it is consistent with the model structure. Specifically, all transactions between an account with itself are eliminated by setting the appropriate cells in the SAM equal to zero. Second, all transfers from domestic institutions to the Rest of the World and between the Rest of the World and domestic institutions are treated net as transfers to the Rest of the World and domestic institutions, by transposing and changing the sign of the payments to the Rest of the World.[19] And third, all transfers between domestic institutions and the government are treated as net and as payments from government to the respective institution. Since these adjustments change the account totals, which are used in calibration, the account totals are recalculated within the model. An example SAM can be found in Appendix 4.

In addition to the SAM, which records transactions in value terms, three additional databases are used by the model. The first records the 'quantities' of primary inputs used by each activity. The second reports the quantities of the different water qualities consumed by each water user (activities and other agents). If such quantity data are not available then the entries in the factor use matrix are the same as those in the corresponding sub matrix of the SAM. The third series of additional data are the elasticities of substitution for imports and exports relative to domestic commodities, the elasticities of substitution for the CES production functions, the income elasticities of demand for the linear expenditure system and the Frisch (marginal utility of income) parameters for each household.

All the data are accessed by the model from data recorded in Excel and GDX (GAMS data exchange) files. All the data recorded in Excel are converted into GDX format as part of the model.

A.1.2 The Computable General Equilibrium Model

The model is a member of the class of single country computable general equilibrium (CGE) models that are descendants of the approach to CGE modeling described by Dervis *et al*., (1982). More specifically, the implementation of this model, using the GAMS (General Algebraic Modeling System) software, is a direct descendant and development of models devised in the late 1980s and

[18] These and other reserved names are specified below as part of the description of the model.
[19] Treating transfers as net can be justified on the grounds that no clear body of economic theory exists that would seem to justify the adoption of specific behavioural relationships.

early 1990s, particularly those models reported by Robinson *et al*., (1990), Kilkenny (1991) and Devarajan *et al*., (1994). The model is a SAM based CGE model, wherein the SAM serves to identify the agents in the economy and provides the database with which the model is calibrated. Since the model is SAM based it contains the important assumption of the law of one price, i.e., prices are common across the rows of the SAM.[20] The SAM also serves an important organisational role since the groups of agents identified by the SAM structure are also used to define sub-matrices of the SAM for which behavioural relationships need to be defined. As such the modelling approach has been influenced by Pyatt's 'SAM Approach to Modeling' (Pyatt, 1989).

The description of the model proceeds in five stages. The first stage is the identification of the behavioural relationships; these are defined by reference to the sub matrices of the SAM within which the associated transactions are recorded. The second stage is definitional, and involves the identification of the components of the transactions recorded in the SAM, while giving more substance to the behavioural relationships, especially those governing inter-institutional transactions, and in the process defining the notation. The third stage uses figures to illustrate the price and quantity systems for commodity and activity accounts that are embodied within the model. In the fourth stage an algebraic statement of the model is provided; the model's equations are summarised in a table that also provides (generic) counts of the model's equations and variables. A full listing of the parameters and variables contained within the model are located in Appendix 1.[21] Finally in the fifth stage there is a discussion of the default and optional macroeconomic closure and market clearing rules available within the model.

A.1.2.1 Behavioural Relationships

While the accounts of the SAM determine the agents that can be included within the model, and the transactions recorded in the SAM identify the transactions that took place, the model is defined by the behavioural relationships. The behavioural relationships in this model are a mix of non-linear and linear relationships that govern how the model's agents will respond to exogenously determined changes in the model's parameters and/or variables. Table A 1.2 summarises these behavioural relationships by reference to the sub matrices of the SAM.

Households are assumed to choose the bundles of commodities they consume so as to maximise utility where the utility function is Stone-Geary. For a developing country a Stone-Geary function may be generally preferable since it allows for subsistence consumption expenditures, which is an arguably

[20] The one apparent exception to this is for exports. However the model implicitly creates a separate set of export commodity accounts and thereby preserves the 'law of one price', hence the SAM representation in the text is actually a somewhat condensed version of the SAM used in the model (see McDonald, 2007).

[21] The model includes specifications for transactions that were zero in the SAM. This is an important component of the model. It permits the implementation of policy experiments with exogenously imposed changes that impact upon transactions that were zero in the base period.

realistic assumption when there are substantial numbers of very poor consumers.[22] The households choose their consumption bundles from a set of 'composite' commodities that are aggregates of domestically produced and imported commodities. These 'composite' commodities are formed as Constant Elasticity of Substitution (CES) aggregates that embody the presumption that domestically produced and imported commodities are imperfect substitutes. The optimal ratios of imported and domestic commodities are determined by the relative prices of the imported and domestic commodities. This is the so-called Armington 'insight' (Armington, 1969), which allows for product differentiation via the assumption of imperfect substitution (see Devarajan *et al*., 1994). The assumption has the advantage of rendering the model practical by avoiding the extreme specialisation and price fluctuations associated with other trade assumptions, e.g., the Salter/Swan or Australian model. In this model the country is assumed to be a price taker for all imported commodities.

[22] A Stone-Geary function reduces to a Cobb-Douglas function given appropriate specification of the parameters.

Table A 1.2. Behavioural Relationships for the Standard Model.

	Commodities	Activities	Factors	Households	Enterprises	Government	Capital	RoW	Total	Prices
Commodities	0	Leontief Input-Output Coefficients	0	Utility Functions (CD or Stone-Geary)	Fixed in Real Terms	Fixed in Real Terms and Export Taxes	Fixed Shares of Savings	Commodity Exports	Commodity Demand	Consumer Commodity Prices Prices for Exports
Activities	Domestic Production	0	0	0	0	0	0	0	Activity Supply	
Factors	0	Factor Demands (CES)	0	0	0	0	0	Factor Income from RoW	Factor Income	
Households	0	0	Fixed Shares of Factor Income	Fixed shares of income	Fixed Shares of Dividends	Fixed (Real) Transfers	0	Remittances	Household Income	
Enterprises	0	0	Fixed Shares of Factor Income	0	0	Fixed (Real) Transfers	0	Transfers	Enterprise Income	
Government	Tariff Revenue Domestic Product Taxes	Indirect Taxes on Activities	Fixed Shares of Factor Income Direct Taxes on Factor Income	Direct Taxes on Household Income	Fixed Shares of Dividends Direct Taxes on Enterprise Income	0	0	Transfers	Government Income	
Capital	0	0	Depreciation	Household Savings	Enterprise Savings	Government Savings (Residual)	0	Current Account 'Deficit'	Total Savings	
Rest of World	Commodity Imports	0	Fixed Shares of Factor Income	0	0	0	0	0	Total 'Expenditure' Abroad	
Total	Commodity Supply	Activity Input	Factor Expenditure	Household Expenditure	Enterprise Expenditure	Government Expenditure	Total Investment	Total 'Income' from Abroad		
	Producer Commodity Prices Domestic and World Prices for Imports	Value Added Prices								

Domestic production uses a four-stage production process. An example-case including four water resources and by-products as well as three water commodities is given in Figure A 1.1. On all levels of the nesting structure, with the exception of the aggregation of intermediate inputs, the user is free to decide to apply either CES or Leontief technology (indicated respectively by the s or 0 in Figure A 1.1). CES technology allows the proportion of inputs used to vary with their prices, while in a Leontief setup the quantity shares of inputs are fixed.

On the lowest level, different water commodities or water resources and by-products are combined to form a water-aggregate. Thereby water resources and by-products can be only used by activities which produce water commodities (water activities). Usually one water activity, e.g., desalination, pumping of groundwater, water reclamation, is linked to one specific water resource, e.g., seawater, groundwater, wastewater, and thus there is no substitution possibilities. However, as described above, the setup of the model allows for this option. That water commodities are moved from the intermediate input nest to the value added side is a special feature of this approach. This is due to the fact, that water commodities can be substituted by several activities, especially in irrigated agriculture. In this case CES-technology can be applied. In the second stage the water-composite is combined with land to form a land-water-aggregate and in the third stage the land-water composite is merged with other factors of production (labour and capital) to form a value added-water-aggregate. At the same level in a second arm all non-water-intermediate inputs are aggregated using Leontief technology, such that activities demand non-water intermediate inputs in fixed proportions relative to aggregated intermediate input of each activity. At the top-level aggregated intermediate inputs are combined with the value added-water aggregate. For activities which do not consume all inputs (e.g. no land or water), this four level nesting structure simply collapses to fewer levels.

As described above, there is usually one activity linked to each water resource or by-product. Utilising additional inputs and production factors it converts the resource or by-product to a water commodity, which is then used as an input in other activities or, in case of potable water, is consumed by households. But one water commodity can be also produced by several activities. In the example depicted in Figure A 1.1 there are four natural resources and by-products from which three water commodities are produced, as the fresh water activity and the desalination activity both produce potable water. The fresh water activity produces potable water from fresh water, which can be ground- or surface water, while desalination requires the use of sea water as an input. Thus two activities with, typically, different cost structures produce an homogenous product. The basic STAGE model assumes that if the “same” commodity is produced by different activities it is heterogeneous – a CES aggregate. This variant is adjusted so that the option exists to define such commodities as homogenous. Given differences in costs structures it is necessary for the model to include instruments that ensure the supply price for the homogeneous is the same from each activity. This is achieved by adjusting the activity tax (TX_a) in a way to equate activity prices (PX_a) of the two activities producing potable water (compare Figure A 1.2).

As all water activities depend on the use of a water-resources or by-product, plus other inputs that may or may not include other types of water, the user has the option to define exogenously determined extraction rates for the different water resources. Thereby one can condition the model, so that water producing activities are limited to a predefined production quantity.

In case water leakage for the distribution network plays a role, water would be an input to its own production; if (aggregate) water is produced with Leontief technologies the implied rate of leakage is fixed while if it is produced with CES technologies it implies the rate of leakage is a function of the price of potable water. This implies a long run scenario where the water authorities respond to changes in prices by "adjusting" the rate of leakage and differs from the approach suggested by Faust *et al.* (2012).

For water consuming activities the various types of water are used according to the input structure contained in the database. Irrigated agricultural activities use (agricultural) land and one, or more, types of water. It is useful to segment these activities and commodities so as to distinguish between activities that can use the different types of water, e.g., to single out crops that are salt resistant and thus can use either brackish or potable water for irrigation or non-food crops that can be irrigated with reclaimed water. Generally non-agricultural activities do not use agricultural land but do use water of different types. In such cases the land/water aggregate collapses to the water aggregate.

Generally the nesting structure of the model is flexible and adjusts to the usage of different water commodities and factors, e.g., land, by different activities. For example, for service activities (e.g. transportation, communication), which typically do not use marginal water (reclaimed wastewater and brackish water) and land, the production structure collapses to two stages, such that potable water is combined with labor and capital in one value added nest.

Finally water resources that are reserved for environmental or other reasons, e.g., to guarantee a certain level of river flow, are not usually accorded a monetary value. Such resources are subtracted from the water resources available to the economy.

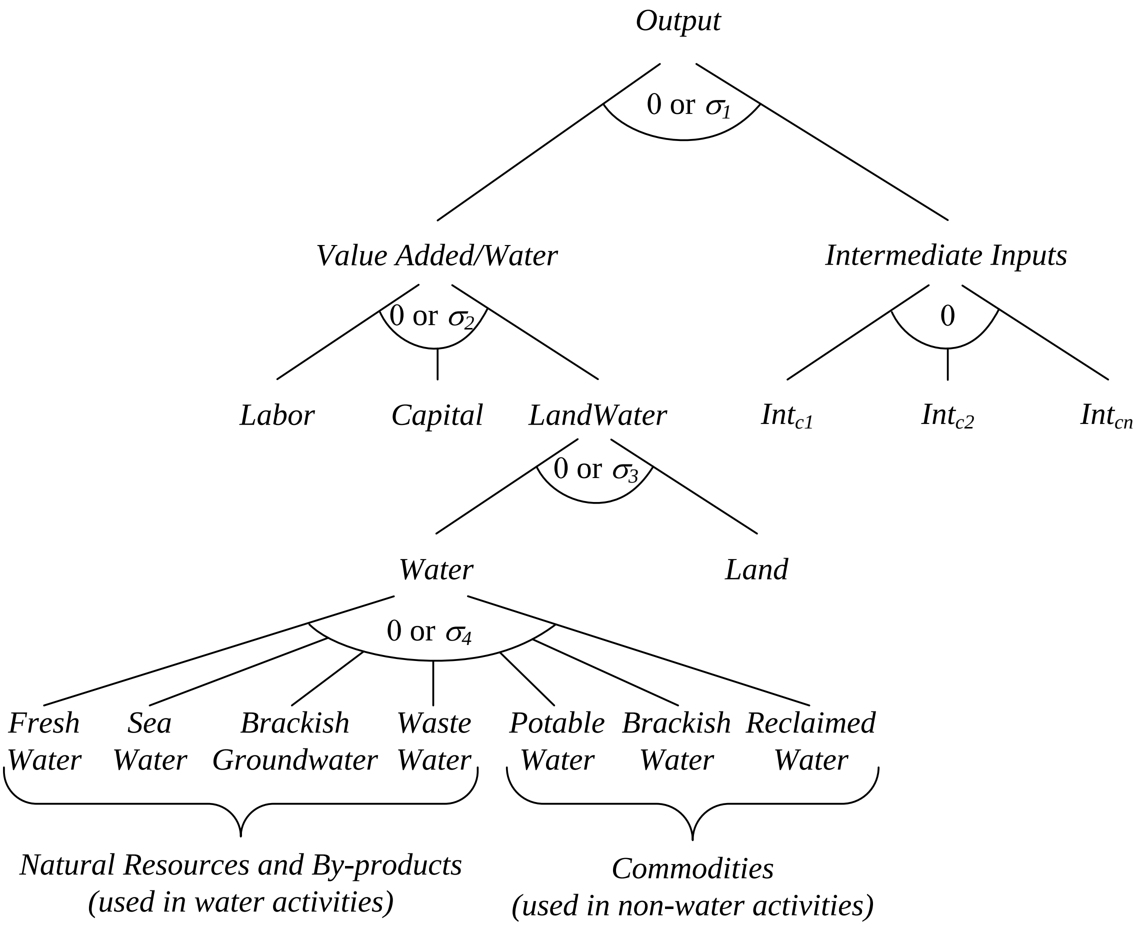

Figure A 1.1. Production System for Activities in STAGE_W.

In general, the activities are defined as multi-product activities with the assumption that the proportionate combinations of commodity outputs produced by each activity/industry remain constant; hence for any given vector of commodities demanded there is a unique vector of activity outputs that must be produced; in essence this is a strong by-product assumption.[23]

The vector of commodities demanded is determined by the domestic demand for domestically produced commodities and export demand for domestically produced commodities. Using the assumption of imperfect transformation between domestic demand and export demand, in the form of a Constant Elasticity of Transformation (CET) function, the optimal distribution of domestically produced commodities between the domestic and export markets is determined by the relative prices on the alternative markets. The model can be specified as a small country, i.e., price taker, on all export markets, or selected export commodities can be deemed to face downward sloping export demand functions, i.e., a large country assumption.

[23] A variant of the model allows activities to modify their output mix in response to changes in the relative prices of the commodities produced by different activities.

The other behavioural relationships in the model are generally linear. A few features do however justify mention. First, all the tax rates are declared as variables with various adjustments and/or scaling factors that are declared as variables or parameters according to how the user wishes to vary tax rates. If a fiscal policy constraint is imposed then one or more of the sets of tax rates can be allowed to vary equiproportionately and/or additively to define a new vector of tax rates that is consistent with the fiscal constraint. Relative tax rates can also be adjusted by the settings chosen by the user. Similar adjustment and/or scaling factors are available for a number of key parameters, e.g., household and enterprise savings rates and inter-institutional transfers. Second, technology changes can be introduced through changes in the activity specific efficiency variables – adjustment and/or scaling factors are also available for the efficiency parameters. Third, the proportions of current expenditure on commodities defined to constitute subsistence consumption can be varied. Fourth, although a substantial proportion of the sub matrices relating to transfers, especially with the rest of the world, contain zero entries, the model allows changes in such transfers, e.g., aid transfers to the government from the rest of the world may be defined equal to zero in the database but they can be made positive, or even negative, for model simulations. And fifth, the model is set up with a range of flexible macroeconomic closure rules and market clearing conditions. For convenience the default closure for the model is a standard neoclassical model closure, e.g., full employment, savings driven investment and a floating exchange rate; this is the simplest option for purposes of calibration and replication. All these closure conditions can all be readily altered; indeed it is rare for the core simulations to be implemented with the default closure.

A.1.2.2 Transaction Relationships

The transactions relationships are laid out in Table A 1.3, which is split in two parts. The prices of domestically consumed (composite) commodities are defined as PQD_c, and they are the same irrespective of which agent purchases the commodity. The quantities of commodities demanded domestically are divided between intermediate demand, $QINTD_c$, and final demand, with final demand further subdivided between demands by households, QCD_c, enterprises, $QENTD_c$, government, QGD_c, investment, $QINVD_c$, and stock changes, $dstocconst_c$. The value of total domestic demand, at purchaser prices, is therefore ($PQD_c * QQ_c$). Consequently the decision to represent export demand, QE_c, as an entry in the commodity row is slightly misleading, since the domestic prices of exported commodities, $PE_c = PWE_c * ER$, do not accord with the law of one price. The representation is a space saving device that removes the need to include separate rows and columns for domestic and exported commodities.[24] The price wedges between domestic and exported commodities are represented by export duties, TE_c, that are entered into the commodity columns. Commodity supplies come from

[24] In this model the allocation by domestic producers of commodities between domestic and export markets is made on the supply side; implicitly there are two supply matrices – supplies to the domestic market and supplies to the export market.

domestic producers who receive the common prices, PXC_c, for outputs irrespective of which activity produces the commodity, with the total domestic production of commodities being denoted as QXC_c. Commodity imports, QM_c, are valued carriage insurance and freight (*cif*) paid, such that the domestic price of imports, PM_c, is defined as the world price, PWM_c, times the exchange rate, ER, plus an *ad valorem* adjustment for import duties, TM_c. All domestically consumed commodities are subject to a variety of product taxes, sales taxes, TS_c, and excise taxes, TEC_c. Other taxes can be readily added.[25]

Domestic production activities receive average prices for their output, PX_a, that are determined by the commodity composition of their outputs. Since activities produce multiple outputs their outputs can be represented as an index, QX_a, formed from the commodity composition of their outputs. In addition to intermediate inputs, activities also purchase primary inputs, $FD_{f,a}$, for which they pay average prices, WF_f. To create greater flexibility the model allows the price of each factor to vary according to the activity that employs the factor. Finally each activity pays production taxes, the rates, TX_a, for which are proportionate to the value of activity outputs.

[25] Various VAT systems, fuel taxes etc., have been used.

Table A 1.3. Transactions Relationships for STAGE_W.

	Commodities	**Activities**	**Factors**	**Households**
Commodities	0	$(PQD_c * QINTD_c)$	0	$(PQD_c * QCD_c)$
Activities	$(PXC_c * QXC_c)$ $(PX_a * QX_a)$	0	0	0
Factors	0	$(WF_f * FD_{f,a})$	0	0
Households	0	0	$\sum_f hovash_{h,f} * YFDISP_f$	$\left(\sum_{hh} hohoconst_{hh,h}\right)$
Enterprises	0	0	$\left(\sum_f entvash_{e,f} * YFDISP_f\right)$	0
Government	$(TM_c * PWM_c * QM_c * ER)$ $(TE_c * PWE_c * QE_c * ER)$ $(TS_c * PQS_c * QQ_c)$ $(TEX_c * PQS_c * QQ_c)$ $(TWAT_c * PQS_c * QQ_c)$	$(TX_a * PX_a * QX_a)$ $(TF_{f,a} * WF_f * WFDIST_{f,a} * FD_{f,a})$ $(TWATA_c * PQD_c$ $* PQDDIST_{c,a} * QWAT2_{c,a})$	$\left(\sum_f govvash_f * YFDISP_f\right)$ $(TYF_f * YFDISP_f)$	$(TYH_h * YH_h)$
Capital	0	0	$\sum_f deprec_f$	$(SSH_h * YH_h)$
Rest of World	$(PWM_c * QM_c * ER)$	0	$\left(\sum_f worvash_f * YFDISP_f\right)$	0
Total	$(PQD_c * QQ_c)$	$(PX_a * QX_a)$	YF_f	YH_h

Table A 1.3. (cont) Transactions Relationships for the Standard Model.

	Enterprises	Government	Capital	RoW	Total
Commodities	$\left(PQD_c * QED_{c,e}\right)$	$\left(PQD_c * QGD_c\right)$	$\left(PQD_c * QINVD_c\right)$ $\left(PQD_c * dstocconst_c\right)$	$\left(PWE_c * QE_c * ER\right)$	$\left(PQD_c * QQ_c\right)$
Activities	0	0	0	0	$\left(PX_a * QX_a\right)$
Factors	0	0	0	$\left(factwor_f * ER\right)$	YF_f
Households	$HOENT_{h,e}$	$\left(hogovconst_h * HGADJ\right)$	0	$\left(howor_h * ER\right)$	YH_h
Enterprises	0	$\left(entgovconst * EGADJ\right)$	0	$\left(entwor_e * ER\right)$	VED_e
Government	$\left(TYE_e * YE_e\right)$	0	0	$\left(govwor * ER\right)$	EG
Capital	$\left(YE_e - VED_e\right)$	$\left(YG - EG\right)$	0	$\left(CAPWOR * ER\right)$	$TOTSAV$
Rest of World	0	0	0	0	Total ‘Expenditure’ Abroad
Total	YE_e	YG	$INVEST$	Total ‘Income’ from Abroad	

The model allows for the domestic use of both domestic and foreign owned factors of production, and for payments by foreign activities for the use of domestically owned factors. Factor incomes therefore accrue from payments by domestic activities and foreign activities, $factwor_f$, where payments by foreign activities are assumed exogenously determined and are denominated in foreign currencies. After allowing for depreciation, $deprec_f$, and the payment of factor taxes, TF_f, the residual factor incomes, $YFDIST_f$, are divided between domestic institutions (households, enterprises and government) and the rest of the world in fixed proportions.

Households receive incomes from factor rentals and/or sales, inter household transfers, $hohoconst_{h,h}$, transfers from enterprises, $hoentconst_h$, and government, $hogovconst_h$, and remittances from the rest of the world, $howor_h$, where remittances are defined in terms of the foreign currency. Household expenditures consist of payments of direct/income taxes, TYH_h, after which savings are deducted, where the savings rates, SHH_h, are fixed exogenously in the base configuration of the model. The residual household income is then divided between inter household transfers and consumption expenditures, with the pattern of consumption expenditures determined by the household utility functions.

The enterprise account receives income from factor sales, primarily in the form of retained profits,[26] transfers from government, $entgovconst_e$, and foreign currency denominated transfers from the rest of the world, $entwor_e$. Expenditures then consist of the payment of direct/income taxes, TYE_e, consumption, which is assumed fixed in real terms,[27] and savings, which are defined as a residual, i.e., the difference between income, YE_e, and committed expenditure, VED_e. There is an analogous treatment of government savings, i.e., the internal balance, which is defined as the difference (residual) between government income, *YG*, and committed government expenditure, *EG*. In the absence of a clearly definable set of behavioural relationships for the determination of government consumption expenditure, the quantities of commodities consumed by the government are fixed in real terms, and hence government consumption expenditure will vary with commodity prices.[28] Transfers by the government to other domestic institutions are fixed in nominal terms, although there is a facility to allow them to vary, e.g., with consumer prices. On the other hand government incomes can vary widely. Incomes accrue from the various tax instruments (import and export duties, sales, production and factor taxes, and direct taxes), that can all vary due to changes in the values of production, trade and consumption. The government also receives foreign currency denominated transfers from the rest of the world, *govwor*, e.g., aid transfers.

[26] Hence the model contains the implicit presumption that the proportions of profits retained by incorporated enterprises are constant.

[27] Hence consumption expenditure is defined as the fixed volume of consumption, $QED_{c,e}$, times the variable prices. It requires only a simple adjustment to the closure rules to fix consumption expenditures. Without a utility function, or equivalent, for enterprises it is not possible to define the quantities consumed as the result of an optimisation problem.

[28] The closure rules allow for the fixing of government consumption expenditure rather than real consumption.

Domestic investment demand consists of fixed capital formation, $QINVD_c$, and stock changes, $dstocconst_c$. The comparative static nature of the model and the absence of a capital composition matrix underpin the assumption that the commodity composition of fixed capital formation is fixed, while a lack of information means that stock changes are assumed invariant. However the value of fixed capital formation will vary with commodity prices while the volume of fixed capital formation can vary both as a consequence of the volume of savings changing or changes in exogenously determined parameters. In the base version of the model domestic savings are made up of savings by households, enterprises, the government (internal balance) and foreign savings, i.e., the balance on the capital account or external balance, *CAPWOR*. The various closure rules available within the model allow for different assumptions about the determination of domestic savings, e.g., flexible versus fixed savings rates for households, and value of ‘foreign’ savings, e.g., a flexible or fixed exchange rate.

Incomes to the rest of the world account, i.e., expenditures by the domestic economy in the rest of the world, consist of the values of imported commodities and factor services. On the other hand expenditures by the rest of the world account, i.e., incomes to the domestic economy from the rest of the world, consist of the values of exported commodities and NET transfers by institutional accounts. All these transactions are subject to transformation by the exchange rate. In the base model the balance on the capital account is fixed at some target value, denominated in foreign currency terms, e.g., at a level deemed equal and opposite to a sustainable deficit on the current account, and the exchange rate is variable. This assumption can be reversed, where appropriate, in the model closure.

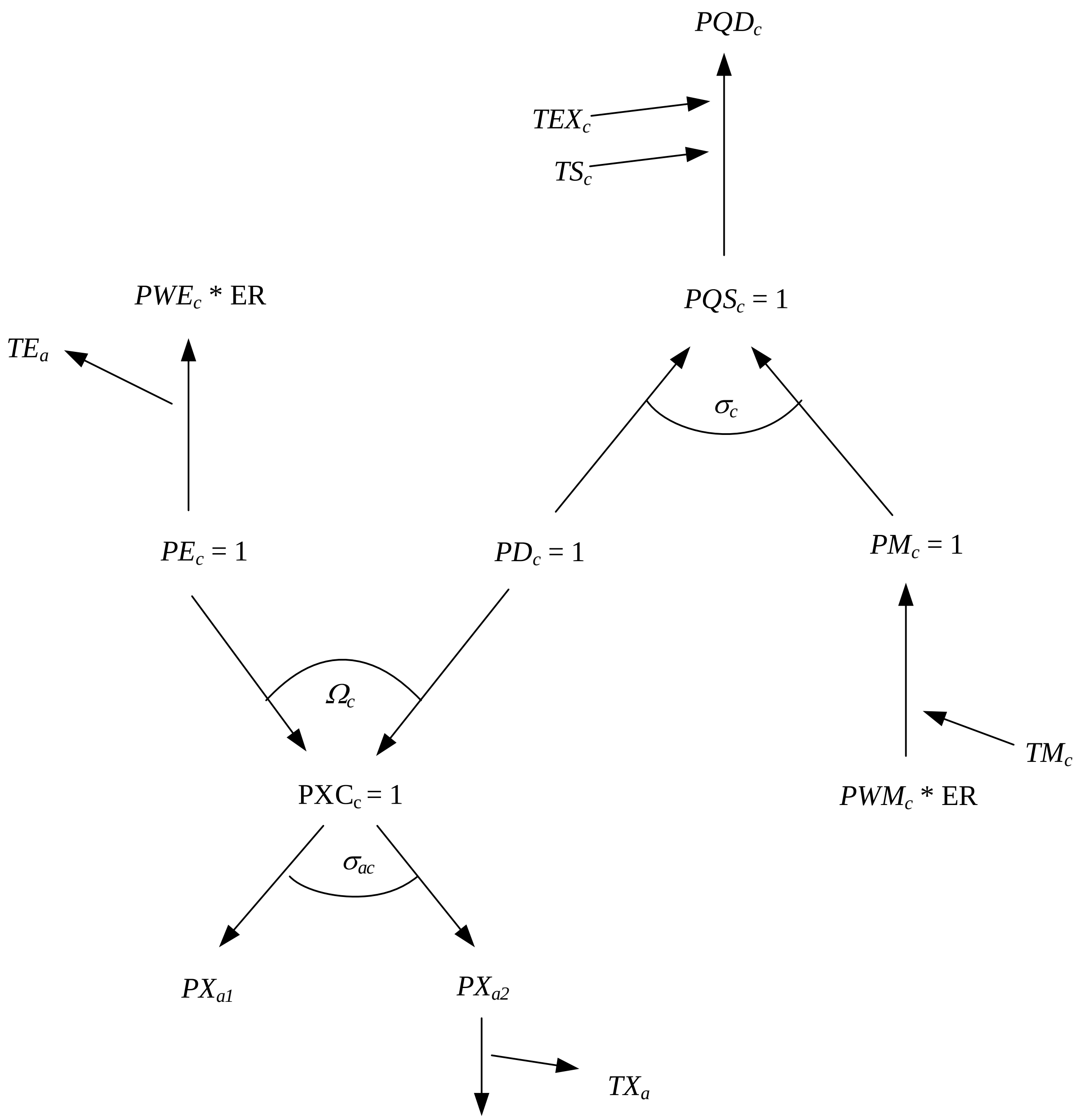

Figure A 1.2. Price Relationships for the STAGE Model.

Figures A 1.2 and A 1.3 provide further detail on the interrelationships between the prices and quantities for commodities and activities. The supply prices of the composite commodities (PQS_c) are defined as the weighted averages of the domestically produced commodities that are consumed domestically (PD_c) and the domestic prices of imported commodities (PM_c), which are defined as the products of the world prices of commodities (PWM_c) and the exchange rate (*ER*) uplifted by *ad valorem* import duties (TM_c). These weights are updated in the model through first order conditions for optima. The average prices exclude sales taxes, and hence must be uplifted by (*ad valorem*) sales taxes (TS_c) and excise taxes (TEX_c) to reflect the composite consumer price (PQD_c). The producer prices of commodities (PXC_c) are similarly defined as the weighted averages of the prices received for domestically produced commodities sold on domestic (PD_c) and export (PE_c) markets. These weights are updated in the model through first order conditions for optima. The prices received on the export market are defined as the products of the world price of exports (PWE_c) and the exchange rate (ER) less any exports duties due, which are defined by *ad valorem* export duty rates (TE_c).

The average price per unit of output received by an activity (PX_a) is defined as the weighted average of the domestic producer prices, where the weights are constant. After paying indirect/production/output taxes (TX_a), this is divided between payments to aggregate value added (PVA_a), i.e., the amount available to pay primary inputs, and aggregate intermediate inputs ($PINT_a$). Total payments for intermediate inputs per unit of aggregate intermediate input are defined as the weighted sums of the prices of the inputs (PQD_c) (Figure A 1.5).

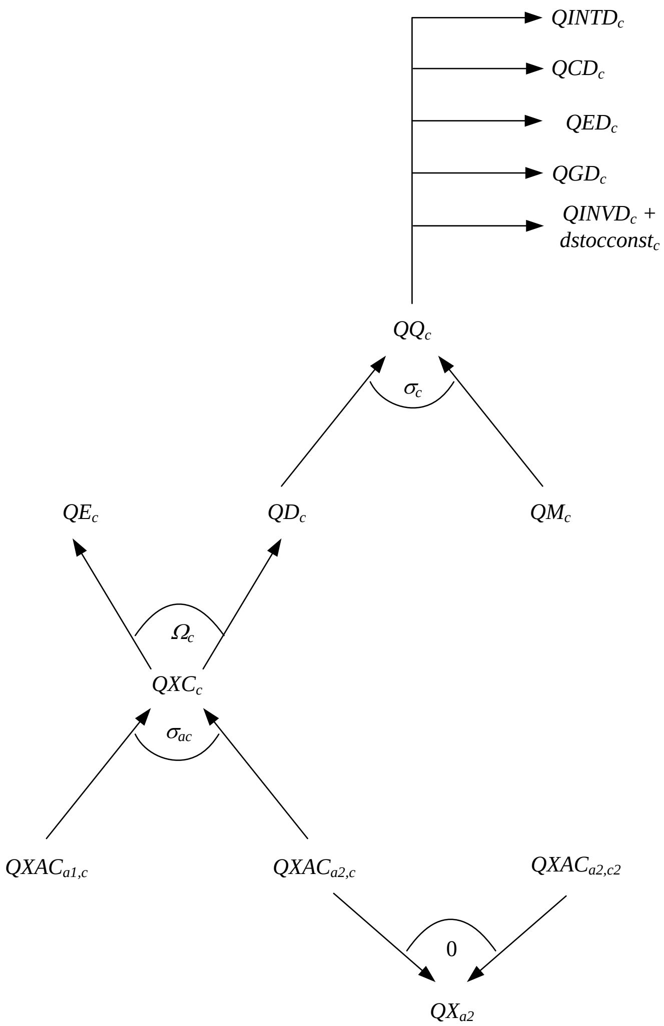

Figure A 1.3. Quantity Relationships for the STAGE Model.

Total demands for the composite commodities (QQ_c) consist of demands for intermediate inputs ($QINTD_c$), consumption by households (QCD_c), enterprises ($QENTD_c$), and government (QGD_c), gross fixed capital formation ($QINVD_c$), and stock changes ($dstocconst_c$). Supplies from domestic producers (QD_c) plus imports (QM_c) meet these demands; equilibrium conditions ensure that the total supplies and demands for all composite commodities equate. Commodities are delivered to both the domestic

(QD_c) and export (QE_c) markets subject to equilibrium conditions that require all domestic commodity production (QXC_c) to be either domestically consumed or exported.

The presence of multiple product activities means that domestically produced commodities can come from multiple activities, i.e., the total production of a commodity is defined as the sum of the amount of that commodity produced by each activity. Hence the domestic production of a commodity (QXC_c) is a CES aggregate of the quantities of that commodity produced by a number of different activities ($QXAC_{a,c}$), which are produced by each activity in activity specific fixed proportions, i.e., the output of $QXAC_{a,c}$ is a Leontief (fixed proportions) aggregate of the output of each activity (QX_a).

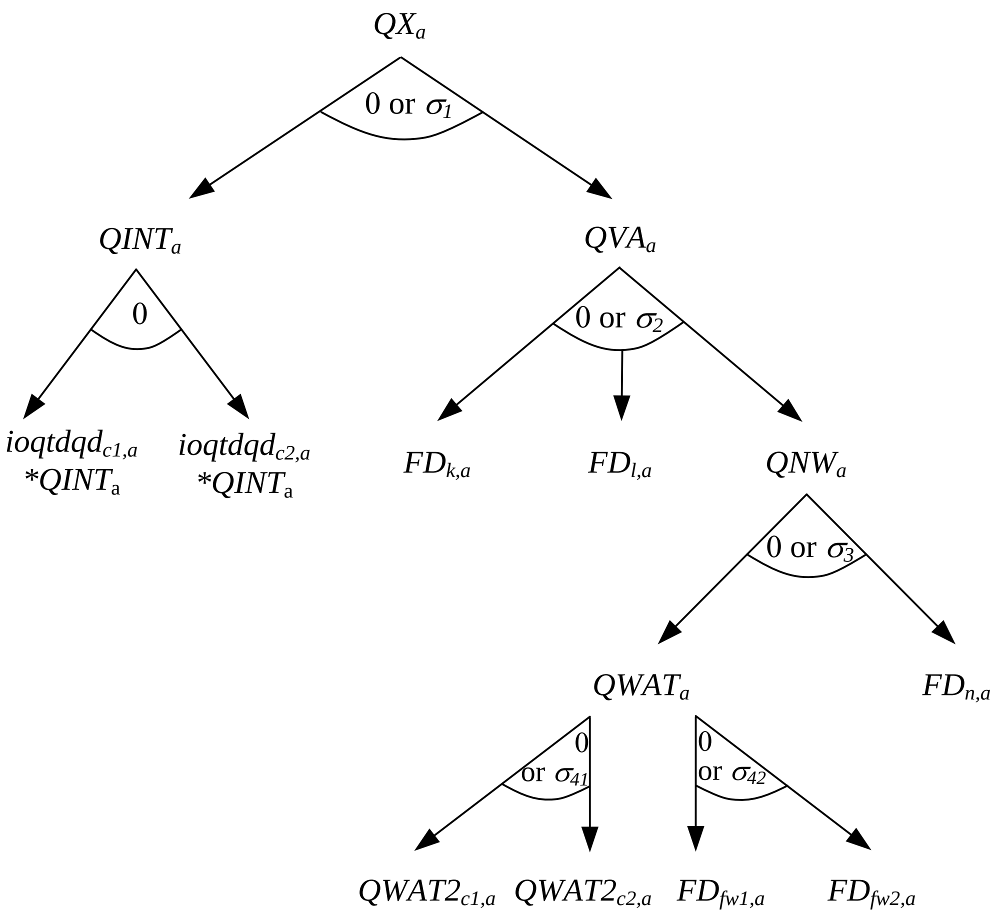

Figure A 1.4. Production Relationships for the STAGE_W Model: Quantities.

Production relationships by activities are defined by a series of nested CES/Leontief production functions[29]. The illustration in Figure A 1.4 shows the general four-level production structure, which holds for all activities. It is simplified, as it is based on a reduced number of inputs on most nests; however the model is flexible to include any number of inputs on all levels.

[29] Peroni and Rutherford (1995) demonstrate that nested CES function can approximate any flexible functional form, e.g., translog. (Perroni, C. and Rutherford, T. F.; (1995). 'Regular Flexibility of Nested CES Functions', *European Economic Review*, Vol 39 (2), pp. 335-43.)

On the lowest level water activities use either their respective water resource or by-product ($FD_{fw,a}$) whereas other activities utilize water commodities ($QWAT2_{c,a}$). Both types of activities aggregate the respective inputs to $QWAT_a$. On the next level the water composit is grouped with land ($FD_{n,a}$) to form a land-water aggregate (QNW_a). This in turn is combined with other factors of production (e.g. capital $FD_{k,a}$ and labour $FD_{l,a}$) to compose value added (QVA_a). On the same level in a second nest non-water intermediate inputs are aggregated in fixed shares (Leontief technology) to form intermediate input ($QINT_a$). Finally, on the highest level QVA_a and $QINT_a$ are combined to form activity output QX_a.

For water activities, in the basic case however, each activity is linked to one specific resource and land requirements do not play a role in the provision of water. In this case, QNW_a equals $FD_{fw,a}$ and thus the production structure collapses to a two level nest [30]. If it is desired to keep the production structure fixed, as most water providing facilities are build in a certain setup and produce for decades without many options to alter the production structure to a large extend, Leontief technology can be applied for water activities on all levels. This also guarantees that the water resource cannot be substituted by other inputs such that the quantity of water resource use directly determines the output of water commodity by the water activity. However, the model allows for a shift to CES-technology, by setting an elasticity, if required.

Water consuming activities, on the other side, usually allow for the substitution of water commodities and other factors of production, such that in the default setup on all levels CES technology is applied (σ_1 - σ_4). The optimal combinations of inputs in each CES aggregate are determined by first order conditions based on relative prices. The only exception is the aggregation of non-water intermediate inputs ($QINT_a$), for which Leontief technology is applied.

The advantage of using such a nesting structure is that it avoids making the assumption that all inputs are equally substitutable in the generation of value added. For activities which do not consume any land and/or water commodities, the nesting structure simply collapses to fewer levels.

[30] Possible exceptions to this are the provision of potable water with a certain mineral level by mixing desalinated seawater (with zero mineral content) with purified freshwater. In the reclamation of wastewater land can play a role, if sewage farms are used.

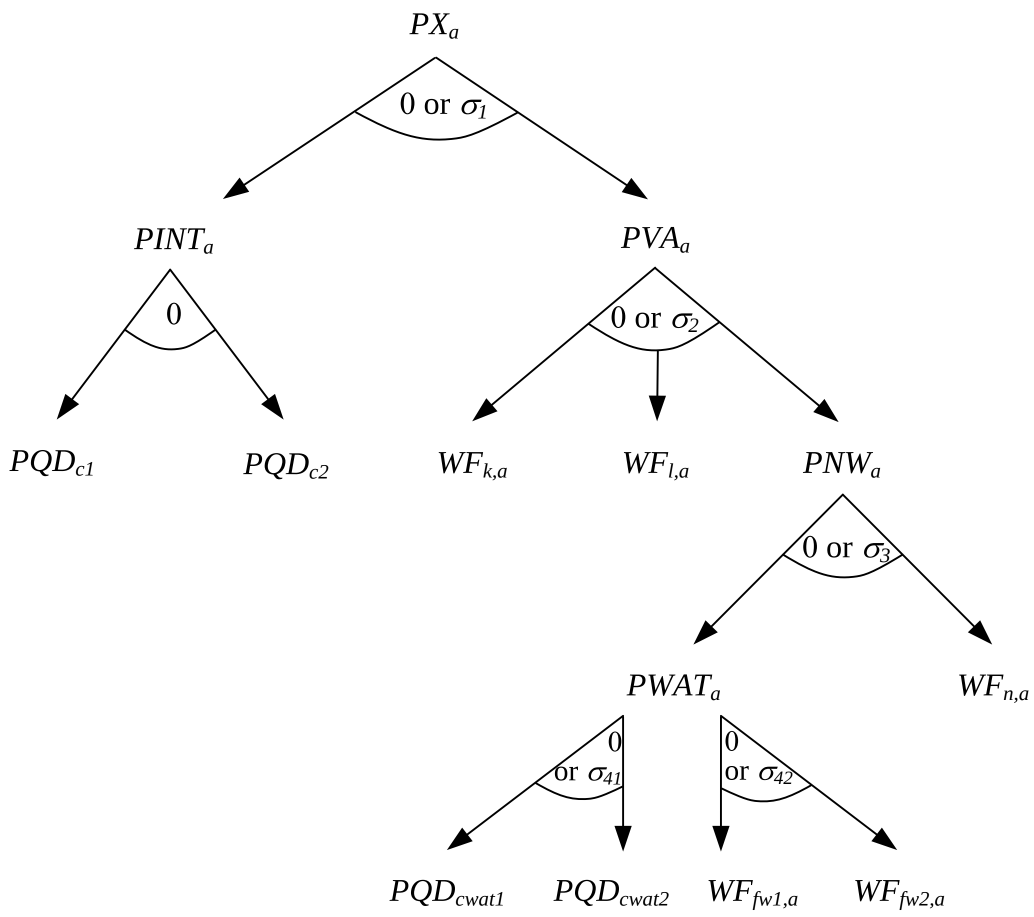

Figure A 1.5. Production Relationships for the STAGE_W Model: Prices.

The price relations for the production system are illustrated in Figure A 1.5. Note how the prices paid for intermediate inputs and water commodities (PQD_c) are the same as paid for final demands, i.e., a ‘law’ of one price relationship holds across all domestic demand. Note also that factor prices are factor and activity specific ($WF_{f,a}$), which means that the allocation of finite supplies of factors (FS_f) between competing activities depends upon relative factor prices via first order conditions for optima.

A.1.3 Algebraic Statement of the Model

A.1.3.1 Sets

The model uses a series of sets, each of which is required to be declared and have members assigned. For the majority of the sets the declaration and assignment takes place simultaneously in a single block of code.[31] However, the assignment for a number of the sets, specifically those used to control the

[31] For practical purposes it is often easiest if this block of code is contained in a separate file that is then called up from within the *.gms file.

modelling of trade relationships is carried out dynamically by reference to the data used to calibrate the model. The following are the basic sets for this model:

$$c = \{\text{commodities}\}$$
$$a = \{\text{activities}\}$$
$$f = \{\text{factors}\}$$
$$h = \{\text{households}\}$$
$$g = \{\text{government}\}$$
$$e = \{\text{enterprises}\}$$
$$i = \{\text{investment}\}$$
$$w = \{\text{rest of the world}\}$$

For each set there is an alias declared that has the same membership as the corresponding basic set. The notation used involves the addition of a '*p*' suffix to the set label, e.g., the alias for *c* is *cp*.

For practical/programming purposes these basic sets are declared and assigned as subsets of a global set, *sac*,

$$sac = \{c, a, f, h, g, e, i, w, total\}.$$

All the dynamic sets relate to the modelling of the commodity and activity accounts and therefore are subsets of the sets *c* and *a*. The subsets are:

$$ce_c = \{\text{export commodities}\}$$
$$cen_c = \{\text{non-export commodities}\}$$
$$ced_c = \{\text{export commodities with export demand functions}\}$$
$$cedn_c = \{\text{export commodities without export demand functions}\}$$
$$cm_c = \{\text{imported commodities}\}$$
$$cmn_c = \{\text{non-imported commodities}\}$$
$$cx_c = \{\text{commodities produced domestically}\}$$
$$cxn_c = \{\text{commodities NOT produced domestically AND imported}\}$$
$$cd_c = \{\text{commodities produced AND demanded domestically}\}$$
$$cdn_c = \{\text{commodities NOT produced AND demanded domestically}\}$$

and members are assigned using the data used for calibration. Additionally there are some sets, referring to commodities and activities, which are used to control the behavioural equations implemented in specific cases. These are:

$$cxac_c = \{\text{differentiated commodities produced domestically}\}$$
$$cxacn_c = \{\text{UNdifferentiated commodities produced domestically}\}$$
$$cwat_c = \{\text{water-commodities,which enter on the value added side of the production function}\}$$
$$cnwat_c = \{\text{non-water-commodities,which enter on the intermediate side of the production function}\}$$
$$aqx_a = \{\text{activities with CES aggregation at Level 1}\}$$
$$aqxn_a = \{\text{activities with Leontief aggregation at Level 1}\}$$
$$afx_a = \{\text{activities with CES aggregation at value added side of Level 2}\}$$
$$afxn_a = \{\text{activities with Leontief aggregation at value added side of Level 2}\}$$
$$af3x_a = \{\text{activities with CES aggregation at Level 3}\}$$
$$af3xn_a = \{\text{activities with Leontief aggregation at Level 3}\}$$
$$af4x_a = \{\text{activities with CES aggregation at Level 4}\}$$
$$af4xn_a = \{\text{activities with Leontief aggregation at Level 4}\}$$

and their memberships are set during the model calibration phase.

Finally a set is declared and assigned for a macro SAM that is used to check model calibration. This set and its members are:

$$ss = \{commdty, activity, valuad, hholds, entp, govtn, kapital, world, totals\}.$$

A.1.3.2 Reserved Names

The model also uses a number of names that are reserved, in addition to those specified in the set statements detailed above. The majority of these reserved names are components of the government set; they are reserved to ease the modelling of tax instruments. The required members of the government set, with their descriptions, are:

$$g = \left\{\begin{array}{cc} IMPTAX & \text{Import Taxes} \\ EXPTAX & \text{Export Taxes} \\ SALTAX & \text{Sales Taxes} \\ ECTAX & \text{Excise Taxes} \\ INDTAX & \text{Indirect Taxes} \\ FACTTAX & \text{Factor Taxes} \\ DIRTAX & \text{Direct Taxes} \\ WATTAX & \text{Water Taxes} \\ WATAXA & \text{Water User Subsidies} \\ GOVT & \text{Government} \end{array}\right\}.$$

The other reserved names are for the factor account and for the capital accounts. For simplicity the factor account relating to residual payments to factors has the reserved name of *GOS* (gross operating surplus); in many SAMs this account would include payments to the factors of production land and physical capital, payments labelled mixed income and payments for entrepreneurial services. Where the factor accounts are fully articulated *GOS* would refer to payments to the residual factor, typically physical capital and entrepreneurial services.

The capital account includes provision for two expenditure accounts relating to investment. All expenditures on stock changes are registered in the account *dstoc*, while all investment expenditures are registered to the account *kap*. All incomes to the capital account accrue to the *kap* account and stock changes are funded by an expenditure levied on the *kap* account to the *dstoc* account.

A.1.3.3 Conventions

The equations for the model are set out in eleven 'blocks'; which group the equations under the following headings 'trade', 'commodity price', 'numéraire', 'production', 'factor', 'household', 'enterprise', 'government', 'kapital', 'foreign institutions' and 'market clearing'. This grouping of equations is intended to ease the reading of the model rather than being a requirement of the model; it also reflects the modular structure that underlies the programme and which is designed to simplify model extensions/developments.

A series of conventions are adopted for the naming of variables and parameters. These conventions are not a requirement of the modelling language; rather they are designed to ease reading of the model.

- All VARIABLES are in upper case.
- Standard prefixes for variable names are: *P* for price variables, *Q* for quantity variables, *E* for expenditure variables, *Y* for income variables, and *V* for value variables
- All variables have a matching parameter that identifies the value of the variable in the base period. These parameters are in upper case and carry a '0' suffix, and are used to initialise variables.
- A series of variables are declared that allow for the equiproportionate adjustment of groups of parameters. These variables are named using the convention ***ADJ*, where ** is the variable/parameter series they adjust.
- All parameters are in lower case, except those used to initialise variables.
- Names for parameters in CES/CET functions use standard prefixes – ρ^{**} for all elasticity parameters, *ac*** and δ^{**} for commodity CES shift and share parameters, *ad*** and δ^{**} for activity CES shift and share parameters and *at*** and γ^{**} for CET shift and share parameters;
- Other parameter names with prefixes or suffix which distinguishes their definition, e.g., *io*** is a quantity coefficient, ***sh* is a value share parameter, ***av* is an average and **const is a constant parameter, as far as possible the ** part of the name seeks to identify the component parts;
- The names for all parameters and variables are kept short.

A.1.3.4 Trade Block Equations

Trade relationships are modelled using the Armington assumption of imperfect substitutability between domestic and foreign commodities. The set of eleven equations are split across two sub-blocks – exports and imports - and provide a general structure that accommodates most eventualities found with single country CGE models. In particular these equations allow for traded and non-traded commodities while simultaneously accommodating commodities that are produced or not produced domestically and are consumed or not consumed domestically and allowing a relaxation of the small country assumption of price taking for exports.

A.1.3.4.1 Exports Block

The domestic price of exports (E1) is defined as the product of the world price of exports (*PWE*), the exchange rate (*ER*) and one minus the export tax rate[32] and are only implemented for members of the set *c* that are exported, i.e., for members of the subset *ce*. The world price of imports and exports are declared as variables to allow relaxation of the small country assumption, and are then fixed as appropriate in the model closure block.

Export Block Equations

$$PE_c = PWE_c * ER * (1 - TE_c) \qquad \forall ce \qquad \text{(E1)}$$

$$QXC_c = at_c * \left(\gamma_c * QE_c^{\rho t_c} + (1-\gamma_c) * QD_c^{\rho t_c} \right)^{\frac{1}{\rho t_c}} \qquad \forall ce \textbf{ AND } cd \qquad \text{(E2)}$$

$$\frac{QE_c}{QD_c} = \left[\frac{PE_c}{PD_c} * \frac{(1-\gamma_c)}{\gamma_c} \right]^{\frac{1}{(\rho t_c - 1)}} \qquad \forall ce \textbf{ AND } cd \qquad \text{(E3)}$$

$$QXC_c = QD_c + QE_c \qquad \forall (cen \textbf{ AND } cd) \textbf{ OR } (ce \textbf{ AND } cdn) \qquad \text{(E4)}$$

$$QE_c = econ_c * \left(\frac{PWE_c}{pwse_c} \right)^{-\eta_c} \qquad \forall ced \qquad \text{(E5)}$$

The output transformation functions (E2), and the associated first-order conditions (E3), establish the optimum allocation of domestic commodity output (*QXC*) between domestic demand (*QD*) and exports (*QE*), by way of Constant Elasticity of Transformation (CET) functions, with commodity specific share parameters (γ), elasticity parameters (ρt) and shift/efficiency parameters (*at*). The first order conditions define the optimum ratios of exports to domestic demand in relation to the relative

[32] ALL tax rates are expressed as variables. How the tax rate variables are modeled is explained below.

prices of exported (*PE*) and domestically supplied (*PD*) commodities. But (E2) is only defined for commodities that are both produced and demanded domestically (*cd*) **and** exported (*ce*). Thus, although this condition might be satisfied for the majority of commodities, it is also necessary to cover those cases where commodities are produced **and** demanded domestically but **not** exported, and those cases where commodities are produced domestically **and** exported but **not** demanded domestically.

If commodities are produced domestically but **not** exported, then domestic demand for domestically produced commodities (*QD*) is, by definition (E4), equal to domestic commodity production (*QXC*), where the sets *cen* (commodities not exported) and *cd* (commodities produced and demanded domestically) control implementation. On the other hand if commodities are produced domestically but **not** demanded by the domestic output, then domestic commodity production (*QXC*) is, by definition (E4), equal to commodity exports (*QE*), where the sets *ce* (commodities exported) and *cdn* (commodities not produced or not demanded domestically) control implementation.

The equations E1 to E4 are sufficient for a general model of export relationships when combined with the small country assumption of price taking on all export markets. However, it may be appropriate to relax this assumption in some instances, most typically in cases where a country is a major supplier of a commodity to the world market, in which case it may be reasonable to expect that as exports of that commodity increase so the export price (*PE*) of that commodity might be expected to decline, i.e., the country faces a downward sloping export demand curve. The inclusion of export demand equations (E5) accommodates this feature, where export demands are defined by constant elasticity export demand functions, with constants (*econ*), elasticities of demand (η) and prices for substitutes on the world market (*pwse*).

A.1.3.4.2 Imports Block

The domestic price of competitive imports (M1) is the product of the world price of imports (*PWM*), the exchange rate (*ER*) and one plus the import tariff rate (*TM*). These equations are only implemented for members of the set *c* that are imported, i.e., for members of the subset *cm*.

The domestic supply equations are modelled using Constant Elasticity of Substitution (CES) functions and associated first order conditions to determine the optimum combination of supplies from domestic and foreign (import) producers. The domestic supplies of the composite commodities (*QQ*) are defined as CES aggregates (M2) of domestic production supplied to the domestic market (*QD*) and imports (*QM*), where aggregation is controlled by the share parameters (δ), the elasticity of substitution parameters (ρ) and the shift/efficiency parameters (*ac*). The first order conditions (M3) define the optimum ratios of imports to domestic demand in relation to the relative prices of imported (*PM*) and domestically supplied (*PDD*) commodities. But (M2) is only defined for commodities that are both produced domestically (*cx*) **and** imported (*cm*). Although this condition might be satisfied for the majority of commodities, it is also necessary to cover those cases where commodities are produced but **not** imported, and those cases where commodities are **not** produced domestically **and** are imported.

Import Block Equations

$$PM_c = PWM_c * ER * (1 + TM_c) \qquad \forall cm \qquad \text{(M1)}$$

$$QQ_c = ac_c \left(\delta_c QM_c^{-\rho_c} + (1-\delta_c) QD_c^{-\rho_c} \right)^{-\frac{1}{\rho_c}} \qquad \forall cm \textbf{ AND } cx \qquad \text{(M2)}$$

$$\frac{QM_c}{QD_c} = \left[\frac{PD_c}{PM_c} * \frac{\delta_c}{(1-\delta_c)} \right]^{\frac{1}{(1+\rho_c)}} \qquad \forall cm \textbf{ AND } cx \qquad \text{(M3)}$$

$$QQ_c = QD_c + QM_c \qquad \forall (cmn \textbf{ AND } cx) \textbf{ OR } (cm \textbf{ AND } cxn) \qquad \text{(M4)}$$

If commodities are produced domestically but **not** imported, then domestic supply of domestically produced commodities (*QD*) is, by definition (M4), equal to domestic commodity demand (*QQ*), where the sets *cmn* (commodities not imported) and *cx* (commodities produced domestically) control implementation. On the other hand if commodities are **not** produced domestically but are demanded on the domestic market, then commodity supply (*QQ*) is, by definition (M4), equal to commodity imports (*QM*), where the sets *cm* (commodities imported) and *cxn* (commodities not produced domestically) control implementation.

A.1.3.5 Commodity Price Block

The supply prices for commodities (P1) are defined as the volume share weighted sums of expenditure on domestically produced (*QD*) and imported (*QM*) commodities. These conditions derive from the first order conditions for the quantity equations for the composite commodities (*QQ*) above.[33] This equation is implemented for all commodities that are imported (*cm*) and for all commodities that are produced and consumed domestically (*cd*). Similarly, domestically produced commodities (*QXC*) are supplied to either or both the domestic and foreign markets (exported). The supply prices of domestically produced commodities (*PXC*) are defined as the volume share weighted sums of expenditure on domestically produced and exported (*QE*) commodities (P2). These conditions derive from the first order conditions for the quantity equations for the composite commodities (*QXC*) below.[34] This equation is implemented for all commodities that are produced domestically (*cx*), with a control to only include terms for exported commodities when there are exports (*ce*).

[33] Using the properties of linearly homogenous functions defined by reference to Eulers theorem.
[34] Using the properties of linearly homogenous functions defined by reference to Eulers theorem.

Commodity Price Block Equations

$$PQS_c = \frac{PD_c * QD_c + PM_c * QM_c}{QQ_c} \qquad \forall cd \textbf{ OR } cm \qquad \text{(P1)}$$

$$PXC_c = \frac{PD_c * QD_c + \left(PE_c * QE_c\right)\$ce_c}{QXC_c} \qquad \forall cx \qquad \text{(P2)}$$

$$PQD_c = PQS_c * \left(1 + TS_c + TEX_c\right) \qquad \text{(P3)}$$

Domestic agents consume composite consumption commodities (*QQ*) that are aggregates of domestically produced and imported commodities. The prices of these composite commodities (*PQD*) are defined (P3) as the supply prices of the composite commodities plus *ad valorem* sales taxes (*TS*) and excise taxes (*TEX*). It is relatively straightforward to include additional commodity taxes.

A.1.3.6 Numéraire Price Block

The price block is completed by two price indices that can be used for price normalisation. Equation (N1) is for the consumer price index (*CPI*), which is defined as a weighted sum of composite commodity prices (*PQD*) in the current period, where the weights are the shares of each commodity in total demand (*comtotsh*). The domestic producer price index (*PPI*) is defined (N2) by reference to the supply prices for domestically produced commodities (*PD*) with weights defined as shares of the value of domestic output for the domestic market (*vddtotsh*).

Numéraire Block Equations

$$CPI = \sum_c comtotsh_c * PQD_c \qquad \text{(N1)}$$

$$PPI = \sum_c vddtotsh_c * PD_c \qquad \text{(N2)}$$

A.1.3.7 Production Block

A.1.3.7.1 Top level

The supply prices of domestically produced commodities are determined by purchaser prices of those commodities on the domestic and international markets. Adopting the assumption that domestic activities produce commodities in fixed proportions (*ioqxacqx*), the proportions provide a mapping (X1) between the supply prices of commodities and the (weighted) average activity prices (*PX*).[35]

In this model a four-stage production process is adopted, with the top level as a CES or Leontief function. If a CES is imposed for an activity the value of activity output can be expressed as the volume share weighted sums of the expenditures on inputs after allowing for the production taxes (*TX*), which are assumed to be applied *ad valorem* (X2). This requires the definition of aggregate prices for non-water intermediates (*PINT*); these are defined as the intermediate input-output coefficient weighted sum of the prices of non-water intermediate inputs (*PQD*), see (X3), whereby *ioqtdqd* are the intermediate input-output coefficients). A condition (*c*\$*cnwat*) is imposed in the summation to guarantee, that only non-water commodities are included.

With CES technology the output by an activity, (*QX*) is determined by the aggregate quantities of factors used (*QVA*), i.e., aggregate value added, and aggregate intermediates used (*QINT*), where δ^{x} is the share parameter, ρ^{cx} is the substitution parameter and ADX is the efficiency variable (X5). Note how the efficiency/shift factor is defined as a variable and an adjustment mechanism is provided (X4), where *adxb* is the base value, *dabadx* is an absolute change in the base value, *ADXADJ* is an equiproportionate (multiplicative) adjustment factor, *DADX* is an additive adjustment factor and *adx*01 is a vector of zeros and non zeros used to scale the additive adjustment factor. The operation of this type of adjustment equation is explained below for the case of an import duty. The associated first order conditions defining the optimum ratios of value added to intermediate inputs can be expressed in terms of the relative prices of value added (*PVA*) and intermediate inputs (*PINT*), see (X6).

Production Block Equations: Top Level

$$PX_a = \sum_{c} ioqxacqx_{a,c} * PXAC_{a,c} \tag{X1}$$

$$PX_a * \left(1 - TX_a\right) * QX_a = \left(PVA_a * QVA_a\right) + \left(PINT_a * QINT_a\right) \tag{X2}$$

$$PINT_a = \sum_{c\$cnwat_c} \left(ioqtdqd_{c,a} * PQD_c\right) \tag{X3}$$

$$AD_a^X = \left[\left(adxb_a + dabadx_a\right) * ADXADJ\right] + \left(DADX * adx01_a\right) \tag{X4}$$

$$QX_a = AD_a^X \left(\delta_a^x * QVA_a^{-\rho_a^{cx}} + \left(1 - \delta_a^x\right) * QINT_a^{-\rho_a^{cx}}\right)^{-\frac{1}{\rho_a^{cx}}} \qquad \forall aqx_a \tag{X5}$$

[35] In the special case of each activity producing only one commodity and each commodity only being produced by a single activity, which is the case in the reduced form model reported in Dervis et al., (1982), then the aggregation weights ioqxacqx correspond to an identity matrix.

$$\frac{QVA_a}{QINT_a} = \left[\frac{PINT_a}{PVA_a} * \frac{\delta_a^x}{\left(1-\delta_a^x\right)}\right]^{\frac{1}{\left(1+\rho_a^{cx}\right)}} \qquad \forall aqx_a \qquad \text{(X6)}$$

$$QVA_a = ioqvaqx_a * QX_a \qquad \forall aqxn_a \qquad \text{(X7a)}$$

$$QINT_a = ioqintqx_a * QX_a \qquad \forall aqxn_a \qquad \text{(X7b)}$$

With Leontief technology at the top level the aggregate quantities of factors used (*QVA*), i.e., aggregate value added, and intermediates used (*QINT*), are determined by simple aggregation functions, (X7a) and (X7b), where *ioqvaqx* and *ioqintqx* are the (fixed) volume shares of *QVA* and *QINT* (respectively) in *QX*. The choice of top level aggregation function is controlled by the membership of the set *aqx*, with the membership of *aqxn* being the complement of *aqx*.

A.1.3.7.2 Second level

There are two arms to the second level production nest. For aggregate value added (*QVA*) the production function can be a multi-factor CES function. For activities with CES setup on the second level (*afx*) (X9) *QVA* is based on the sum of consumed factors (*FD*) multiplied by the activity specific factor use efficiency (*ADFD*).Thereby δ^{va} is a share parameter, ρ^{va} is a substitution parameter and $ADVA_a$ is an efficiency factor. Again the efficiency/shift factor is defined as a variable with an adjustment mechanism (X8), where *advab* is the base values, *dabadva* is an absolute change in the base value, *ADVAADJ* is an equiproportionate (multiplicative) adjustment factor, *DADVA* is an additive adjustment factor and *adva*01 is a vector of zeros and non zeros used to scale the additive adjustment factor. For activities which are consuming water and/or land (conditioned by $\$\delta^{va}_{"cnw"}$) the production function is expanded by an additional term for the land-water-composite (*QNW*) multiplied by its share parameter $\delta^{va}_{"cnw"}$.

The associated first order conditions for profit maximisation determine the wage rate of factors (*WF*) (X10) and, for those activities it applies to, the price of the land-water aggregate (*PNW*) (X11). Thereby the ratio of factor payments to factor *f* from activity *a* (*WFDIST*) is included to allow for non-homogenous factors, and is derived directly from the first order condition for profit maximisation as equality between the wage rates for each factor in each activity and the values of the marginal products of those factors in each activity. For activities with Leontief production technology on the second level (*afxn*), factor and aggregated land-water quantities (*FD* and *QNW*) as well as the price of value added (*PVA*) are determined by simple aggregation functions (X12 to X14) with the help of share parameters *io***.

On the second arm of the second level production nest (X15) intermediate input demand (*QINTD*) is defined as the product of the fixed (Leontief) input coefficients of demand for commodity *c* by activity *a* (*ioqtdqd*), multiplied by the quantity of activity intermediate input (*QINT*) to which the consumption of water commodities by activities (*QWAT2*) is added.

Production Block Equations: Second Level

$$AD_a^{VA} = \left[\left(advab_a + dabadva_a\right) * ADVAADJ\right] + \left(DADVA * adva01_a\right) \tag{X8}$$

$$QVA_a = AD_a^{VA} * \begin{bmatrix} \sum_{f2\$\delta^{va}_{f2,a}} \delta^{va}_{f2,a} * AD^{FD}_{f2,a} * FD_{f2,a}^{-\rho_a^{cva}} \\ +(\delta^{va}_{"cnw",a} * QNW_a^{-\rho_a^{cva}})\$\delta^{va}_{"cnw",a} \end{bmatrix}^{-1/\rho_a^{cva}} \quad \forall afx_a \tag{X9}$$

$$WF_{f2} * WFDIST_{f2,a} * \left(1 + TF_{f2,a}\right) = PVA_a * QVA_a * \begin{bmatrix} \sum_{f2p\$\delta^{va}_{f2p,a}} \delta^{va}_{f2p,a} * AD^{FD}_{f2,a} * FD_{f2p,a}^{-\rho_a^{cva}} \\ +(\delta^{va}_{"cnw",a} * QNW_a^{-\rho_a^{cva}})\$\delta^{va}_{"cnw",a} \end{bmatrix}^{-1} * \delta^{va}_{f2,a} * AD^{FD\ -\rho_a^{cva}}_{f2,a} * FD_{f2,a}^{\left(-\rho_a^{cva}-1\right)} \quad \forall afx_a \tag{X10}$$

$$PNW_a = PVA_a * QVA_a * \left[\sum_{f2p\$\delta^{va}_{f2p,a}} \delta^{va}_{f2p,a} * AD^{FD}_{f2p,a} * FD_{f2p,a}^{-\rho_a^{cva}} + \delta^{va}_{"cnw",a} * QNW_a^{-\rho_a^{cva}}\right]^{-1} * \delta^{va}_{"cnw",a} * QNW_a^{\left(-\rho_a^{cva}-1\right)} \quad \forall afx_a \tag{X11}$$

$$FD_{f2,a} * AD^{FD}_{f2,a} = ioffqva_{f2,a} * QVA_a \quad \forall afxn_a \tag{X12}$$

$$QNW_a = \sum_{cwat} ioqnwqva_a * QVA_a \quad \forall afxn_a \tag{X13}$$

$$PVA_a = PNW_a * ioqnwqva_a + \sum_{f2} ioffqva_{f2,a} * WF_{f2} * WFDIST_{f2,a} * (1 + TF_{f2,a}) \quad \forall afxn_a \tag{X14}$$

$$QINTD_c = \sum_a ioqtdqd_{c,a} * QINT_a + \sum_a QWAT2_{c,a} \tag{X15}$$

A.1.3.7.3 Third level

On the third level land enters the production function. Equation X16 is a CES production function forming the land-water aggregate (*QNW*). It holds for all activities which use land (*an*) and which allow for the substitution (*af3x*) between the water aggregate and land. It is structurally similar to equation X9 on level 2 [36] and so are the first order conditions for the prices of land (X17) and water-aggregate (X18), which resemble equations X10 and X11. For activities which do not consume water, the water term in equations X16 and X17 as well as equation X18 are dropped (conditioned by $\$\delta^{nw}_{"cwat",a}$).

Equations X19 to X21 represent the case of no substitution (Leontief production technology) (*af3xn*). Thereby equation X19 and X20 calculate factor and aggregated water demand quantities (*FD* and *QWAT*) as shares of *QNW* and X21 sums factor and aggregate water prices proportionally to form *PNW*.

For activities, which do not consume land (*ann*) *iocwatqnw* is 1 and *iof3qnw* is 0. This guarantees that quantity and price of the aggregate (*QNW* and *PNW*) are equal to the quantity and price of the water aggregate (*QWAT* and *PWAT*) (X20 and X21).

Production Block Equations: Third Level

$$QNW_a = at^{nw}_a * \left[\begin{array}{l} \sum\limits_{f3\$\delta^{nw}_{f3p,a}} \delta^{nw}_{f3,a} * AD^{FD}_{f3,a} * FD^{-\rho^{nw}_a}_{f3,a} \\ +(\delta^{nw}_{"cwat",a} * QWAT_a^{-\rho^{nw}_a})\$\delta^{nw}_{"cwat",a} \end{array} \right]^{-1/\rho^{nw}_a} \qquad \forall af3x_a \ \textbf{AND} \ an_a \qquad \text{(X16)}$$

$$\begin{aligned} WF_{f3} * WFDIST_{f3,a} * \left(1+TF_{f3,a}\right) = PNW_a * QNW_a \\ * \left[\begin{array}{l} \sum\limits_{f3p\$\delta^{nw}_{f3p,a}} \delta^{nw}_{f3p,a} * AD^{FD}_{f3p,a} * FD^{-\rho^{nw}_a}_{f3p,a} \\ +(\delta^{nw}_{"cwat",a} * QWAT_a^{-\rho^{nw}_a})\$\delta^{nw}_{"cwat",a} \end{array} \right]^{-1} * \delta^{nw}_{f3p,a} * AD^{FD\ -\rho^{nw}_a}_{f3,a} * FD_{f3,a}^{\left(-\rho^{nw}_a - 1\right)} \end{aligned} \qquad \forall af3x_a \qquad \text{(X17)}$$

$$\begin{aligned} PWAT_a = PNW_a * QNW_a \\ * \left[\begin{array}{l} \sum\limits_{f3p\$\delta^{nw}_{f3p,a}} \delta^{nw}_{f3p,a} * AD^{FD}_{f3p,a} * FD^{-\rho^{nw}_a}_{f3p,a} \\ +\delta^{nw}_{"cwat",a} * QWAT_a^{-\rho^{nw}_a} \end{array} \right]^{-1} * \delta^{nw}_{"cwat",a} * QWAT_a^{\left(-\rho^{nw}_a - 1\right)} \end{aligned} \qquad \forall af3x_a \qquad \text{(X18)}$$

$$FD_{f3,a} * AD^{FD}_{f3,a} = iof3qnw_{f3,a} * QNW_a \qquad \forall af3xn_a \qquad \text{(X19)}$$

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[36] The only exception is the shift parameter (atnw) which is not an endogenous variable in this case. This reflects the expectation that there will be no endogenously determined changes in this shift factor.

$$QWAT_a = iocwatqnw_a * QNW_a \qquad \forall af3xn_a \textbf{ OR } ann_a \qquad \text{(X20)}$$

$$PNW_a = PWAT_a * iocwatqnw_a + \sum_{f3} iof3qnw_{f3,a} * WF_{f3} * WFDIST_{f3,a} * (1 + TF_{f3,a}) \quad \forall af3xn_a \textbf{ OR } ann_a \qquad \text{(X21)}$$

A.1.3.7.4 Fourth Level

The lowest level of the production nest aggregates water commodities and water factors again for the two cases of CES (*af4x*) and Leontief (*af4xn*) production technology.

For activities with CES technology and which use water commodities or factors the production function is X22, with the first order conditions X23 for water factor prices and X24 for water commodity prices, analogous to X16 to X18 in the third nest. As the water commodity price (*PQD*) is defined over the set *cwat* only, the price ratio (*PQDDIST*) is included in X24 to allow for price discrimination for payments to water commodity *cwat* from activity *a*, similar to (*WFDIST*) on the factor price side.

In case Leontief technology is assumed equation X25 to X27 are applied. Thereby X25 holds for activities which consume water commodities (*acwat*) and X26 is applied for activities which use water factors (*afwat*). In both cases quantities of water commodities (*QWAT2*) or factors (*FD*) are simple shares of the water aggregate (*QWAT*). Also the price of the water aggregate is formed by a summation of the weighted shares of water commodity and/or factor input prices, including tax rates (*TWATA* and *TF*, respectively) (X27).

If additional levels of nesting are required then it is only necessary to add additional primal and first-order conditions that will have the same structures as for the third and fourth level nests but with appropriately revised set identifiers.[37]

Also the allocation of production factors on the various nesting levels can be varied. Currently this is done in an Excel workbook that contains the sets and data used to calibrate the model.

[37] The only tricky parts are the derivation of the set mappings and the extensions to the code for calibrating the parameters.

Production Block Equations: Fourth Level

$$QWAT_a = at_a^{wat} * \left[\begin{array}{l} \sum_{f4\$\delta_{f4,a}^{wat}} \delta_{f4,a}^{wat} * AD_{f4,a}^{FD} * FD_{f4,a}^{-\rho_a^{wat}} \\ + \sum_{cwat} \delta_{cwat,a}^{wat} * QWAT2_{cwat,a}^{-\rho_a^{wat}} \end{array} \right]^{-1/\rho_a^{wat}} \quad \forall af4x_a \textbf{ AND } awat_a \qquad (X22)$$

$$\begin{array}{l} WF_{f4} * WFDIST_{f4,a} * \left(1 + TF_{f4,a}\right) = PWAT_a * QWAT_a \\ * \left[\begin{array}{l} \sum_{f4p\$\delta_{f4p,a}^{wat}} \delta_{f4p,a}^{wat} * AD_{f4p,a}^{FD} * FD_{f4p,a}^{-\rho_a^{wat}} \\ + \sum_{cwatp\$\delta_{cwatp,a}^{wat}} \delta_{cwatp,a}^{wat} * QWAT2_{cwatp,a}^{-\rho_a^{wat}} \end{array} \right]^{-1} \\ * \delta_{f4p,a}^{wat} * AD_{f4,a}^{FD\ -\rho_a^{wat}} * FD_{f4,a}^{\left(-\rho_a^{wat} - 1\right)} \quad \forall af4x_a \end{array} \qquad (X23)$$

$$\begin{array}{l} PQD_{cwat} * PQDDIST_{cwat,a} * (1 + TWATA_{cwat,a}) = PWAT_a * QWAT_a \\ * \left[\begin{array}{l} \sum_{f4p\$\delta_{f4p,a}^{wat}} \delta_{f4p,a}^{wat} * AD_{f4p,a}^{FD} * FD_{f4p,a}^{-\rho_a^{wat}} \\ + \sum_{cwatp\$\delta_{cwatp,a}^{wat}} \delta_{cwatp,a}^{wat} * QWAT2_{cwatp,a}^{-\rho_a^{wat}} \end{array} \right]^{-1} \\ * \delta_{cwatp,a}^{wat} * QWAT2_{cwat,a}^{\left(-\rho_a^{wat} - 1\right)} \quad \forall af4x_a \end{array} \qquad (X24)$$

$$QWAT2_{c,a} = ioqwat_{c,a} * QWAT_a \quad \forall af4xn_a \textbf{ AND } acwat_a \qquad (X25)$$

$$FD_{f4,a} * AD_{f4,a}^{FD} = iof4aggf4_{f4,a} * QWAT_a \quad \forall af4xn_a \textbf{ AND } afwat_a \qquad (X26)$$

$$\begin{array}{l} PWAT_a = \sum_{c\$cwat_c} ioqwat_{c,a} * PQD_c * PQDDIST_{c,a} * (1 + TWATA_{c,a}) \\ \quad + \sum_{f4} iof4aggf4_{f4agg,f4,a} * WF_{f4} * WFDIST_{f4,a} * (1 + TF_{f4,a}) \\ \quad \forall af4xn_a \end{array} \qquad (X27)$$

A.1.3.7.5 Commodity Outputs

Equation X28 aggregates the commodity outputs by each activity (*QXAC*) to form the composite supplies of each commodity (*QXC*). The default assumption is that when a commodity is produced by multiple activities it is differentiated by reference to the activity that produces the commodity; this is achieved by defining total production of a commodity as a CES aggregate of the quantities produced by each activity. This provides a practical/modelling solution for two typical situations; first, where there are quality differences between two commodities that are notionally the same, e.g., modern digital vv disposable cameras, and second, where the mix of commodities within an aggregate differ between activities, e.g., a cereal grain aggregate made up of wheat and maize (corn) where different activities produce wheat and maize in different ratios. This assumption of imperfect substitution is implemented by a CES aggregator function with ad^{xc} as the shift parameter, δxc as the share parameter and ρ^{xc} as the elasticity parameter.

The matching first order condition for the optimal combination of commodity outputs is therefore given by (X29), where *PXAC* are the prices of each commodity produced by each activity. Note how, as with the case of the value added production function two formulations are given for the first-order conditions and the second version is the default version used in the model. Further note that the efficiency/shift factor is in this case declare as a parameter; this reflects the expectation that there will be no endogenously determined changes in these shift factors.

Production Block Equations: Commodity Outputs

$$QXC_c = ad_c^{xc} * \left[\sum_{a\$\delta_{a,c}^{xc}} \delta_{a,c}^{xc} * QXAC_{a,c}^{-\rho_c^{xc}} \right]^{-1/\rho_c^{xc}} \qquad \forall cx_c \textbf{ AND } cxac_c \qquad \text{(X28)}$$

$$PXAC_{a,c} = PXC_c * ad_c^{xc} * \left[\sum_{a\$\delta_{a,c}^{xc}} \delta_{a,c}^{xc} * QXAC_{a,c}^{-\rho_c^{xc}} \right]^{-\left(\frac{1+\rho_c^{xc}}{\rho_c^{xc}}\right)} * \delta_{a,c}^{xc} * QXAC_{a,c}^{\left(-\rho_c^{xc}-1\right)}$$

$$= PXC_c * QXC_c * \left[\sum_{a\$\delta_{a,c}^{xc}} \delta_{a,c}^{xc} * QXAC_{a,c}^{-\rho_c^{xc}} \right]^{-\left(\frac{1+\rho_c^{xc}}{\rho_c^{xc}}\right)} * \delta_{a,c}^{xc} * QXAC_{a,c}^{\left(-\rho_c^{xc}-1\right)}$$

$$\forall cxac_c \qquad \text{(X29)}$$

$$QXC_c = \sum_a QXAC_{a,c} \qquad \forall cx_c \textbf{ AND } cxacn_c \qquad \text{(X30)}$$

$$PXAC_{a,c} = PXC \qquad \forall cxacn_c . \qquad \text{(X31)}$$

$$QXAC_{a,c} = ioqxacqx_{a,c} * QX_a \qquad \text{(X32)}$$

However there are circumstances where perfect substitution may be a more appropriate assumption given the characteristics of either or both of the activity and commodity accounts. Thus an alternative specification for commodity aggregation is proved where commodities produced by different activities are modelled as perfect substitutes, (X30), and the matching price condition therefore requires that *PXAC* is equal to *PXC* for relevant commodity activity combinations (X31). The choice of aggregation function is controlled by the membership of the set *cxac*, with the membership of *cxacn* being the complement of *cxac*.

Finally the output to commodity supplies, where the 'weights' (*ioqxacqx*) identify the amount of each commodity produced per unit of output of each activity (X32). This equation not only captures the patterns of secondary production it also provides the market clearing conditions for equality between the supply and demand of domestic output.

A.1.3.8 Factor Block

There are two sources of income for factors. First there are payments to factor accounts for services supplied to activities, i.e., domestic value added, and second there are payments to domestic factors that are used overseas, the value of these are assumed fixed in terms of the foreign currency. Factor incomes (*YF*) are therefore defined as the sum of all income to the factors across all activities (F1).

Factor Block Equations

$$YF_f = \left(\sum_a WF_f * WFDIST_{f,a} * FD_{f,a} \right) + \left(factwor_f * ER \right) \quad \text{(F1)}$$

$$YFDISP_f = \left(YF_f * \left(1 - deprec_f \right) \right) * \left(1 - TYF_f \right) \quad \text{(F2)}$$

Before distributing factor incomes to the institutions that supply factor services allowance is made for depreciation rates (*deprec*) and factor (income) taxes (*TYF*) so that factor income for distribution (*YFDISP*) is defined (F2).

A.1.3.9 Household Block

A.1.3.9.1 Household Income

Households receive income from a variety of sources (H1). Factor incomes are distributed to households as fixed proportions (*hovash*) of the distributed factor income for all factors owned by the household, plus inter household transfers (*HOHO*), distributed payments/dividends from incorporated enterprises (*HOENT*) and real transfers from government (*hogovconst*) that are adjustable using a scaling factor (*HGADJ*) and transfers from the rest of the world (*howor*) converted into domestic currency units.

A.1.3.9.2 Household Expenditure

Inter household transfers (*HOHO*) are defined (H2) as a fixed proportions of household income (*YH*) after payment of direct taxes and savings, and then household consumption expenditure (*HEXP*) is defined as household income after tax income less savings and transfers to other households (H3).

Household Block Equations

$$YH_h = \left(\sum_f hovash_{h,f} * YFDISP_f\right) + \left(\sum_{hp} HOHO_{h,hp}\right) + HOENT_h + \left(hogovconst_h * HGADJ * CPI\right) + \left(howor_h * ER\right) \quad \text{(H1)}$$

$$HOHO_{h,hp} = hohosh_{h,hp} * \left(YH_h * (1 - TYH_h)\right) * (1 - SHH_h) \quad \text{(H2)}$$

$$HEXP_h = \left(\left(YH_h * (1 - TYH_h)\right) * (1 - SHH_h)\right) - \left(\sum_{hp} HOHO_{hp,h}\right) \quad \text{(H3)}$$

$$QCD_{c,h} * PQD_c = PQD_c * qcdconst_{c,h} + \sum_h beta_{c,h} * \left(HEXP_h - \sum_{cp}\left(PQD_{cp} * qcdconst_{cp,h}\right)\right) \quad \text{(H4)}$$

Households are then assumed to maximise utility subject to Stone-Geary utility functions. In a Stone-Geary utility function household consumption demand consists of two components; 'subsistence' demand (*qcdconst*) and 'discretionary' demand, and the equation must therefore capture both elements. This can be written as (H4) where discretionary demand is defined as the marginal budget shares (*beta*) spent on each commodity out of 'uncommitted' income, i.e., household consumption expenditure less total expenditure on 'subsistence' demand. If the user wants to use Cobb-Douglas utility function this can be achieved by setting the Frisch parameters equal to minus one and all the income elasticities of demand equal to one (the model code includes documentation of the calibration steps).

A.1.3.10 Enterprise Block

A.1.3.10.1 Enterprise Income

Similarly, income to enterprises (EN1) comes from the share of distributed factor incomes accruing to enterprises (*entvash*) and real transfers from government (*entgovconst*), which are adjustable using a scaling factor (*EGADJ*) and the rest of the world (*entwor*); all converted in to domestic currency units.

Enterprise Block Equations

$$YE_e = \left(\sum_f entvash_{e,f} * YFDISP_f \right) + \left(entgovconst_e * EGADJ * CPI \right) + \left(entwor_e * ER \right) \qquad \text{(EN1)}$$

$$QED_{c,e} = qedconst_{c,e} * QEADJ \qquad \text{(EN2)}$$

$$HOENT_{h,e} = hoentsh_{h,e} * \left(\begin{array}{l} \left(YE_e * \left(1 - TYE_e\right)\right) * \left(1 - SEN_e\right) \\ -\sum_c \left(QED_{c,e} * PQD_c \right) \end{array} \right) \qquad \text{(EN3)}$$

$$GOVENT_e = goventsh_e * \left(\begin{array}{l} \left(YE_e * \left(1 - TYE_e\right)\right) * \left(1 - SEN_e\right) \\ -\sum_c \left(QED_c * PQD_c \right) \end{array} \right) \qquad \text{(EN4)}$$

$$VED_e = \left(\sum_c QED_{c,e} * PQD_c \right) \qquad \text{(EN5)}$$

A.1.3.10.2 Enterprise Expenditure

The consumption of commodities by enterprises (*QED*) is defined (EN2) in terms of fixed volumes (*qedconst*), which can be varied via the volume adjuster (*QEDADJ*), and associated with any given volume of enterprise final demand there is a level of expenditure (*VED*); this is defined by (EN5) and creates an option for the macroeconomic closure conditions that distribute absorption across domestic institutions (see below).

If *QEDADJ* is made flexible, then *qedconst* ensures that the quantities of commodities demanded are varied in fixed proportions; clearly this specification of demand is not a consequence of a defined set of behavioural relationships, as was the case for households, which reflects the difficulties inherent to defining utility functions for non-household institutions.[38] If *VED* is fixed then the volume of consumption by enterprises (*QED*) must be allowed to vary, via the variable *QENTDADJ*.

The incomes to households from enterprises, which are assumed to consist primarily of distributed profits/dividends, are defined by (EN3), where *hoentsh* are defined as fixed shares of enterprise income after payments of direct/income taxes, savings and consumption expenditure. Similarly the income to government from enterprises, which is assumed to consist primarily of distributed profits/dividends on government owned enterprises, is defined by (EN4), where *goventsh* is defined as

[38] Some models use some form of utility function for non-household domestic institutions. If a Cobb-Douglas function is used then value shares of demand by institution are held constant, other choices typical alter value and quantity shares.

a fixed share of enterprise income after payments of direct/income taxes, savings and consumption expenditure.

A.1.3.11 Government Block

A.1.3.11.1 Tax Rates

All tax rates are variables in this model. The tax rates in the base solution are defined as parameters, e.g., tmb_c are the import duties by commodity c in the base solution, and the equations then allow for varying the tax rates in 5 different ways. For each tax instrument there are four methods that allow adjustments to the tax rates; two of the methods use variables that can be solved for optimum values in the model according to the choice of closure rule and two methods allow for deterministic adjustments to the structure of the tax rates. The operation of this method is discussed in detail only for the equations for import duties while the other equations are simply reported.

Import duty tax rates are defined by (GT1), where tmb_c is the vector of import duties in the base solution, $dabtm_c$ is a vector of absolute changes in the vector of import duties, *TMADJ* is a variable whose initial value is ONE, *DTM* is a variable whose initial value is ZERO and $tm01_c$ is a vector of zeros and non zeros. In the base solution the values of $tm01_c$ and $dabtm_c$ are all ZERO and *TMADJ* and *DTM* are fixed as their initial values – a closure rule decision – then the applied import duties are those from the base solution. Now the different methods of adjustment can be considered in turn:

2. If *TMADJ* is made a variable, which requires the fixing of another variable, and all other initial conditions hold then the solution value for *TMADJ* yields the optimum equiproportionate change in the import duty rates necessary to satisfy model constraints, e.g., if *TMADJ* equals 1.1 then all import duties are increased by 10%.
3. If any element of *dabtm* is non zero and all the other initial conditions hold, then an absolute change in the initial import duty for the relevant commodity can be imposed using *dabtm*, e.g., if *tmb* for one element of *c* is 0.1 (a 10% import duty) and *dabtm* for that element is 0.05, then the applied import duty is 0.15 (15%).
4. If *TMADJ* is a variable, any elements of *dabtm* are non zero and all other initial conditions hold then the solution value for *TMADJ* yields the optimum equiproportionate change in the applied import duty rates.
5. If *DTM* is made a variable, which requires the fixing of another variable, AND at least one element of *tm*01 is equal to ONE then the subset of elements of *c* identified by *tm*01 are allowed to (additively) increase by an equiproportionate amount determined by the solution value for *DTM*. Note how it is necessary to both ‘free’ a variable and give values to a parameter for a solution to emerge.
6. If *DTM* is made a variable AND at least one element of *tm*01 is NOT equal to ZERO then the subset of elements of *c* identified by *tm*01 are allowed to (additively) increase by an

equiproportionate amount determined by the solution value for *DTM* times the values of *tm*01. Note how using different values of *tm*01 for different members of the set c will cause commodity specific changes in import duty rates, e.g., the values of *tm*01 for food commodities could be set to 0.5 and manufactured commodities set to 1, with the result that the additive increases in import duties for food commodities would be half those for other manufactured commodities.

This combination of alternative adjustment methods covers a range of common tax rate adjustment used in many applied applications while being flexible and easy to use.

Tax Rate Block Equations

$$TM_c = \left(\left(tmb_c + dabtm_c\right)*TMADJ\right) + \left(DTM * tm01_c\right) \quad \text{(GT1)}$$

$$TE_c = \left(\left(teb_c + dabte_c\right)*TEADJ\right) + \left(DTE * te01_c\right) \quad \text{(GT2)}$$

$$TS_c = \left(\left(tsb_c + dabts_c\right)*TSADJ\right) + \left(DTS * ts01_c\right) \qquad \forall cd_c \textbf{ OR } cm_c \quad \text{(GT3)}$$

$$TEX_c = \left(\left(texb_c + dabtex_c\right)*TEXADJ\right) + \left(DTEX * tex01_c\right) \qquad \forall cd_c \textbf{ OR } cm_c \quad \text{(GT4)}$$

$$TX_a = \left(\left(txb_a + dabtx_a\right)*TXADJ\right) + \left(DTX * tx01_a\right) \quad \text{(GT5)}$$

$$TF_{ff,a} = \left(\left(tfb_{ff,a} + dabtf_{ff,a}\right)*TFADJ\right) + \left(DTF * tf01_{ff,a}\right) \quad \text{(GT6)}$$

$$TYF_f = \left(\left(tyfb_f + dabtyf_f\right)*TYFADJ\right) + \left(DTYF * tyf01_f\right) \quad \text{(GT7)}$$

$$TYH_h = \left(\left(tyhb_h + dabtyh_h\right)*TYHADJ\right) + \left(DTYH * DTY * tyh01_h\right) \quad \text{(GT8)}$$

$$TYE_e = \left(\left(tyeb_e + dabtye_e\right)*TYEADJ\right) + \left(DTYE * DTY * tye01_e\right). \quad \text{(GT9)}$$

$$TWAT_c = ((twatb_c + dabtwat_c)*TWATADJ) + (DTWAT * twat01_c) \quad \text{(GT10)}$$

$$TWATA_{c,a} = ((twatab_{c,a} + dabtwata_{c,a})*TWATAADJ) + (DTWATA * twata01_{c,a}) \quad \text{(GT11)}$$

Export tax rates are defined by (GT2), where teb_c is the vector of export duties in the base solution, $dabte_c$ is a vector of absolute changes in the vector of export duties, *TEADJ* is a variable whose initial value is ONE, *DTE* is a variable whose initial value is ZERO and $te01_c$ is a vector of zeros and non zeros. Sales tax rates are defined by (GT3), where tsb_c is the vector of sales tax rates in the base solution, $dabts_c$ is a vector of absolute changes in the vector of sales taxes, *TSADJ* is a variable whose initial value is ONE, *DTS* is a variable whose initial value is ZERO and $ts01_c$ is a vector of zeros and non zeros. Excise tax rates are defined by (GT4), where $texb_c$ is the vector of excise tax rates in the base solution, $dabtex_c$ is a vector of absolute changes in the vector of import duties, *TEXADJ* is a variable whose initial value is ONE, *DTEX* is a variable whose initial value is ZERO and $tex01_c$ is a vector of zeros and non zeros.

Indirect tax rates on production are defined by (GT5), where txb_c is the vector of production taxes in the base solution, $dabtx_c$ is a vector of absolute changes in the vector of production taxes, *TXADJ* is a variable whose initial value is ONE, *DTX* is a variable whose initial value is ZERO and $tx01_c$ is a vector of zeros and non zeros.

Taxes on factor use by each factor and activity are defined by (GT6), where $tfb_{ff,a}$ is the matrix of factor use tax rates in the base solution, $dabtf_{ff,a}$ is a matrix of absolute changes in the matrix of factor use taxes, *TFADJ* is a variable whose initial value is ONE, *DTF* is a variable whose initial value is ZERO and $tf01_{ff,a}$ is a matrix of zeros and non zeros. An important feature of taxes on factor use is they enter into the first order conditions of the production functions that determine factor input choices by activities.

Factor income tax rates[39] are defined by (GT7), where $tyfb_f$ is the vector of factor income taxes in the base solution, $dabtyy_f$ is a vector of absolute changes in the vector of factor income taxes, *TYFADJ* is a variable whose initial value is ONE, *DTYF* is a variable whose initial value is ZERO and $tyf01_f$ is a vector of zeros and non zeros. Household income tax rates are defined by (GT8), where $tyhb_h$ is the vector of household income tax rates in the base solution, $dabtyh_h$ is a vector of absolute changes in the vector of income tax rates, *TYFADJ* is a variable whose initial value is ONE, *DTYH* and *DTY* [40]are variables whose initial values are ZERO and $tyh01_c$ is a vector of zeros and non zeros. Enterprise income tax rates are defined by (GT9), where $tyeb_e$ is the vector of enterprise income tax rates in the base solution, $dabtye_e$ is a vector of absolute changes in the income tax rates, *TYEADJ* is a variable whose initial value is ONE, *DTYE* and *DTY* are variables whose initial values are ZERO and $tye01_e$ is a vector of zeros and non zeros.

Finally two water specific tax instruments are added to the model, to allow for different pricing policy scenarios (GT10 and GT11). TWAT is a water commodity tax set up accordingly to the sales tax (GT3) and allows to drive a margin between production costs and consumer price of water commodities. Thereby $twatb_c$ is the vector of water commodity tax rates in the base solution, $dabtwat_c$ is a vector of absolute changes in the water commodity tax rates, *TWATADJ* is a variable whose initial value is ONE, *DTWAT* is a variable whose initial value is ZERO and $twat01_c$ is a vector of zeros and non zeros. *TWATA* is a water user specific tax rate, allowing to charge differentiated prices from different water users. Thereby $twatab_{c,a}$ is the matrix of water use tax rates in the base solution, $dabtwata_{c,a}$ is a matrix of absolute changes in the matrix of water use taxes, *TWATAADJ* is a variable

[39] These are defined as taxes on factor incomes that are independent of the activity that employs the factor. They could include social security type payments.
[40] DTY is also included in GT9 and thereby allows for simultaneous changes in the income tax rate of households and enterprises.

whose initial value is ONE, *DTWATA* is a variable whose initial value is ZERO and $tf01_{ff,a}$ is a matrix of zeros and non zeros. Similar to facter use taxes, water user taxes enter into the first order conditions of the production functions and by this determine factor input choices by activities.

A.1.3.11.2 Tax Revenues

Although it is not necessary to keep the tax revenue equations separate from other equations, e.g., they can be embedded into the equation for government income (*YG*), it does aid clarity and assist with implementing fiscal policy simulations, e.g., when seeking to fix total revenues from a tax instrument. For this model there are ten tax revenue equations. The patterns of tax rates are controlled by the tax rate variable equations. In all cases the tax rates can be negative indicating a ‘transfer’ from the government.

There are six tax instruments that are dependent upon expenditure on commodities, with each expressed as an *ad valorem* tax rate. Tariff revenue (*MTAX*) is defined (GR1) as the sum of the product of tariff rates (*TM*) and the value of expenditure on imports at world prices, the revenue from export duties (*ETAX*) is defined (GR2) as the sum of the product of export duty rates (*TE*) and the value of expenditure on exports at world prices. The sale tax revenues (*STAX*) are defined (GR3) as the sum of the product of sales tax rates (*TS*) and the value of domestic expenditure on commodities, and excise tax revenues (*EXTAX*) are defined (GR4) as the sum of the product of excise tax rates (*TEX*) and the value of domestic expenditure on commodities.

Government Tax Revenue Block Equations

$$MTAX = \sum_c \left(TM_c * PWM_c * ER * QM_c \right) \tag{GR1}$$

$$ETAX = \sum_c \left(TE_c * PWE_c * ER * QE_c \right) \tag{GR2}$$

$$\begin{aligned} STAX &= \sum_c \begin{pmatrix} TS_c * PQS_c * \\ \left(QINTD_c + QCD_c + QENTD_c + QGD_c + QINVD_c + dstocconst_c \right) \end{pmatrix} \\ &= \sum_c \left(TS_c * PQS_c * QQ_c \right) \end{aligned} \tag{GR3}$$

$$EXTAX = \sum_c \left(TEX_c * PQS_c * QQ_c \right) \tag{GR4}$$

$$ITAX = \sum_a \left(TX_a * PX_a * QX_a \right) \tag{GR5}$$

$$FTAX = \sum_{f,a} \left(TF_{f,a} * WF_f * WFDIST_{f,a} * FD_{f,a} \right) \tag{GR6}$$

$$FYTAX = \sum_f \left(TYF_f * \left(YF_f * \left(1 - deprec_f \right) \right) \right) \tag{GR7}$$

$$DTAX = \sum_h \left(TYH_h * YH_h \right) + \sum_e \left(TYE_e * YE_e \right) \quad \text{(GR8)}$$

$$WATTAX = \sum_c (TWAT_c * PQS_c * QQ_c) \quad \text{(GR9)}$$

$$WATATAX = \sum_{c,a} (TWATA_{c,a} * PQD_c * PQDDIST_{c,a} * QWAT2_{c,a}) \quad \text{(GR10)}$$

There is a single tax on production (*ITAX*). As with other taxes this is defined (GR5) as the sum of the product of indirect tax rates (*TX*) and the value of output by each activity evaluated in terms of the activity prices (*PX*). In addition activities can pay taxes based on the value of employed factors – factor use taxes (*FTAX*). The revenue from these taxes is defined (GR6) as the sum of the product of factor income tax rates and the value of the factor services employed by each activity for each factor; the sum is over both activities and factors. These two taxes are the instruments most likely to yield negative revenues through the existence of production and/or factor use subsidies.

Income taxes are collected on both factors and domestic institutions. The income tax on factors (*FYTAX*) is defined (GR7) as the product of factor tax rates (*TYF*) and factor incomes for all factors, while those on institutions (*DTAX*) are defined (GR8) as the sum of the product of household income tax rates (*TYH*) and household incomes plus the product of the direct tax rate for enterprises (*TYE*) and enterprise income.

Revenue from water commodity taxes (*WATTAX*) is defined (GR9) as the sum of the product of water commodity tax rates (*TWAT*) and the value of domestic expenditure on water commodities. The revenue from the water user tax (*WATATAX*) is negative in most cases, as usually user groups are charged reduced water prices. It is defined (GR10) as the sum of the product of water user tax rates and the value of water commodities employed by each activity; the sum is over both activities and commodities.

A.1.3.11.3 Government Income

The sources of income to the government account (G1) are more complex than for other institutions. Income accrues from ten tax instruments; tariff revenues (*MTAX*), export duties (*ETAX*), sales taxes (*STAX*), excise taxes (*EXTAX*), production taxes (*ITAX*), factor use taxes (*FTAX*), factor income taxes (*FYTAX*) direct income taxes (*DTAX*), water commodity tax (*WATTAX*), and water user tax (*WATATAX*), which are defined in the tax equation block above. In addition the government can receive income as a share (*govvash*) of distributed factor incomes, distributed payments/dividends from incorporated enterprises (*GOVENT*) and transfers from abroad (*govwor*) converted in to domestic currency units. It would be relatively easy to subsume the tax revenue equations into the equation for government income, but they are kept separate to facilitate the implementation of fiscal policy experiments. Ultimately however the choice is a matter of personal preference.

A.1.3.11.4 Government Expenditure

The demand for commodities by the government for consumption (*QGD*) is defined (G2) in terms of fixed proportions (*qgdconst*) that can be varied with a scaling adjuster (*QGDADJ*), and associated with any given volume of government final demand there is a level of expenditure defined by (G3); this creates an option for the macroeconomic closure conditions that distribute absorption across domestic institutions (see below).

Hence, total government expenditure (*EG*) can be defined (G4) as equal to the sum of expenditure by government on consumption demand at current prices, plus real transfers to households ($hogovconst_h$) that can be adjusted using a scaling factor (*HGADJ*) and real transfers to enterprises ($entgovconst_e$) that can also be adjusted by a scaling factor (*EGADJ*)

As with enterprises there are difficulties inherent to defining utility functions for a government.[41] Changing *QGDADJ*, either exogenously or endogenously, by allowing it to be a variable in the closure conditions, provides a means of changing the behavioural assumption with respect to the 'volume' of commodity demand by the government. If the value of government final demand (*VGD*) is fixed then government expenditure is fixed and hence the volume of consumption by government (*QGD*) must be allowed to vary, via the *QGDADJ* variable. If it is deemed appropriate to modify the patterns of commodity demand by the government then the components of $qgdconst_c$ must be changed.

Government Income and Expenditure Block Equations

$$YG = MTAX + ETAX + STAX + EXTAX + FTAX + ITAX + FYTAX + DTAX + WATTAX + WATATAX + \left(\sum_f govvash_f * YFDISP_f\right) + GOVENT + \left(govwor * ER\right) \quad \text{(G1)}$$

$$QGD_c = qgdconst_c * QGDADJ \quad \text{(G2)}$$

$$VGD = \left(\sum_c QGD_c * PQD_c\right) \quad \text{(G3)}$$

$$EG = \left(\sum_c QGD_c * PQD_c\right) + \left(\sum_h hogovconst_h * HGADJ * CPI\right) + \left(\sum_e entgovconst_e * EGADJ * CPI\right) \quad \text{(G4)}$$

[41] Some models use some form of utility function for non-household domestic institutions. If a Cobb-Douglas function is used then value shares of demand by institution are held constant, other choices typical alter value and quantity shares.

A.1.3.12 Kapital Block

A.1.3.12.1 Savings Block

The savings rates for households (*SHH* in I1) and enterprises (*SEN* in I2) are defined as variables using the same adjustment mechanisms used for tax rates; $shhb_h$ and $senb_e$ are the savings rates in the base solution, $dabshh_h$ and $dabsen_e$ are absolute changes in the base rates, *SHADJ* and *SEADJ* are multiplicative adjustment factors, *DSHH* and *DSEN* are additive adjustment factors and $shh01_h$ and $sen01_e$ are vectors of zeros and non zeros that scale the additive adjustment factors. However, each of the savings rates equations has two additional adjustment factors – SADJ and DS. These allow the user to vary the savings rates for households and enterprises in tandem; this is useful when the macroeconomic closure conditions require increases in savings by domestic institutions and it is not deemed appropriate to force all the adjustment on a single group of institutions.

Kapital Block Equations

$$SHH_h = \left(\left(shhb_h + dabshh_h\right) * SHADJ * SADJ\right) + \left(DSHH * DS * shh01_h\right) \tag{I1}$$

$$SEN_e = \left(\left(sen_e + dabsen_e\right) * SEADJ * SADJ\right) + \left(DSEN * DS * sen01_e\right) \tag{I2}$$

$$\begin{aligned} TOTSAV = &\sum_h \left(\left(YH_h * \left(1 - TYH_h\right)\right) * SHH_h\right) \\ &+ \sum_e \left(\left(YE * \left(1 - TYE_e\right)\right) * SEN_e\right) \\ &+ \sum_f \left(YF_f * deprec_f\right) + KAPGOV + \left(CAPWOR * ER\right) \end{aligned} \tag{I3}$$

$$QINVD_c = IADJ * qinvdconst_c \tag{I4}$$

$$INVEST = \sum_c \left(PQD_c * \left(QINVD_c + dstocconst_c\right)\right) \tag{I5}$$

Total savings in the economy are defined (I3) as shares (*SHH*) of households' after tax income, where direct taxes (*TYH*) have first call on household income, plus the allowances for depreciation at fixed rates (*deprec*) out of factor income, the savings by enterprises at fixed rates (*SEN*) out of after tax income, the government budget deficit/surplus (*KAPGOV*) and the current account deficit/surplus (*CAPWOR*). The last two terms of I3 – *KAPGOV* and *CAPWOR* - are defined below by equations in the market clearing block.

A.1.3.12.2 Investment Block

The same structure of relationships as for enterprises and government is adopted for investment demand (I4). The volumes of commodities purchased for investment are determined by the volumes in the base period (*qinvdconst*) and can be varied using the adjuster (*IADJ*).[42] Then value of investment expenditure (*INVEST*) is equal (I5) to the sum of investment demand valued at current prices plus the current priced value of stock changes (*dstocconst*) that are defined as being fixed, usually in volume terms at the levels in the base period. If *IADJ* is made variable then the volumes of investment demand by commodity will adjust equiproportionately, in the ratios set by *qinvdconst*, such as to satisfy the closure rule defined for the capital account. Changes to the patterns of investment demand require changes in the ratios of investment demand set by *qinvdconst*.

A.1.3.13 Foreign Institutions Block

The economy also employs foreign owned factors whose services must be recompensed. It is assumed that these services receive fixed proportions of the factor incomes available for distribution, (W1).

Foreign Institutions Block Equations

$$YFWOR_f = worvash_f * YFDISP_f \qquad \text{(W1)}$$

A.1.3.14 Market Clearing Block

The market clearing equations ensure the simultaneous clearing of all markets. In this model there are six relevant markets: factor and commodity markets and enterprise, government, capital and rest of world accounts. Market clearing with respect to activities has effectively been achieved by (X20), wherein the supply and demand equality for domestically produced commodities was enforced, while the demand system and the specification of expenditure relationships ensures that the household markets are cleared.

The description immediately below refers to the default set of closure rules/market clearing conditions imposed for this model; a subsequent section explores alternative closure rule configurations available with this model.

A.1.3.15 Account Closures

Adopting an initial assumption of full employment, which the model closure rules will demonstrate can be easily relaxed, amounts to requiring that the factor market is cleared by equating factor supplies (*FS*) for all factors with factor demands (*FD*) (C1).

Market clearing for the composite commodity markets requires that the supplies of the composite commodity (*QQ*) are equal to total of domestic demands for composite commodities, which consists of intermediate demand (*QINTD*), household (*QCD*), enterprise (*QED*) and government (*QGD*) and

[42] Some models use some form of utility function for non-household domestic institutions. If a Cobb-Douglas function is used then value shares of demand by institution are held constant, other choices typical alter value and quantity shares.

investment (*QINVD*) final demands and stock changes ($dstocconst_c$) (C2). Since the markets for domestically produced commodities are also cleared (X20) this ensures a full clearing of all commodity markets.

Making savings a residual for each account clears the two institutional accounts that are not cleared elsewhere – government and rest of the world. Thus the government account clears (C3) by defining government savings (*KAPGOV*) as the difference between government income and other expenditures, i.e., a residual. The rest of world account clears (C4) by defining the balance on the capital account (*CAPWOR*) as the difference between expenditure on imports, of commodities and factor services, and total income from the rest of the world, which includes export revenues and payments for factor services, transfers from the rest of the world to the household, enterprise and government accounts, i.e., it is a residual.

Account Closure Block Equations

$$FS_f = \sum_a FD_{f,a} \tag{C1}$$

$$QQ_c = QINTD_c + \sum_h QCD_{c,h} + \sum_e QED_{c,e} + QGD_c + QINVD_c + dstocconst_c \tag{C2}$$

$$KAPGOV = YG - EG \tag{C3}$$

$$\begin{aligned} CAPWOR = {} & \left(\sum_{cm} PWM_{cm} * QM_{cm}\right) + \left(\sum_f \frac{YFWOR_f}{ER}\right) \\ & - \left(\sum_{ce} PWE_{ce} * QE_{ce}\right) - \left(\sum_f factwor_f\right) \\ & - \left(\sum_h howor_h\right) - \left(\sum_e entwor_e\right) - govwor \end{aligned} \tag{C4}$$

A.1.3.15.1 Absorption Closure

The total value of domestic final demand (absorption) (*VFDOMD*) is defined (C5) as the sum of the expenditures on final demands by households and other domestic institutions (enterprises, government and investment).

It is also useful to express the values of final demand by each non-household domestic institution as a proportion of the total value of domestic final demand; this allows the implementation of what has been called a 'balanced macroeconomic closure'[43]. Hence the share of the value of final demand by

[43] The adoption of such a closure rule for this class of model has been advocated by Sherman Robinson and is a feature, albeit implemented slightly differently, of the IFPRI standard model.

enterprises (C6) can be defined as a proportion of total final domestic demand, and similarly for government's value share of final demand (C7) and for investment's value share of final demand (C8).

Absorption Closure Block Equations

$$VFDOMD = \sum_{c} PQD_{c} * \left(\sum_{h} QCD_{c,h} + \sum_{e} QED_{c,e} + QGD_{c} + QINVD_{c} + dstocconst_{c} \right) \quad \text{(C5)}$$

$$VEDSH_{e} = {VED_{e}} / {VFDOMD} \quad \text{(C6)}$$

$$VGDSH = {VGD} / {VFDOMD} \quad \text{(C7)}$$

$$INVESTSH = {INVEST} / {VFDOMD} \quad \text{(C8)}$$

If the share variables (*VEDSH*, *VGDSH* and *INVESTSH*) are fixed then the quantity adjustment variables on the associated volumes of final demand by domestic non-household institutions (*QEDADJ*, *QGDADJ* and *IADJ* or *S*ADJ*) must be free to vary. On the other hand if the volume adjusters are fixed the associated share variables must be free so as to allow the value of final demand by 'each' institution to vary.

A.1.3.15.2 Slack

The final account to be cleared is the capital account. Total savings (*TOTSAV*), see I3 above, is defined within the model and hence there has been an implicit presumption in the description that the total value of investment (*INVEST*) is driven by the volume of savings. This is the market clearing condition imposed by (C9). But this market clearing condition includes another term, *WALRAS*, which is a slack variable that returns a zero value when the model is fully closed and all markets are cleared, and hence its inclusion provides a quick check on model specification.

SLACK Block Equation

$$TOTSAV = INVEST + WALRAS \quad \text{(C9)}$$

A.1.3.16 Model Closure Conditions or Rules

In mathematical programming terms the model closure conditions are, at their simplest, a matter of ensuring that the numbers of equations and variables are consistent. However economic theoretic dimensions of model closure rules are more complex, and, as would be expected in the context of an economic model, more important. The essence of model closure rules is that they define important and fundamental differences in perceptions of how an economic system operates (see Sen, 1963; Pyatt, 1987; Kilkenny and Robinson, 1990). The closure rules can be perceived as operating on two levels; on a general level whereby the closure rules relate to macroeconomic considerations, e.g., is investment expenditure determined by the volume of savings or exogenously, and on a specific level where the closure rules are used to capture particular features of an economic system, e.g., the degree of intersectoral capital mobility.

This model allows for a range of both general and specific closure rules. The discussion below provides details of the main options available with this formulation of the model by reference to the accounts to which the rules refer.

A.1.3.16.1 Foreign Exchange Account Closure

The closure of the rest of the world account can be achieved by fixing either the exchange rate variable (AC1a) or the balance on the current account (AC1b). Fixing the exchange rate is appropriate for countries with a fixed exchange rate regime whilst fixing the current account balance is appropriate for countries that face restrictions on the value of the current account balance, e.g., countries following structural adjustment programmes. It is a common practice to fix a variable at its initial level by using the associated parameter, i.e., ***0, but it is possible to fix the variable to any appropriate value.

The model is formulated with the world prices for traded commodities declared as variables, i.e., PWM_c and PWE_c. If a strong small country assumption is adopted, i.e., the country is assumed to be a price taker on all world commodity markets, then all world prices will be fixed. When calibrating the model the world prices will be fixed at their initial levels, (AC1c), but this does not mean they cannot be changed as parts of experiments.

Foreign Exchange Market Closure Equations

$$ER = \overline{ER} \tag{AC1a}$$

$$CAPWOR = \overline{CAPWOR} \tag{AC1b}$$

$$PWE_c = \overline{PWE_c}$$
$$PWM_c = \overline{PWM_c} \tag{AC1c}$$

$$PWE_{cedn} = \overline{PWE_{cedn}} \tag{AC1d}$$

However, the model allows for a relaxation of the strong small country assumption, such that the country may face a downward sloping demand curve for one or more of its export commodities. Hence the world prices of some commodities are determined by the interaction of demand and supply on the world market, i.e., they are variables. This is achieved by limiting the range of world export prices that are fixed to those for which there are no export demand function, (AC1d), by selecting membership of the set *cedn*.[44]

A.1.3.16.2 Capital Account Closure

To ensure that aggregate savings equal aggregate investment, the determinants of either savings or investment must be fixed. There are multiple ways of achieving this result. For instance this can be achieved by fixing either the saving rates for households or the volumes of commodity investment. This involves fixing either the savings rates adjusters (AC2a) or the investment volume adjuster (AC2c). Note that fixing the investment volume adjuster (AC2c) means that the value of investment expenditure might change due to changes in the prices of investment commodities (*PQD*). Note also that only one of the savings rate adjusters should be fixed; if *SADJ* is fixed the adjustment takes place through equiproportionate changes in the savings rates of households and enterprises, if *SHADJ* is fixed the adjustment takes place through equiproportionate changes in the savings rates of households, and if *SEADJ* is fixed the adjustment takes place through equiproportionate changes in the savings rates of enterprises. Alternatively savings rates can be adjusted through the additive adjustment factors (*DS*, *DSHH*, *DSEN*) with the same relationships between the savings rates of different classes of institutions (AC2b). Note that there are other sources of savings. The magnitudes of these other savings sources can also be changed through the closure rules (see below).

[44] Practically membership of *cedn* is set by assigning a non zero value to the export demand elasticity in the model database. The set *ced* is then defined as a complement.

Fixing savings, and thus deeming the economy to be savings-driven, could be considered a Neo-Classical approach. Closing the economy by fixing investment could be construed as making the model reflect the Keynesian investment-driven assumption for the operation of an economy.

The model includes a variable for the value of investment (*INVEST*), which can also be used to close the capital account (AC2d). If *INVEST* is fixed in an investment driven closure, then the model will need to adjust the savings rates to maintain equilibrium between the value of savings (*TOTSAV*) and the fixed value of investment. This can only be achieved by changes in the volumes of commodities demanded for investment (*QINVD*) or their prices (*PQD*). But the prices (*PQD*) depend on much more than investment, hence the main adjustment must take place through the volumes of commodities demanded, i.e., *QINVD*, and therefore the volume adjuster (*IADJ*) must be variable, as must a savings rate adjuster (*SADJ*).

Capital Account Closure Equations

$$SADJ = \overline{SADJ}$$
$$SHADJ = \overline{SHADJ}$$
$$SEADJ = \overline{SEADJ} \qquad \text{(AC2a)}$$

$$DS = \overline{DS}$$
$$DSHH = \overline{DSHH}$$
$$DSEN = \overline{DSEN} \qquad \text{(AC2b)}$$

$$IADJ = \overline{IADJ} \qquad \text{(AC2c)}$$

$$INVEST = \overline{INVEST} \qquad \text{(AC2d)}$$

$$INVESTSH = \overline{INVESTSH} \qquad \text{(AC2e)}$$

Alternatively the share of investment expenditure in the total value of domestic final demand can be fixed, (AC2e), which means that the total value of investment is fixed by reference to the value of total final demand, which requires that the investment volumes must be free to vary, i.e., IADJ must be made variable. Otherwise the adjustment mechanisms follow the same processes as for fixing *INVEST* equal to some level.

A.1.3.16.3 Enterprise Account Closure

Fixing the volumes of commodities demand by enterprises, (AC3a), closes the enterprise account. Note that this rule allows the value of commodity expenditures by the enterprise account to vary, which *ceteris paribus* means that the value of savings by enterprises (*CAPENT*) and thus total savings

(*TOTSAV*) vary. If the value of this adjuster is changed, but left fixed, this imposes equiproportionate changes on the volumes of commodities demanded.

If *QEDADJ* is allowed to vary then another variable must be fixed; the most likely alternative is the value of consumption expenditures by enterprises (*VED*) (AC3b). This would impose adjustments through equiproportionate changes in the volumes of commodities demanded, and would feed through so that enterprise savings (*CAPENT*) reflecting directly the changes in the income of enterprises (*YE*). Alternatively the share of enterprise expenditure in the total value of domestic final demand can be fixed, (AC3c), which means that the total value of enterprise consumption expenditure (*VED*) is fixed by reference to the value of total final demand, but otherwise the adjustment mechanisms follow the same processes as for fixing *VED* equal to some level.

Enterprise Account Closure Equations

$$QEDADJ = \overline{QEDADJ} \quad \text{(AC3a)}$$

$$VED = \overline{VED} \quad \text{(AC3b)}$$

$$VEDSH = \overline{VEDSH} \quad \text{(AC3c)}$$

$$HEADJ = \overline{HEADJ} \quad \text{(AC3d)}$$

Finally the scaling factor for enterprise transfers to households (*HEADJ*) needs fixing (AC3d).

A.1.3.16.4 Government Account Closure

The closure rules for the government account are slightly more tricky because they are important components of the model that are used to investigate fiscal policy considerations. The base specification uses the assumption that government savings are a residual; when the determinants of government income and expenditure are ‘fixed’, government savings must be free to adjust.

Thus in the base specification all the tax rates (variables) are fixed by declaring the base tax rates as parameters and then fixing all the multiplicative and additive tax rate scaling factors (AC4a – AC4u).

Consequently changes in tax revenue to the government are consequences of changes in the other variables that enter into the tax income equations (GR1 to GR10). The two other sources of income to the government are controlled by parameters, *govvash* and *govwor*, and therefore are not a source of concern for model closure.[45]

[45] The values of income from non-tax sources can of course vary because each component involves a variable.

Tax Rate Adjustment Closure Equations

$$TMADJ = \overline{TMADJ} \tag{AC4a}$$

$$TEADJ = \overline{TEADJ} \tag{AC4b}$$

$$TSADJ = \overline{TSADJ} \tag{AC4c}$$

$$TEXADJ = \overline{TEXADJ} \tag{AC4d}$$

$$TXADJ = \overline{TXADJ} \tag{AC4e}$$

$$TFADJ = \overline{TFADJ} \tag{AC4f}$$

$$TYADJ = \overline{TYADJ} \tag{AC4g}$$

$$TYEADJ = \overline{TYEADJ} \tag{AC4h}$$

$$TYHADJ = \overline{TYHADJ} \tag{AC4i}$$

$$TWATADJ = \overline{TWATADJ} \tag{AC4j}$$

$$TWATAADJ = \overline{TWATAADJ} \tag{AC4k}$$

$$DTM = \overline{DTM} \tag{AC4l}$$

$$DTE = \overline{DTE} \tag{AC4m}$$

$$DTS = \overline{DTS} \tag{AC4n}$$

$$DTEX = \overline{DTEX} \tag{AC4o}$$

$$DTX = \overline{DTX} \tag{AC4p}$$

$$DTF = \overline{DTF} \tag{AC4q}$$

$$DTY = \overline{DTY} \tag{AC4r}$$

$$DTYF = \overline{DTYF} \tag{AC4s}$$

$$DTYH = \overline{DTYH} \tag{AC4t}$$

$$DTYE = \overline{DTYE} \tag{AC4u}$$

$$DTWAT = \overline{DTWAT} \qquad \text{(AC4v)}$$

$$DTWATA = \overline{DTWATA} \qquad \text{(AC4w)}$$

Also note that because there are equations for the revenues by each tax instrument (GR1 to GR10) it is straightforward to adjust the tax rates to achieve a given volume of revenue from each tax instrument; this type of arrangement is potentially useful in circumstances where it is argued/believed that there are binding constraints upon the revenue possibilities from specific tax instruments.

In the base specification government expenditure is controlled by fixing the volumes of commodity demand (*QGD*) through the government demand adjuster (*QGDADJ*) in (AC4x). Alternatively either the value of government consumption expenditure (*VGD*) can be fixed, (AC4y), or the share of government expenditure in the total value of domestic final demand (*VGDSH*) can be fixed, (AC4z). The scaling factor on the values of transfers to households and enterprises through the household (*HGADJ*) and enterprise (*EGADJ*) adjusters, (AC4aa and AC4ab) also need to be fixed.

Government Expenditure Closure Equations

$$QGDADJ = \overline{QGDADJ} \qquad \text{(AC4x)}$$

$$VGD = \overline{VGD} \qquad \text{(AC4y)}$$

$$VGDSH = \overline{VGDSH} \qquad \text{(AC4z)}$$

$$HGADJ = \overline{HGADJ} \qquad \text{(AC4aa)}$$

$$EGADJ = \overline{EGADJ} \qquad \text{(AC4ab)}$$

$$KAPGOV = \overline{KAPGOV} \qquad \text{(AC4ac)}$$

This specification ensures that all the parameters that the government can/does control are fixed and consequently that the only determinants of government income and expenditure that are free to vary are those that the government does not <u>directly</u> control. Hence the equilibrating condition is that government savings, the internal balance, is not fixed.

If however the model requires government savings to be fixed (AC4ac), then either government income or expenditure must be free to adjust. Such a condition might reasonably be expected in many circumstances, e.g., the government might define an acceptable level of borrowing or such a condition might be imposed externally. In its simplest form this can be achieved by allowing one of the previously fixed adjusters (AC4a to AC4ab) to vary. Thus if the sales tax adjuster (*TSADJ*) is made variable then the sales tax rates will be varied equiproportionately so as to satisfy the internal balance condition. More complex experiments might result from the imposition of multiple conditions, e.g., a halving of import duty rates coupled with a reduction in government deficit, in which case the variables *TMADJ* and *KAPGOV* would also require resetting. But these conditions might create a model that is infeasible, e.g., due to insufficient flexibility through the sales tax mechanism, or unrealistically high rates of sales taxes. In such circumstances it may be necessary to allow adjustments in multiple tax adjusters. One method then would be to fix the tax adjusters to move in parallel with each other.

However, if the adjustments only take place through the tax rate scaling factors the relative tax rates will be fixed. To change relative tax rates it is necessary to change the relevant tax parameters. Typically such changes would be implemented in policy experiment files rather than within the closure section of the model.

A.1.3.16.5 Numéraire

The model specification allows for a choice of two price normalisation equations (AC5a and AC5b), the consumer price index (CPI) and a producer price index (PPI). A *numéraire* is needed to serve as a base since the model is homogenous of degree zero in prices and hence only defines relative prices.

Numéraire Closure Equations

$$CPI = \overline{CPI} \tag{AC5a}$$

$$PPI = \overline{PPI} \tag{AC5b}$$

A.1.3.16.6 Factor Market Closure

The factor market closure rules are more difficult to implement than many of the other closure rules. Hence the discussion below proceeds in three stages; the first stage sets up a basic specification whereby all factors are deemed perfectly mobile, the second stage introduces a more general specification whereby factors can be made activity specific and allowance can be made for unemployed factors, while the third stage introduces the idea that factor market restrictions may arise from activity specific characteristics, rather than the factor inspired restrictions considered in the second stage.

A.1.3.16.7 Full Factor Mobility and Employment Closure

This factor market closure requires that the total supply (*FS*) of and total demand for factors (*FD*) equate (AC6a). The total supplies of each factor are determined exogenously and hence define the first set of factor market closure conditions. The demands for factor *f* by activity *a* and the wage rates for factors are determined endogenously. But the model specification includes the assumption that the wage rates for factors are averages, by allowing for the possibility that the payments to notionally identical factors might vary across activities through the variable that captures the 'sectoral proportions for factor prices'. These proportions are assumed to be a consequence of the use made by activities of factors, rather than of the factors themselves, and are therefore assumed fixed, (AC6b). The same holds true for the 'sectoral proportions for water commodity prices' (AC6c). Finally while it may seem that factor prices must be limited to positive values the actual bounds placed upon the average factor prices, (AC6d) are plus or minus infinity. This is a consequence of the use of the PATH solver.

Basic Factor Market and Water Commodity Price Closure Equations

$$FS_f = \overline{FS}_f \quad \text{(AC6a)}$$

$$WFDIST_{f,a} = \overline{WFDIST_{f,a}} \quad \text{(AC6b)}$$

$$PQDDIST_{c,a} = \overline{PQDDIST_{c,a}} \quad \text{(AC6c)}$$

$$\begin{aligned} &\text{Min } WF_f = -\text{infinity} \\ &\text{Max } WF_f = +\text{infinity} \end{aligned} \quad \text{(AC6d)}$$

A.1.3.16.8 Factor Immobility and/or Unemployment Closures

More general factor market closures wherein factor immobility and/or factor unemployment are assumed can be achieved by determining which of the variables referring to factors are treated as variables and which of the variables are treated as parameters. If factor market closure rules are changed it is important to be careful to preserve the equation and variable counts when relaxing conditions, i.e., converting parameters into variables, and imposing conditions, i.e., converting variables into parameters, while preserving the economic logic of the model.

A convenient way to proceed is to define a block of conditions for each factor. For this model this amounts to defining the following possible equations (AC6e) where *fact* indicates the specific factor and *activ* a specific activity. This block of equations includes all the variables that were declared for the model with reference to factors plus an extra equation for *WFDIST*, i.e., $WFDIST_{fact,activ} = \overline{WFDIST_{fact,activ}}$, whose role will be defined below. The choice of which equations are binding and which are not imposed will determine the factor market closure conditions.

Factor Block Equations

$$FS_{fact} = \overline{FS_{fact}}$$
$$WFDIST_{fact,a} = \overline{WFDIST_{fact,a}}$$
$$\text{Min } WF_{fact} = -\text{infinity}$$
$$\text{Max } WF_{fact} = +\text{infinity}$$
$$FD_{fact,a} = \overline{FD_{fact,a}}$$
$$WF_{fact} = \overline{WF_{fact}}$$
$$WFDIST_{fact,activ} = \overline{WFDIST_{fact,activ}}$$
$$\text{Min } FS_{fact} = -\text{infinity}$$
$$\text{Max } FS_{fact} = +\text{infinity}$$

(AC6e)

As can be seen the first four equations in the block (AC6f) are the same as those in the ‘Full Factor Mobility and Employment Closure’; hence ensuring that these four equations are operating for each of the factors is a longhand method for imposing the ‘Full Factor Mobility and Employment Closure’. Assume that this set of conditions represents a starting point, i.e., the first four equations are binding and the last five equations are not imposed.

Assume now that it is planned to impose a short run closure on the model, whereby a factor is assumed to be activity specific, and hence there is no inter sectoral factor mobility. Typically this would involve making capital activity specific and immobile, although it can be applied to any factor. This requires imposing the condition that factor demands are activity specific, i.e., the condition ($FD_{fact,a} = \overline{FD_{fact,a}}$) must be imposed. But the returns to this factor in different uses (activities) must now be allowed to vary, i.e., the condition (AC6b) must now be relaxed.

Factor Market Closure Equations

$$FD_{fact,a} = \overline{FD_{fact,a}} \tag{AC6f}$$

$$WFDIST_{fact,a} = \overline{WFDIST_{fact,a}} \tag{AC6g}$$

$$FS_{fact} = \overline{FS_{fact}} \tag{AC6h}$$

$$WFDIST_{fact,activ} = \overline{WFDIST_{fact,activ}} \tag{AC6i}$$

$$WF_{fact} = \overline{WF_{fact}} \tag{AC6j}$$

$$FS_{fact} = \overline{FS_{fact}} \tag{AC6k}$$

$$\text{Min } FS_{fact} = 0$$
$$\text{Max } FS_{fact} = +\text{infinity} \tag{AC6l}$$

The number of imposed conditions is equal to the number of relaxed conditions, which suggests that the model will still be consistent. But the condition fixing the total supply of the factor is redundant since if factor demands are fixed the total factor supply cannot vary. Hence the condition (AC6a) is redundant and must be relaxed. Hence at least one other condition must be imposed to restore balance between the numbers of equations and variables. This can be achieved by fixing one of the sectoral proportions for factor prices for a specific activity, i.e., (AC6b), which means that the activity specific returns to the factor will be defined relative to the return to the factor in *activ*.[46]

Start again from the closure conditions for full factor mobility and employments and then assume that there is unemployment of one or more factors in the economy; typically this would be one type or another of unskilled labour. If the supply of the unemployed factor is perfectly elastic, then activities can employ any amount of that factor at a fixed price. This requires imposing the condition that factor prices are fixed (AC6j) and relaxing the assumption that the total supply of the factor is fixed at the base level, i.e., relaxing (AC6a). It is useful however to impose some restrictions on the total supply of the factor that is unemployed. Hence the conditions (AC6l) can be imposed.[47]

This also holds for water factors in most cases: The consumption of water factors mostly depends on the demand for water commodities. Therefore extraction rates and thus *FD* need to vary. As usually

[46] It can be important to ensure a sensible choice of reference activity. In particular this is important if a factor is not used, or little used, by the chosen activity.
[47] If the total demand for the unemployed factor increases unrealistically in the policy simulations then it is possible to place an upper bound of the supply of the factor and then allow the wage rate from that factor to vary.

one water activity is linked to one specific water factor this means also *FS* needs to be relaxed. If required an upper limit can be set by adjusting (AC6l).

On the other hand usually prices for the usage of water factors, if existent, are rather politically fixed and do not vary with extraction rates. In this case *WF* and also *WFDIST* should be fixed (AC6j and AC6i).

A.1.3.16.9 Activity Inspired Restrictions on Factor Market Closures

There are circumstances where factor use by an activity might be restricted as a consequence of activity specific characteristics. For instance it might be assumed that the volume of production by an activity might be predetermined, e.g., known mineral resources might be fixed and/or there might be an exogenously fixed restriction upon the rate of extraction of a mineral commodity. In such cases the objective might be to fix the quantities of all factors used by an activity, rather than to fix the amounts of a factor used by all activities. This is clearly a variation on the factor market closure conditions for making a factor activity specific.

Factor Market Clearing Equations

$$FD_{f,activ} = \overline{FD_{f,activ}} \qquad \text{(AC6m)}$$

$$WFDIST_{f,activ} = \overline{WFDIST_{f,activ}} \qquad \text{(AC6n)}$$

If all factors used by an activity are fixed, this requires imposing the conditions that factor demands are fixed, (AC6m), where *activ* refers to the activity of concern. But the returns to these factors in this activities must now be allowed to vary, i.e., the conditions (AC6n) must now be relaxed. In this case the condition fixing the total supply of the factor is not redundant since only the factor demands by *activ* are fixed and the factor supplies to be allocated across other activities are the total supplies unaccounted for by *activ*.

Such conditions can be imposed by extending the blocks of equations for each factor in the factor market closure section. However, it is often easier to manage the model by gathering together factor market conditions that are inspired by activity characteristics after the factor inspired equations. In this context it is useful to note that when working in GAMS that the last condition imposed, in terms of the order of the code, is binding and supersedes previous conditions.

The full set of equations included in the STAGE_W model and described in this document as well as the closure rules can be found in Appendix 2, while Appendix 3 provides a translation of the equations into GAMS-code. Appendix 4 provides an example SAM, depicting the Israeli economy in 2004.

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A.1.5 Appendices

A.1.5.1 Appendix 1: Parameter and Variable Lists

The parameter and variable listings are in alphabetic order, and are included for reference purposes. The parameters listed below are those used in the behavioural specifications/equations of the model, in addition to these parameters there are a further set of parameters. This extra set of parameters is used in model calibrated and for deriving results; there is one such parameter for each variable and they are identified by appending a '0' (zero) to the respective variable name.

Parameter List

Parameter Name	Parameter Description
ac(c)	Shift parameter for Armington CES function
actcomactsh(a,c)	Share of commodity c in output by activity a
actcomcomsh(a,c)	Share of activity a in output of commodity c
adva(a)	Shift parameter for CES production functions for QVA
adx(a)	Shift parameter for CES production functions for QX
adxc(c)	Shift parameter for commodity output CES aggregation
alphah(c,h)	Expenditure share by commodity c for household h
at(c)	Shift parameter for Armington CET function
atnw(a)	Shift parameter for CES function for land-water nest
atwat(a)	Shift parameter for CES function for water nest
beta(c,h)	Marginal budget shares
caphosh(h)	Shares of household income saved (after taxes)
comactactco(c,a)	intermediate input output coefficients
comactco(c,a)	use matrix coefficients
comentconst(c,e)	Enterprise demand volume
comgovconst(c)	Government demand volume
comhoav(c,h)	Household consumption shares
comtotsh(c)	Share of commodity c in total commodity demand
dabte(c)	Change in base export taxes on comm'y imported from region w
dabtex(c)	Change in base excise tax rate
dabtf(f)	Change in base factor use tax rate
dabtm(c)	Change in base tariff rates on comm'y imported from region w
dabts(c)	Change in base sales tax rate
dabtwat(c)	Change in base water tax rate
dabtwata(c,a)	Change in base water use tax rate
dabtx(a)	Change in base indirect tax rate
dabtye(e)	Change in base direct tax rate on enterprises
dabtyf(f)	Change in base direct tax rate on factors
dabtyh(h)	Change in base direct tax rate on households

Parameter Name	Parameter Description
delta(c)	Share parameter for Armington CES function
deltafd4(f4,a)	Share parameter for factors on 4. level
deltanw(f3,a)	Share parameter of land and water factors for land-water nest
deltanwva(a)	Share parameter for land-water composite in QVA
deltava(ff,a)	Share parameters for CES production functions for QVA
deltawat(a)	Share parameter for water commodity composite in land water nest
deltawat2(c,a)	Share parameter for single water commodities in water nest
deltax(a)	Share parameter for CES production functions for QX
deltaxc(a,c)	Share parameters for commodity output CES aggregation
deprec(f)	depreciation rate by factor f
dstocconst(c)	Stock change demand volume
econ(c)	constant for export demand equations
entgovconst(e)	Government transfers to enterprise e
entvash(e,f)	Share of income from factor f to enterprise e
entwor(e)	Transfers to enterprise e from world (constant in foreign currency)
eta(c)	export demand elasticity
factwor(f)	Factor payments from RoW (constant in foreign currency)
frisch(h)	Elasticity of the marginal utility of income
gamma(c)	Share parameter for Armington CET function
goventsh(e)	Share of entp' income after tax save and consump to govt
govvash(f)	Share of income from factor f to government
govwor	Transfers to government from world (constant in foreign currency)
hexps(h)	Subsistence consumption expenditure
hoentconst(h,e)	transfers to hhold h from enterprise e (nominal)
hoentsh(h,e)	Share of entp' income after tax save and consump to h'hold
hogovconst(h)	Transfers to hhold h from government (nominal but scalable)
hohoconst(h,hp)	interhousehold transfers
hohosh(h,hp)	Share of h'hold h after tax and saving income transferred to hp
hovash(h,f)	Share of income from factor f to household h
howor(h)	Transfers to household from world (constant in foreign currency)
invconst(c)	Investment demand volume
iocwatqnw(a)	Water commodity i-o coefficients in QNW for Level 3 Leontief agg
iocwatqva(c,a)	Water com i-o coefficients in QVA for Level 2 Leontief agg
ioffqva(ff,a)	Factor input output coefficients in QVA for Level 2 Leontief agg
iof3qnw(f3,a)	Factor input output coefficients in QNW for Level 3 Leontief agg
iof4aggf4(f4,a)	Factor input output coefficients in QWAT for Level 4 Leontief agg
ioqintqx(a)	Agg intermed quantity per unit QX for Level 1 Leontief agg
ioqvaqx(a)	Agg value added quant per unit QX for Level 1 Leontief agg
ioqwat(c,a)	Water com i-o coefficient in QWAT for Level 4 Leontief agg

Parameter Name	Parameter Description
kapentsh(e)	Average savings rate for enterprise e out of after tax income
predeltax(a)	dummy used to estimated deltax
pwse(c)	world price of export substitutes
qcdconst(c,h)	Volume of subsistence consumption
rhoc(c)	Elasticity parameter for Armington CES function
rhocva(a)	Elasticity parameter for CES production function for QVA
rhocx(a)	Elasticity parameter for CES production function for QX
rhocxc(c)	Elasticity parameter for commodity output CES aggregation
rhonw(a)	Elasticity parameter for CES prod function for land-water nest
rhot(c)	Elasticity parameter for Output Armington CET function
rhowat(a)	Elasticity parameter for CES production function for CWAT
sumelast(h)	Weighted sum of income elasticities
te01(c)	0-1 par for potential flexing of export taxes on comm'ies
tex01(c)	0-1 par for potential flexing of excise tax rates
tf01(ff)	0-1 par for potential flexing of factor use tax rates
tm01(c)	0-1 par for potential flexing of Tariff rates on comm'ies
ts01(c)	0-1 par for potential flexing of sales tax rates
twat01(c)	0-1 par for potential flexing of water tax rates
twata01(c,a)	0-1 par for potential flexing of water use tax rates
tx01(a)	0-1 par for potential flexing of indirect tax rates
tye01(e)	0-1 par for potential flexing of direct tax rates on e'rises
tyf01(f)	0-1 par for potential flexing of direct tax rates on factors
tyh01(h)	0-1 par for potential flexing of direct tax rates on h'holds
use(c,a)	use matrix transactions
vddtotsh(c)	Share of value of domestic output for the domestic market
worvash(f)	Share of income from factor f to RoW
yhelast(c,h)	(Normalised) household income elasticities

Variable List

Variable Name	Variable Description
ADFD(f,a)	Shift parameter for factor and activity specific efficiency
ADX(a)	Shift parameter for CES production functions for QX
ADXADJ	Scaling Factor for shift parameter on CES functions for QX
CAPWOR	Current account balance
CPI	Consumer price index
DADX	Partial scaling factor for shift parameter on CES functions for QX
DS	Partial household and enterprise savings rate scaling factor
DSEN	Partial enterprise savings rate scaling factor
DSHH	Partial household savings rate scaling factor
DTAX	Direct income tax revenue
DTE	Partial export tax rate scaling factor
DTEX	Partial excise tax rate scaling factor
DTF	Uniform adjustment to factor use tax by activity
DTM	Partial tariff rate scaling factor
DTS	Partial sales tax rate scaling factor
DTWAT	Partial water tax rate scaling factor
DTWATA	Uniform adjustment to water use tax by activity
DTX	Partial indirect tax rate scaling factor
DTY	Partial direct tax on enterprise and households rate scaling factor
DTYE	Partial direct tax on enterprise rate scaling factor
DTYF	Partial direct tax on factor rate scaling factor
DTYH	Partial direct tax on households rate scaling factor
EG	Expenditure by government
EGADJ	Transfers to enterprises by government scaling factor
ER	Exchange rate (domestic per world unit)
ETAX	Export tax revenue
EXTAX	Excise tax revenue
FD(f,a)	Demand for factor f by activity a
FS(f)	Supply of factor f
FTAX	Factor use tax revenue
FYTAX	Factor income tax revenue
GDPVA	GDP from value added
GOVENT(e)	Government income from enterprise e
HEADJ	Scaling factor for enterprise transfers to households
HEXP(h)	Household consumption expenditure
HGADJ	Scaling factor for government transfers to households
HOENT(h,e)	Household Income from enterprise e
HOHO(h,hp)	Inter household transfer

Variable Name	Variable Description
IADJ	Investment scaling factor
INVEST	Total investment expenditure
INVESTSH	Value share of investment in total final domestic demand
ITAX	Indirect tax revenue
KAPGOV	Government savings
MTAX	Tariff revenue
PD(c)	Consumer price for domestic supply of commodity c
PE(c)	Domestic price of exports by activity a
PINT(a)	Price of aggregate intermediate input
PM(c)	Domestic price of competitive imports of commodity c
PNW(a)	Water and Land composite price
PPI	Producer (domestic) price index
PQD(c)	Purchaser price of composite commodity c
PQDDIST(c,a)	Secotral proportion of water prices
PQS(c)	Supply price of composite commodity c
PVA(a)	Value added price for activity a
PWAT(sac)	Composite price for water demand
PWE(c)	World price of exports in dollars
PWM(c)	World price of imports in dollars
PX(a)	Composite price of output by activity a
PXAC(a,c)	Activity commodity prices
PXC(c)	Producer price of composite domestic output
QCD(c,h)	Household consumption by commodity c
QD(c)	Domestic demand for commodity c
QE(c)	Domestic output exported by commodity c
QENTD(c,e)	Enterprise consumption by commodity c
QENTDADJ	Enterprise demand volume scaling factor
QGD(c)	Government consumption demand by commodity c
QGDADJ	Government consumption demand scaling factor
QINT(a)	Aggregate quantity of intermediates used by activity a
QINTD(c)	Demand for intermediate inputs by commodity
QINVD(c)	Investment demand by commodity c
QM(c)	Imports of commodity c
QNW(a)	Water and Land composite quantity
QQ(c)	Supply of composite commodity c
QVA(a)	Quantity of aggregate value added for level 1 production
QWAT(sac)	Domestic demand for water composite
QWAT2(c,sac)	Domestic demand of (single) water commodities
QX(a)	Domestic production by activity a

Variable Name	Variable Description
QXAC(a,c)	Domestic commodity output by each activity
QXC(c)	Domestic production by commodity c
SADJ	Savings rate scaling factor for BOTH households and enterprises
SEADJ	Savings rate scaling factor for enterprises
SEN(e)	Enterprise savings rates
SHADJ	Savings rate scaling factor for households
SHH(h)	Household savings rates
STAX	Sales tax revenue
TE(c)	Export taxes on exported comm'y c
TEADJ	Export subsidy scaling factor
TEX(c)	Excise tax rate
TEXADJ	Excise tax rate scaling factor
TF(f)	Factor use tax rate
TFADJ	Factor use tax rate scaling factor
TM(c)	Tariff rates on imported comm’y c
TMADJ	Tariff rate scaling factor
TOTSAV	Total savings
TS(c)	Sales tax rate
TSADJ	Sales tax rate scaling factor
TWAT(c)	Water commodity tax rate
TWATADJ	Water tax rate scaling factor
TWATA(c,a)	Water user tax rate
TWATAADJ	Water user tax rate scaling factor
TX(a)	Indirect tax rate
TXADJ	Indirect tax scaling factor
TYE(e)	Direct tax rate on enterprises
TYEADJ	Enterprise income tax scaling factor
TYF(f)	Direct tax rate on factor income
TYFADJ	Factor tax scaling factor
TYH(h)	Direct tax rate on households
TYHADJ	Household income tax scaling factor
VENTD(e)	Value of enterprise e consumption expenditure
VENTDSH(e)	Value share of Ent consumption in total final domestic demand
VFDOMD	Value of final domestic demand
VGD	Value of Government consumption expenditure
VGDSH	Value share of Govt consumption in total final domestic demand
WALRAS	Slack variable for Walras's Law
WATTAX	Water commodity tax revenue
WATATAX	Water user tax revenue

Variable Name	Variable Description
WF(f)	Price of factor f
WFDIST(f,a)	Sectoral proportion for factor prices
YE(e)	Enterprise incomes
YF(f)	Income to factor f
YFDISP(f)	Factor income for distribution after depreciation
YFWOR(f)	Foreign factor income
YG	Government income
YH(h)	Income to household h

A.1.5.2 Appendix 2: Equation and Variable Counts for the Model

Name	Equation		Number of Equations	Variable	Number of Variables
	EXPORTS BLOCK				
$PEDEF_c$	$PE_c = PWE_c * ER * (1 - TE_c)$	$\forall ce$	ce	PE_c	ce
CET_c	$QXC_c = at_c * \left(\gamma_c * QE_c^{rhot_c} + (1-\gamma_c) * QD_c^{rhot_c}\right)^{\frac{1}{rhot_c}}$	$\forall ce$ **AND** cd	c	QDD_c	c
$ESUPPLY_a$	$\frac{QE_c}{QD_c} = \left[\frac{PE_c}{PD_c} * \frac{(1-\gamma_c)}{\gamma_c}\right]^{\frac{1}{(rhot_c - 1)}}$	$\forall ce$ **AND** cd	c	QE_c	c
$EDEMAND_c$	$QE_c = econ_c * \left(\frac{PWE_c}{pwse_c}\right)^{-eta_c}$	$\forall ced$			
$CETALT_c$	$QXC_c = QD_c + QE_c$	$\forall (cen$ **AND** $cd)$ **OR** $(ce$ **AND** $cdn)$			
	IMPORTS BLOCK				
$PMDEF_c$	$PM_c = PWM_c * ER * (1 + TM_c)$	$\forall cm$	cm	PM_c	cm
$ARMINGTON_c$	$QQ_c = ac_c \left(\delta_c QM_c^{-rhoc_c} + (1-\delta_c) QD_c^{-rhoc_c}\right)^{-\frac{1}{rhoc_c}}$	$\forall cm$ **AND** cx	c	QQ_c	c
$COSTMIN_c$	$\frac{QM_c}{QD_c} = \left[\frac{PD_c}{PM_c} * \frac{\delta_c}{(1-\delta_c)}\right]^{\frac{1}{(1+rhoc_c)}}$	$\forall cm$ **AND** cx	c	QM_c	c
$ARMALT$	$QQ_c = QD_c + QM_c$	$\forall (cmn$ **AND** $cx)$ **OR** $(cm$ **AND** $cxn)$			
	COMMODITY PRICE BLOCK				
$PQDDEF_c$	$PQD_c = PQS_c * (1 + TS_c + TEX_c)$		c	PQD_c	c

Name	Equation		Number of Equations	Variable	Number of Variables
PQSDEF$_c$	$PQS_c = \frac{PD_c * QD_c + PM_c * QM_c}{QQ_c}$	$\forall cd$ **OR** cm	c	PQS_c	c
PXCDEF$_c$	$PXC_c = \frac{PD_c * QD_c + \left(PE_c * QE_c\right)\$ce_c}{QXC_c}$	$\forall cx$	cx	PXC_c	cx
	NUMERAIRE BLOCK				
CPIDEF	$CPI = \sum_c comtotsh_c * PQD_c$		1	*CPI*	1
PPIDEF	$PPI = \sum_c vddtotsh_c * PD_c$		1	*PPI*	1
	PRODUCTION BLOCK				
PXDEF$_a$	$PX_a = \sum_c ioqxacqx_{a,c} * PXC_c$		a	*PXa*	a
PVADEF$_a$	$PX_a * \left(1 - TX_a\right) * QX_a = \left(PVA_a * QVA_a\right) + \left(PINT_a * QINT_a\right)$		a	PVA_a	a
PINTDEF$_a$	$PINT_a = \sum_c \left(ioqtdqd_{c,a} * PQD\right)_c$		a	$PINT_a$	a
ADXEQ$_a$	$AD_a^X = \left[\left(adxb_a + dabadx_a\right) * ADXADJ\right] + \left(DADX * adx01_a\right)$		a	AD_a^X	a
QXPRODFN$_a$	$QX_a = AD_a^X \left(\delta_a^x * QVA_a^{-\rho_a^{cx}} + \left(1 - \delta_a^x\right) * QINT_a^{-\rho_a^{cx}}\right)^{-\frac{1}{\rho_a^{cx}}}$	$\forall aqx_a$	a	QX_a	a
QXFOC$_a$	$\frac{QVA_a}{QINT_a} = \left[\frac{PINT_a}{PVA_a} * \frac{\delta_a^x}{\left(1 - \delta_a^x\right)}\right]^{\frac{1}{\left(1+\rho_a^{cx}\right)}}$	$\forall aqx_a$	a	$QINT_a$	a
QVADEF	$QVA_a = ioqvaqx_a * QX_a$	$\forall aqxn_a$			
QINTDEF	$QINT_a = ioqintqx_a * QX_a$	$\forall aqx_a$			
ADVAEQ	$AD_a^{VA} = \left[\left(advab_a + dabadva_a\right) * ADVAADJ\right] + \left(DADVA * adva01_a\right)$		a	AD_a^{VA}	a

Name	Equation		Number of Equations	Variable	Number of Variables
QVAPRODFN$_a$	$QVA_a = AD_a^{VA} * \left[\sum_{f2\$\delta_{f2,a}^{va}} \delta_{f2,a}^{va} * AD_{f2,a}^{FD} * FD_{f2,a}^{-\rho_a^{cva}} + (\delta_{"cnw",a}^{va} * QNW_a^{-\rho_a^{cva}})\$\delta_{"cnw",a}^{va} \right]^{-1/\rho_a^{cva}}$	$\forall afx_a$	*a*	*QVA*$_a$	*a*
QVAFOC1$_{f2,a}$	$WF_{f2} * WFDIST_{f2,a} * \left(1 + TF_{f2,a}\right) = PVA_a * QVA_a * \left[\sum_{f2p\$\delta_{f2p,a}^{va}} \delta_{f2p,a}^{va} * AD_{f2,a}^{FD} * FD_{f2p,a}^{-\rho_a^{cva}} + (\delta_{"cnw",a}^{va} * QNW_a^{-\rho_a^{cva}})\$\delta_{"cnw",a}^{va} \right]^{-1} * \delta_{f2,a}^{va} * AD_{f2,a}^{FD\ -\rho_a^{cva}} * FD_{f2,a}^{\left(-\rho_a^{cva}-1\right)}$	$\forall afx_a$	*f2*a*	*FD*$_{f2,a}$	*f2*a*
QVAFOC2$_a$	$PNW_a = PVA_a * QVA_a * \left[\sum_{f2p\$\delta_{f2p,a}^{va}} \delta_{f2p,a}^{va} * AD_{f2p,a}^{FD} * FD_{f2p,a}^{-\rho_a^{cva}} + \delta_{"cnw",a}^{va} * QNW_a^{-\rho_a^{cva}} \right]^{-1} * \delta_{"cnw",a}^{va} * QNW_a^{\left(-\rho_a^{cva}-1\right)}$	$\forall afx_a$	*a*	*QNW*$_a$	*a*
QVAEQ1$_{f2,a}$	$FD_{f2,a} * AD_{f2,a}^{FD} = ioqnwqva_{f2,a} * QVA_a$	$\forall afxn_a$	*f2*a*	*FD*$_{f2,a}$	*f2*a*
QVAEQ2$_a$	$QNW_a = ioqnwqva_{"cnw",a} * QVA_a$	$\forall afxn_a$	*a*	*QNW*$_a$	*a*
PVAEQ$_a$	$PVA_a = PNW_a * ioqnwqva_{"cnw",a} + \sum_{f2} ioqnwqva_{f2,a} * WF_{f2} * WFDIST_{f2,a} * (1 + TF_{f2,a})$	$\forall afxn_a$	*a*	*QVA*$_a$	*a*
QINTDEQ$_c$	$QINTD_c = \sum_a ioqtdqd_{c,a} * QINT_a + \sum_a QWAT2_{c,a}$		*c*	*QINTD*$_c$	*c*
QNWPRODFN1$_a$	$QNW_a = ad_a^{nw} * \left[\sum_{f3\$\delta_{f3p,a}^{nw}} \delta_{f3,a}^{nw} * AD_{f3,a}^{FD} * FD_{f3,a}^{-\rho_a^{nw}} + (\delta_{"cwat",a}^{nw} * QWAT_a^{-\rho_a^{nw}})\$\delta_{"cwat",a}^{nw} \right]^{-1/\rho_a^{nw}}$	$\forall af3x_a$ **AND** an_a	*a*	*QNW*$_a$	*a*

Name	Equation	Number of Equations	Variable	Number of Variables
$QNWFOC1_{f3,a}$	$WF_{f3} * WFDIST_{f3,a} * \left(1+TF_{f3,a}\right) = PNW_a * QNW_a * \left[\sum_{f3p \$ \delta^{nw}_{f3p,a}} \delta^{nw}_{f3p,a} * AD^{FD}_{f3p,a} * FD_{f3p,a}^{-\rho^{nw}_a} + (\delta^{nw}_{"cwat",a} * QWAT_a^{-\rho^{nw}_a}) \$ \delta^{nw}_{"cwat",a}\right]^{-1} * \delta^{nw}_{f3p,a} * AD^{FD\ -\rho^{nw}_a}_{f3,a} * FD_{f3,a}^{\left(-\rho^{nw}_a - 1\right)}$ $\forall af3x_a$	$f3*a$	$FD_{f3,a}$	$f3*a$
$QNWFOC2_a$	$PWAT_a = PNW_a * QNW_a * \left[\sum_{f3p \$ \delta^{nw}_{f3p,a}} \delta^{nw}_{f3p,a} * AD^{FD}_{f3p,a} * FD_{f3p,a}^{-\rho^{nw}_a} + \delta^{nw}_{"cwat",a} * QWAT_a^{-\rho^{nw}_a}\right]^{-1} * \delta^{nw}_{"cwat",a} * QWAT_a^{\left(-\rho^{nw}_a - 1\right)}$ $\forall af3x_a$	a	$QWAT_a$	a
$QNWEQ1_{f3,a}$	$FD_{f3,a} * AD^{FD}_{f3,a} = ioqwatqnw_{f3,a} * QNW_a$ $\forall af3xn_a$	$f3*a$	$FD_{f3,a}$	$f3*a$
$QNWEQ2_a$	$QWAT_a = ioqwatqnw_{"cwat",a} * QNW_a$ $\forall af3xn_a$ **OR** ann_a	a	$QWAT_a$	a
$PNWEQ_a$	$PNW_a = PWAT_a * ioqwatqnw_{"cwat",a} + \sum_{f3} ioqwatqnw_{f3,a} * WF_{f3} * WFDIST_{f3,a} * (1+TF_{f3,a})$ $\forall af3xn_a$ **OR** ann_a	a	QNW_a	a
$WATDPRODFN_a$	$QWAT_a = ad^{wat}_a * \left[\sum_{f4 \$ \delta^{wat}_{f4,a}} \delta^{wat}_{f4,a} * AD^{FD}_{f4,a} * FD_{f4,a}^{-\rho^{wat}_a} + \sum_{cwat} \delta^{wat}_{cwat,a} * QWAT2_{cwat,a}^{-\rho^{wat}_a}\right]^{-1/\rho^{wat}_a}$ $\forall af4x_a$ **AND** $awat_a$	a	$QWAT_a$	a

Name	Equation	Number of Equations	Variable	Number of Variables
FD4FOC$_{f4,a}$	$WF_{f4} * WFDIST_{f4,a} * \left(1+TF_{f4,a}\right) = PWAT_a * QWAT_a * \left[\sum_{f4p\$\delta^{wat}_{f4p,a}} \delta^{wat}_{f4p,a} * AD^{FD}_{f4p,a} * FD^{-\rho^{wat}_a}_{f4p,a} + \sum_{cwatp\$\delta^{wat}_{cwatp,a}} \delta^{wat}_{cwatp,a} * QWAT2^{-\rho^{wat}_a}_{cwatp,a}\right]^{-1} * \delta^{wat}_{f4p,a} * AD^{FD}_{f4,a}{}^{-\rho^{wat}_a} * FD^{\left(-\rho^{wat}_a-1\right)}_{f4,a} \quad \forall af4x_a$	*f4*a*	*FD$_{f4,a}$*	*f4*a*
WATDFOC$_{cwat,a}$	$PQD_{cwat} * PQDDIST_{cwat,a} * (1+TWATA_{cwat,a}) = PWAT_a * QWAT_a * \left[\sum_{f4p\$\delta^{wat}_{f4p,a}} \delta^{wat}_{f4p,a} * AD^{FD}_{f4p,a} * FD^{-\rho^{wat}_a}_{f4p,a} + \sum_{cwatp\$\delta^{wat}_{cwatp,a}} \delta^{wat}_{cwatp,a} * QWAT2^{-\rho^{wat}_a}_{cwatp,a}\right]^{-1} * \delta^{wat}_{cwatp,a} * QWAT2^{\left(-\rho^{wat}_a-1\right)}_{cwat,a} \quad \forall af4x_a$	*cwat*a*	*QWAT2$_{cwat,a}$*	*cwat*a*
QWATEQ1$_{c,a}$	$QWAT2_{c,a} = iofcqwat_{c,a} * QWAT_a \quad \forall af4xn_a \textbf{ AND } acwat_a$	*cwat*a*	*QWAT2$_{cwat,a}$*	*cwat*a*
QWATEQ2$_{f4,a}$	$FD_{f4,a} * AD^{FD}_{f4,a} = iofcqwat_{f4,a} * QWAT_a \quad \forall af4xn_a \textbf{ AND } afwat_a$	*f4*a*	*FD$_{f4,a}$*	*f4*a*
PWATEQ$_a$	$PWAT_a = \sum_{c\$cwat_c} iofcqwat_{c,a} * PQD_c * PQDDIST_{c,a} * (1+TWATA_{c,a}) + \sum_{f4} iofcqwat_{f4,a} * WF_{f4} * WFDIST_{f4,a} * (1+TF_{f4,a}) \quad \forall af4xn_a$	*a*	*PWAT$_a$*	*a*
COMOUT$_c$	$QXC_c = ad^{xc}_c * \left[\sum_{a\$\delta^{xc}_{a,c}} \delta^{xc}_{a,c} * QXAC^{-\rho^{xc}_c}_{a,c}\right]^{-1/\rho^{xc}_c} \quad \forall cx_c \textbf{ AND } cxac_c$	*c*	*QXC$_c$*	*c*
COMOUT2$_c$	$QXC_c = \sum_a QXAC_{a,c} \quad \forall cx_c \textbf{ AND } cxacn_c$	*c*	*QXC$_c$*	*c*

Name	Equation	Number of Equations	Variable	Number of Variables
COMOUTFOC$_{a,c}$	$PXAC_{a,c} = PXC_c * ad_c^{xc} * \left[\sum_{a\$\delta_{a,c}^{xc}} \delta_{a,c}^{xc} * QXAC_{a,c}^{-\rho_c^{xc}}\right]^{-\left(\frac{1+\rho_c^{xc}}{\rho_c^{xc}}\right)} * \delta_{a,c}^{xc} * QXAC_{a,c}^{\left(-\rho_c^{xc}-1\right)}$ $= PXC_c * QXC_c * \left[\sum_{a\$\delta_{a,c}^{xc}} \delta_{a,c}^{xc} * QXAC_{a,c}^{-\rho_c^{xc}}\right]^{-\left(\frac{1+\rho_c^{xc}}{\rho_c^{xc}}\right)} * \delta_{a,c}^{xc} * QXAC_{a,c}^{\left(-\rho_c^{xc}-1\right)} \quad \forall cxac_c$	*a*c*	*PXAC*$_{a,c}$	*a*c*
COMOUTFOC2$_{a,c}$	$PXAC_{a,c} = PXC \quad \forall cxacn_c$	*a*c*	*PXAC*$_{a,c}$	*a*c*
ACTIVOUT$_{a,c}$	$QXAC_{a,c} = ioqxacqx_{a,c} * QX_a$	*a*c*	*QXAC*$_{a,c}$	*a*c*
	FACTOR BLOCK			
YFEQ$_f$	$YF_f = \left(\sum_a WF_f * WFDIST_{f,a} * FD_{f,a}\right) + \left(factwor_f * ER\right)$	*f*	*YF*$_f$	*f*
YFDISPEQ$_f$	$YFDISP_f = \left(YF_f * \left(1 - deprec_f\right)\right) * \left(1 - TYF_f\right)$	*f*	*YFDIST*$_f$	*f*
	HOUSEHOLD BLOCK			
YHEQ$_h$	$YH_h = \left(\sum_f hovash_{h,f} * YFDISP_f\right) + \left(\sum_{hp} HOHO_{h,hp}\right)$ $+ HOENT_h + \left(hogovconst_h * HGADJ * CPI\right) + \left(howor_h * ER\right)$	*h*	*YH*$_h$	*h*
HOHOEQ$_{h,hp}$	$HOHO_{h,hp} = hohosh_{h,hp} * \left(YH_h * \left(1 - TYH_h\right)\right) * \left(1 - SHH_h\right)$	*h*hp*	*HOHO*$_{h,hp}$	*h*hp*
HEXPEQ$_h$	$HEXP_h = \left(\left(YH_h * \left(1 - TYH_h\right)\right) * \left(1 - SHH_h\right)\right) - \left(\sum_{hp} HOHO_{hp,h}\right)$	*h*	*HEXP*$_h$	*h*

Name	Equation	Number of Equations	Variable	Number of Variables
$QCDEQ_c$	$QCD_c = \left(\sum_h \left(\begin{array}{l} PQD_c * qcdconst_{c,h} + \sum_h beta_{c,h} \\ * \left(HEXP_h - \sum_c \left(PQD_c * qcdconst_{c,h} \right) \right) \end{array} \right) \right) * \frac{1}{PQD_c}$	c	QCD_c	c
	ENTERPRISE BLOCK			
$YEEQ_e$	$YE_e = \left(\sum_f entvash_{e,f} * YFDISP_f \right) + \left(entgovconst_e * EGADJ * CPI \right) + \left(entwor_e * ER \right)$	e	YE_e	e
$QENTDEQ_{c,e}$	$QED_{c,e} = qedconst_{c,e} * QEDADJ$	c*e	$QED_{c,e}$	c*e
$VEDEQ_e$	$VED_e = \left(\sum_c QED_{c,e} * PQD_c \right)$	e	VED_e	e
$HOENTEQ_{h,.}$	$HOENT_{h,e} = hoentsh_{h,e} * \left(\left(YE_e * \left(1 - TYE_e\right)\right) * \left(1 - SEN_e\right) - \sum_c \left(QED_{c,e} * PQD_c \right) \right)$	h*e	$HOENT_{h,e}$	h*e
$GOVENTEQ_e$	$GOVENT_e = goventsh_e * \left(\left(YE_e * \left(1 - TYE_e\right)\right) * \left(1 - SEN_e\right) - \sum_c \left(QED_c * PQD_c \right) \right)$	e	$GOVENT_e$	e
	TAX RATE BLOCK			
$TMDEF_c$	$TM_c = \left(\left(tmb_c + dabtm_c \right) * TMADJ \right) + \left(DTM * tm01_c \right)$	cm	TM_c	cm
$TEDEF_c$	$TE_c = \left(\left(teb_c + dabte_c \right) * TEADJ \right) + \left(DTE * te01_c \right)$	ce	TE_c	ce
$TSDEF_c$	$TS_c = \left(\left(tsb_c + dabts_c \right) * TSADJ \right) + \left(DTS * ts01_c \right)$	c	TS_c	c
$TEXDEF_c$	$TEX_c = \left(\left(texb_c + dabtex_c \right) * TEXADJ \right) + \left(DTEX * tex01_c \right)$	c	TEX_c	c
$TXDEF_a$	$TX_a = \left(\left(txb_a + dabtx_a \right) * TXADJ \right) + \left(DTX * tx01_a \right)$	a	TX_a	a
$TFDEF_{ff,a}$	$TF_{ff,a} = \left(\left(tfb_{ff,a} + dabtf_{ff,a} \right) * TFADJ \right) + \left(DTF * tf01_{ff,a} \right)$	f*a	$TF_{f,a}$	f*a
$TYFDEF_f$	$TYF_f = \left(\left(tyfb_f + dabtyf_f \right) * TYFADJ \right) + \left(DTYF * tyf01_f \right)$	f	TYF_f	f

Name	Equation	Number of Equations	Variable	Number of Variables
$THYDEF_h$	$TYH_h = \left(\left(tyhb_h + dabtyh_h\right) * TYHADJ\right) + \left(DTYH * DTY * tyh01_h\right)$	*h*	TYH_h	*h*
$TYEDEF_e$	$TYE_e = \left(\left(tyeb_e + dabtye_e\right) * TYEADJ\right) + \left(DTYE * DTY * tye01_e\right)$	*e*	TYE_e	*e*
$TWATDEF_c$	$TWAT_c = ((twatb_c + dabtwat_c) * TWATADJ) + (DTWAT * twat01_c)$	*c*	$TWAT_c$	*c*
$TWATADEF_{c,a}$	$TWATA_{c,a} = ((twatab_{c,a} + dabtwata_{c,a}) * TWATAADJ) + (DTWATA * twata01_{c,a})$	*c*a*	$TWATA_{c,a}$	*c*a*
	TAX REVENUE BLOCK			
MTAXEQ	$MTAX = \sum_c \left(TM_c * PWM_c * ER * QM_c\right)$	1	*MTAX*	1
ETAXEQ	$ETAX = \sum_c \left(TE_c * PWE_c * ER * QE_c\right)$	1	*ETAX*	1
STAXEQ	$STAX = \sum_c \left(TS_c * PQS_c * \left(QINTD_c + QCD_c + QED_c + QGD_c + QINVD_c + dstocconst_c\right)\right) = \sum_c \left(TS_c * PQS_c * QQ_c\right)$	1	*STAX*	1
EXTAXEQ	$EXTAX = \sum_c \left(TEX_c * PQS_c * QQ_c\right)$	1	*EXTAX*	1
ITAXEQ	$ITAX = \sum_a \left(TX_a * PX_a * QX_a\right)$	1	*ITAX*	1
FTAXEQ	$FTAX = \sum_{f,a} \left(TF_{f,a} * WF_f * WFDIST_{f,a} * FD_{f,a}\right)$	1	*FTAX*	1
FYTAXEQ	$FYTAX = \sum_f \left(TYF_f * \left(YF_f * \left(1 - deprec_f\right)\right)\right)$	1	*FYTAX*	1
DTAXEQ	$DTAX = \sum_h \left(TYH_h * YH_h\right) + \sum_e \left(TYE_e * YE\right)$	1	*DTAX*	1
WATTAXEQ	$WATTAX = \sum_c (TWAT_c * PQS_c * QQ_c)$	1	*WATTAX*	1
WATATAXEQ	$WATATAX = \sum_{c,a} (TWATA_{c,a} * PQD_c * PQDDIST_{c,a} * QWAT2_{c,a})$	1	*WATATAX*	1

Name	Equation	Number of Equations	Variable	Number of Variables
	GOVERNMENT BLOCK			
YGEQ	$YG = MTAX + ETAX + STAX + EXTAX + FTAX + ITAX + FYTAX + DTAX + WATTAX + WATATAX + \left(\sum_{f} govvash_{f} * YFDISP_{f}\right) + GOVENT + \left(govwor * ER\right)$	1	*YG*	1
QGDEQ$_c$	$QGD_{c} = qgdconst_{c} * QGDADJ$	*c*	QGD_{c}	*c*
VGDEQ	$VGD = \left(\sum_{c} QGD_{c} * PQD_{c}\right)$	1	*VQGD*	1
EGEQ	$EG = \left(\sum_{c} QGD_{c} * PQD_{c}\right) + \left(\sum_{h} hogovconst_{h} * HGADJ * CPI\right) + \left(\sum_{e} entgovconst_{e} * EGADJ * CPI\right)$	1	*EG*	1
	INVESTMENT BLOCK			
SHHDEF$_h$	$SHH_{h} = \left(\left(shhb_{h} + dabshh_{h}\right) * SHADJ * SADJ\right) + \left(DSHH * DS * shh01_{h}\right)$	*h*	*SHH*	*H*
SENDEF$_e$	$SEN_{e} = \left(\left(sen_{e} + dabsen_{e}\right) * SEADJ * SADJ\right) + \left(DSEN * DS * sen01_{e}\right)$	*e*	*SEN*	*e*
TOTSAVEQ	$TOTSAV = \sum_{h}\left(\left(YH_{h} * \left(1 - TYH_{h}\right)\right) * SHH_{h}\right) + \sum_{e}\left(\left(YE * \left(1 - TYE_{e}\right)\right) * SEN_{e}\right) + \sum_{f}\left(YF_{f} * deprec_{f}\right) + KAPGOV + \left(CAPWOR * ER\right)$	1	TOTSAV	1
QINVDEQ$_c$	$QINVD_{c} = \left(IADJ * qinvdconst_{c}\right)$	*c*	$QINVD_c$	*c*
INVEST	$INVEST = \sum_{c}\left(PQD_{c} * \left(QINVD_{c} + dstocconst_{c}\right)\right)$	1	*INVEST*	1
	FOREIGN INSTITUTIONS BLOCK			
$YFWOREQ_{f}$	$YFWOR_{f} = worvash_{f} * YFDISP_{f}$	*f*	$YFWOR_f$	*f*

Name	Equation	Number of Equations	Variable	Number of Variables
	MARKET CLEARING BLOCK			
FMEQUIL$_f$	$FS_f = \sum_a FD_{f,a}$	*f*	*FS$_f$*	*f*
QEQUIL$_c$	$QQ_c = QINTD_c + \sum_h QCD_{c,h} + \sum_e QED_{c,e} + QGD_c + QINVD_c + dstocconst_c$	*c*		
CAPGOVEQ	$KAPGOV = YG - EG$	1	*CAPGOV*	1
CAEQUIL	$CAPWOR = \left(\sum_c pwm_c * QM_c\right) + \left(\sum_f \frac{YFWOR_f}{ER}\right) - \left(\sum_c pwe_c * QE_c\right) - \left(\sum_f factwor_f\right) - \left(\sum_h howor_h\right) - entwor - govwor$	1	*CAPWOR*	1
VFDOMDEQ	$VFDOMD = \sum_c PQD_c * \left(\sum_h QCD_{c,h} + \sum_e QED_{c,e} + QGD_c + QINVD_c + dstocconst_c\right)$	1	*VFDOMD*	1
VENTDSHEQ	$VENTDSH_e = VENTD_e / VFDOMD$	1	*VENTDSH*	1
VGDSHEQ	$VGDSH = VGD / VFDOMD$	1	*VGDSH*	1
INVESTSHEQ	$INVESTSH = INVEST / VFDOMD$	1	*INVESTSH*	1
WALRASEQ	$TOTSAV = INVEST + WALRAS$	1	*WALRAS*	1

Name	Equation	Number of Equations	Variable	Number of Variables
	MODEL CLOSURE			
			$\overline{ER}$ or $\overline{CAPWOR}$	1
			$\overline{PWM_c}$ and $\overline{PWE_c}$ or $\overline{PWE_{cedn}}$	2*c*
			$\overline{PQDDIST_{c,a}}$	*c*a*
			$\overline{SADJ}$, $\overline{SHADJ}$, $\overline{SEADJ}$ or $\overline{IADJ}$ or $\overline{INVEST}$ or $\overline{INVESTSH}$	1
			$\overline{QEDADJ}$ or $\overline{VED}$ or $\overline{VEDSH}$	1
			at least **one** of $\overline{TMADJ}$, $\overline{TEADJ}$, $\overline{TSADJ}$, $\overline{TEXADJ}$, $\overline{TYFADJ}$, $\overline{TXADJ}$, $\overline{TFADJ}$, $\overline{TYHADJ}$, $\overline{TYEADJ}$, $\overline{TYADJ}$, $\overline{TWATADJ}$, $\overline{TWATAADJ}$, $\overline{DTM}$, $\overline{DTE}$, $\overline{DTS}$, $\overline{DTEX}$, $\overline{DTYF}$, $\overline{DTX}$, $\overline{DTF}$, $\overline{DTYH}$, $\overline{DTYE}$, $\overline{DTY}$, $\overline{DTWAT}$, $\overline{DTWATA}$ and $\overline{CAPGOV}$	7
			at least **two** of $\overline{QGDADJ}$, $\overline{HGADJ}$, $\overline{EGADJ}$, $\overline{VGD}$ and $\overline{VGDSH}$	3
			$\overline{FS_f}$ and $\overline{WFDIST_{f,a}}$	(*f**(*a*+1))
			$\overline{CPI}$ or $\overline{PPI}$	1

A.1.5.3 Appendix 3: Equation Code

```
*################ 15. EQUATIONS ASSIGNMENTS ###############
* ------- TRADE BLOCK ----------------------------------------------
* #### Exports Block

* For some c there are no exports hence only implement for ce(c)

 PEDEF(c)$ce(c)..  PE(c) =E= PWE(c) * ER * (1 - TE(c)) ;

* For some c there are no exports hence only implement for ce(c)

 CET(c)$(cd(c) AND ce(c))..
           QXC(c) =E= at(c)*(gamma(c)*QE(c)**rhot(c) +
                      (1-gamma(c))*QD(c)**rhot(c))**(1/rhot(c)) ;

 ESUPPLY(c)$(cd(c) AND ce(c))..
                  QE(c) =E= QD(c)*((PE(c)/PD(c))*((1-gamma(c))
                                /gamma(c)))**(1/(rhot(c)-1)) ;

 EDEMAND(c)$ced(c)..
                  QE(c) =E= econ(c)*((PWE(c)/pwse(c))**(-eta(c))) ;

* For c with no exports OR for c with no domestic production
* domestic supply is by CETALT

 CETALT(c)$((cd(c) AND cen(c)) OR (cdn(c) AND ce(c)))..
                 QXC(c) =E= QD(c) + QE(c) ;

* #### Imports Block

* For some c there are no imports hence only implement for cm(c)

 PMDEF(c)$cm(c)..  PM(c) =E= (PWM(c) *(1 + TM(c))) * ER ;

* For some c there are no imports or domestic production
* hence only implement for cd(c) AND cm(c)

 ARMINGTON(c)$(cx(c) AND cm(c) )..
       QQ(c)  =E= ac(c)*(delta(c)*QM(c)**(-rhoc(c)) +
                  (1-delta(c))*QD(c)**(-rhoc(c)))**(-1/rhoc(c)) ;

 COSTMIN(c)$(cx(c) AND cm(c))..
                  QM(c) =E= QD(c)*((PD(c)/PM(c))*(delta(c)/
                                (1-delta(c))))**(1/(1+rhoc(c))) ;

* For c with no imports OR for c with no domestic production
* supply is from ARMALT
```

```
 ARMALT(c)$((cx(c) AND cmn(c)) OR (cxn(c) AND cm(c)))..
                   QQ(c) =E= QD(c) + QM(c) ;

* ------- COMMODITY PRICE BLOCK -----------------------------------
 PQDDEF(c)$(cd(c) OR cm(c))..
            PQD(c) =E= PQS(c) * (1 + TS(c) + TEX(c)+ TWAT(c)) ;

 PQSDEF(c)$((cd(c) OR cm(c)))..
           PQS(c)*QQ(c) =E= (PD(c)*QD(c))+(PM(c)*QM(c)) ;

 PXCDEF(c)$(cx(c))..
          PXC(c)*QXC(c) =E= (PD(c)*QD(c)) + (PE(c)*QE(c))$ce(c) ;

* ------- NUMERAIRE PRICE BLOCK -----------------------------------

 CPIDEF..            CPI =E= SUM(c,comtotsh(c)*PQD(c)) ;

 PPIDEF..            PPI =E= SUM(c,vddtotsh(c)*PD(c)) ;

* ------- PRODUCTION BLOCK ----------------------------------------

*------------- Level 1---------------------------

 PXDEF(a)$QINT0(a)..     PX(a) =E= SUM(c,ioqxacqx(a,c)*PXAC(a,c)) ;

 PVADEF(a)..  PX(a)*(1 - TX(a))*QX(a)
                           =E= (PVA(a)*QVA(a)) + (PINT(a)*QINT(a)) ;

 PINTDEF(a)..     PINT(a) =E= SUM(c$cnwat(c),ioqtdqd(c,a) * PQD(c)) ;

 ADXEQ(a)..       ADX(a) =E= ((adxb(a) + dabadx(a)) * ADXADJ)
                                        + (DADX * adx01(a)) ;

* CES aggregation functions for Level 1 of production nest
 QXPRODFN(a)$aqx(a)..
                  QX(a) =E= ADX(a)*(deltax(a)*QVA(a)**(-rhocx(a))
                             + (1-deltax(a))*QINT(a)**(-rhocx(a)))
                             **(-1/rhocx(a)) ;

 QXFOC(a)$aqx(a)..
                 QVA(a) =E= QINT(a)*((PINT(a)/PVA(a))*(deltax(a)/
                                (1-deltax(a))))**(1/(1+rhocx(a))) ;

* Leontief aggregation functions for Level 1 of production nest
```

```
 QINTDEF(a)$aqxn(a)..
                QINT(a) =E= ioqintqx(a) * QX(a) ;

 QVADEF(a)$aqxn(a)..
                 QVA(a) =E= ioqvaqx(a) * QX(a) ;

*------------------------ Level 2----------------------------------

* CES aggregation functions for Level 2 of production nest

 ADVAEQ(a)..     ADVA(a) =E= ((advab(a) + dabadva(a)) * ADVAADJ)
                                    + (DADVA * adva01(a)) ;

* CES Prod'n func'n
 QVAPRODFN(a)$(QVA0(a) and afx(a))..
        QVA(a)  =E= ADVA(a)*(SUM(f2$deltava(f2,a), deltava(f2,a)
                    *(ADFD(f2,a)* FD(f2,a))**(-rhocva(a)))
                      +(deltava("cnw",a)*QNW(a)
                      **(-rhocva(a)))$deltava("cnw",a))
                      **(-1/rhocva(a));

* FOC for the factor composite
 QVAFOC1(f2,a)$(deltava(f2,a)and afx(a) )..
        WF(f2)*WFDIST(f2,a)*(1 + TF(f2,a) )
          =E= PVA(a)*QVA(a)
             *(SUM(f2p$deltava(f2p,a),deltava(f2p,a)
             *(ADFD(f2p,a)*FD(f2p,a))**(-rhocva(a)))
             + (deltava("cnw",a)*QNW(a)
              **(-rhocva(a)))$deltava("cnw",a))**(-1)
             * deltava(f2,a)*ADFD(f2,a)**(-rhocva(a))
             * FD(f2,a)**(-rhocva(a)-1) ;

 QVAFOC2(a)$(afx(a)and deltava("cnw",a) )..
     PNW(a) =E= PVA(a)*QVA(a)
               *(SUM(f2p$deltava(f2p,a),deltava(f2p,a)
               *(ADFD(f2p,a)*FD(f2p,a))**(-rhocva(a)))
               + deltava("cnw",a)*QNW(a) **(-rhocva(a)))**(-1)
               * deltava("cnw",a)*QNW(a)**(-rhocva(a)-1) ;

 QVAEQ1(f2,a)$afxn(a)..
               FD(f2,a)*ADFD(f2,a) =E= ioffqva(f2,a)*QVA(a)  ;

 QVAEQ2(a)$afxn(a)..
               QNW(a)    =E=   ioqnwqva(a)*QVA(a);

 PVAEQ(a)$afxn(a)..
   PVA(a)  =E=  PNW(a)* ioqnwqva(a)
          +SUM(f2,ioffqva(f2,a)*WF(f2)*WFDIST(f2,a)*(1+TF(f2,a)));

* Intermediate Input Demand
```

```
 QINTDEQ(c)..   QINTD(c) =E= SUM(a,ioqtdqd(c,a)*QINT(a))
                                + SUM(a, QWAT2(c,a));

*------------- Level 3---------------------------------------------

 QNWPRODFN1(a)$(af3x(a) and an(a) )..
     QNW(a)  =E= atnw(a)*(SUM(f3$deltanw(f3,a),
                deltanw(f3,a)*(ADFD(f3,a)* FD(f3,a))**(-rhonw(a)))
                  +(deltanw("cwat",a)*QWAT(a)
                  **(-rhonw(a)))$deltanw("cwat",a))**(-1/rhonw(a));

* FOC for the factor composite

 QNWFOC1(f3,a)$(af3x(a) and deltanw(f3,a))..
      WF(f3)*WFDIST(f3,a)*(1 + TF(f3,a))
                  =E= PNW(a)*QNW(a)
                     *(SUM(f3p$deltanw(f3p,a),deltanw(f3p,a)
                     *(ADFD(f3p,a)*FD(f3p,a))**(-rhonw(a)))
                      + (deltanw("cwat",a)*QWAT(a)
                      **(-rhonw(a)))$deltanw("cwat",a))**(-1)
                      * deltanw(f3,a)*ADFD(f3,a)**(-rhonw(a))
                         * FD(f3,a)**(-rhonw(a)-1) ;

* FOC for the water-commodity composite

QNWFOC2(a)$(af3x(a) and deltanw("cwat",a) and SUM(f3,deltanw(f3,a)))
     PWAT(a) =E= PNW(a)*QNW(a)
                  *(SUM(f3p$deltanw(f3p,a),deltanw(f3p,a)
                  *(ADFD(f3p,a)*FD(f3p,a))**(-rhonw(a)))
                  + deltanw("cwat",a)*QWAT(a) **(-rhonw(a)))**(-1)
                  * deltanw("cwat",a)*QWAT(a)**(-rhonw(a)-1) ;

 QNWEQ1(f3,a)$af3xn(a)..
             FD(f3,a)*ADFD(f3,a) =E= iof3qnw(f3,a)*QNW(a) ;

 QNWEQ2(a)$(af3xn(a)or ann(a))..
              QWAT(a) =E= iocwatqnw(a)*QNW(a) ;

 PNWEQ(a)$ (af3xn(a) or ann(a))..
  PNW(a) =E= PWAT(a)*iocwatqnw(a)
     +SUM(f3,iof3qnw(f3,a)* WF(f3)*WFDIST(f3,a)*(1 + TF(f3,a)));

*------------- Level 4---------------------------

 WATDPRODFN(a)$(af4x(a) and awat(a) )..
  QWAT(a) =E= atwat(a)*(SUM(f4$deltafcwat(f4,a),deltafcwat(f4,a)
                *(ADFD(f4,a)* FD(f4,a)) **(-rhowat(a)))
               + SUM(cwat,deltafcwat(cwat,a)*QWAT2(cwat,a)
                            **(-rhowat(a))))**(-1/rhowat(a)) ;
```

```
 WATDFOC(cwat,a)$(af4x(a) and deltafcwat(cwat,a))..
    PQD(cwat)*PQDDIST(cwat,a)*(1+TWATA(cwat,a))
            =E=  PWAT(a)*QWAT(a)* (
                 SUM(f4p$deltafcwat(f4p,a),deltafcwat(f4p,a)
                * ADFD(f4p,a)*FD(f4p,a)**(-rhowat(a)))+
                  SUM(cwatp$deltafcwat(cwatp,a),
                  deltafcwat(cwatp,a)*QWAT2(cwatp,a)
                  **(-rhowat(a))))**(-1)
                 *deltafcwat(cwat,a)*QWAT2(cwat,a)**(-rhowat(a)-1) ;

* FOC  for factor prices

 FD4FOC(f4,a)$(af4x(a) and  deltafcwat(f4,a))..
         WF(f4)*WFDIST(f4,a)*(1 + TF(f4,a))
                 =E=  PWAT(a)*QWAT(a)*
                      (SUM(f4p$deltafcwat(f4p,a),deltafcwat(f4p,a)
                       * ADFD(f4p,a)*FD(f4p,a)**(-rhowat(a)))
                       +  SUM(cwatp$deltafcwat(cwatp,a),
                         deltafcwat(cwatp,a)*QWAT2(cwatp,a)
                         **(-rhowat(a))))**(-1)
                         * deltafcwat(f4,a)*ADFD(f4,a)**(-rhowat(a))
                         * FD(f4,a)**(-rhowat(a)-1) ;

QWATEQ1(c,a)$ (af4xn(a) and acwat(a))  ..
          QWAT2(c,a)=E= ioqwat(c,a)*QWAT(a)    ;

QWATEQ2(f4,a)$(af4xn(a) and afwat(a))..
         FD(f4,a)*ADFD(f4,a)  =E=  iof4aggf4(f4,a)*QWAT(a);

 PWATEQ(a)$(af4xn(a))  ..
         PWAT(a) =E=   SUM(c$cwat(c),ioqwat(c,a)*PQD(c)*PQDDIST(c,a)
                          *(1+TWATA(c,a)))
                     + SUM(f4, iof4aggf4(f4,a)*WF(f4)*WFDIST(f4,a)
                                *(1 + TF(f4,a)));

*-----------------------------------------------------------------
* Commodity Output

* CES aggregation of differentiated commodities

 COMOUT(c)$(cx(c) and cxac(c))..
             QXC(c) =E= adxc(c)*(SUM(a$deltaxc(a,c),deltaxc(a,c)
                       *QXAC(a,c)**(-rhocxc(c))))**(-1/rhocxc(c)) ;

 COMOUTFOC(a,c)$(deltaxc(a,c) and cxac(c)  )..
          PXAC(a,c) =E= PXC(c)*QXC(c)
                        *(SUM(ap$deltaxc(ap,c),deltaxc(ap,c)
                        *QXAC(ap,c)**(-rhocxc(c))))**(-1)
                       *deltaxc(a,c)*QXAC(a,c)**(-rhocxc(c)-1) ;
```

```
* Aggregation of homogenous commodities

 COMOUT2(c)$(cx(c) and cxacn(c))..
                  QXC(c) =E= SUM(a,QXAC(a,c)) ;

 COMOUTFOC2(a,c)$(deltaxc(a,c) and cxacn(c))..
               PXAC(a,c) =E= PXC(c) ;

* Activity Output

 ACTIVOUT(a,c)$ioqxacqx(a,c)..
               QXAC(a,c) =E= ioqxacqx(a,c) * QX(a) ;

* ######## FACTOR BLOCK

 YFEQ(f)..         YF(f) =E= SUM(a,WF(f)*WFDIST(f,a)*FD(f,a))
                             + (factwor(f)*ER) ;

 YFDISPEQ(f)..
    YFDISP(f) =E= (YF(f) * (1- deprec(f)))*(1 - TYF(f)) ;

* ######## HOUSEHOLD BLOCK
* ## Household Income

 YHEQ(h)..         YH(h) =E= SUM(f,hovash(h,f)*YFDISP(f))
                             + SUM(hp,HOHO(h,hp))
                             + SUM(e,HOENT(h,e))
                             + (HGADJ * hogovconst(h)*CPI)
                             + (howor(h)*ER) ;

* Household Expenditure

 HOHOEQ(h,hp)..
              HOHO(h,hp) =E= hohosh(h,hp)
                             *((YH(h) * (1 - TYH(h))) * (1 - SHH(h)))
;

 HEXPEQ(h)..     HEXP(h) =E= ((YH(h) * (1 - TYH(h))) * (1 - SHH(h)))
                             - SUM(hp,HOHO(hp,h)) ;

 QCDEQ(c,h) ..
    PQD(c)*QCD(c,h)  =E= PQD(c)*qcdconst(c,h)
                      + beta(c,h)
                      *(HEXP(h)-SUM(cp,PQD(cp)*qcdconst(cp,h))) ;

* ------- ENTERPRISE BLOCK ----------------------------------------
* ## Enterprise Income

 YEEQ(e)..         YE(e) =E= SUM(f,entvash(e,f)*YFDISP(f))
```

```
                            + (EGADJ * entgovconst(e) * CPI)
                            + (entwor(e)*ER) ;

* ## Enterprise Expenditure

 QEDEQ(c,e)..
               QED(c,e) =E= QEDADJ*qedconst(c,e) ;

 HOENTEQ(h,e)..
               HOENT(h,e) =E= hoentsh(h,e)
                            * (((YE(e) * (1 - TYE(e))) * (1 -
SEN(e)))
                            - SUM(c,QED(c,e)*PQD(c))) ;

 GOVENTEQ(e).. GOVENT(e) =E= goventsh(e)
                        * (((YE(e) * (1 - TYE(e))) * (1 - SEN(e)))
                             - SUM(c,QED(c,e)*PQD(c))) ;

 VEDEQ(e)..       VED(e) =E= SUM(c ,QED(c,e)*PQD(c)) ;

* ------- GOVERNMENT BLOCK ------------------------------------------
* #### Government Income Block

* ## Government Tax Rates

 TMDEF(c)..        TM(c) =E= ((tmb(c) + dabtm(c)) * TMADJ)
                                 + (DTM * tm01(c)) ;

 TEDEF(c)..        TE(c) =E= ((teb(c) + dabte(c)) * TEADJ)
                                 + (DTE * te01(c)) ;

 TSDEF(c)$(cd(c) OR cm(c))..
                   TS(c) =E= ((tsb(c) + dabts(c)) * TSADJ)
                                 + (DTS * ts01(c)) ;

 TEXDEF(c)$(cd(c) OR cm(c))..
                  TEX(c) =E= ((texb(c) + dabtex(c)) * TEXADJ)
                                 + (DTEX * tex01(c)) ;

 TXDEF(a)..       TX(a) =E= ((txb(a) + dabtx(a)) * TXADJ)
                                 + (DTX * tx01(a)) ;

 TFDEF(f,a)..     TF(f,a) =E= ((tfb(f,a) + dabtf(f,a))* TFADJ)
                                 + (DTF*tf01(f,a)) ;

 TYFDEF(f)..      TYF(f) =E= ((tyfb(f) + dabtyf(f)) * TYFADJ)
                                + (DTYF * tyf01(f)) ;

 TYHDEF(h)..      TYH(h) =E= ((tyhb(h) + dabtyh(h)) * TYHADJ * TYADJ)
                                + (DTYH * DTY * tyh01(h)) ;

 TYEDEF(e)..      TYE(e) =E= ((tyeb(e) + dabtye(e)) * TYEADJ * TYADJ)
                                 + (DTYE * DTY * tye01(e)) ;

 TWATDEF(c)..      TWAT(c)   =E= ((twatb(c) + dabtwat(c))* TWATADJ)
                                 + (DTWAT*twat01(c)) ;

 TWATADEF(c,a)..
          TWATA(c,a)=E= ((twatab(c,a)+dabtwata(c,a))* TWATAADJ)
                                 + (DTWATA*twata01(c,a)) ;

* ## Government Tax Revenues

 MTAXEQ..            MTAX =E= SUM(c,TM(c)*PWM(c)*ER*QM(c)) ;

 ETAXEQ..            ETAX =E= SUM(c,TE(c)*PWE(c)*ER*QE(c)) ;

 STAXEQ..            STAX =E= SUM(c,TS(c)*PQS(c)*QQ(c)) ;

 EXTAXEQ..           EXTAX =E= SUM(c,TEX(c)*PQS(c)*QQ(c)) ;

 ITAXEQ..            ITAX =E= SUM(a,TX(a)*PX(a)*QX(a)) ;

 FTAXEQ..
        FTAX =E= SUM((f,a),TF(f,a)*WF(f)*WFDIST(f,a)*FD(f,a)) ;

 FYTAXEQ..       FYTAX =E= SUM(f,TYF(f)*(YF(f) * (1- deprec(f)))) ;

 DTAXEQ..            DTAX =E= SUM(h,TYH(h)*YH(h))
                            + SUM(e,TYE(e)*YE(e));

 WATTAXEQ..          WATTAX  =E= SUM(c,TWAT(c)*PQS(c)*QQ(c));

 WATATAXEQ..
   WATATAX =E= SUM((c,a),TWATA(c,a)*PQD(c)*PQDDIST(c,a)*QWAT2(c,a)) ;

* ## Government Income

 YGEQ..               YG =E= MTAX + ETAX
                           + STAX + EXTAX + ITAX + FTAX
                           + FYTAX + DTAX
                           + WATTAX + WATATAX
                           + SUM(f,govvash(f)*YFDISP(f))
                           + SUM(e,GOVENT(e)) + (govwor*ER)  ;

* #### Government Expenditure Block

 QGDEQ(c)..       QGD(c) =E= QGDADJ*comgovconst(c) ;

 EGEQ..               EG =E= SUM(c,QGD(c)*PQD(c))
```

```
                              + SUM(h,hogovconst(h)*CPI*HGADJ)
                              + SUM(e,EGADJ*entgovconst(e)*CPI) ;

 VGDEQ..             VGD =E= SUM(c,QGD(c)*PQD(c)) ;

* ------- KAPITAL BLOCK -------------------------------------------
* ## Savings Block

 SHHDEF(h)..     SHH(h) =E= ((shhb(h) + dabshh(h)) * SHADJ * SADJ)
                               + (DSHH * DS * shh01(h)) ;

 SENDEF(e)..     SEN(e) =E= ((senb(e) + dabsen(e)) * SEADJ * SADJ)
                               + (DSEN * DS * sen01(e)) ;

 TOTSAVEQ..       TOTSAV =E= SUM(f,(deprec(f)*YF(f)))
                            + SUM(h,(YH(h) * (1 - TYH(h))) * SHH(h))
                            + SUM(e,(YE(e) * (1 - TYE(e))) * SEN(e))
                            + KAPGOV
                            + (CAPWOR*ER) ;

* ## Investment Block

 QINVDEQ(c)..     QINVD(c) =E= IADJ*invconst(c);

 INVESTEQ..       INVEST =E= SUM(c,PQD(c)*(QINVD(c) + dstocconst(c)))
;

* ------- FOREIGN INSTITUTIONS BLOCK ------------------------------
 YFWOREQ(f)..   YFWOR(f) =E= worvash(f)*YFDISP(f) ;

* ------- MARKET CLEARING BLOCK -----------------------------------

* ##### Account Closure

 FMEQUIL(f)..      FS(f) =E= SUM(a,FD(f,a)) ;

 QEQUIL(c)..
    QQ(c)  =E= QINTD(c) + SUM(h,QCD(c,h)) + SUM(e,QED(c,e))
                               + QGD(c) + QINVD(c) + dstocconst(c) ;

 GOVEQUIL..       KAPGOV =E= YG - EG ;

 CAEQUIL..        CAPWOR =E= SUM(cm,PWM(cm)*QM(cm))
                            + (SUM(f,YFWOR(f))/ER)
                            - SUM(ce,PWE(ce)*QE(ce))
                            - SUM(h,howor(h))
                            - SUM(e,entwor(e))
                            - govwor
                            - SUM(f,factwor(f)) ;
```

```
* #### Absorption Closure

 VFDOMDEQ..       VFDOMD =E= SUM(c, PQD(c) *
                                  (SUM(h,QCD(c,h)) + SUM(e,QED(c,e))
                                   + QGD(c) + QINVD(c) +
dstocconst(c))) ;

 INVESTSHEQ..
       INVESTSH * VFDOMD =E= INVEST ;

 VGDSHEQ..
          VGDSH * VFDOMD =E= VGD ;

 VEDSHEQ(e)..
       VEDSH(e) * VFDOMD =E= VED(e) ;

* ##### GDP

 GDPVAEQ..         GDPVA =E= SUM((f,a),WF(f)*WFDIST(f,a)*FD(f,a))
                             + MTAX + ETAX + STAX + EXTAX + ITAX + FTAX
                             + WATTAX + WATATAX  ;

* ##### Slack

 WALRASEQ..       TOTSAV =E= INVEST + WALRAS ;
```

A.1.5.4 Appendix 4: Example SAM

2004 SAM for Israel in 100 Million New Israeli Shekel

	ccrops	cvegfruit	cmixfarm	cagri	cind	cser	cwatpot	cwatrec	cwatsal	acrops	avegfruit	amixfarm	aagri	aind	aser	awatpot	awatrec	awatsal	awatdsal	flab	fcap	fland	fwat	hj	hao	twat	twata	tother	gov	ent	kap	row	**TOTAL**
ccrops										3.17	2.68	3.08	4.36	9.55	1.18									9.42	1.39						2.74	17.61	**55.18**
cvegfruit										0.01	0.20	0.01	0.09	10.43	8.46									71.14	13.66						0.29	24.11	**128.37**
cmixfarm										0.01				0.50	13.37	0.16	0.01		0.05					6.00	1.14						1.63	0.17	**23.06**
cagri										0.08	0.25	0.32	10.30	83.15	4.09									17.77	3.70						1.06	9.49	**130.21**
cind										7.64	21.99	6.15	26.47	1498.61	917.02	9.70	1.16	0.21	2.44					1014.80	160.44						425.65	1635.01	**5727.31**
cser										11.49	57.19	0.69	25.91	1000.80	2260.66	7.61	0.64	0.20	1.24					1606.05	230.94				1495.46		555.74	660.77	**7915.40**
cwatpot										4.94	14.77	0.41	4.18	4.86	9.83									17.73	3.07								**59.80**
cwatrec										0.88	2.62	0.06																					**3.55**
cwatsal										0.48	1.44																						**1.93**
acrops	38.09				1.02																												**39.11**
avegfruit		124.55			0.44																												**124.99**
amixfarm			20.82																														**20.82**
aagri				95.98	0.92																												**96.90**
aind				6.14	3382.14																												**3388.29**
aser					10.64	7196.40																											**7207.04**
awatpot							31.34																										**31.34**
awatrec								2.70																									**2.70**
awatsal									0.68																								**0.68**
awatdsal							3.04																										**3.04**
flab										8.56	18.79	8.96	16.67	700.35	2607.80	5.87	0.41	0.15	0.33													13.35	**3381.25**
fcap										4.63	13.64	1.17	10.82	66.80	1257.59	3.61	0.45	0.10	0.84													121.20	**1480.84**
fland										0.47	1.25	0.05	0.25																				**2.02**
fwat																4.04																	**4.04**
hj																				2708.60	62.34			17.38	2.51				588.83	290.29		105.90	**3775.85**
hao																				356.09	3.97			3.92	0.33				99.78	28.63		17.73	**510.45**
twat							21.35	0.61	1.11																								**23.06**
twata										-3.71	-11.08	-0.31	-3.14	-2.46																			**-20.69**
tother	0.30	-1.89	1.20	3.81	493.86	259.65	4.07	0.23	0.14	0.46	1.24	0.25	0.99	15.71	127.02	0.35	0.02	0.01	-1.85	217.19				550.03	38.88					263.45		7.58	**1982.71**
gov																							4.04			23.06	-20.69	1982.71				149.40	**2138.53**
ent																					1214.62	2.02							40.10				**1256.73**
kap																								461.61	54.37				-85.64	674.37	53.31	-117.60	**1040.42**
row	16.79	5.71	1.03	24.28	1838.29	459.35														99.36	199.91												**2644.73**
TOTAL	**55.18**	**128.37**	**23.06**	**130.21**	**5727.31**	**7915.40**	**59.80**	**3.55**	**1.93**	**39.11**	**124.99**	**20.82**	**96.90**	**3388.29**	**7207.04**	**31.34**	**2.70**	**0.68**	**3.04**	**3381.25**	**1480.84**	**2.02**	**4.04**	**3775.85**	**510.45**	**23.06**	**-20.69**	**1982.71**	**2138.53**	**1256.73**	**1040.42**	**2644.73**	**43179.65**

Legend of accounts

Commodities		Activities		Factors and Taxes		Others	
ccrops	field crops	acrops	field crops	flab	labour	gov	government
cvegfruit	fruits and vegetables	avegfruit	fruits and vegetables	fcap	capital	ent	enterprises
cmixfarm	mixed farming, gardening, forestry	amixfarm	mixed farming, gardening, forestry	fland	Land	kap	capital and stock changes
cagri	other agriculture	aagri	other agriculture	fwat	fresh water resources	row	rest of the world
cind	industrial commodities	aind	industrial activities	hj	Jewish households		
cser	service commodities	aser	services	hao	Arab and other households		
cwatpot	potable water	awatpot	fresh water purification	twat	water commodity tax		
cwatrec	reclaimed water	awatrec	wastewater reclamation	twata	water user subsidy		
cwatsal	brackish water	awatsal	pumping of brackish water	tother	other taxes		
		awatdsal	desalination				