האוניברסיטה העברית בירושלים
The Hebrew University of Jerusalem

המרכז למחקר בכלכלה חקלאית
The Center for Agricultural Economic Research

המחלקה לכלכלה חקלאית ומנהל
The Department of Agricultural Economics and Management

Discussion Paper No. 10.07

A General Equilibrium Analysis of Conjunctive Ground and Surface Water Use with an Application to Morocco

by

Xinshen Diao, Ariel Dinar, Terry Roe and Yacov Tsur

P.O. Box 12, Rehovot 76100

ת.ד. 12, רחובות 76100

A General Equilibrium Analysis of Conjunctive Ground and Surface Water Use with an Application to Morocco

Xinshen Diao[1], Ariel Dinar[2], Terry Roe[3], Yacov Tsur[4]

Revised: March 2007

Abstract: Groundwater resources (GW) account for nearly 30 percent of the world sustainable water supplies. Yet, this resource, which is fraught with externalities, has largely been left unregulated. The economic literature on GW is predominantly of a partial equilibrium type, taking the rest of the economy parametrically. We analyze GW regulation in a general equilibrium setting, focusing on the stabilization value of GW under natural (draught) and economic (rural-urban water transfer) shocks. A general equilibrium approach allows evaluating direct and indirect effects of GW regulation on agriculture and non-agriculture sectors and extends the scope for water policy. The analysis is applied to Morocco by extending an existing computable general equilibrium (CGE) model to include ground and surface water (SW) resources. We study effects of (i) an increase in GW extraction cost (e.g., as a result of prolonged extraction beyond natural recharge that lowers the aquifer's water table), (ii) a transfer of SW from rural (irrigation) to urban (domestic) use, and (iii) a reduction of water availability due to severe drought. We estimate the value of GW and assess the direct (partial equilibrium) and indirect (general equilibrium) impacts. We find that GW has a critical role in mitigating the negative effects of these types of shocks.

---

[1]Development Strategy and Governance Division, International Food Policy Research Institute, 2033 K Street, NW Washington DC, 20006 USA (x.diao@cgiar.org).

[2]Agriculture and Rural Development Department, The World Bank , 1818 H Street, NW, Washington DC, 20433, USA (adinar@worldbank.org).

[3]Department of Applied Economics, University of Minnesota, St. Paul

[4]Department of Agricultural Economics and Management, The Hebrew University of Jerusalem, P.O. Box 12, Rehovot 76100, Israel (tsur@agri.huji.ac.il).

1. Introduction

Groundwater provides nearly 30 percent of the annually renewable freshwater resources worldwide, compared to the (surprisingly) tiny 0.3 percent provided by lakes and rivers and 0.9 percent due to soil moisture, swamps and permafrost (WMO, 2005).[5] As many as two billion people depend directly on aquifers for drinking water, which provide 30 to 75 percent of drinking water supply in Europe, Asia-Pacific, Central and South America, and the USA. About 40 percent of the world's food is produced by irrigated agriculture that derives water mainly from GW aquifers (UNEP, 2003). Population growth coupled with industrial and agricultural pollution lead to a decline in fresh water supplies, both in absolute and per capita values. Water use has increased six-fold since 1900. By 2025 per capita fresh water supplies are expected to shrink to a half of their current level and today they are only half of what they were in 1960. In many arid and semi-arid regions GW has been the only source of water for all purposes. Where lakes and rivers are drying out, GW is the main (if not only) possible alternative to the diminishing SW supplies (WMO, 2005).

Aquifers have a number of properties that make them desirable water sources. First, they can serve as "buffer storage" during periods of water shortage in SW supplies, thus stabilizing and amending fluctuating and dwindling SW sources. Second, aquifer water is typically of good quality because of natural purification processes. Third, GW is less susceptible to pollution compared to SW. Our focus in this work is on the first characteristic, namely the stabilizing role of GW when SW supplies fluctuate both within (intra) and between (inter) years, which calls for conjunctive water management. The term conjunctive signifies that the ground and SW sources are two components of one system and should be analyzed as such.

The benefits from conjunctive management increase with the scarcity and variability of precipitation, both of which are critical in many parts of the world. These benefits are further enhanced due to the increased water demand from a growing

[5] Similar estimates are reported also in Shiklomanov (1999) and Clarke and King (2004).

population, and due to climate change, which tends to exacerbate unexpected events such as floods and extended droughts. In spite of the above-mentioned features, in actual practice GW is rarely managed conjunctively with SW, it is often misused and rarely incorporated into the water system (WMO, 2005). The present work addresses these issues.

The economics of conjunctive water use was initiated by Burt (1964), who was the first to recognize the importance of treating ground and SW as two elements of a unified water system. Tsur (1990) and Tsur and Graham-Tomasi (1991) introduced the notions of Stabilization Value and Buffer Value of GW when SW supplies are uncertain. Surface water supplies derived from rainfall and snowmelt fluctuate randomly from year to year and within a year. Groundwater stocks, on the other hand, are relatively stable because the slow subsurface flows tend to smooth out temporal fluctuations. Groundwater thus performs a dual function, *increasing* the mean and *reducing* the variability of total water supply. The variability-reducing role of GW carries an economic value, which is designated as the stabilization value (or buffer values in the dynamic context) of GW. Empirical studies (Tsur 1990, 1997, in Israel and California) found that the stabilization value amounted to more than 50 percent of the total value of GW. He concluded that assuming stable SW supplies in these cases would have lead to a substantial undervaluation of GW. Other work that deals with conjunctive management aspects include Provencher and Burt (1994) and Knapp and Olson (1995).

Why should we be interested in the stabilization value as a distinct concept? Suppose that a GW development project can be implemented at some cost and the decision whether or not to undertake the project is based on a cost-benefit criterion. Clearly, determining the benefit generated by the GW project assuming that SW is stable at the mean, while easier to obtain, ignores the stochastic nature of SW supplies and the ensuing stabilization value. If the stabilization value of GW is non-negligible, this simpler approach can lead to a serious underestimation of the GW benefit and bias assessment of the GW project.

A conjunctive ground and SW system appears in a number of forms, which differ according to the ground and SW sources. Surface water may consist of stream flows

emanating from aquifers, surface reservoirs or lakes, snowmelt, rainfall or any combination of these. It may be stable or stochastically fluctuate over time. Aquifers may be non-replenishable or replenishable, deep or shallow, confined or unconfined. The two cases in which only SW or only GW is used lie on both ends of the conjunctive spectrum; these extreme cases occur when one source is always cheaper than the other (scarcity cost included). Conjunctive systems, viewed in this larger context, encompass most possible cases.

Groundwater serves mainly irrigators and urban households. In regions where the share of agriculture in total GDP and employment is non-negligible, its impact can extend beyond the local farm or region, especially during years of low water availability, by releasing SW for use in other sectors. Previous GW studies were limited in that they focused on local and partial equilibrium effects. For example, recent work on GW-SW conjunctive use (e.g., Hafi, 2003; Pulido-Velazquez, 2004, 2006) extended the basis for economic analysis in the context of a given aquifer, basin and region. However, with such a vital role in the livelihood and development prospects of billions of people around the Globe, addressing GW only through partial/local considerations may lead to suboptimal water use and misleading policy recommendations.

To empirically evaluate the importance of conjunctive management in a general equilibrium setting, we extend the CGE model of Diao et al. (2005) to include surface and GW as two "intermediate sectors". We then use the model to assess the total value of GW under three situations commonly faced by water scarce economies, and Morocco in particular. These are (i) an increase in GW extraction cost, (ii) a transfer of SW from rural (irrigation) to urban (domestic) use, and (iii) a reduction of surface water availability. An increase in GW extraction costs comes about from an increase in energy costs or a decrease in the water table. The need to transfer water from rural to urban use comes about as economies grow, urban centers expand and larger share of the economy's resources are allocated to the production of manufactured and service goods. Because these major centers typically only dominate certain geographic areas of a country, the repercussion on adjacent rural areas is, at the margin, to decrease their comparative advantage in water intensive crops, and to increase their use of GW relative to more distant rural areas. Variation in SW results from a decrease in precipitation in water

holding areas, such as a decline in the accumulation of snow in the Atlas mountains of Morocco. The empirical results show that each of these effects has economy-wide implications. We find that GW is a critical resource in regions that face major water supply fluctuations and from swelling urban water demand. We also find that greater GW dependency does not necessarily lead to lower profitability when extraction costs of GW increase.

2. Background for the CGE analysis

We apply our analysis to the case of Morocco, where rainfall fluctuations and rural-to-urban water transfers are influential shocks affecting irrigators. We begin in this section with a brief background of the economic and water situation in Morocco, relevant to the present work (a detailed discussion can be found in Tsur et al. 2004). The CGE analysis is presented in the next section.

2.1 The agricultural sector and water resources in Morocco

Moroccan agriculture accounts for about 15 percent of the country's gross domestic product and employs about 40 percent of the country's labor force. Of the 9.2 million hectares of arable land, ten percent is irrigated but the products from irrigated agriculture account for 75 percent of total primary and processed agricultural exports.

Morocco has invested heavily in developing its water resources, and is now reaching the physical limits of water availability from surface sources (snowmelt in the Atlas mountains). The management of this critical resource for irrigation is carried out by nine administrative regional authorities (ORMVAs) in each of the nine large scale irrigation schemes, seven of which account for over 90 percent of the total irrigation water managed by the public authority. The problem faced by the regional ORMVAs is how to increase returns to SW. The irrigated sector consumes about 85 percent of the country's total available water supplies. Besides the uneven geographic distribution of the country's water resources, an uneven and erratic rainfall pattern persists with large year-to-year fluctuations from the arid South to the Northern regions. This erratic pattern places pressures on the extraction of ground water using largely imported energy, and thus accounts for the shock to GW cost.

A second major challenge is the growth in urban water demand. While 85 percent of water is consumed by agriculture, urban demand for water has grown much more rapidly than that in agriculture. Further, the per capita consumption of water varies substantially across urban centers in Morocco. Casablanca, the country's largest city, averages 147.7 liters of water per day per capita (Saghir, et al, 2000), the highest of any major city among the MENA countries. However, this value is much lower than the USA equivalent of 493 liters per person per day or London's 260 liters per person per day.

Urban growth in water demand places uneven regional pressures on SW needs of irrigated areas closest to the country's major cities. Reallocating of SW from adjoining irrigated areas to supply the major cities tends to decrease the regional comparative advantage of irrigated agriculture in these regions at some possible benefit to irrigated agriculture located farther from the major cities. The extent to which the reallocation of SW to cities affects adjoining areas depends on the cost they face in replacing the SW with ground water. More distant areas may gain in comparative advantage as the higher cost of producing crops from ground water supplies causes some resources to move from one region to another.

Like many other water scarce economies, Morocco experiences erratic patterns of precipitation that affects the accumulation of snow in the Atlas mountains, the source of SW for irrigation that further complicates water policy at national and regional levels. Morocco has faced more than 10 severe droughts, county wide, in the past century. The most important recent ones are those of 1982-1983 and 1994-1995. Drought is becoming of frequent occurrence, almost every other year in the 1990s with serious impacts on the agricultural production and the economy as a whole, affecting the AG GDP and GDP by up to 50 percent and 10 percent per event, respectively (Moroccan Academy of Science, 2000).

2.2 Water availability and use

Morocco's renewable water resources are estimated at 29 billion cubic meters (BCM) per year, of which renewable GW resources are 4 BCM. GW extraction is estimated at 2.6 BCM per year (Ruta 2006). As Morocco approaches its physical limit (Table 1) in the

allocation of SW supplies to the economy, the cost of pumping GW and consequent external costs are likely to become increasingly important. While our pumping cost data, and subsequent analysis, is limited to the single region of Souss-Massa, it is evident that this is an emerging national problem. Table 1 below demonstrates the acute situation as of 1990, which has only been deteriorated in the past 15 years by 2006.

Table 1: Supply of and Usage for Water in Eight Basins in Morocco in 1990 (MCM**)**

Basins	Supply of Water			Demand for Water				Balance
	Surface	Groundwater	Total	Municipal and Industry	Irrigation	Other	Total	
Loukkos	630	90	720	110	380	230	720	0
Moulouya	930	230	1,180	70	1,090	0	1,180	0
Sebou	1,690	350	2,040	230	1,560	60	1,840	160
Bou Regreg	310	250	560	380	160	30	570	30
Om-er-Rbia	3,010	280	3,290	190	2,490	80	2,740	360
Tensift	880	850	1,330	150	1,300	150	1,800	-80
Souss-Massa	300	590	890	60	890	0	950	-60
South of Atlas	710	290	1,000	20	1,330	0	1,350	-350
Total	**8,260**	**2,730**	**10,990**	**1,210**	**9,190**	**530**	**10,930**	**60**

Source: Doukkali (2005)

Over 50 percent of Morocco's 8.7 million hectares of cropland is located in regions with average annual precipitation below 400 mm. Moreover, even in the wetter regions, rainfall fluctuates quite substantially from year to year, as can be seen from the chart below. For example, in 1982, Morocco received less than 60 % of mean rainfall. In 1994, six of Morocco's 11 hydrological basins faced more than 50% deficit in their water balance (Doukkali 2005).

Because of both the inter-annual and spatial variation on rainfall, Morocco's water sector has to be heavily dependent on storage. The scarcity of rainfall in certain regions explains the increasing reliance on irrigation. The large rainfall fluctuations imply that SW alone is an unreliable source, necessitating the use of GW conjunctively with SW.

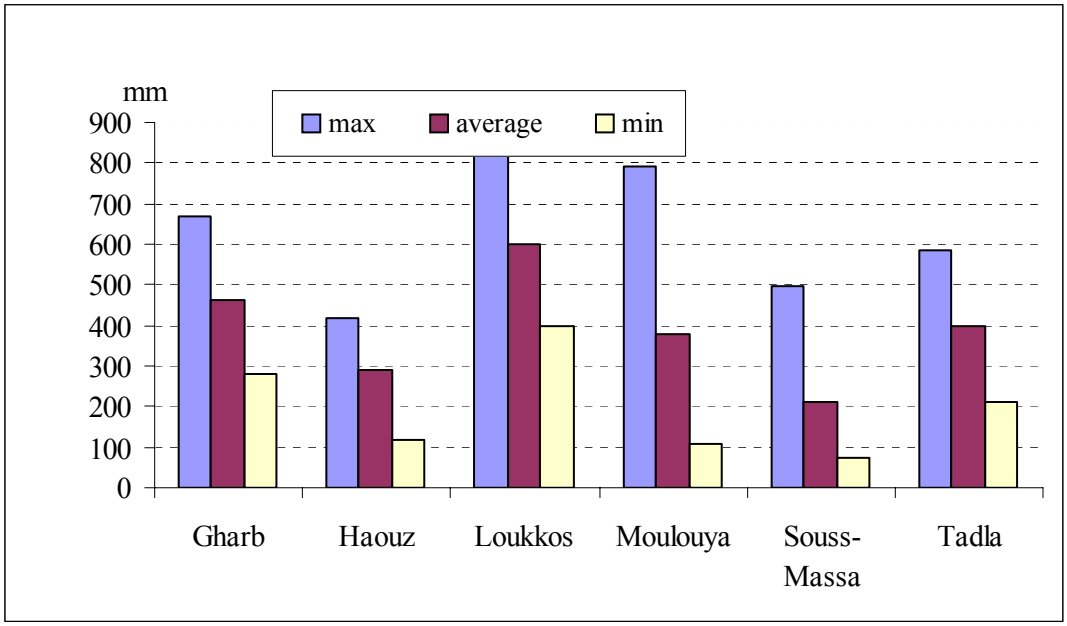


Figure 3: Annual rainfall fluctuations in 6 Moroccan regions.

Source: An unpublished memo (Doukkali, 2001)

2.3 Urban water demand

As in the case of many developing countries, the growth in urban household demand for water is increasing due to three major factors: (1) high rates of rural to urban migration, (2) the country's efforts to speed-up the provision of municipal services which has tended to lag migration over the last decade, and (3) the growth in urban disposable income. Currently, about half of Morocco's 30.1 million people live in urban areas and by 2010 it is projected to increase to 70 percent. This growth in urban population is about 5.5 percent per annum, which is more than double the country's average population growth rate of 2.4 percent per annum.

The 1989 census found that 23 percent of the urban population lives in precarious and illegally built shacks and substandard housing built without permit on un-serviced land. The government of Morocco (GOM), with the help of international agencies (in 1993 the World Bank lent $130 million to upgrade these areas) is making major investments in urban infrastructure to provide sanitary, water and electrical services to these areas. Satisfying this pent-up demand is also expected to account for the major

source of growth in urban residential water demand. The growth in water demand due to growth in per capita income is expected to have the smallest effect on total demand. Growth in the country's real disposable per capita income has averaged a dismal 1.2 percent over the period 1992-02 (WDI, 2004). However, the growth in urban income has exceeded this average by about 1 percentage point per year over the same period.

Together, these three factors are expected to increase residential household consumption of water by about 48 percent by the year 2010, and by about 86 percent by the year 2025 (these estimates correspond closely to those of Rosegrant et al, 2002, which in turn are derived from the work of Shiklomanov, 1999 and Gleick, 1993).

Estimates of Morocco's industrial consumption of water (i.e., non-residential, non-farm) are difficult to find. Rosegrant et al, 2004, draw upon the estimates of Shiklomanov, 1999 and Gleick, 1993 for the case of North Africa. They estimate that in 1995, industrial water use accounted for about 45 percent of North Africa's urban water consumption. By the year 2010, they estimate industrial water consumption to grow by about 34 percent of the 1995 base, and to grow about 75 percent of this base by 2025. Industrial demand varies by urban area depending upon composition of the sector, with wood pulp and paper processing being a relatively intensive user of water, while construction activities consume little water.

Our rural-urban transfer analysis is applied to the Casablanca area – the biggest urban center in Morocco. The data available for the Moroccan social accounting matrix does not include industrial water consumption, thus we must extrapolate consumption for Casablanca from the above mentioned estimates. These appear in Table 2.

Water supply to Morocco's major cities varies by source, by management, and by the way in which wastewater is treated. In the case of Casablanca, Saghir et al (2000) indicate that water supply to households and most enterprises are managed under contract with the private sector. Morocco's cities generate about 350 million cubic meters of wastewater of which about 50 million cubic meters are reused. In the case of Casablanca, about 70 percent of wastewater is treated.

Table 2: Water consumption in the city of Casablanca, Morocco

	Annual per capita water consumption	Annual household consumption[2/]	Annual non-household consumption[2/]	Total Water Consumption
	Cubic meter per person per year	Million Cubic Meter (MCM) per year	MCM per year	MCM per year
2000 (actual)[1/]	53.5	103	84.3	187.2
2010 (estimated) [4/]	53.5	183.2	149.9	333.1

1/ Source: Saghir et al (2000)
2/ Water share allocation for urban household is 0.55 and 0.45 for industrial use. Estimates are taken from Appendix table B.2 in Rosegrant et al., 2004. Population growth rate in Casablanca is estimated at 5.76 percent.
3/ Casablanca's population in 2000 was 3.48 million
4/ Per capita water consumption is assumed to remain unchanged.

As cities grow in size, the cost of water supplies and sanitation is rising because water has to be supplied from further away. As mentioned above, of the 147.4 liters of water per capita supplied to residents of Casablanca, over 35 percent is unaccounted for (i.e., unmetered). Moreover, water tariffs are reportedly below levels needed to meet cost recovery.

The main source of water supply to Morocco's major metropolitan areas is SW. The potential growth in demand mentioned above is thus likely to place high demands on SW used in irrigation. This growth in demand is likely to strike the hardest those ORMVA areas closest to the Morocco's major cites. The three ORMVA areas are Doukkla, which supplies the majority Casablanca's water, Haouz ORMVA which is a major supplier of water to Marrakech, and the ORMVA of Souss-Massa which supplies water to the Agadir area.

3. Empirical application and simulation results

We extend the computable general equilibrium-water (CGE-water) model of Diao et al. (2005) by including ground water and urban demand. The spatial identification of the irrigation districts and urban centers is particularly important for such analysis because of

the spatial heterogeneity of irrigated agriculture, the proximity of major metropolitan areas to some irrigation districts whose growth affects the scarcity of water in some regions relative to others, and the obstacles of transporting water over distance and elevation. Constrained by the data, however, we only consider the ground water in the 3 irrigation districts adjacent to the Casablanca metropolitan area, which is assumed to represent urban water demand.

3.1 A spatially disaggregated CGE model with water

Two distinguished features have made the model used for this study different from most other CGE models. First, the model disaggregates Moroccan economy (irrigated agricultural economy) spatially according to 7 major irrigation regions and 21 water districts, which will be discussed in detail later. Second, the model explicitly captures irrigated water as an input in crop production. Because of this, the model considers quite disaggregate crop activities such that crop-specific water demand in their production process can be captured. In this paper, by including groundwater and urban water demand, the model further links irrigated water with urban economy through competition between rural and urban over surface water. While due to the data constraint, water demand in the livestock sector is not considered, livestock production are included in the model as five production activities, and hence, the inter-linkage between crop and livestock is captured on both production and consumption sides.[6]

While the metropolitan Casablanca area receives special attention in water demand, as it is the country's largest urban center, the non-agricultural component of the economy is fully captured by 11 agriculture-processing sectors and 6 nonagricultural sectors. On the trade side, since the European Union (EU) is the major trading partner, Morocco's imports and exports between the rest of the world and the EU are identified separately at commodity level. The model also considers five different macroeconomic policy instruments that are embedded in the data, including taxes, subsidies, tariffs, and payments for water.

[6] For example, coarse grain and fodder, a by product of cereal production, are explicitly modeled as inputs for livestock production, and there exists substitution between livestock products and other agricultural and nonagricultural commodities in the household demand functions.

As mentioned above, Morocco's irrigated agriculture is modeled into seven separate geographic districts corresponding to the 7 major irrigation authorities located in these respective regions. Within each of these 7 regions, two to four separate irrigation perimeters are identified. The perimeters are independent in the sense that they are at different elevations, access different primary water sources or are otherwise separated by other physical barriers. For this reason, the model does not permit water to be allocated across perimeters within any of the 7 regions. The number of perimeters is totally 21. Among the 71 primary agricultural activities, 66 are in crop production, which are captured spatially as irrigated and non-irrigated, and within or outside the ORMVAs. There are totally 33 crop production activities within the water irrigation authority perimeters, of which, 21 are irrigated crop production and 11 are rain-fed since not all of the land within an irrigation district is irrigated. Detailed mathematical description of the extended CGE-water model for Morocco can be found in Appendix 1[7].

The data[8] are organized into a social accounting matrix (SAM). The data include perimeter level information on water charge fees,[9] cropping mix, water and land allocation by crop and area, employment of labor and capital and intermediate input use by crop. National level data on employment, trade, non-farm production and resource flows are also entered into the SAM. These data are used to calculate the parameters of the model in such a manner that a solution of the model reproduces the base data exactly. This solution is referred to as the base.

---

[7] The program code and the data used for the analyses can be obtained from the corresponding author upon request.

[8] The World Bank closed in 2000 the project PSDA (Project de Soutien Au Developpment Agricole dans les Perimeters Relevant des ORMVA, Loan 3688-MOR) in Morocco. One important component in that project was the OTE (Technical and Economical Observatory). This component comprises a detailed survey that was conducted by DPAE (Direction de la Programmation et des Affaires Economiques). It consisted of farms' survey in all nine water districts (ORMVAs) in Morocco (Gharb, Loukkos, Doukkala, Tadla, Souss-Massa, Moulouya, Haouz, Tafilalate, Ouarzazate). A sample of representative farms in each ORMVA were included in the survey that took place during 1996/7-1998/9. A total of 296 farms were included in the 3 year survey. The data for one year 1996/7 was already processed by DPAE, and was made available to us. The variables in the data set include for each farm and each crop for the full growing year: (1) all detailed production outputs (in physical and monetary values) of field crops and livestock, production factors and production cost of purchased and non-purchased inputs, including a very detailed accounting of irrigation water; (2) physical characteristics (soil, technologies, etc…), and human capital variables characterizing the farm operators.

[9] Due to that data about irrigation water demand and water charge fee outside water irrigation authority is not available. Therefore we focus on the 21 irrigation districts in the analysis related to any shock on the water supply, marginal cost of water and quantitative constraints

3.2 Results of increasing groundwater costs

Groundwater costs can increase for numerous reasons, including the lowering of the water table caused by draught and over-pumping, or a rise in energy costs. Increases in the marginal costs of GW are modeled for the three water districts in Souss-Massa ORMVA only due to the data constraint. That is, the availability of data restricts our analysis of GW from being applied to the other regions, and hence, we have to ignore GW as an input in irrigated agriculture for the rest of the economy. An increase in GW marginal costs is modeled as an exogenous shock in the simulation. Specifically, we exogenously increase the variable cost of GW supply by 20 percent and solve the model to obtain a new equilibrium solution. We compare the values of a number of endogenous variables at the new equilibrium with their base levels (given in the data). In order to depict the main effects associated with this shock to the economy, we use the following flowchart to illustrate the inter-linkages between GW and the rest of economy.

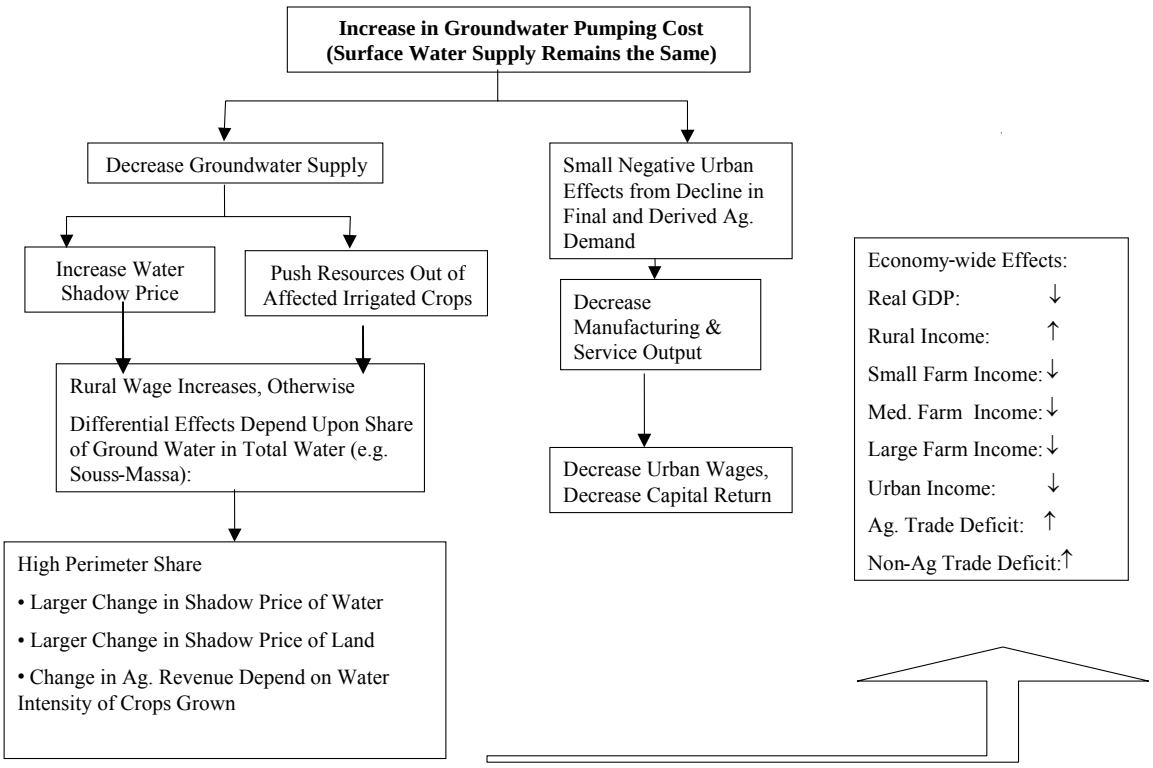


Figure 4: Flow chart of the major effects of a ground water shock on the economy

The left hand panel of the flowchart focuses on the agriculture and rural economy. The immediate effect of increased GW costs is the decline in GW supply. Since the

government's assignment of SW supply is binding, total water available to agriculture falls due to the increase in GW cost. The decline in ground water supply causes an increase in the shadow price of surface irrigation water, and a reduction in irrigated water demand. In general equilibrium, other resources are also affected since the reduction in water tends to decrease their marginal product. Consequently, at the margin, other resources are pushed out of irrigated crop production and into non-irrigated crops (water and other inputs are not perfect substitutes and need to be combined in crop production). This can increase or decrease rural wages, depending on whether agricultural production in the irrigated crops is more or less labor intensive. In the present case we observe a small increase in rural wage of 0.12 percent (Table 3, column 2). The decline in value added in the food processing of irrigated crops has an even smaller, though detectable, negative effect on urban wages. The flowchart (Figure 4, right panel) also indicates the direction of economy-wide effects, which are mostly negative. As the role of GW in the overall economy is small, these effects are modest (Table 3).

Given different GW dependencies across regions, a similar increase in GW cost may have a differential effect across perimeters on water price, returns to land and farm revenue. Results are shown in Table 4 for the case of three water districts in Souss-Massa region. The GW dependence rates (share of GW in total irrigation water) in this region are 13.5, 34.3 and 29.2 percent, respectively, in perimeters 1, 2 and 3 The shadow price of water rises in all three perimeters, ranging from 12.9 to 27.3 percent of the base values (row two, Table 4). The increased scarcity of water lowers the productivity and hence returns to land by 2.3 to 5.7 percent, relative to base. The effect on farm revenue in each perimeter also depends on the level of water intensity of crops grown in this perimeter. That is, the share of water costs in the total cost of growing a particular crop. The lower the share of water costs in total cost, the less farm revenues are affected by a decline in water availability. Consequently, the perimeter with higher dependence on GW may not necessarily be afflicted more than other perimeters. This relationship explains why farm revenues are negatively affected by about 3.8 percent in perimeter 1 which is has a dependency rate of 13.5 percent (column 1), compared to perimeter 2 where the dependency rate is higher but the effect on farm profits are modestly lower, 3.6 percent (column 2).

Table 3: Macroeconomic effects of groundwater, drought and urban water demand shocks on the Moroccan economy.

	Base	Groundwater shock	Surface water shock*	Urban shock
		---------- Percent change from the base ----------		
All perimeters real output	6,741	-1.65	-11.20	-2.65
All non-perimeters crop output	27,160	0.11	0.53	0.09
All non-perimeters real output	60,711	0.02	0.07	-0.87
Real GDP	323,781	-0.04	-0.41	1.24
Total consumption	26,294	-0.06	-0.60	0.14
Total rural income	69,594	0.01	-0.37	-0.82
Rural wage income	13,776	0.14	-0.33	-1.41
Small farm income	18,313	-0.03	-0.71	-1.45
Medium farm income	20,651	-0.03	-0.30	-0.58
Large farm income	16,854	-0.01	-0.12	0.04
Urban Income	204,659	-0.03	-0.28	1.65
Return to capital in crop production	1.00	0.19	0.50	-0.91
Return to capital in livestock production	1.00	-0.22	-2.59	-4.08
Return to non-ag capital	1.00	-0.03	-0.33	1.74
Rural wage	0.72	0.12	-0.56	-1.45
Urban wage	1.00	-0.02	-0.26	1.71
Agricultural trade surplus				
Ag with EU	3,530	-1.53	-13.58	-3.39
Ag with ROW	-4,419	0.35	2.61	-0.23
Nonag trade surplus				
Nonag with EU	402	9.76	8.56	37.72
Nonag with ROW	-10,155	-0.30	-2.47	0.41

* SW shock is introduced only in the 21 irrigated districts.

Table 4: Differential effects of increased groundwater costs in the three perimeters of Souss-Massa

	Perimeter 1	Perimeter 2	Perimeter 3
Share of groundwater in total irrigation water	13.5	34.3	29.2
Change in water shadow price (% of base)	12.9	27.3	21.1
Change in total irrigation water demand (% of base)	-8.2	-20.7	-17.7
Change in returns to land (% of base)	-3.3	-5.7	-2.3
Change in farm revenues (% of base)	-3.8	-3.6	-2.7

3.3 Results of a decrease in surface water allocation

Next, we consider a situation in which the availability of SW is reduced due to a decline in the amount of snow and rainfall in the Atlas Mountains. We choose a negative reduction of one standard deviation from a ten year average annual supply of SW. For this analysis, we presume no change in ground water supplies, although these supplies may actually decline in some regions. Lack of data prevents us from better characterizing this situation. The flowchart in Figure 5 illustrates the major effects due to this shock.

The left hand panel of Figure 5 focuses on the rural economy. A decrease in SW allocated to irrigation increases the shadow price of irrigation water, which in turn induces an increase in the use of ground water to substitute for the reduction in SW. However, since the marginal cost of GW supply is fairly inelastic due to its very high share in total water supply, the SW replaced by ground water is only partial so that total water allocated to production is a fraction of the water observed in the base solution.

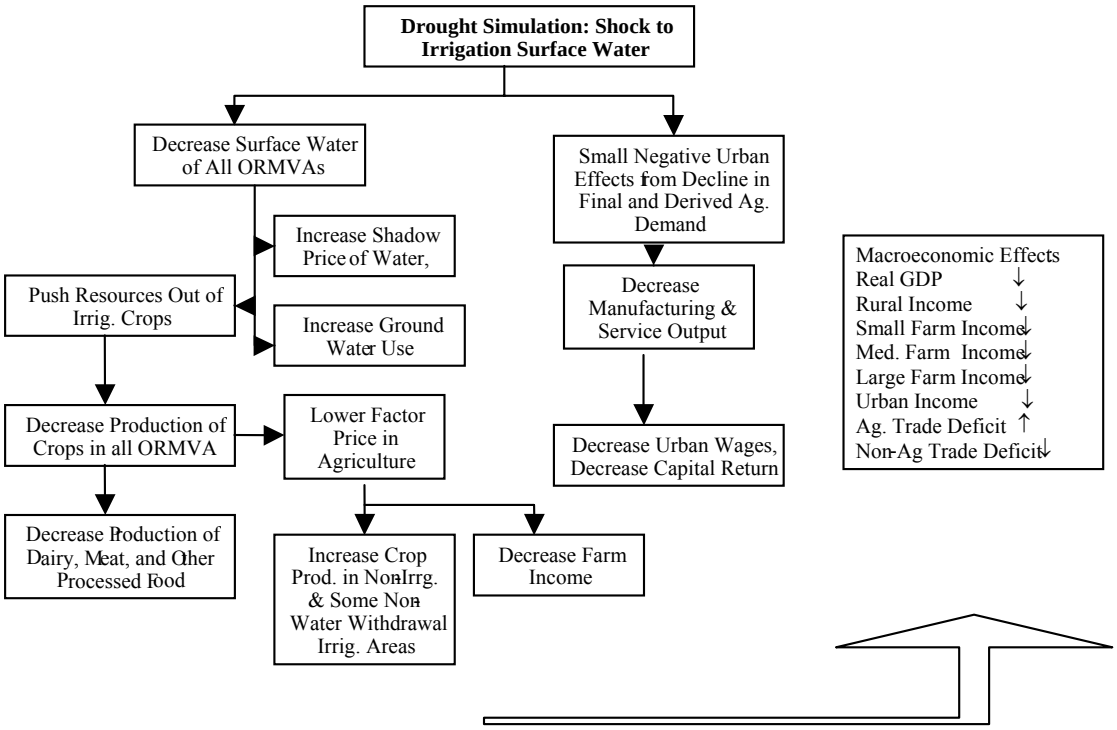


Figure 5: Flow chart of the major effects of a SW shock on the economy

Table 4 displays the change in the shadow price of water. The increase in the shadow price of water ranges from an increase of about 12.7 percent to over 95 percent over the entire irrigated sector. The increase in ground water supply ranges from a low of less than 1 percent to over 11 percent. This small increase is due to the inelastic GW supply function suggested by our data. Note that the percent increase in ground water supply is virtually zero in perimeter 4 of Moulouya to a high of about 12 percent in perimeter 2 of Loukkos (Table 5, column 3). Again, depending upon the share of water costs in the total cost of crop production, the rise in the shadow price is not necessary directly related to the increase in ground water use. For example, in Tadla, perimeter 2, ground water supply increased by one percent while the shadow price of water increased by over 95 percent. In the Moulouya region, ground water supplies only increased by 0.6 percent and the shadow price of water increased by 23.5 percent. This difference reflects, in addition to the cost of GW pumping, the different types of crops grown in these regions and their respective intensity of water use.

Agricultural production declines in irrigated areas by about 11 percent (Table 3, column 3), and especially so for the water intensive crops (not shown). This decline has a negative effect on sectors that use irrigated crops as intermediate inputs, such as livestock and up-stream sectors that processing food (flour milling, vegetable oil). However, the decline in productivity causes some resources to move out of the affected crops, so some factor prices decline. This decline, all else constant, tends to have modest positive effects on agriculture production in non-irrigated areas. It is important to note that the negative effects on the irrigated areas would have been larger without the mitigating effects of GW.

The right panel of Figure 5 identifies the effects on non-agriculture and on the economy-wide indicators. While rural income declines for all farmers, small farms are hurt the most. This result occurs because small sized farms in our data tend to produce a smaller number of different crops then do larger farmers, and their water withdrawing is marginally more costly than for the larger farms in our data. Regarding economy-wide effects, real GDP and total consumption are slightly lowered (by 0.4 and 0.6 percent respectively). Agricultural exports to the European Union declines by about 14 percent, mainly due to the decline in vegetables and fruits (Table 3, column 3).

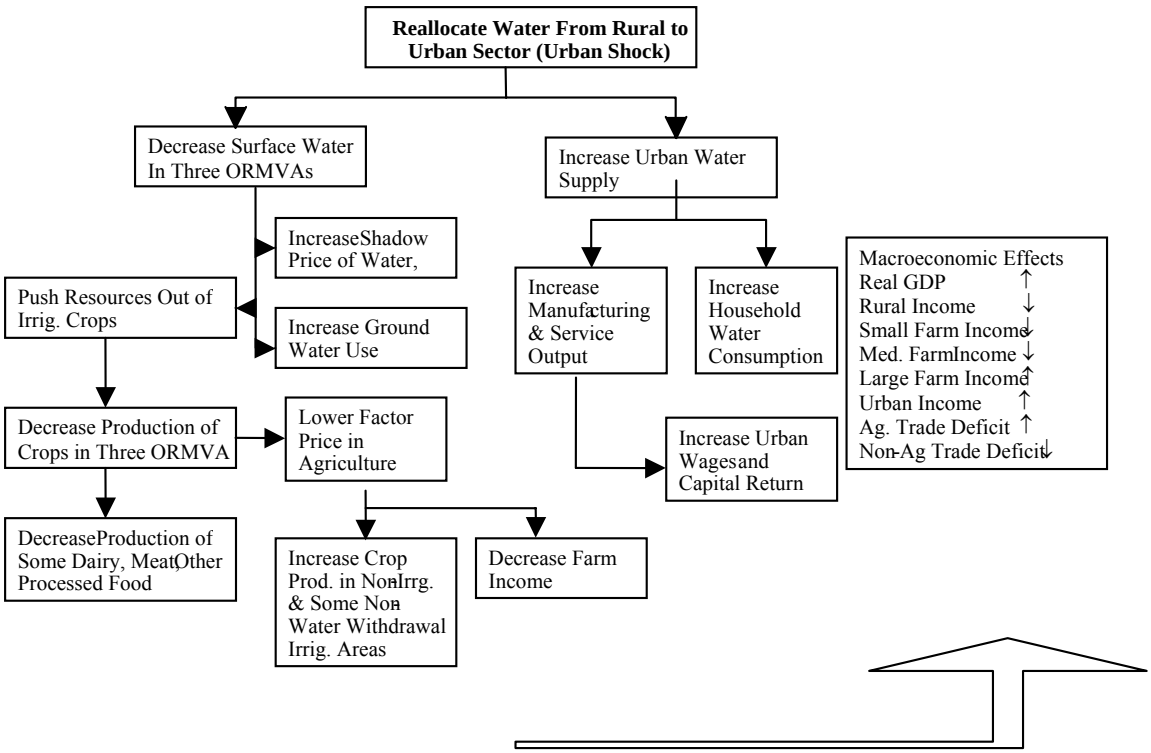
3.4 Results of the reallocation of water from the rural to the urban sector

An overview of the economy-wide effects due to the reduction of irrigation water available to farmers by one-third (Table 5, column 2) in the three ORMVAs (Doukkla, Haouz and Souss-Massa) and the corresponding increase in urban water demand in the urban centers of Casablanca, Marrakech, and Agadir) is shown in Figure 6. The key economic effects at the regional (perimeter) level are reported in Table 5. In this table, we also delineate the indirect effects on the other irrigation regions whose output and input prices are affected indirectly by the growth in urban water demand in the Doukkala, Haouz and Sous-Massa regions.

Table 5: Change in water shadow price and groundwater demand due to the SW shock

ORMVA	Perimeter	Water shadow price	GW demand
		Percent change from the base	
Doukkala	1	44.3	2.6
	2	30.1	1.7
Haouz	1	46.9	3.7
	2	30.3	2.9
	3	40.3	2.5
Sous-Massa	1	41.1	1.4
	2	61.5	0.6
	3	52.0	0.9
Gharb	1	41.4	3.4
	2	12.7	3.2
	3	89.1	7.1
Loukkos	1	35.5	4.4
	2	31.8	11.6
	3	21.3	0.8
Moulouya	1	89.3	1.4
	2	23.5	0.6
	3	22.9	0.9
	4	65.5	0.0
Tadla	1	54.5	1.8
	2	95.8	1.0

The left hand panel of Figure 6 shows that a decrease in SW supply in agriculture causes an increase in the water shadow price in the three ORMVAs. The increase in the marginal product of SW induces an increase in the use of ground water. However, since the increase in ground water use is insufficient to entirely replace the decrease in SW, the productivity of other resources in the three ORMVAs fall, thus pushing resources out of most, but not all, of the crops grown in these three water districts. The crops suffering the largest declines are those that use water relatively intensively, including e.g., vegetables, fruits, and some tree crops.



Figrue 6. Flow chart of the major effects of reallocating water from three ORMVAs to the city of Casablanca

The "pushing out" of some resources from the decline in crop production in these districts places downward pressures on variable input prices (such as hired labor) faced by farmers. This decrease in the prices of some variable inputs gives rise to positive indirect effects on water shadow prices and crop production in other ORMVAs whose water supplies are unaffected by the growth in urban demand, as well as small but positive effects on output supply in non-irrigated areas. Nevertheless, the net overall affect is to decrease rural wage income by about 1.4 percent and the total real agricultural output from all perimeters falls by about 2.7 percent (Table 3, column 4).

The right hand panel of Figure 6 identifies the major non-farm effects of increased urban water demand. More households have access to piped water, and the model predicts that manufacturing and service sector output increases. As cautioned earlier, our data is secondary so that these results must be interpreted accordingly. The

increase in manufacturing and service output causes an increase in return to non-agricultural capital and to urban wages of about 1.7 percent (Table 3, column 4). The rise in urban income increases both the derived and final demand for agricultural products. This increase in demand is transmitted back to agriculture in terms of slightly higher agricultural prices. These higher prices only partially offset the effects from the decline in irrigation water.

The net effect of the general equilibrium adjustments is to increase the country's real GDP by about 1.2 percent, total consumption by about 0.2 percent, and urban income by about 1.7 percent. However, farm income declines for all except the large farms (Table 3). Large farmers are able to diversify into other crops more easily than can small farmers and, as the data suggest, they tend to face lower average costs to extract ground water. The country's agricultural trade deficit increases by about 8 percent (Table 3) while its non-agricultural trade deficit declines slightly owing to the increase in production of manufactured goods.

The change in the total amount of irrigation water ranged from a decline of about 23 to 31 percent in Souss-Massa to about 27 to 35percent in Doukkla (Table 6, column 3). These differences in the total amount of irrigation water allocated is largely due to differences in the costs of ground water extraction in the various irrigation regions. (Table 6, column 4). As pointed out in the "ground water shock" analysis of the previous section, the percent increase in the use of ground water is affected by the elasticity of farm level demand for water, and the elasticity of ground water supply. As shown in Tsur et al (2004), the farm level elasticity of water demand depends upon the relative intensity (importance) of water in the production of a crop. The more important is water, the more elastic is the derived demand for water.

We observe quite different changes in water shadow prices among the perimeters in the three affected districts. In Doukkla the shadow price increased by 48 percent and 38 percent, in perimeter 1 and 2, respectively, by 22, 41 and 15 percent in perimeters 1, 2 and 3 of Haouz, and by 27, 26 and 32 percent in the perimeters of Souss-Massa (Table 6, column 5). In general, the larger is the percent increase in GW, the less is the rise in the shadow price of water. For example, the percent increase in the use of GW in Doukkla is

about one percent in the two perimeters, while GW uses rose by 4 percent, and 11percent in the perimeters 1 and 3 of Haouz. Because it, the water shadow price rises more in Doukkla than in Haouz.

Table 6: Differential effects at the perimeter level from an increase in urban water demand

ORMVA	Peri-meter	Base-year: Share of GW in total water demand	Base-year: Water shadow price (Dh/m^3)	Total water	GW	Water shadow price	Return to land	Farm revenue	Revenue loss*
				----------Percent change from the base ----------					
Direct effect									
Doukkala	1	0.50	36.4	-35.4	0.8	48.46	-3.08	-3.79	-2.77
	2	5.31	32.4	-33.7	0.5	38.17	-5.20	-6.71	-5.03
Haouz	1	22.72	47.4	-26.5	4.4	21.61	-9.45	-14.10	-10.73
	2	0.61	21.2	-35.4	0.7	41.49	-6.63	-10.03	-5.84
	3	17.92	74.6	-27.2	10.9	14.79	-14.33	-15.90	-13.45
Sous-Massa	1	13.46	56.4	-30.7	0.8	26.57	-8.19	-8.82	-7.63
	2	34.27	77.2	-23.2	0.4	25.80	-7.20	-3.72	-3.21
	3	29.20	101.2	-25.0	0.7	32.13	-4.49	-4.06	-3.51
Indirect effect									
Gharb	1	0.89	42.3		0.0	-0.62	-0.88	0.08	
	2	0.62	49.1		0.0	-1.01	-0.90	0.02	
	3	1.14	178.1		0.0	-0.16	-0.80	0.11	
Loukkos	1	2.32	54.8		0.0	-1.02	-1.04	0.11	
	2	3.04	44.5		-0.1	-1.41	-1.24	0.00	
	3	1.08	54.5		0.0	-0.73	-1.04	0.23	
Moulouya	1	8.12	67.8		0.0	0.00	-0.40	0.16	
	2	5.47	62.7		-0.1	-0.14	-0.49	0.19	
	3	16.17	38.6		0.0	-0.54	-0.85	0.15	
	4	12.79	60.8		-0.2	0.14	-0.31	0.15	
Tadla	1	2.86	36.3		0.0	0.22	-0.45	0.24	
	2	5.36	33.5		-0.1	0.27	-0.45	0.26	

* Revenue loss solely due to the SW withdrawn and as percent of total farm revenue in the base

As less water is allocated to land, its marginal value product also falls. The return to land falls in all three of the ORMVAs (Table 6, column 6). The extent of the decline corresponds to the relative intensity of land in the production of the various crops. In general, the higher is land share in total production costs (i.e., the product of the marginal value product and the quantity of land divided by total production cost) the less is the decrease in land's shadow price. The change in farm revenue reported in Table 5 (column

5) largely accrue from returns to land, hence this change is closely associated with the change in land rents.

The change in agricultural production by crop is reported in Table 7. At the national level, the effect on individual crop production is modest. Nationally, pulses, potato, peppers, other vegetables, olive and apricot trees experience a decline in production of about one percent. (Table 7 last row). Within the ORMVA areas, the changes are larger. For example, the decline in water intensive horticultural crops is in the range of 3.1 – 19.5 percent (Table 7, second row from the bottom). At the individual perimeter level, however, the different effect is not only observed at crop level, but also across perimeters. The aggregated effect at national level from increased urban water demand is mainly for vegetable and fruit, while at perimeter level (for ORMVAs directly affected—upper panel), the effect on other crops, such as staple crops is also large.

In Haouz, for example, hard wheat production declines by 9.6 and 12 percent in the two perimeters, while in Sous-Massa, the other cereal production suffers with a decline in the rage of 6.9 – 12.8 percent.

The indirect effects from the re-equilibration of markets in those districts whose SW supplies are not affected by urban water demands are quite small (Table 6, lower panel). Such indirect effects are mainly caused by the change in factor prices due to the "pushing out" of resources from the three directed affected districts, the reallocation of these resources into the remaining component of the agricultural sector, and the modest increase in food prices. At crop level, the indirect effect in these perimeters is mixed: some crop production even increases (Table 7, second panel). As a result, farm revenues in these districts rise, with shadow prices of water either decline or rises slightly (Table 6, row 7, lower panel).

In the above analysis, the farm sector is *not* compensated for the water withdrawn. Based on the base-year's water shadow prices at district level, the direct revenue loss from water withdrawn is about 3.3 percent of total farm revenue of the three districts. Due to the difference in the initial shadow price of water, this ratio is different across districts (Table 6, row 1). If there is more GW available in a district, the water shadow price is relatively low. With a similar decline of SW availability across the three regions,

the percent of revenue loss in districts' farm revenue is smaller in Souss-Massa (2.7 percent), while the percent of revenue loss is 3.5 percent and 4.4 percent for Doukkala and Haouz, respectively. The reason is in the base year, GW accounts for one-third of total irrigation water in Souss-Massa, but accounts for less than 20 percent in Doukkala and Haouz (Table 6, column 1).

Table 7: Production effects by crop from an increase in urban water demand

Irrigated within ORMVA	Perimeter	Hard wheat	Soft wheat	Barley	Other cereal	Pulses	Fodder	Sugar beet
Direct effect								
Doukkala	1	-0.5	-6.7	-1.9			-29.6	-5.2
	2	-5.9	4.8	1.9			-30.1	-4.2
Haouz	1	-9.6	-3.8	-8.2		-21.9	-24.4	
	2	-12.0	-3.8	-4.3		-19.3	-4.0	
	3		-2.5	-2.6		-19.7	-14.7	
Sous-Massa	1				-6.9		-32.3	
	2				-9.4		-30.5	
	3				-12.8		-31.7	
Indirect effect								
Gharb	1	-0.3	0.0		0.7	-0.1	2.0	1.0
	2	-0.2	0.1	-0.4		0.1	1.3	0.3
	3	0.0	-0.2		0.3			0.4
Loukkos	1	-1.3	-0.2			-0.1	3.5	
	2	0.1			0.7			1.0
	3	-1.2	0.1				2.5	1.3
Moulouya	1	-1.3	-0.9			-0.9	1.0	0.1
	2	-0.4	-0.5	-0.5		-0.4	0.5	0.5
	3	0.2	0.0	-0.2		-0.2	0.3	1.1
	4	-1.3	-0.2	-1.6	-0.8	-1.0	0.7	0.2
Tadla	1	-0.6	-0.5		0.6	-0.1	0.7	1.1
	2	-1.1	-1.1		0.7	-0.4	1.2	0.9
Total irrigated within ORMVA		-2.1	-0.4	-2.1	-1.6	-1.3	-10.8	-1.3
National total*		-0.1	-0.3	-0.6	0.3	-1.0	-0.6	-0.7

* including both irrigated and rainfed

Table 7 (continue)

Irrigated within ORMVA	Perimeter	Sugar cane	Other industrial crops	Tomato	Potato	Pepper	Green beans	Melon
Direct effect								
Doukkala	1		-23.8	-8.9	-1.3	-5.8		-0.4
	2			-14.7	-10.0			
Haouz	1				3.9			-21.3
	2				0.3			
	3		-21.2		-3.4	-6.7		-21.4
Sous-Massa	1		-4.6		-11.1		-7.6	-13.2
	2			0.5	-7.2	-6.0	-10.0	-5.0
	3			4.8	-10.8	-5.2		
Indirect effect								
Gharb	1	-1.0	0.1	1.0				1.7
	2	-0.5	0.2	0.9				0.5
	3		-0.3					0.6
Loukkos	1	-0.6	0.6		0.9	1.4		
	2	-0.4		0.6				
	3	-0.5	0.4	1.2				0.7
Moulouya	1			-0.9	0.7		-0.4	
	2		0.5		0.7			
	3	-1.1	0.7	0.8				
	4				0.7			0.3
Tadla	1		0.6		0.7			1.3
	2		-0.1					1.2
Total irrigated within ORMVA		-0.7	-0.2	0.2	-3.3	-5.8	-3.9	-3.1
National total*		-0.7	0.1	0.1	-1.3	-1.0	-0.3	-0.8

* including both irrigated and rainfed

Table 7 (continue)

Irrigated within ORMVA	Perimeter	Cucumber	Zucchini	Other vegetable	Olive	Citrus	Apricot	Other fruit trees
Direct effect								
Doukkala	1			-9.7				-1.9
	2			-7.1				
Haouz	1		-9.5	-4.1	-25.4	-13.5	-23.6	-15.7
	2			-2.5	-24.9			
	3			-10.3	-28.0		-23.9	-16.1
Sous-Massa	1			-6.2	-13.9	-13.3		
	2			-9.1		-14.2		-5.0
	3			-8.0	-31.5	-2.9		-12.8
Indirect effect								
Gharb	1			0.0		0.4		0.2
	2							
	3			-0.1		0.4		0.2
Loukkos	1			0.1				
	2				1.0			
	3			0.2				
Moulouya	1			-0.9	0.8	0.4	3.6	-0.2
	2			-0.2	0.7			
	3			-0.1	1.4	1.2		0.5
	4			-1.3	0.6	0.4	4.6	-0.4
Tadla	1	0.4		0.1	0.8			
	2			-0.3	0.7	1.0		
Total irrigated within ORMVA		0.4	-9.5	-5.0	-17.3	-0.8	-19.5	-2.6
National total*		-0.8	-0.5	-1.1	-1.9	0.1	-2.3	-0.7

* including both irrigated and rainfed

The negative effect on farmers' revenue leaves open the possibility for government to compensate them as a way of addressing the inequity consequences of using irrigation water to meet the assumed growth in non-farm water demand. The compensation payments can be supported by higher water tariffs paid by urban households. The results analyzed above suggest that small farmers need to get more compensation, as they are often difficult to get access to GW supply due to high initial investment costs.

3.5 Policy implications

We found that a 20 percent increase in the cost of extracting ground water in the single irrigated region of Souss-Massa has economy-wide implications. The shadow price of SW increases, but not in direct proportion to the increase in cost. The increase depends upon the water intensity of the crops grown. The higher the water intensity of crops grown in a perimeter, the larger is the increase in the shadow price of SW. Wages of farm workers increase slightly because water is reallocated, at the margin, from crops that are relatively water intensive to labor intensive crops. The net result is a modest increase in the demand for labor, and a decrease in total irrigated water demand.

The simulation of a reduction of one-standard deviation in SW supplies, due for instance to the lack of snow in the Atlas Mountains, is shown to be relatively devastating to the Moroccan economy. Real output from all perimeters falls by about 11 percent. Since a majority of the country's agricultural exports are composed of irrigated crops, the decline in SW supplies causes a 13.6 percent decline in the country's agricultural exports to the European Union. As economy-wide resources are pushed out of the irrigated sector and their prices fall, their employment in rain-fed crops causes a small increase in their production. Because of the up and down stream linkages that irrigated crop production has with the rest of the economy, the non-farm sector experiences a decline in real GDP and total consumption.

The analysis of a decrease in irrigation water by about 1/3 in three regions to meet the growth in urban water demand for Morocco's largest city, Casablanca, shows the nature of hard policy choices faced by Moroccan water authorities. The shadow price of water rises substantially in the three regions while the productivity of other resources falls, as do farm revenues. This decline in profitability pushes resources out of the affected region, some of which are re-allocated to production in other regions not required to give up water to Casablanca. Farm revenues in these regions rise modestly as a result. However, the economy of the Casablanca non-farm sector is affected positively, with a modest growth in non-farm employment and an increase in the production of manufactured goods. At the economy-wide level, GDP increases by 1.24 percent relative to the base period and total consumption rises by about 0.13 percent. The political-

economy implications of these trade-offs are likely to be onerous. Perhaps these trade-offs could be made slightly less onerous if farmers in the three ORMVAs adjacent to the city where given user rights to their water that could, in turn, be lent for use in the urban area.

4. Conclusion

In this paper we demonstrated the importance of incorporating GW resources, into the national water system, in an economy-wide analytical framework. Groundwater has, undoubtedly, a key role in mitigating various economic and physical shocks that affect the availability and relative cost of various factors of production in the economy. Our model includes for the first time the ground water supply and urban water demand that allow addressing various policy issues and external physical shocks in an economy-wide manner. Therefore, although our model has country-level specifications, the conclusions derived can be generalized and used for other economic systems as well.

While the directions of the results are expected, their quantification is the important outcome of this paper. We found that the three types of shocks that have been applied to the Moroccan economy, namely, increased cost of GW extraction, cut in SW supply, and transfer of SW from agriculture to urban centers, have similar impacts on most of the state variables. Especially the drought impact on the SW supply and the increase in cost of extraction of GW shocks, affect most of the economy's sectors in a similar way, with regions that have better access to GW, facing a less dramatic effect. Transfer of SW water from the agricultural to the urban sector has clearly benefited directly the urban sector and only indirectly the rural sector (with an overall negative effect). The small farm agriculture (the majority of the rural economy in Morocco), is particularly vulnerable, and is negatively affected by all types of shocks used in our analysis, thus call for special consideration.

As an overall conclusion of the various analyses, the larger the percentage increase in GW use the less is the rise in the shadow price of water and the lower the negative impacts from the various shocks. However a couple of important conclusions can be drawn:

1. GW is important resource to a national water system that faces fluctuations in water supply, need for inter-annual water storage, and increase in urban water demand.

2. Dependency on GW (measured in share of GW in total water resources) doesn't necessarily affect agricultural sector profitability when extraction costs increase. The importance of GW in terms of increase in its use is affected by both the elasticity of demand for water in the agricultural production sector and the elasticity of the marginal cost of supply of GW. Therefore, regional differences matter a great deal, especially if transfer of water between regions is not allowed or technically infeasible.

3. To facilitate use of GW in critical years and under various policy interventions, an income transfer from urban gainers to agricultural losers from the particular SW transfer shock may make all sectors better off.

Further research is needed to improve model relevancy, especially by including within-ORMVAs farmers' interactions, by expanding the commercial sector activities, by addressing the crop-livestock interactions, and by closing the data gap on GW extraction cost.

Acknowledgement

The authors thank Rachid Doukkali for making available some of the data related to farm production in the various ORMVAs, and the pumping cost of ground water. We would also like to thank Mohamed Ait-Kadi for providing the information on drought years and their economic cost. Very constructive comments were provided by two journal referees. This paper is the result of the first phase of the research project "Macro-Micro Linkages of Irrigated Water Management" funded by the World Bank Research Committee and DECRG.

References

Burt, O. R. 1964. The economics of conjunctive use of ground and surface water, *Hilgardia*: 36, 31-111.

Clarke, Robin and Jannet King, 2004. *The Atlas of Water*. London: Eartscan.

Diao, X., T. Roe, and R. Doukkali. 2005. Economy-wide gains from decentralized water allocation in a spatially heterogeneous agricultural economy, *Environment and Development Economics*, 10:249-269.

Doukkali, Rashid. 2005. Water Institutional Reforms in Morocco. Water Policy, 7(1):71-88.

Gleick, P. (ed.) 1993. *Water in Crisis: A Guide to the World's Water Resources*. New York: Oxford University Press.

Hafi, Ahmed, 2003. Conjunctive Use of Groundwater and Surface Water in the Burdekin Delta Area. *Economic Record*, Vol. 79, pp. 52-62.

Knapp, K.C. and L.J. Olson. 1995. The economics of conjunctive groundwater management with stochastic surface supplies, *Journal of Environmental Economics and Management* 28, 340-356.

Kingdom of Morocco. 2000. Drought Events in Morocco During the XXth Century. Proceedings of the Academy of the Kingdom of Morocco, Session on "Water and Food Security in the XXI century", November 2000. Rabat: Moroccan Academy of Science.

Pulido-Velazquez, Manuel, Marion W. Jenkins and Jay R. Lund. 2004. Economic values for conjunctive use and water banking in southern California. Water Resources Research, 40, W03401, Doi:10.1029/2003wr002626.

Pulido-Velázquez, Manuel, Joaquín Andreu, and Andrés Sahuquillo. 2006. Economic Optimization of Conjunctive Use of Surface Water and Groundwater at the Basin Scale. *Journal of Water Resources Plning. and Management*, 132(6):454-467.

Provencher, B. and O. Burt. 1994. Approximating the optimal groundwater pumping policy in a multiaquifer stochastic conjunctive use setting, *Water Resources*

Research 30, 833-843.

Rosegrant, M, X Cai and S. Cline. 2002. World Water and Food to 2025, International Food Policy Research Institute, Washington, DC.

Ruta, Giovanni. (2006) Ruta Giovanni. 2005. "Deep wells and shallow savings – the economic aspect of groundwater depletion in MENA countries", World Bank, Environment Department, mimeo.

Saghir, J., M. Schiffler, and M. Woldu. 2000. *Urban Water and Sanitation in the Middle East and North Africa Region: The Way Forward*, Middle East and North Africa Region Infrastructure Development Group, The World Bank, Washington, DC

Shiklomanov, I. A. 1999. World Water Resources: An Appraisal for the 21st Century. IHP Report. Paris: UNESCO.

Tsur, Y., Roe, T., Doukkali, R. and Dinar, A. 2004. *Pricing Irrigation Water: Principles and Cases from Developing Countries,* RFF Press, 1616 P Street, NW, Washington D.C.

Tsur, Y. 1997. The economics of conjunctive ground and surface water irrigation systems: Basic principles and empirical evidence from Southern California, in D. Parker and Y. Tsur (eds.) *Decentralization and coordination of water resource management*, pp. 339-361, Kluwer Academic Publisher: London.

Tsur, Y. and T. Graham-Tomasi. 1991. The buffer value of groundwater with stochastic surface water supplies, *Journal of Environmental Economics and Management* 21, 811-818.

Tsur, Y. 1990. The stabilization value of groundwater when surface water supplies are uncertain: The implications for groundwater development, *Water Resources Research*, 26, 811-818.

UNEP (United Nations Environmental Program), with DFID (Department for International Development), DGDC (Belgian Development Cooperation, and British Geological Survey. 2003. Groundwater and its Susceptibility to Degradation. Division of Early Warning and Assessment, UNEP, Nairobi, Kenya.

WMO (World Meteorological Organization). 2005. Groundwater: The Invisible Resource (http://www.wmo.ch/web-en/Wdwfea.html, visited on 11/30.2005)

APPENDIX 1: Mathematic presentation of the Morocco CGE model with water

Model Notations

Sets

A	Activities
$APIR \subset A$	Activities inside water districts (perimeters)
C	Commodities
F	Factors, including water, employed in activities
$EF \subset F$	Economy-wide factor
$PF \subset F$	Perimeter specific factor
$WAT \subset F$	Water
INS	Institutions such as households, government, and foreign trading paterner countries
$H \subset INS$	Households
$ROW \subset INS$	Foreign trading paterner countries
R	Water adiministrative regions (ORMVA) in Morocco
I	Water adiministrative districts (perimeters) in Morocco

Variables

Exogenous Variables at National Level

$PWE_{c,row}$	Export prices (f.ob.), $c \in C$, $row \in ROW$
$PWM_{row,c}$	Import prices (f.ob.), $c \in C$, $row \in ROW$
EXR	Foreign exchange rate, $row \in ROW$
$TFSAV$	Total trade deficits
$INVEST$	Total investment value
$WatQtot$	Total water supply

Endogenous Prices at National Level

CPI	Consumer price index
PA_a	Production activity price (unit gross revenue), $a \in A$
PVA_a	Value added price, $a \in A$
$PXAC_{a,c}$	Price from activity to commodity $a \in A$, $c \in C$
PX_c	Aggregated producer price, $c \in C$
PD_c	Price for commodity produced and sold domestically, $c \in C$
PQ_c	Composite commodity prices, $c \in C$
$PE_{c,row}$	Export prices with margins and subsidies, $c \in C$, $row \in ROW$
$PM_{row,c}$	Import prices with margins and tariffs, $c \in C$, $row \in ROW$
WF_f	Factor price, including water price, $f \in F$

$WFDIST_{f,a}$	Factor market distortion variables, $f \in F$, $a \in A$

Production-related Endogenous Variables at National Level

QA_a	Production activity in quantity, $a \in A$
$QXAC_{a,c}$	Output from activity to commodity, $a \in A$, $c \in C$
QX_c	Commodity output, $c \in C$
QD_c	Commodity produced and sold domestically, $c \in C$
$QINT_c$	Aggregated intermediated demand, $c \in C$
$QF_{f,a}$	Demand for factor by sector, $f \in F$, $a \in A$
QFS_f	Factor supply, $f \in F$

Demand-related Endogenous Variables at National Level

QQ_c	Armington composite commodity, $c \in C$
$QE_{c,row}$	Exports, $c \in C$, $row \in ROW$
$QM_{row,c}$	Imports, $c \in C$, $row \in ROW$
QM_c	Imports, $c \in C$
$QH_{c,h}$	Household demand, $c \in C$, $h \in H$
QG_c	Government demand, $c \in C$
$QINV_c$	Investment demand, $c \in C$
WatQurb	Ground water urban demand
WatQrur	Total rural water demand in irrigated areas

Aggregated and Macroeconomic Endogenous Variables at National Level

EG	Government expenditure
YG	Government income
GSAV	Government savings
GADJ	Government demand scaling factors
YF_f	Factor income, $f \in F$
$YIF_{h,f}$	Factor income for different households, $h \in H$, $f \in F$
YI_h	Household income, $h \in H$
SADJ	Savings adjustment factor factors
SAVINGS	Total savings
$FSAV_{row}$	Trade deficits, $row \in ROW$

Endogenous Prices at Sub-national Level

$FPA_{i,r,a}$	Production activity price at Perimeter level, $i \in I$, $r \in R$, $a \in APIR$
$RPA_{r,a}$	Production activity price at ORMVA level, $r \in R$, $a \in APIR$
$FPVA_{i,r,a}$	Value-added price at Perimeter level, $i \in I$, $r \in R$, $a \in APIR$
$FWF_{i,r,f}$	Factor price, including water market equilibrium price, at perimeter level, $r \in R$, $f \in F$

$FWFDIST_{i,r,f,a}$	Factor market distortion variables, including differences between water shadow prices and water market equilibrium price at Perimeter level, $i \in I$, $r \in R$, $f \in F$, $a \in APIR$

Production-related Endogenous Variables at Sub-national Level

$FQA_{i,r,a}$	Production activity quantity at Perimeter level, $i \in I$, $r \in R$, $a \in APIR$
$RQA_{r,a}$	Production activity quantity at ORMVA level, $r \in R$, $a \in APIR$
$FQF_{i,r,f,a}$	Demand for factor, including water, by sector at Perimeter level, $i \in I$, $r \in R$, $f \in F$, $a \in APIR$
$FQFS_{i,r,f}$	Factor, including irrigated water, supply at Perimeter level, $i \in I$, $r \in R$, $f \in F$,
$FQFS\_G_{i,r}$	ground water supply at Perimeter level, $i \in I$, $r \in R$, $f \in F$, $a \in APIR$
$FQF\_Tot_{i,r}$	Total water demand at Perimeter level, $i \in I$, $r \in R$, $f \in F$, $a \in$
$QINT\_G_{i,r,c,a}$	Energy demand for intermediate input in ground water production function at Perimeter level, $i \in I$, $r \in R$, $a \in APIR$

Parameters

Assumed parameters in Equations for the National Economy

σ_a	Elasticity of substitution between factor inputs in CES value-added function
σ_c^c	Elasticity of substitution between activities in CES function for commodity
$\sigma_{row,c}^m$	Armington elasticity of substitution between domestic and import good
$\sigma_{c,row}^e$	CET elasticity of substitution between exports and domestically sold goods

Computed Parameters in Equations for the National Economy

$\beta_{c,h}$	Share parameter in household's demand function
$\gamma_{c,h}$	Subsistence parameter in Stone-Geary utility function
$\alpha_{f,a}^a$	Share parameter in CES value-added function
Λ_a	Shift parameter in CES value-added function
$io_{c,a}$	Input-output coefficient
$\delta_{a,c}$	Share parameters in CES function for transferring activities into commodity

$\delta^{m}_{row,c}$	Share parameters in Armington function for imports
$\delta^{e}_{c,row}$	Share parameters in CET function for exports
$\Lambda^{a}_{a,c}$	Shift parameter in CES function for transferring activities into commodity
$\Lambda^{m}_{row,c}$	Shift parameter in Armington function
$\Lambda^{e}_{c,row}$	Shift parameter in CET function

Parameters in Equations for the Sub-national Economy

σ^{r}_{a}	Elasticity of substitution between regional level output in CES composite acticity function for the country
$\sigma^{i}_{r,a}$	Elasticity of substitution between perimeter level output in CES composite activity function for the region
$\alpha^{r}_{r,a}$	Share parameter in CES activity composite function from region to national level aggregation
$\alpha^{i}_{i,r,a}$	Share parameter in CES activity composite function from perimeter to regional level aggregation
Λ^{r}_{a}	Shift parameter in CES activity composite function from region to national level aggregation
$\Lambda^{i}_{r,a}$	Shift parameter in CES activity composite function from perimeter to regional level aggregation
$\sigma^{i}_{i,r,a}$	Elasticity of substitution between factor inputs in CES value-added function at perimeter level
$\alpha^{i}_{i,r,f,a}$	Share parameter in CES value-added function at perimeter level
$\Lambda^{i}_{i,r,a}$	Shift parameter in CES value-added function at perimeter level
$fio_{i,r,c,a}$	Input-output coefficient at perimeter level
$\vartheta_{a,c}$	yield of output *c* per unit of activity *a*

Other Computed Parameters

---

ta_a	tax rate on production activity
tq_c	tax rate on consumption
te_c	tax rate on exports
tm_c	tariff rate on imports
tf_f	tax rate on factor income
$twa_{i,r,a}$	government water charge rate
$fta_{i,r,a}$	tax rate on production activity at perimeter level
$trnsfr_{ins,ins'}$	Transfers between institutions
$shif_{h,f}$	Initial distribution of facor income across households

mps_h	Household saving rate
$\overline{qg}_c$	Initial value of government spending on commodity
$shinv_c$	Initial share of investment on commodity
$cwts_c$	Commodity weight in *CPI*
$shwat_{i,r,a}$	Coefficient share of each perimeter in total water supply
$shwat_{urb}$	Coefficient converting urban processed water into demand for surface water

Model Equations

Price Equations

---

(1) $$PM_{row,c} = (1 + tm_{row,c}) \times pwm_{row,c} \times exr$$

(2) $$PE_{c,row} = (1 + te_{c,row}) \times pwe_{c,row} \times exr$$

(3) $$(1 - tq_c) \times PQ_c \times QQ_c = PD_c \times QD_c + \sum_{row} [PM_{c,row} \times QM_{c,row}]$$

(4) $$PX_c \times QX_c = PD_c \times QD_c + \sum_{row} [PE_{row,c} \times QE_{row,c}]$$

(5) $$PA_a = \sum_c \vartheta_{a,c} PXAC_{a,c}$$

(6) $$CPI = \sum_c cwts_c PQ_c$$

Production-related Equations Defined at the National Level

CES value-added function

(7) $$PVA_a = \left(\Lambda_a\right)^{-1} \times \left[\sum_f \left(\alpha_f^{\sigma_a} \times [(1 + WFDIST_{f,a}) WF_f]^{1-\sigma_a} \right) \right]^{\frac{1}{(1-\sigma_a)}}$$

Factor demand

(8) $$QF_{f,a} = \left(\Lambda_a\right)^{\sigma_a - 1} \times \left(\frac{PVA_a \times \alpha_{f,a}}{(1 + WFDIST_{f,a}) WF_f} \right)^{\sigma_a} \times QA_a$$

Intermediate demand

$$QINT_c = \sum_{a \notin APIR} \left(io_{c,a} \times QA_a \right) + \sum_{a \in APIR} \sum_{i,r} \left(fio_{i,r,c,a} \times FQA_{i,r,a} \right) + \sum_{a \in APIR} \sum_{i,r} QINT\_G_{i,r,c,a} \tag{9}$$

Relationship between value-added and activity prices

$$(1 - ta_a) PA_a = PVA_a + \sum_c \left[io_{c,a} \times PQ_c \right] \tag{10}$$

Production-related Equations Defined at the Sub-national Level

---

CES value-added function at perimeter level

$$FPVA_{i,r,a} = \left(\Lambda^i_{i,r,a} \right)^{-1} \times \{ \sum_{f \in EF} (\alpha^i_{i,r,f})^{\sigma^i_{i,r,a}} \times [(1 + FWFDIST_{pi,r,f,a}) WF_f]^{1-\sigma^i_{i,r,a}} + \sum_{f \in PF} (\alpha^i_{i,r,f})^{\sigma^i_{i,r,a}} \times [(1 + FWFDIST_{i,r,f,a}) FWF_{i,r,f}]^{1-\sigma^i_{i,r,a}} + \sum_{f \in WAT} (\alpha^i_{i,r,f})^{\sigma^i_{i,r,a}} \times [twa_{i,r,a} + (1 + FWFDIST_{i,r,f,a}) FWF_{i,r,f}]^{1-\sigma^i_{i,r,a}} \}^{\frac{1}{(1-\sigma^i_{i,r,a})}} \tag{11}$$

Factor demand at perimeter level for economy-wide factor

$$FQF_{i,r,f,a} = \left(\Lambda^i_{i,r,a} \right)^{\sigma^i_{i,r,a}-1} \times \left(\frac{FPVA_{i,r,a} \times \alpha^i_{i,r,f,a}}{(1 + FWFDIST_{i,r,f,a}) WF_f} \right)^{\sigma^i_{i,r,a}} \times FQA_{i,r,a} \tag{12}$$

Factor demand at perimeter level for perimeter specific factor

$$FQF_{i,r,f,a} = \left(\Lambda^i_{i,r,a} \right)^{\sigma^i_{i,r,a}-1} \times \left(\frac{FPVA_{i,r,a} \times \alpha^i_{i,r,f,a}}{(1 + FWFDIST_{i,r,f,a}) FWF_{i,r,f}} \right)^{\sigma^i_{i,r,a}} \times FQA_{i,r,a} \tag{13}$$

Relationship between value-added and activity prices at perimeter level

$$(1 - fta_{i,r,a}) FPA_{i,r,a} \times FQA_{i,r,a} = FPVA_{i,r,a} \times FQA_{i,r,a} + \sum_c \left[fio_{i,r,c,a} \times PQ_c \right] \times FQA_{i,r,a} + \sum_c \left[FQINT\_G_{i,r,c,a} \times PQ_c \right] \tag{14}$$

CES composite function between national and regional level activity prices

(15) $$PA_a = \left(\Lambda_a^r\right)^{-1} \times \left[\sum_r \left(\alpha_{r,a}^r{}^{\sigma_a^r} \times RPA_{r,a}{}^{1-\sigma_a^r}\right)\right]^{\frac{1}{\left(1-\sigma_a^r\right)}}$$

CES composite function between national and regional level activity prices

(16) $$RPA_{r,a} = \left(\Lambda_{r,a}^i\right)^{-1} \times \left[\sum_i \left(\alpha_{i,r,a}^i{}^{\sigma_{r,a}^i} \times FPA_{i,r,a}{}^{1-\sigma_{r,a}^i}\right)\right]^{\frac{1}{\left(1-\sigma_{r,a}^i\right)}}$$

FOC for CES composite function from region to national level activity aggregation

(17) $$RQA_{r,a} = \left(\Lambda_a^r\right)^{\sigma_a^r - 1} \times \left(\frac{PA_a \times \alpha_{r,a}^r}{RPA_{r,a}}\right)^{\sigma_a^r} \times QA_a$$

FOC for CES composite function from perimeter to regional level activity aggregation

(18) $$FQA_{r,a} = \left(\Lambda_{r,a}^i\right)^{\sigma_{r,a}^i - 1} \times \left(\frac{RPA_{r,a} \times \alpha_{i,r,a}^i}{FPA_{i,r,a}}\right)^{\sigma_{r,a}^i} \times RQA_{r,a}$$

Water Demand and Supply

Demand at perimeter level for irrigated water
(If irrigated water quarter is given by government, this equation will give us water shadown prices)

(19) $$FQF_{i,r,water,a} = \left(\Lambda_{i,r,a}^i\right)^{\sigma_{i,r,a}^i - 1} \times \left(\frac{FPVA_{i,r,a} \times \alpha_{i,r,water,a}^i}{[twa_{i,r,a} + (1 + FWFDIST_{i,r,water,a})FWF_{i,r,water}]}\right)^{\sigma_{i,r,a}^i} \times FQA_{i,r,a}$$

Urban water demand

(20) $$WatQurb = shwat_{urb} \times QS_{elec\_wat}$$

Total water demand at perimeter level
(Given constraint on total water supply, this equation gives us ground water demand at perimeter level)

(21) $$FQF\_Tot_{i,r,a} = FQF_{i,r,water,a} + FQF\_G_{i,r,a}$$

Rural irrigated water supply at perimeter level
(Given total water as an exogenous variable, increased urban demand for water will reduce water availability for irrigation)

(22) $$FQFS_{i,r,water} = shwat_{i,r}\left(WatQtot - WatQurb\right)$$

Equations Transfering Activity into Commodity

---

(23) $$QXAC_{a,c} = \vartheta_{a,c} QA_a$$

(24) $$PX_c = \left(\Lambda_c^c\right)^{-1} \times \left(\sum_a \delta_{a,c}^{a\ \sigma_c^c} \times PXAC_{a,c}^{1-\sigma_c^c}\right)^{\frac{1}{\left(1-\sigma_c^c\right)}}$$

(25) $$QXAC_{a,c} = \left(\Lambda_c^c\right)^{\sigma_c^c - 1} \times \left(\frac{\delta_{a,c} \times PX_c}{PXAC_{a,c}}\right)^{\sigma_c^c} \times QX_c$$

Imports and exports

Armington function

(26) $$PQ_c = \left(\Lambda_c^m\right)^{-1} \times \left(\sum_{row} (\delta_{row,c}^{m\ \sigma_c^m} \times PM_{row,c}^{1-\sigma_c^m}) + \left(1 - \sum_{row} \delta_{row,c}^m\right)^{\sigma_c^m} PD_c^{1-\sigma_c^m}\right)^{\frac{1}{\left(1-\sigma_c^m\right)}}$$

Demand for import goods

(27) $$QM_{row,c} = \left(\Lambda_c^m\right)^{\sigma_c^m - 1} \times \left(\frac{\delta_{row,c} \times PQ_c}{PM_{row,c}}\right)^{\sigma_c^m} \times QQ_c$$

Demand for domestically produced goods

(28) $$QD_c = \left(\Lambda_c^m\right)^{\sigma_c^m - 1} \times \left(\frac{\left(1 - \sum_{row} \delta_{row,c}\right) \times PQ_c}{PD_c}\right)^{\sigma_c^m} \times QQ_c$$

CET function

$$(29)\quad PX_c = \left(\Lambda_c^e\right)^{-1} \times \left(\sum_{row} (\delta_{c,row}^{e\ -\sigma_c^e} \times PE_{c,row}^{1+\sigma_c^e}) + \left(1 - \sum_{row} \delta_{c,row}^e\right)^{-\sigma_c^e} PD_c^{1+\sigma_c^e} \right)^{-\frac{1}{1+\sigma_c^e}}$$

Supply of export goods

$$(30)\quad QE_{c,row} = \left(\Lambda_c^e\right)^{-\left(1+\sigma_c^e\right)} \times \left(\frac{\delta_c^e \times PX_c}{PE_{c,row}} \right)^{-\sigma_c^e} \times QX_{c,row}$$

Supply to domestic markets

$$(31)\quad QD_c = \left(\Lambda_c^e\right)^{-\left(1+\sigma_c^e\right)} \times \left(\frac{\left(1 - \sum_{row} \delta_{c,row}^e\right) \times PX_c}{PD_c} \right)^{-\sigma_c^e} \times QX_c$$

Incomes and Demands

Economy-wide factor income

$$(32)\quad \begin{aligned} YF_{f \in EF} = & \sum_{a \notin APIR} (1 + WFDIST_{f,a}) \times WF_f \times QF_{f,a} \\ & + \sum_{a \in APIR} \sum_{i,r} (1 + FWFDIST_{i,r,f,a}) \times WF_f \times FQF_{i,r,f,a} \end{aligned}$$

Perimeter specific factor income

$$(33)\quad YF_{f \in PF} = \sum_{a \in APIR} \sum_{i,r} (1 + FWFDIST_{i,r,f,a}) \times FWF_{i,r,f} \times FQF_{i,r,f,a}$$

Water income

$$(34)\quad \begin{aligned} YF_{f \in WAT} = & \sum_{a \notin APIR} (1 + WFDIST_{f,a}) \times WF_f \times QF_{f,a} \\ & + \sum_{a \in APIR} \sum_{i,r} (1 + FWFDIST_{i,r,f,a}) \times WF_{i,r,f} \times FQF\_Tot_{i,r,f,a} \\ & - \sum_{a \in APIR} \sum_{i,r} twa_{i,r,a}) \times FQF_{i,r,f,a} \end{aligned}$$

Factor income distributed to households

$$(35)\quad YIF_{h,f} = shif_{h,f} \times YF_f (1 - tf_f)$$

Household income

(36) $$YI_h = \sum_f YIF_{h,f} + \sum_{ins} trnsfr_{ins,h}$$

Household demand

(37) $$QH_{c,h} = \frac{\beta_{c,h} \times \left(YI_h \times \left(1 - SADJ \times mps_h\right) - \sum_{c'} PQ_{c'} \times \gamma_{c',h} \right)}{PQ_c} + \gamma_{c,h}$$

Government revenue

(38) $$\begin{aligned} YG_r = & \sum_{a \notin APIR} ta_a \times PA_a \times QA_a + \sum_{a \in APIR} \sum_{i,r} fta_{i,r,a} FPA_{i,r,a} FQA_{i,r,a} \\ & + \sum_{row} \sum_{c} \left[tm_{row,c} \times exr \times pwm_{row,c} \times QM_{row,c} \right] \\ & + \sum_{c} \sum_{row} \left[te_{c,row} \times exr \times pwe_{c,row} \times QE_{c,row} \right] \\ & + \sum_{c} \left[tq_c \times PQ_{i,r} \times QQ_c \right] + \sum_{f} tf_f \times YF_f \\ & + \sum_{i,r} twa_{i,r} \times FQF_{i,r,water} \\ & + \sum_{row} \left(trnsfr_{row,gov't} - trnsfr_{gov't,row} \right) \times exr \end{aligned}$$

Government spending on commodities

(39) $$PQ_c \times QG_c = GADJ \times \overline{qg}_c$$

Government total expenditure

(40) $$EG = \sum_c PQ_c \times QG_c + \sum_h trnsfr_{gov't,h}$$

Government budget surplus

(41) $$GSAV = YG - EG$$

Investment demand

(42) $$PQ_c \times QINV_c = shinv_c \times totvinv$$

National level savings

(43) $$SAVINGS_c = \sum_h SADJ \times mps_h \times YI_h + GSAV + tfsav \times exr$$

Equilibrium Conditions

Commodity markets

(44) $$QQ_c = QINT_c + \sum_h QH_{c,h} + QG_c + QINV_c$$

Factor markets

Markets for the factors employed in non-*APIR* sectors only

(45) $$\sum_{a \notin APIR} QF_{f,a} = FS_f$$

Segmented markets at perimeter level for the factors employed in *APIR* sectors only

(46) $$\sum_{a \in APIR} FQF_{i,r,f,a} = FFS_{i,r,f}$$

Markets for the economy-wide factors

(47) $$\sum_{a \notin APIR} QF_{f,a} + \sum_{a \in APIR} \sum_{i,r} FQF_{i,r,f,a} = FS_f$$

Foreign savings

(48) $$FSAV_{row} = \sum_c \left(pwm_{c,row} \times QM_{c,row} - pwe_{row,c} \times QE_{row,c} \right) + \sum_{ins} \left(trnsfr_{ins,row} - trnsfr_{row,ins} \right)$$

(49) $$tfsav = \sum_{row} FSAV_{row}$$

PREVIOUS DISCUSSION PAPERS

1.01 Yoav Kislev - Water Markets (Hebrew).

2.01 Or Goldfarb and Yoav Kislev - Incorporating Uncertainty in Water Management (Hebrew).

3.01 Zvi Lerman, Yoav Kislev, Alon Kriss and David Biton - Agricultural Output and Productivity in the Former Soviet Republics.

4.01 Jonathan Lipow & Yakir Plessner - The Identification of Enemy Intentions through Observation of Long Lead-Time Military Preparations.

5.01 Csaba Csaki & Zvi Lerman - Land Reform and Farm Restructuring in Moldova: A Real Breakthrough?

6.01 Zvi Lerman - Perspectives on Future Research in Central and Eastern European Transition Agriculture.

7.01 Zvi Lerman - A Decade of Land Reform and Farm Restructuring: What Russia Can Learn from the World Experience.

8.01 Zvi Lerman - Institutions and Technologies for Subsistence Agriculture: How to Increase Commercialization.

9.01 Yoav Kislev & Evgeniya Vaksin - The Water Economy of Israel--An Illustrated Review. (Hebrew).

10.01 Csaba Csaki & Zvi Lerman - Land and Farm Structure in Poland.

11.01 Yoav Kislev - The Water Economy of Israel.

12.01 Or Goldfarb and Yoav Kislev - Water Management in Israel: Rules vs. Discretion.

1.02 Or Goldfarb and Yoav Kislev - A Sustainable Salt Regime in the Coastal Aquifer (Hebrew).

2.02 Aliza Fleischer and Yacov Tsur - Measuring the Recreational Value of Open Spaces.

3.02 Yair Mundlak, Donald F. Larson and Rita Butzer - Determinants of Agricultural Growth in Thailand, Indonesia and The Philippines.

4.02 Yacov Tsur and Amos Zemel - Growth, Scarcity and R&D.

5.02 Ayal Kimhi - Socio-Economic Determinants of Health and Physical Fitness in Southern Ethiopia.

6.02 Yoav Kislev - Urban Water in Israel.

7.02 Yoav Kislev - A Lecture: Prices of Water in the Time of Desalination. (Hebrew).

8.02 Yacov Tsur and Amos Zemel - On Knowledge-Based Economic Growth.

9.02 Yacov Tsur and Amos Zemel - Endangered aquifers: Groundwater management under threats of catastrophic events.

10.02 Uri Shani, Yacov Tsur and Amos Zemel - Optimal Dynamic Irrigation Schemes.

1.03 Yoav Kislev - The Reform in the Prices of Water for Agriculture (Hebrew).

2.03 Yair Mundlak - Economic growth: Lessons from two centuries of American Agriculture.

3.03 Yoav Kislev - Sub-Optimal Allocation of Fresh Water. (Hebrew).

4.03 Dirk J. Bezemer & Zvi Lerman - Rural Livelihoods in Armenia.

5.03 Catherine Benjamin and Ayal Kimhi - Farm Work, Off-Farm Work, and Hired Farm Labor: Estimating a Discrete-Choice Model of French Farm Couples' Labor Decisions.

6.03 Eli Feinerman, Israel Finkelshtain and Iddo Kan - On a Political Solution to the Nimby Conflict.

7.03 Arthur Fishman and Avi Simhon - Can Income Equality Increase Competitiveness?

8.03 Zvika Neeman, Daniele Paserman and Avi Simhon - Corruption and Openness.

9.03 Eric D. Gould, Omer Moav and Avi Simhon - The Mystery of Monogamy.

10.03 Ayal Kimhi - Plot Size and Maize Productivity in Zambia: The Inverse Relationship Re-examined.

11.03 Zvi Lerman and Ivan Stanchin - New Contract Arrangements in Turkmen Agriculture: Impacts on Productivity and Rural Incomes.

12.03 Yoav Kislev and Evgeniya Vaksin - Statistical Atlas of Agriculture in Israel - 2003-Update (Hebrew).

1.04 Sanjaya DeSilva, Robert E. Evenson, Ayal Kimhi - Labor Supervision and Transaction Costs: Evidence from Bicol Rice Farms.

2.04 Ayal Kimhi - Economic Well-Being in Rural Communities in Israel.

3.04 Ayal Kimhi - The Role of Agriculture in Rural Well-Being in Israel.

4.04 Ayal Kimhi - Gender Differences in Health and Nutrition in Southern Ethiopia.

5.04 Aliza Fleischer and Yacov Tsur - The Amenity Value of Agricultural Landscape and Rural-Urban Land Allocation.

6.04 Yacov Tsur and Amos Zemel – Resource Exploitation, Biodiversity and Ecological Events.

7.04 Yacov Tsur and Amos Zemel – Knowledge Spillover, Learning Incentives And Economic Growth.

8.04 Ayal Kimhi – Growth, Inequality and Labor Markets in LDCs: A Survey.

9.04 Ayal Kimhi – Gender and Intrahousehold Food Allocation in Southern Ethiopia

10.04 Yael Kachel, Yoav Kislev & Israel Finkelshtain – Equilibrium Contracts in The Israeli Citrus Industry.

11.04 Zvi Lerman, Csaba Csaki & Gershon Feder – Evolving Farm Structures and Land Use Patterns in Former Socialist Countries.

12.04 Margarita Grazhdaninova and Zvi Lerman – Allocative and Technical Efficiency of Corporate Farms.

13.04 Ruerd Ruben and Zvi Lerman – Why Nicaraguan Peasants Stay in Agricultural Production Cooperatives.

14.04 William M. Liefert, Zvi Lerman, Bruce Gardner and Eugenia Serova - Agricultural Labor in Russia: Efficiency and Profitability.

1.05 Yacov Tsur and Amos Zemel – Resource Exploitation, Biodiversity Loss and Ecological Events.

2.05 Zvi Lerman and Natalya Shagaida – Land Reform and Development of Agricultural Land Markets in Russia.

3.05 Ziv Bar-Shira, Israel Finkelshtain and Avi Simhon – Regulating Irrigation via Block-Rate Pricing: An Econometric Analysis.

4.05 Yacov Tsur and Amos Zemel – Welfare Measurement under Threats of Environmental Catastrophes.

5.05 Avner Ahituv and Ayal Kimhi – The Joint Dynamics of Off-Farm Employment and the Level of Farm Activity.

6.05 Aliza Fleischer and Marcelo Sternberg – The Economic Impact of Global Climate Change on Mediterranean Rangeland Ecosystems: A Space-for-Time Approach.

7.05 Yael Kachel and Israel Finkelshtain – Antitrust in the Agricultural Sector: A Comparative Review of Legislation in Israel, the United States and the European Union.

8.05 Zvi Lerman – Farm Fragmentation and Productivity Evidence from Georgia.

9.05 Zvi Lerman – The Impact of Land Reform on Rural Household Incomes in Transcaucasia and Central Asia.

10.05 Zvi Lerman and Dragos Cimpoies – Land Consolidation as a Factor for Successful Development of Agriculture in Moldova.

11.05 Rimma Glukhikh, Zvi Lerman and Moshe Schwartz – Vulnerability and Risk Management among Turkmen Leaseholders.

12.05 R.Glukhikh, M. Schwartz, and Z. Lerman – Turkmenistan's New Private Farmers: The Effect of Human Capital on Performance.

13.05 Ayal Kimhi and Hila Rekah – The Simultaneous Evolution of Farm Size and Specialization: Dynamic Panel Data Evidence from Israeli Farm Communities.

14.05 Jonathan Lipow and Yakir Plessner - Death (Machines) and Taxes.

1.06 Yacov Tsur and Amos Zemel – Regulating Environmental Threats.

2.06 Yacov Tsur and Amos Zemel - Endogenous Recombinant Growth.

3.06 Yuval Dolev and Ayal Kimhi – Survival and Growth of Family Farms in Israel: 1971-1995.

4.06 Saul Lach, Yaacov Ritov and Avi Simhon – Longevity across Generations.

5.06 Anat Tchetchik, Aliza Fleischer and Israel Finkelshtain – Differentiation & Synergies in Rural Tourism: Evidence from Israel.

6.06 Israel Finkelshtain and Yael Kachel – The Organization of Agricultural Exports: Lessons from Reforms in Israel.

7.06 Zvi Lerman, David Sedik, Nikolai Pugachev and Aleksandr Goncharuk – Ukraine after 2000: A Fundamental Change in Land and Farm Policy?

8.06 Zvi Lerman and William R. Sutton – Productivity and Efficiency of Small and Large Farms in Moldova.

9.06 Bruce Gardner and Zvi Lerman – Agricultural Cooperative Enterprise in the Transition from Socialist Collective Farming.

10.06 Zvi Lerman and Dragos Cimpoies - Duality of Farm Structure in Transition Agriculture: The Case of Moldova.

11.06 Yael Kachel and Israel Finkelshtain – Economic Analysis of Cooperation In Fish Marketing. (Hebrew)

12.06 Anat Tchetchik, Aliza Fleischer and Israel Finkelshtain – Rural Tourism: Developmelnt, Public Intervention and Lessons from the Israeli Experience.

13.06 Gregory Brock, Margarita Grazhdaninova, Zvi Lerman, and Vasilii Uzun - Technical Efficiency in Russian Agriculture.

14.06 Amir Heiman and Oded Lowengart - Ostrich or a Leopard – Communication Response Strategies to Post-Exposure of Negative Information about Health Hazards in Foods

15.06 Ayal Kimhi and Ofir D. Rubin – Assessing the Response of Farm Households to Dairy Policy Reform in Israel.

16.06 Iddo Kan, Ayal Kimhi and Zvi Lerman – Farm Output, Non-Farm Income, and Commercialization in Rural Georgia.

17.06 Aliza Fleishcer and Judith Rivlin – Quality, Quantity and Time Issues in Demand for Vacations.

1.07 Joseph Gogodze, Iddo Kan and Ayal Kimhi – Land Reform and Rural Well Being in the Republic of Georgia: 1996-2003.

2.07 Uri Shani, Yacov Tsur, Amos Zemel & David Zilberman – Irrigation Production Functions with Water-Capital Substitution.

3.07 Masahiko Gemma and Yacov Tsur – The Stabilization Value of Groundwater and Conjunctive Water Management under Uncertainty.

4.07 Ayal Kimhi – Does Land Reform in Transition Countries Increase Child Labor? Evidence from the Republic of Georgia.

5.07 Larry Karp and Yacov Tsur – Climate Policy When the Distant Future Matters: Catastrophic Events with Hyperbolic Discounting.

6.07 Gilad Axelrad and Eli Feinerman – Regional Planning of Wastewater Reuse for Irrigation and River Rehabilitation.

7.07 Zvi Lerman – Land Reform, Farm Structure, and Agricultural Performance in CIS Countries.

8.07 Ivan Stanchin and Zvi Lerman – Water in Turkmenistan.

9.07 Larry Karp and Yacov Tsur – Discounting and Climate Change Policy.

10.07 Xinshen Diao, Ariel Dinar, Terry Roe and Yacov Tsur – A General Equilibrium Analysis of Conjunctive Ground and Surface Water Use with an Application To Morocco.