FINAL REPORT

The Conjunctive Use of Irrigation Water Over Time in Morocco:

Strengthening Ecosystems and Development Linkages

United Nations Environmental Program
Project number 00042903

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EXECUTIVE SUMMARY AND POLICY IMPLICATIONS

Project design

This project implements an analysis of the economy-wide effects over time of surface and ground water used for irrigation in two regions of Morocco: Souss Massa and Tadla Azilal. These regions together account for about 23 percent of the country's value added by irrigated crops. With a semiarid climate and variable rainfall, yet blessed by water harnessed from snow melt in mountainous regions, agriculture's 15 percent share in total value added underestimates the importance of agriculture and water to the national economy. The contribution of surface and ground water to gross domestic product do not appear in official product accounts, and consequently the degradation of this resource over time and how degradation affects the country's natural resource wealth may not receive the attention it warrants in policy analyses.

The methodology fits to data two almost analytically identical albeit empirically different models. One model empirically focuses on the region of Souss Massa and the rest of Morocco, while the other focuses on the Tadla Azilal region and the rest of Morocco. Following a base analysis with each model, we perform two simulations. The first simulation examines the adjustments over time made by irrigated agriculture, in the context of the broader Moroccan economy, to a ten percent decrease in surface water supplies. The second simulation considers a ten percent increase in the productivity – efficiency of irrigated water. These analyses provide insights and policy implications on the natural resource services generated by land and more importantly water in these two major regions of Morocco.

Major findings

In the case of Souss Massa over the next 40 years, the results suggest the unit value of water (i.e. the shadow value of water) in conjunctive use (surface and ground) will rise by almost 300 percent, as the percent of ground water used in irrigation rises by about 6 percent, and the water table declines rather precipitously, from a depth index of 1 to 33.8. The cost of pumping water from greater depths dampens ground water use, and especially in the production of cereals and pulses. The drought shock decreases Souss Massa sector value added for those crops that tend to use water intensively per unit of output; these are cereals and pulses and other irrigated agriculture. Relative to the base solution, the shadow value of water rises, reflecting increased water scarcity. The depth to the water table increases relative to base, but rather modestly, by about 2.2 percent more than base in 2015, with an increase in depth per year declining to about 1.0 percent more than base in year 2040. Eventually, the rate of water outflow cannot exceed the rate of water infiltration.

The water productivity/efficiency analysis increased efficiency by ten percent. In Souss Massa, the increase in value added is the highest for the competitive crops, fodder and fruits and vegetables. In the case of Tadla Azilal, the results of the base analysis suggest the unit value of water in conjunctive use will rise by about 62 percent, (or only about 20 percent of the rise experienced for Souss Massa) over the 2011 to 2045 period. Moreover, the depth index of the water table only falls to 7.1 in 2045.

Surface water is a larger percentage of total irrigation water in the Tadla Azilal region than it is in the Souss Massa region. Consequently, a drought tends to have larger absolute effects on production than a drought in the Souss Massa region. Otherwise, we obtain almost the same pattern of results for Tadla Azilal as obtained for Souss Massa. A ten percent increase in water productivity – efficiency, tends to increase Tadla Azilal's value added of those crops having a relatively large surface water assignment relative to ground water in total irrigation water. Those crops that are relatively water intensive (cereals and pulses, and other irrigated agriculture) are also affected more strongly than others.

The last part of our analysis focuses on the stock value of land and water in both regions, and for each of the simulations discussed above. The stock value of land in the base solution tends to fall for crops whose value added is also declining over time, e.g., cereals and pulses in Souss Massa, and rising for other crops. The stock value of land planted to fruits and vegetables in Souss Massa rises from about 40,171 DH per Ha. in 2011 to about 76,800 DH in 2045. In the Souss Massa region, the stock value of the aquifer, and the stock value of surface water both increase over time. The stock value of the Souss Massa aquifer increases from 3,727 DH per Ha irrigated in 2011 to 4,108 DH per Ha irrigated in 2045. In total value terms, the stock value increased from 416 MDH in 2011 to 458 MDH in 2045. The stock value of surface water used conjunctively with ground water increases from 13,562 DH per Ha. in 2011 to 32,725 DH per Ha in 2045. The stock value of surface water per cubic meter is more valuable than the stock value of ground water due to the cost of pumping.

The drought simulation and the water productivity – efficiency simulations show an increase in the stock value of both surface and ground water in Souss Massa. The results for the region of Tadla Azilal follow the same general pattern, but differ substantially in magnitude, particularly land producing cereals and pulses. Land planted to cereals and pulses in Tadla Azilal is predicted to have a stock value of 38,558 DH per Ha in 2011 to 45,958 DH per ha in 2045. Land planted to Fodder tends to have a higher stock value in Souss Massa than in Tadla Azilal where land in this category ranges in stock price of 42,775 DH per Ha in 2011 to 49,029 DH per Ha in 2045.

The stock value of the Tadla Azilal aquifer is about twice the stock value of the Souss Massa aquifer. The value ranges from 901 MDH in 2011 to 996 MDH in 2045. The Tadla Azilal's aquifer stock value in terms of Ha irrigated ranges from 4,436 DH per Ha irrigated in 2011 to 4,906 DH in 2045. The stock value of surface water is also higher initially in this region than in Souss Massa. The value ranges from 15,728 DH per Ha irrigated in 2011 to 24,168 DH per Ha irrigated in 2045, whereas Souss Massa ranges from 13,562 DH to 32,725 DH per Ha irrigated.

Policy Implications

Decreasing water intensity*:* The services of land, surface and ground water in irrigated crop production account for about 5 percent of value added by primary resources in the Souss Massa region, and for about 17 percent of value added in Tadla Azilal. This difference indicates that crop technology is more land and water intensive in Tadla Azilal than it is in Souss Massa. That is, in the less arid and more water abundant region of Tadla Azilal, farming methods are more reliant on land and water resources, relative to labor and capital, than are farmers in the Souss Massa region. Per unit of value added, the technology farmers employ in Souss Massa is more water saving (and closely linked land saving) than the technology farmers use in Tadla Azilal. *A policy implication is for public authorities and private organizations to help farmers find those crop production technologies that save the relatively most scares resource, water.* This strategy is also consistent with the World Bank (200b) findings that the proportion of natural resource value in total national asset values falls with the level of GDP per capita. That is, the stock value of capital, labor services and institutional services rise in proportion to the stock value of natural resources over time as GDP per capita increase on a relatively persistent basis. This suggests that the aggregate production of goods and services in advanced countries become less dependent on the services of natural resources. State another way, the unit of natural resource services produces a higher level of GDP in advanced countries.

Substituting capital for water. Our analysis shows that in the process of economic growth, capital in production grows per unit of labor, and water resources. This results largely because capital rental rates fall with time while wages rise, and the shadow value of water increases. The substitution of cheaper capital for labor and water over time lowers production costs, while increasing the productivity of the natural resource services of land and water. *Policy that places downward pressures on the costs farmers face in substituting capital for other resources, such as lower cost banking and credit market structures, and introducing farmers to new farming methods that make substitution more profitable should be encouraged.*

Reallocation of surface water. Cereals and pulses are often viewed as food staples and important to food security considerations. At the same time, this crop category is a relatively intensive user of water per unit of value added. In periods of drought, cost of cereal and pulses production tends to rise relative to other crops as the shadow value of irrigation water increases. Effectively, other crops, particularly the use of ground water to produce fruits and vegetables, places pressures on cereal and pulses producers since fruit and vegetable producers draw more heavily on ground water causing water's shadow price to rise. *Food security might be better achieved by a policy which decreases the amount of surface water assigned to produce cereals and pulses and increasing the amount assigned to more competitive crops, such as fruits and vegetables.* By exporting the crops for which Morocco has a comparative advantage and import cereals, more reliance is placed on surface water in producing competitive crops which will lessen pressures on lowering the ground water table and decreasing pumping costs.. Of course, for Morocco to important cereals, domestic and foreign trade barriers to Morocco's exports of fruit and vegetables need to be addressed as well.

Water saving technology. Our analysis suggests the economic rent to land and water resources per irrigated Ha are lower in the Souss Massa region than in the Tadla Azilal region. This is largely caused by the mentioned differences in land and water intensity in irrigated crop production being higher in the Tadla Azilal region. However, the growth in land and water rents over the period 2011 to 2045 rise by over 230 percent in the Souss Massa region compared to about 30 percent in the Tadla Azilal region. Rents to surface water per Ha in irrigated crops rises be almost 300 percent in Souss Massa, as does the shadow price of water, while ground water rent rises by only 7 percent (compared to 4 percent in Tadla Azilal). Thus, relative to Tadla Azilal, the flow of services, from especially water, in irrigated crop production in Souss Massa is becoming a more limiting resource than are these same services from crop production in the Tadla Azilal region. *The policy implication is that attention or policy emphasis should be given to new water saving technologies in the Souss Massa region to reduce pressures on water as a more limiting resource to expanding production of irrigated crops.* This action strengthens the former recommendation, that is, decreasing water assignments in the less competitive crops, such as cereals and pulses, and increasing assignment to the more competitive crops such as fodder, and fruits and vegetables.

***Aquifer as a buffer stock*.** In the case of surface water shortages, our drought analysis shows that crops using water more intensively than other cops experienced the largest decline in value added. The more competitive crops, such as fodder and fruits and vegetables, experienced the least decline in value added. Effectively, the latter crops could "pull" ground water away from the less competitive crops as the water shadow value, relative to the base analysis, rose over time. The surface water shortage decreased land rents, but increased water rents. The Souss Massa aquifer served as a buffer for the first 5 to 8 years of the drought simulation, increasing the depth to the water table. After about ten years, withdrawals were largely unchanged from base withdrawals. These results suggest the aquifer can only be relied upon for replacing surface water in the short run. A similar result, but less extreme, is predicted for ground water as a buffer stock in the Tadla Azilal. This result places pressures on policy makers and advisers to, once again, allocate surface water particularly efficiently among crops, with the likelihood that the most water competitive crops receiving a somewhat higher allocation of water during a drought than the less water competitive crops, such as cereals and pulses. *Subsidies to ground water pumping will only speed up the increase in the depth of the water table, a depth that is unlikely to be sustainable in the longer run without subsidies.*

Water productivity A ten percent increase in water productivity – efficiency increased value added in both regions, and by the greatest percentage per Ha. planted to fruits and vegetables in Souss Massa. In the case of cereals and pulses the average annual gain (2011 to 2040) in value added per Ha was higher than for Tadla Azilal, otherwise the gains per Ha of the other irrigated crops are predicted to be higher in Souss Massa. These average annual gains per Ha are a guide to the gross value of gains to research and farm extension expenditures that seek to increase the productivity – efficiency of irrigation water. The increase in the type of water productivity – efficiency considered here increase the depth of the water table in both regions relative to the base. The differences in water table depth between the two regions link to features of the aquifers captured by our data, the most important of which is the larger ground water recharge per unit of water extracted in the Tadla Azilal region. The ten percent increase in efficiency increased the water table depth by a greater percentage, relative to base, in Souss Massa relative to Tadla Azilal. Another type of technological change, which is not investigated in this study, would be to decrease the "importance" of water in crop production for the same amount of value added as the base solution. This type of technological change would tend to lower, rather than raise, the shadow value of water and lessen the depth of the water table relative to base.

***The temporal rate of ground water withdrawal*.** Our assumption that farmers do not take into account that their individual withdrawal of water has no effect on the depth of the aquifer almost surely leads our modeling results to "over extract" water in yearly years and under extract ground water in later years. Over extract means withdrawing ground water at an annual rate that does not maximize the discounted present value of the stream of rents to the resource. *A policy implication is that public authority or a farmers' water association might be delegated with convincing farmers of this possible consequence of their behavior*. Changing behavior would likely serve to conserve the profitable extraction of ground water over a longer period of time as well as serve as an insurance to buffer periodic if not long-term trends in surface water declines.

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I. Introduction

This study focuses on the economy-wide effects over time of surface and ground water used for irrigation in two regions of Morocco. In the case of Morocco, irrigated agriculture accounts for about 18 percent of total area cropped. This area produces about 45 percent of agricultures' value added in 2011 and can reach 70 percent in dry years[1].

Worldwide, irrigated agriculture accounts for about 70 percent of total freshwater withdrawals (Molden, 2007, FAO, 2011). Approximately 20 percent of the world's cultivated land is irrigated, accounting for an estimated 40 percent of total agricultural production (Rosegrant et al., 2009). The United Nations report (2013) projects the world population to rise to 9.6 billion by 2050, or a factor of 1.35. Rising incomes will increase the quantity of food consumed and the animal protein content of diets. Given the relatively high virtual water content of animal protein, water demand will increase in far greater proportion than the increase in food demand. Between 1990 and 2000, the world's population grew by about 17 percent, but freshwater demand grew by a factor nine (FAO. 2009). Without efficiency gains, global water withdrawals are projected to increase from 3,100 billion cubic meters (bm3) to 4,500 bm3 by 2030, leaving one-third of the world population living in countries afflicted by water scarcity (World Bank, 2006a).

Freshwater, including rain, snow melt and ground water are forms of *natural capital*. With variable rainfall, Morocco is blessed with surface water emanating from mountainous areas, and numerous aquifers. On average, Moroccan agriculture accounts for around 85 percent of total freshwater consumed (Doukkali and Legars (2015)). The World Bank sponsored study "Where Is The Wealth Of Nations" (2006b), finds that 69 percent of the

[1] see : http://www.agriculture.gov.ma/pages/lirrigation-au-maroc

total value of natural capital lies in cropland and pastureland in low income countries, and falls to about 40 percent of natural capital in high income countries. The report suggests the lower percentage of natural capital in high income countries results from the fact that they have allocated some rents from natural capital to invest in other forms of capital. The income stream or rent earned from natural capital--if properly managed--is a critical source of revenues to invest in ways that sustains economic growth and development. In the case of water, the rent or profit farmers earn can be reinvested in ways that increase water productivity, which in turn, can help to sustain the flows of surface and ground water for future generations.

Since agriculture comprises a relatively high share of most low and middle income countries' gross domestic product, (about 14.8% in 2011 for the case of Morocco), and agriculture consumes upwards of 70 to 90 percent of disposable fresh water supplies (FAO, 2011), water is "food oriented" and clearly an economy-wide resource. Water scarcity and its reallocation in agriculture not only affects food production, but also the allocation of land, labor, capital, chemical and biological resources. The rest of the economy benefits from a productive agriculture in many ways. Agriculture's upstream factor markets experience a growth in demand for biological, chemical and mechanical inputs, while downstream market channels experience growth in wholesale and food processing firms, which typically translates into greater access to food at lower prices. The savings on food purchases that households experience can be reallocated to savings, investment in own human capital, and the consumption of industrial and service goods, thus fostering a multiplier effect on the total economy. This is an evolutionary process over time, and one in which water as a natural resources plays a critical role, particularly in water scarce economies where agriculture comprises a relatively large share of total gross domestic product (GDP).

I.1 Focus

We focus on the area of Souss Massa, and in a separate analysis, the area of Tadla Azilal both in the context the rest of the Moroccan economy. We model the conjunctive use of water, and attempt to capture the dynamics of the hydrological properties of these regions' aquifers as water is withdrawn for irrigation purposes over time. Together, these two regions account for about 14 percent of total surface water allocated to irrigation. The Souss Massa region draws about 78 percent of its total water use from ground water (table 7). The Tadla Azilal region draws about 38 percent from ground water (table 10). If water withdrawals maintain their more recent volumes, some evidence suggests the Souss Massa aquifers may not be sustainable. In addition to a better understanding of the exploitation of these aquifers and effects on the broader economy, we also estimate the "wealth value" of these resources.

The economics of water in Morocco has received considerable attention relative to most other countries. These include economy-wide, but static, studies by Roe et al. (2005), Diao et al. (2005), and Diao, et al. (2008). The latter economy-wide study also considered the conjunctive use of ground and surface water, but in a static context. That is, totally ignored in these studies are: the hydrological issues associated with the net balance between water withdrawal over time, the implications to a rise in the cost of pumping, concern of when the cost of pumping may reach the level where withdrawals of water from an aquifer balance with inflows, and the implications this has to crop production and effects, over time, on the rest of the economy.

An ambitious world-wide static general equilibrium model was developed by Calzadilla et al (2010). They found that increasing irrigation efficiency led to global water savings, but the efficiency gains are not beneficial for all regions, mostly as a consequence of changes in trade patterns. A summary of many of these studies is given by Dinar (2012).

The closest to this study is a forthcoming paper by Smith et al. (2016). They show the effects over time of water withdrawal for irrigation from an aquifer in the Punjab of India on the Punjab and rest of the Indian economy. They find that over exploitation of the aquifer leads to an increasing comparative disadvantage of the region's agriculture, a disadvantage that is hard to reverse because of the subsidies provided to electricity used in pumping. Several other economy-wide studies also appear in the recent literature, but they too are static in nature. In their recent paper, Doukkali and Lejars focus on the energy cost of irrigation policy in Morocco. They report energy subsidies, particularly through the National Irrigation Water Saving Program Support Project, provide substantial support for the conversion of existing irrigation systems (sprinkler and gravity) to localized irrigation systems which are assumed to be water-saving techniques. However, they find these subsidies are excessive; they exceed the Department of Agriculture's total investment budget and suggest the multiplier effects of the subsidies are higher in rain fed agriculture than irrigated agriculture.

I.2 Organization of paper

The following section provides background and the nature of the data used in this study. The first subsection gives a brief discussion of the evolution of the economy over time since our analysis is also about economic growth and structural transition. The second subsection describes the Moroccan economy with most attention given to irrigated agriculture. The next subsection describes the Souss Massa region using the same crop and economy-wide categories as those used for all of Morocco in order to facilitate comparison and to highlight the relative importance of the region in the broader economy. The next subsection does likewise for the case of the Tadla Azilal region. Then, we provide a verbal description of our analytical model, (a mathematical summary appears in the appendix) followed by a discussion of fitting the model to data.

The next major section comprises the empirical analysis. The analysis has three major parts. The first subpart focuses on the empirical results for Souss Massa and rest of Morocco. We refer to this analysis as the base analysis. This subpart is followed by two analyses. The first analysis investigates how a ten percent decline in surface water (drought) in the Souss Massa sub region affects the base analysis. The second analysis investigates how a ten percent increase in irrigated water productivity (or efficiency) alters the base solution. This same pattern of analysis is conducted for the Tadla Azilal region in the second subpart. The third subpart is an analysis of the stock or asset value of land and water resources in each region, and the effects of the mentioned shocks to surface water and water productivity –efficiency on asset values. Summary and discussion of seven major policy implications to conserve the ecosystem services of water conclude the paper.

II. Background

This section has three parts. We first discuss the nature of economic growth of the Moroccan economy over the last few decades. This section is followed by a discussion of the economy's structural features with particular attention to the subsectors of cereals and pulses, fodder, fruit and vegetable production, and production of other irrigated crops. These subsectors are discussed for the regions of Souss Massa, and Tadla Azilal.

II.1 Transition-growth features of the Moroccan economy

The average annual rate of growth in Moroccan real GDP averaged about 4.2 percent over the entire 1971-2012 period, with a slightly higher rate of 4.5 percent over 2000-2012 (table 1). A growth accounting exercise attempts to estimate the contribution that growth in capital stock and labor make to these rates of GDP growth and, as a residual, the contribution of technological change which we refer to as total factor productivity (tfp). These results are also reported in table 1. They suggest that growth in the country's stock of capital, which averaged on an annual basis a rate of growth of about 5.8 percent over the period 1971-2012, contributed an average of about 2.1 percentage points to growth in GDP, while the growth in labor employed contributed another 1.9 percentage points. Growth in the countries capital stock sustained its percentage point contribution on average over the 2000-2012 period, while labor's percentage point contribution declined to an annual average of only 0.7 percent. This decline reflects a decline in labor market participation rate, and some slowing of growth in the labor force. Growth in the countries total factor productivity averaged only 0.01 percentage points per annum on average over the entire period, but rose to an annual average of 1.8 percent during the 2000-2012 period. Thus, growth in multifactor productivity compensated for the decline in labor's contribution during 2000-2012.

These factor contributions to growth are accompanied by a structural transition of the economy, Figure 1. The share of service sector GDP in total GDP rose from about 43 percent in 1970 to about 60 percent in 2012, while agriculture's share declined from about 30 percent in 1970 to about 16 percent in 2012. This pattern of structural transition, while somewhat weak, is along the lines of what successful economies experience in the process of growth, Herrendorf et al (2013). In contrast, the industrial sector's GDP share in total GDP has declined from its peak of about 30 percent in the late 1970s to about 25 percent in 2012.

When attention is placed on sector contributions to growth in the country's GDP, agriculture stands out (table 2). Agricultures' average annual rate of growth over the 1971-2012 period was 5.1 percent, higher than the other two sectors, although, with considerable annual variation. Weighting these percentage points by the sector share in GDP, we see that agriculture contributed an annual average of 1.2 percentage points to the countries 4.2 percent growth in GDP. The largest sector, service, contributed 2.2 percentage points and industry at only 0.09 percentage points. The last column of table 2 shows that agriculture contributed about 27% to the countries growth in GDP. This contribution is higher than the agriculture's average annual share in GDP. Agriculture can be said to be contributing more than its share to growth in economy GDP. Industry's contribution is less than its share in GDP while the service sector's contribution is about equal to its share in GDP. If the supply of irrigation water slows the growth of agriculture, the direct effects on its contribution to growth will surely be diminished.

II.2 Structural features of the Moroccan economy

Table 3 provides a structural view of the Moroccan economy, as well as the manner in which some of the data for the study are organized. We have aggregated the agricultural sector into five subsectors, four of which are irrigated. The irrigated subsectors are: cereals and pulses, fodder, fruits and vegetables, and other irrigated agriculture. All other of none irrigated agriculture is aggregated into a single dry land sector called other agriculture. The rest of the economy is aggregated into two sectors, industry and service. All values in the table are in millions of 2011 Dirhams (DH).

The first column of table 3, Cereals and Pulses, shows the total value of resources employed economy-wide in their production. The row titles categorize the type of resource including government transactions. The category "Value of intermediate inputs" includes the value of outputs produced in the row-indicated sectors that are employed in the production of cereals and pulses. The value of labor, land, irrigation water and capital are the primary resources employed in production.

Special note should be made of the value of irrigation water. This estimate is based on the view that, in the absence of a water market, the value of water is embodied in the rental value of land. Thus, in the case of cereals and pulses, the annual total rent to all of the land employed in the production of this commodity is 406 plus 1252 million of 2011DH. This estimate is based on selected farm level interviews where the farmer is asked to report the value of rent on irrigated land planted to cereals and pulses, and the value of rent on land of equal quality but not irrigated. Thus, if the land was not irrigated, total rent would be 406 MDH.

Subsector value added[2] (VAD) is given as the sum of primary resources, which for the case of cereals and pulses, is 3,026.4 million of 2011DH. The difference between total gross value (i.e., the column sum) and value added is the cost of intermediate resource employed in cereal and pulses production, and the ratio gives the share in gross cost that is accounted for by intermediate factors (0.35 in the case of cereals and pulses).

[2] Value added refers to the value of primary resources employed in production such as labor, capital, land, and later in this report, surface water.

This structure of organizing data prevails for other subsectors and sectors of the entire economy. Summing subsector and sector VAD yields a value for total economy-wide VAD of 773,338 million of 2011DH This value differs from other estimates of 2011 GDP mostly because we are accounting for the value of water in the value-cost of agricultural production, and we are omitting taxes on production, net of subsidies including tariffs on imports. We see from structuring the data in this manner that irrigated fruits and vegetables make up almost 25 percent of agricultural VAD, while dryland agriculture accounts for about 65 percent of agricultural VAD.   The share of agriculture in total VAD is 14.8 percent, followed by industry and service at 28.6 and 56.6 percent respectively.

The data reported in table 3 can be used to show the share (importance) in subsector value added of the primary resources, labor, land, irrigation water and capital. Table 4 reports these factor shares in sector value added. These factor shares in value added are not necessarily in a farmer's cost-accounting since the farmer is unlikely to pay the cost for water, or necessarily for land if the farmer is an owner operator, nor pay for labor if only family labor is used. In this case, proper accounting would show the sum of these values as profit, and if disaggregated, the value of these resources in production. Of first importance is the cost share of irrigation water, the value 0.414 (table 4, column one). This value is the ratio of 1,252/3,024 appearing in table 3. This share (0.414) is the highest of the other three irrigated subsectors. An implication is that as water becomes scarce, it is likely that the cereals and pluses sector, all else constant, will give up some of the water (most likely ground water) it employs so that some of the water can be reallocated to other crops. The reason is that, all else constant, a uniform rise in the unit (shadow) value of water will raise costs or cut profits in the production of cereals pulses relative to the other subsectors. A similar logic applies to the implication of cost shares for other subsectors and sectors of the economy. With the exception of cereals and pluses, the share of capital in value added is over 70 percent. This relatively high share suggests that, all else unchanged, the change in the level of agricultural production will be relatively sensitive to the availability of capital, i.e., the cost (including lending) of machinery and other equipment. This might be a partial explanation for capital's contribution to growth reported in table 1, and the agricultures contribution to growth in GDP reported in table 2.

The share of value added by labor and capital in industry and service production shows that relative to the service sector, and all else constant, the availability of lower new capital well tend to benefit the industrial sector by lowering its cost of production to a greater extent than it will lower the cost of production in the service sector. Since the service sector's value added has a larger labor component (0.434) than industry (0.271), a rise in wages, all else constant, will tend to raise the cost of production of service goods relative to a rise in the cost of producing industrial goods. We return to discuss the economic forces and the sectoral competition for economy-wide resources in the analysis section.

Estimates of area irrigated and the volume (in millions of cubic meters, denoted by mm3) of water allocated to the various crop categories for all of Morocco appear in table 5. Fruits and vegetables dominate with an estimated 869,007 Ha planted to these crops, followed by cereals and pulses, fodder and other irrigated agriculture. The available data indicate that about 18 percent (1,745,652 Ha) of the total hectares planted to crops are irrigated. While data on the quantity of ground water allocated to crop production in all of Morocco are only available for fruits and vegetables, ground water comprise about 60 percent (2,746 mm3) of total water used in the production of this crop in 2011.

These tables show that irrigated agriculture produces about 35 percent of agriculture value added on about 18 percent of the country's cultivatable land (including fallow which comprises about 15 percent of total cultivate land). As noted in the introduction to this paper, the world average is 40 percent of total agricultural production produced on irrigated lands that comprise only 20 percent of total cultivated area

II.3 Structural features of the Souss Massa economy.

Souss Massa is located in the geographical center of Morocco, between the Atlantic Ocean and the mountains of the High Atlas and the Anti Atlas with a population of about 1,680,000 inhabitants, about 53 percent of which live in rural areas. The region covers an area on the order of 23,950 km^2 and contains three watersheds, drained by major rivers. These surface water sources tend to be limited and very irregular. Oued Souss is characterized by a strong seasonal flow with the maximum flows occurring during the months of January through March. The Souss Massa region comprises two main hydrogeological formations, the Souss formation and that of Chtouka. While considerable yearly variation characterizes these aquifers, table 6 provides a snapshot of the ground water balance sheet for the Souss and Chtouka aquifers. The net balance for the Souss aquifer shows an negative balance of 283.5 mm^3 in 2007, and a reported yearly variation that ranges from a negative 100 to a negative 370 mm^3 . The negative net yearly balance since 1968 is estimated to have led to a decline in the stock of water in the aquifer by 7 bm3, and an average decline of the piezometric level ranging from 0.5m to 3m per year.

The Chtouka formation extends over an area of more than 94 km^2. A snapshot of its water balance sheet for 2007 in the second column of table 6. This formation too is overdrawn, with an estimated negative balance of 57.4 mm^3 in 2007. In terms of the negative water balance as a percent of total water withdrawal, the Chtouka formation experienced a deficit of about 64% compared to that of the Souss Massa formation which experienced a deficit to withdrawal of about 51 percent. This increase will tend, all else constant, to raise the cost of production of those crops for which water is more heavily used in per unit of production.

This region has been one of the fastest growing economies in Morocco, and produces over half of Morocco's citrus and vegetable for export (Bouchaou et al. 2008). The area cropped and irrigation water employed are shown in table 7, for the same aggregate crop categories discussed for all of Morocco. Of the 501,635 hectares cultivated, irrigated crops account for 22 percent (111,594 Ha) of the area. Fruits and vegetables tend to dominate the area irrigated; they comprise about 71 percent of the area, or 79,243 hectares, and consume a like percentage of irrigation water. This region also relies heavily on ground water which comprises about 78 percent of total water allocated to irrigated crops.

The structure of the Souss Massa economy is depicted in table 8, which shows the same categories of inputs and outputs as for all of Morocco (table 3), and expressed in millions of 2011 Dirhams. Agriculture comprises about 22.5 percent of the regions VAD, about the same percentage as industry, while service sector VAD is about 55 percent. Fruits and vegetables alone account of over 46 percent of the region's agriculture value added while dryland agriculture accounts for almost 50 percent. Together with table 7, total irrigated agriculture accounts for about 51 percent of total agricultural value added but only accounts for about 22 percent of cropped area. This level of irrigated crop productivity stands in contrast to all of Morocco where irrigated agriculture produces about 35 percent of agricultural value added on 18 percent of total cultivated land.

Table 8 shows the share of intermediate inputs in the value of gross output. These shares range from a low of 0.21 for dryland agriculture to a high of 0.38 and 0.39 for fruits and vegetables, and cereals and pulses, respectively. These shares suggest the importance of intermediate inputs in the production of these crops, that is, the share in gross output form "linkages" to upstream and downstream markets for intermediate factor of production such as chemical, mechanical (other than capital) and biological inputs. If water becomes more costly and production of irrigated crops decline, the direct negative multiplier effects on the economy will be transmitted through these linkages.

The structure of production of each crop is characterized by the primary resources of labor, land, irrigation water and capital. Their share in total cost in producing VAD is given by "cost" shares in VAD (table 9). Agricultural capital is relatively important share of value added for all crops, ranging from 0.67 for cereals and pulses to about 0.80 for fodder crops and 0.815 for fruits and vegetables. The capital share of 0.67 in value added for cereals and pulses contrasts with that of 0.17, table 4 for the case of all of Morocco. Irrigation water in Souss Massa, as a share in subsector value added, tends to be somewhat lower than for the case of all of Morocco, and particularly so for the case of cereals and pulses. Otherwise, for other crops the factor shares follow a similar pattern as for all of Morocco.

An indicator of productivity is the value added per hectare by irrigated crops. In the all Morocco case, calculations from table 3 and table 5 yield a value added of 23,110 DH per hectare for all irrigated crops, while the same calculation for Souss Massa yields an average value added of 46,855 DH per hectare. This higher productivity in value added per hectare is also associated with higher use of intermediate inputs from agriculture, industry and services than all of Morocco. For all of Morocco, the employment of intermediate inputs amounts to about 6,556 DH per hectare while for the case of Souss Massa, the value of intermediate inputs per hectare irrigated amounted to about 27,428 DH. The higher use of the value of factors of production per hectare also carries over to water allocated per hectare. An indicator of intensification of production in Souss Massa is water use per hectare. In the case of cereal and pulses, water allocation per hectare exceed that of all of Morocco by a factor of 1.26, a factor of 1,7 for fodder, 1.5 for fruits and vegetable but only 0.7 for other irrigated agriculture.

II.4 Structural features of the Tadla Azilal (Oum Er Rabia) economy.

The basin of Tadla Azilal extends over an area of about 33,520 square km. The Oued of Oum Er Rbia originates in the Middle Atlas mountains at about 1800 m of altitude, and eventually flows into the Atlantic Ocean. This region is home to roughly 4 million inhabitants, about 65 percent of which live in rural areas. Rain fall varies from 1100 mm in the Middle Atlas to only 300 mm in the areas downstream of the river. The Oued of Oum Er Rbia and its tributaries are the major supply of surface water, although the amount of snow and rate of melting causes some unpredictability of water availability.

Aquifers form a multilayered system composed of 4 bunk aquifers separated by levels of strata that in some areas are impermeable and semi permeable in others. The overall water balance sheet for the region is given in the last column of table 6. Inflows of water total about 447 mm3 while outflows are estimated at 450 mm3 in the year 2007. The net balance is an over withdrawal of only 3 mm3 . Thus, relative to Souss Massa, this snapshot suggests that the present level of water withdrawal has little effect on the aquifer's capacity to meet the needs of "buffer storage" during at least short periods of surface water shortages. However, the quality of groundwater is declining. In addition to an increase in nitrate concentration at rates higher than 50mg/l, salinity of the water in certain aquifers, including the Beni Amir and Beni Moussa West aquifers is increasing.

Table 10 reports the area and water allocated to the same crop categories discussed previously. Of the 618,161 hectares cultivated, irrigated crops account for 33 percent of the area, or 207,048 hectares. No irrigated crop category dominates area cropped. Cereals and pulses account for about 38 percent of area cropped, followed by fruits and vegetables at 34 percent, fodder at 20 percent and other irrigated crops at about 8 percent. Fruits and vegetables, and fodder consume 34 and 33 percent, respectively, of total water allocated to production. The quantity of ground water used exceeds the quantity of surface water used in the production of fodder (60 percent) and other irrigated crops (61 percent). No ground water is reported for the production of cereals and pulses[3].

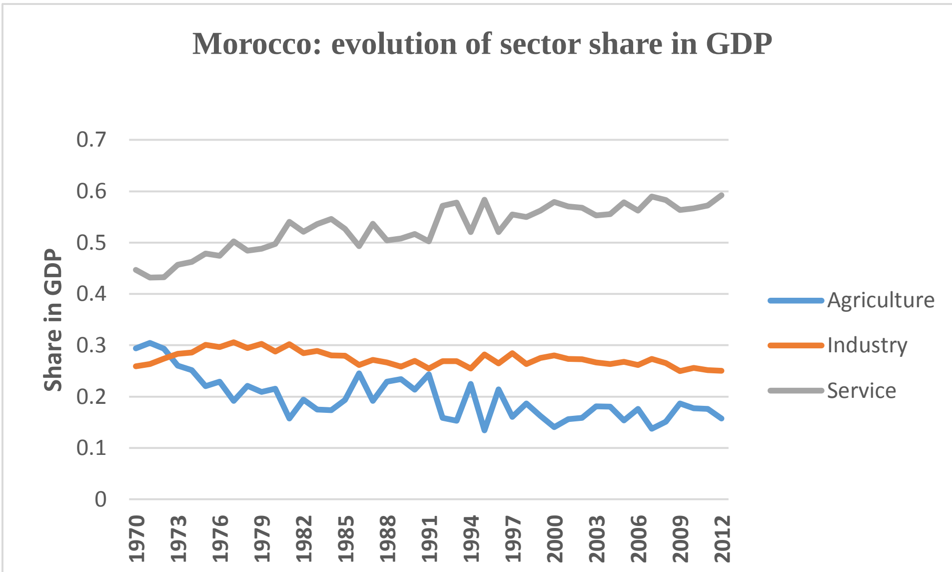
The structure of production of each crop is characterized by the labor, land, irrigation water and capital "cost" shares in total value added (table 11). Agriculture comprises almost 37 percent of the regions value added, which is twice as large as the value added by the region's industry (15.7 percent). The service sector accounts for about 48 percent of value added. Within agriculture, crops in dryland agriculture account for about 46 percent of the value added by all crops. Fruits and vegetables account for over one-fourth of agriculture value added. Dryland agriculture accounts for over 66 percent of the area cropped, but only produces about 46 percent

[3] Our analysis in the next section shows that the value of the last unit of surface water in production of cereals and pulses is less than the cost of pumping ground water to irrigate this crop. Thus, to pay the extra cost to use surface water, farmers are more likely to decrease the area in cereals and pulses and plant a different irrigated crop.

of agriculture's value added. Thus, over one-half of agriculture's value added is produced by irrigated crops on about 34 percent of land area.

In terms of down and upstream market linkages for irrigated agriculture, as measured by the share of intermediate inputs in the value of gross production, the Souss Massa region tends to dominate both all of Morocco and the Tadla Azilal region for cereals and pulses, fodder and fruits and vegetables. Tadla Azilal dominates all of Morocco for cereals and pulses, fodder, and other irrigated agriculture. Hence, the rest of the economy is likely to be more affected through these linkages by a unit of water shortage in Souss Massa than in Tadla Azilal.

The importance of labor, land, water and capital in value added is shown in table 12. Capital's share in value added is the highest of all crops in the production of fruits and vegetables (0.79), but similar to all of Morocco (0.75) and somewhat lower than the same share for the case of Souss (0.82). The share of irrigated crop value added of water is marginally higher for all irrigated crops in Tadla Azilal than are these shares for case of Souss Massa. In comparison to all of Morocco however, the value share of water in each irrigated crops' value added is marginally lower. From the perspective of water alone, this ranking suggests that Souss Massa can produce a unit of value added in irrigated crops at less water cost (and volume) than can Tadla Azilal, while both can produce a unit of value added at lower water cost than can all of Morocco. These factor shares show that the ratio of capital to water, for a given level of production, tends to be higher in Souss Massa than in the Tadla Azilal region. When this condition exists for the same crop produced, it can be said the farmers in Souss Massa, relative to farmers in the Tadla Azilal area, are using water saving farm technology and practices relative to farmers in Tadla Azilal where water per unit of value added by irrigated crops is in greater relative abundance than in Souss Massa.



Morocco: evolution of sector share in GDP
Share in GDP
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
1970
1973
1976
1979
1982
1985
1988
1991
1994
1997
2000
2003
2006
2009
2012
Agriculture
Industry
Service

Figure 1.

Table 1. Rate and sources of growth in Moroccan real GDP, 1971 to 2012

	1971-2012	2000-2012
Average annual growth of the number of workers	0.032	0.012
Average annual growth of capital stock	0.058	0.054
Average annual percentage point contirubtion of		
labor to growth in GDP	0.019	0.007
capital stock to growth in GDP	0.021	0.020
multi-factor produtivity to growth in GI	0.001	0.018
Average annual growth in real GDP (In constant 2007 LC	0.042	0.045

Source: Roe, T., R. Smith and D. Choi (2014).

Table 2. Sector contributions to growth Moroccan real GDP, 1971 to 2012

	1971-2012	1971-2012 percent contrib.
Average annual growth of agricultural GDP	0.051	
Average annual growth of industrial GDP	0.039	
Average annual growth of service GDP	0.047	
Average annual percentage point contribution to GDP growth		
Agriculture	0.012	28%
Industry	0.009	21%
Service	0.022	51%
Average annual growth in real GDP (In constant 2007 LC	0.043	100%

Source: Roe, T., R. Smith and D. Choi (2014).

Table 3. Total value of primary and intermediate factors of production in sector gross value of production, all of Morocco, in MDH 2011*/

	Cereals & Pulses	Fodder	Fruits & Vegetables	Other Irrigated Agriculture	Other Agriculture	Industry	Service
Value of intermediate inputs from							
Agriculture	937.1	456.5	4568.5	178.7	5621.3	59984.0	1841.0
Industry	682.2	567.3	3716.5	210.5	8944.4	286601.0	66382.0
Service	13.9	17.7	89.8	7.2	1365.4	19244.0	69407.0
ue of primary factor of production							
labor	846.2	568.7	4138.0	276.2	12589.7	59787.0	189783.0
Land	406.0	202.7	657.4	90.2	7487.4		
Irrigation water**/	1252.0	595.7	2464.3	224.6	0.0	0.0	0.0
Capital	522.1	4953.2	21174.6	1970.5	54291.4	161193.0	247864.0
Government	0.0	0.0	0.0	0.0	155.0	3576.0	2308.0
Total gross value	4659.6	7361.8	36809.2	2957.9	90454.7	590385.0	577585.0
Value Added (VAD)	3026.4	6320.2	28434.3	2561.5	74368.5	220980.0	437647.0
Share of intermediates in gro:	0.35	0.14	0.23	0.13	0.18	0.62	0.24
Subsector share in agricultur	2.6%	5.5%	24.8%	2.2%	64.8%		
Agriculture, industry and service share in total value added					14.8%	28.6%	56.6%

*/ Based on Doukkali, 2015.

**/ Estimated based on the rental value of near identical land with and without irrigation value.

Table 4. Estimates of factor cost shares in agricultrue and economy-wide value added (VAD), 2011

	Cereals & Pulses	Fodder	Fruits & Vegetables	Other Irrigated Agriculture	Other Agriculture	Industry	Service
Labor	**0.280**	**0.090**	**0.146**	**0.108**	**0.169**	**0.271**	**0.434**
Land	**0.134**	**0.032**	**0.023**	**0.035**	**0.101**	**0.000**	**0.000**
Irrigation water	**0.414**	**0.094**	**0.087**	**0.088**			
Capital	**0.173**	**0.784**	**0.745**	**0.769**	**0.730**	**0.729**	**0.566**

Calculated from table 3.

Table 5. Estimates of area irrigated and volume of surface and ground water allocated to various aggregate crop categories for all of Morocco, 2011

	Cereals & Pulses	Fodder	Fruits & Vegetables	Other Irrigated Agriculture	Other Agriculture*/
Cropped area					
Hectares	**566,394**	**221,051**	**869,007**	**89,200**	**7,831,018**
Quantity of water (in mm3)	**1,695**	**1,579**	**4,548**	**726**	
Surface water	**1,695**	**1,579**	**1,803**	**726**	
Ground water	**NA**	**NA**	**2,746**	**NA**	

***/ Includes 1,497,814 Ha of fallow**

Table 6. Aquifer balance sheet for the area of Souss-Massa and Tadla Azilal, in mm3, 2007

	Aquifer balances Souss-Massa		Aquifer balance Tadla
	Souss	Chtouka	(Oum Er Rbia)
Rain infiltration	31	3.5	15
Irrigated water infiltration	4.5	15.7	400
River infiltration	160	2	10
Other, including under ground water flows	72	11.8	22
Total Inputs	267.5	33	447
Subterranean outflow	4	3	190
Irrigation withdrawal	521	78	240
Withdrawal for portable use	26	7.2	
Other		2.2	20
Total output	551	90.4	450
Balance	-283.5	-57.4	-3

Source: Taken from data published by Moroccan government sources.

Table 7. Souss-Massa: estimates of area irrigated and volume of surface and ground water allocated to various aggregate crop categories

	Cereals & Pulses	Fodder	Fruits & Vegetables	Other Irrigated	Other Agriculture*
Cropped area					
Hectares	14,500	17,341	79,243	510	390,059
Total quantity of water (in m3)	54,549,207	213,571,400	639,670,242	2,788,885	
Surface water	24,405,889	48,514,804	127,527,596	1,542,470	
Ground water	30,143,318	165,056,596	512,142,647	1,246,415	
Percent ground water	55%	77%	80%	45%	

*/Includes 174,654 ha of fallow

Table 8. Souss-Massa: total value of primary and intermediate factors of production in sector gross value of production, in MDH 2011

	Cereals & Pulses	Fodder	Fruits & Vegetables	Other Irrigated Agriculture	Other Agriculture	Industry	Service
Value of intermediate inputs from							
Agriculture	2.3	10.6	942.0	2.5	116.4	2492.4	239.4
Industry	37.9	130.5	1740.4	3.4	929.4	1770.2	3649.0
Service	1.0	3.3	186.2	0.6	275.9	389.8	5513.4
Value of primary factor of production							
labor	9.4	22.7	679.4	3.8	1035.8	1088.9	11036.3
Land	5.2	8.9	83.7	0.9	85.7	0.0	0.0
Irrigation water**/	6.3	10.2	116.6	1.2	0.0	0.0	0.0
Capital	42.4	334.7	3888.4	15.2	3884.4	8973.3	14061.3
Total gross value	104.4	520.9	7636.7	27.7	6327.6	14714.6	34499.5
Value Added (VAD)	63.2	376.5	4768.1	21.1	5005.9	10062.1	25097.6
Share of intermediates in gross valı	0.39	0.28	0.38	0.24	0.21	0.32	0.27
Subsector share in agriculture VAD	0.6%	3.7%	46.6%	0.2%	48.9%		
Agriculture, industry and service share in total value added					22.5%	22.2%	55.3%

Based on Doukkali, 2015.

**/ These values are estimated based on the rental value of near identical land with and without irrigation value.

Table 9. Souss - Massa: estimates of factor cost shares in agricultrue, industry and service, 2011

	Cereals & Pulses	Fodder	Fruits & Vegetables	Other Irrigated Agriculture	Other Agriculture	Industry	Service
Labor	0.148	0.060	0.142	0.179	0.207	0.108	0.440
Land	0.082	0.024	0.018	0.041	0.017		
Irrigation water	0.099	0.027	0.024	0.059			
Capital	0.671	0.889	0.815	0.722	0.776	0.892	0.560

Calculated from table 8.

Table 10. Tadla Azilal: estimates of area irrigated and volume of surface and ground water allocated to various aggregate crop categories, 2011

	Cereals & Pulses	Fodder	Fruits & Vegetables	Other Irrigated Agriculture	Other Agriculture*
Cropped area					
Hectares	78,307	42,303	70,673	15,764	411,161
Total quantity of water (in m3)	233,889,196	340,646,592	352,283,975	119,688,608	
Surface water	233,889,196	135,417,656	233,962,016	46,289,495	
Ground water	0	205,228,936	118,321,959	73,399,113	
Percent ground water	0	60.2%	33.6%	61.3%	

*/ Includes 63,003 Ha of fallow

Table 11. Tadla Azilal : total value of primary and intermediate factors of production in sector gross value, in MDH 2011

	Cereals & Pulses	Fodder	Fruits & Vegetables	Other Irrigated Agriculture	Other Agriculture	Industry	Service
Value of intermediate inputs from							
Agriculture	60.2	20.4	82.8	31.6	917.5	426.0	11.6
Industry	379.7	227.7	261.6	130.9	308.1	1,296.5	1,134.6
Service	29.4	26.6	20.3	7.9	441.4	138.0	1,469.3
Value of primary factor of production							
labor	100.8	99.3	180.1	75.8	686.4	476.0	3,825.8
Land	140.1	50.8	99.6	19.7	212.2	0.0	0.0
Irrigation water**/	126.1	50.8	131.2	33.8	0.0	0.0	0.0
Capital	371.1	674.3	1,556.9	239.8	2,527.4	2,680.0	5,774.2
Total gross value	1207.5	1149.9	2332.4	539.5	5092.9	5016.5	12215.4
Va;ie Added (VAD)	738.1	875.1	1967.7	369.1	3426.0	3156.0	9600.0
Share of intermediates in gross value	0.39	0.24	0.16	0.32	0.33	0.37	0.21
Subsector share in agriculture VAD	10.0%	11.9%	26.7%	5.0%	46.4%		
Agriculture, industry and service share in total value added					36.6%	15.7%	47.7%

*/ Based on Doukkali, 2015.

**/ Based on the rental value of near identical land with and without irrigation value (Doukkali 2015)

Table 12. Tadla Azilal: estimates of factor cost shares in agriculture, industry and service, 2011

	Cereals & Pulses	Fodder	Fruits & Vegetables	Other Irrigated Agriculture	Other Agriculture	Industry	Service
Labor	0.137	0.113	0.092	0.205	0.200	0.151	0.399
Land	0.190	0.058	0.051	0.053	0.062		
Irrigation water	0.171	0.058	0.067	0.092			
Capital	0.503	0.770	0.791	0.650	0.738	0.849	0.601

Calculated from table 11.

III. Model Basics

The analytical description of the model appears in the appendix. The model is based on neoclassical growth theory in which households are assumed to choose their path of consumption and savings over time so as to maximize the discounted present value of utility over their current and future generations. Firms are assumed to maximize returns to resources: labor, capital, intermediate inputs, and resources used to pump ground water, in a competitive market environment, given constant annual allocations of surface water to various crops. In the background, institutions are presumed to assemble the savings of households and lend to firms and other households at competitive rates of return. There is no risk of loan default.

In this framework, the stock of a country's capital (e.g., machinery and equipment), less depreciation, accumulates over time. Depending on a number of conditions, the total stock of capital per worker grows over time, albeit at diminishing rates as more capital leads to diminishing rates of growth in output per worker. However, the growth in capital means that each worker has "more capital" to work with thus increasing worker productivity. The basic framework of this structure appears in Barro and Sala-i-Martin (2004). They date the basics to Ramsey (1928), Cass (1965) and Koopmans (1965). Roe, Smith and Saracoglu (2010), among others (Gollin et al, 2004) have extended the basic framework to multi-sector economies.

An extension of the basic framework for this study is incorporating into the growth model the rudiments of aquifer dynamics. We refer to rudiments of aquifer dynamics because there is considerable spatial variation in water table depth and the balance of water inflow and outflow. Consequently, our framework must select a specific water pattern of out and inflows. Our empirical results must thus be interpreted with caution, yet they provide fundamental and overall insights into water as a scarce economy-wide resource.

Table 6 provides a balance sheet for the main Souss Massa and Tadla Azilal region. Other data suggest the depth to the water table, and the various estimates on the increase in the depth of the table over time. The key feature is that the change in the depth of the aquifer is a function of water withdrawal in each period of time less water infiltration into the aquifer. If water is withdrawn more rapidly than infiltration then, over time, the depth to the water level in the aquifer increases. An increase in the depth increases the resources, mostly energy, to pump water from greater and greater depths. At some point in time, the cost of pumping water from greater depths rises to the point where water withdrawal is equal to infiltration so that the depth to the water level remains constant. In this process, the rise in cost of pumping implies, all else constant, a rise in the cost of producing crops using ground water, thus placing these crops at a comparative disadvantage to other crops.

A simple diagram illustrates these basic points.

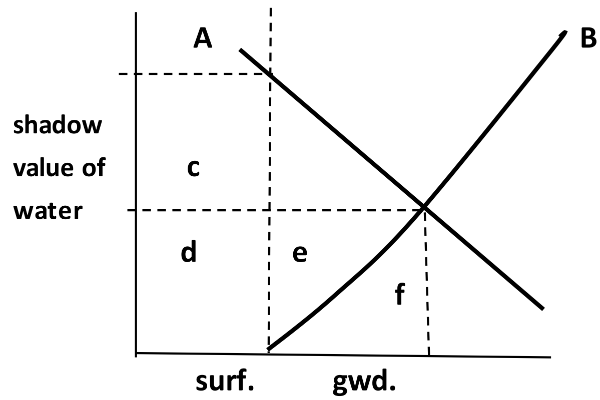


Figure 2: Conjunctive use of water

The horizontal axis is the quantity of irrigation water which includes surface water (surf.) and ground water (gwd.). The vertical axes is the shadow value of water. Line A is the farmer's demand for irrigation water while line B is the total supply of irrigation water. Surface water is presumed to be available at no cost but limited as indicated by the vertical dotted line. It can be shown that if this is all the water a farmer has access to, the rectangular area c plus d is the total return to surface water, and hence, the vertical axes gives the unit value of water which we call the shadow value because the farmer does not pay this value. Instead, the area c plus d becomes part of the farmer's profit.

If the farmer has access to ground water, resources are required to pump water, and the more of water pumped in a given time period, the higher is the cost per cubic meter of pumping. Greater volume of pumped water causes the farmer to "move up" the ground water supply line B. At the same time, the farmer is "moving down" his demand for water, line A, because more water applied to the same and unchanging amount of land leads to lower and lower returns to each additional unit of water allocated. Consequently, the shadow value of water falls to the point where the farmer's demand for irrigation water is just equal to the total supply of water (the intersection of line A with line B). At this point, the total return to both surface and ground water is the rectangle d plus the triangle e. The triangle f is the cost of allocating labor, capital and energy to pump water. Note that the farmer in this example will first choose to allocate surface water, and if the shadow value of surface water is greater than the unit cost of pumping, the next step is to pump ground water.

Suppose the demand A for water intersects the vertical axis to the left of the ground water supply function B. In this case, the farmer will not use ground water for irrigation, and may not use all of the surface water available. If the farmer produces two crops, say cereals and vegetables, an extension of this diagram will show that cereals may only be irrigated with surface water while vegetables will be irrigated by both surface and ground water. Moreover, the diagram only depicts the allocation of water at a point in time. Overtime, wages tend to rise, capital rental rates tend to fall, competition among sectors for economy-wide resources tend to increase the price of service sector goods, and thus resources are pulled into the service sector and away from other sectors. Consequently, lines A and B are shifting over time as are the shadow values and the rent values (i.e., the rectangular and triangular area) shown in the diagram. The model captures these many interactions over time.

Finally, pose the question: If the farmer earns at each point in time the flow of rents represented by area d plus e, what is the value of water as a natural resource? How much would society be willing to pay for this natural resource as an asset or as a stock? How will this value change over time? If the ground water becomes exhausted (which we define later), and - or drought decreases the availability of surface water, what is the effect on the Moroccan economy, and what does this imply for the discounted present value of water as an asset? These are some of the questions we address later in this report.

The results reported below are based on two separate empirical, but analytically very similar, models. We construct a model for the region Souss Massa and the rest of Morocco, and another for Tadla Azilal and the rest of Morocco. The empirical model has two major components. One component is a system of empirical equations that depict intra-temporal equilibrium; this part of the model resembles the standard static computable general equilibrium models popular in the literature. The second part of the model depicts inter-temporal equilibrium. This structure captures the temporal effects of the endogenous savings of households, capital allocations, and the evolution, over time of other endogenous variables. This general structure is explained in Roe, Smith and Saracoglu.

The data employed to estimate model parameters are taken from the Section II of this report. In both empirical models, the agricultural sectors of Souss Massa and Tadla Azilal regions are aggregated into the categories reported in the background section of this report: they are cereals and pulses, fodder, fruits and vegetables, and an aggregate category we refer to as other irrigated agriculture. The rest of Morocco is aggregated into only three sectors, other rest of Morocco agriculture, industry and the production of services. Services includes construction, transportation, business and retail services, and residential housing. We treat agriculture and industry as being open to international markets for exports and imports, while the service sector is mostly not traded internationally.

Total water for irrigation is surface plus ground. Surface water is treated as though it is assigned to each crop category in the same quantities for every year of the analysis. That is, surface water is not allocated by a market. Surface and ground water are treated as perfect substitutes in production so no account is taken of the possible differences in ground compared to surface water quality. In terms of figure 2, the vertical dotted line is the amount of surface water assigned to produce a crop. The farmer is then allowed to choose whether to pump grouns water. Further, we assume all farmers have the same water pumping technology, and no account is taken of traditional compared to modern water pumping technologies. Surely differences in water pumping technology affect the rate at which an aquifer might be depleted, with modern methods lowering the water table at a faster rate than traditional methods. We also treat the aquifer as an open access resource to which farmers take no account of the fact that their personal withdrawal of water alone lowers the water table.

IV. Empirical results

We first present the results for the region of Souss Massa in the context of the broader Moroccan economy. The results of the base solution, which depicts the evolution of the economy over time given our data and basic assumptions, is discussed in some detail. Then two simulations are performed. One simulation assumes a draught which forces farmers to draw more heavily on ground water, and in the process, compete more dearly for economy wide resources of labor and capital. The second simulation considers an increase in water productivity – efficiency. Since the fundamental forces of economic growth that prevail in the base solution also prevail, albeit modified, in the simulations, the discussion of simulation results are consequently made more brief. The discussion of the base solution and simulations for Tadla Azilal follow the same pattern with tables in the same format used to explain the Souss Massa results.

IV.1 Souss Massa and the rest of Morocco

We present results obtained from a solution to the model based on the data discussed in the previous section, which we refer to as the base solution. We then conduct two simulations. The first provides insights into the effect of a drought in the Souss Massa region with emphasis on the water economy. The second simulation focuses on increasing the productivity of water in the region. Both of the simulations are compared to the base results.

IV.1.1 Economy-wide results: base solution

The results from the base solution are presented in tables 13 to 17. As shown in table 13, the results suggest that the Moroccan economy's total value added by primary resources will increase from 769,978 million 2011 DH in 2011 to 1,057,273 million 2011 DH by the year 2040. This amounts to an increase of almost 40 percent in thirty years, and an average annual rate of growth in output per worker close to the 1.28 percent per annum, a rate that Morocco experienced over the period 2000-2012. Household saving grew modestly in level terms over the 2011 to 2040 period, but as a percentage of value added, it falls from about 43 percent in 2011 to about 37 percent of value added by 2040. This decline reflects the decline in the real rate of return to saving as the stock of capital grows over time which lessens households' willingness to forego consumption.

Capital deepening, defined as an increase in the capital to labor ratio, increased from about 439,778 million of 2011 DH per worker to about 681,024 MDH in 2040. This amounts to an average annual increase of about 7.6 percent per annum. Capital deepening tends to increase labor productivity, and consequently the average country-wide wage rate. The wage rate for a full-time equivalent worker rose from the model's estimated country-wide average of 22,637 2011 DH in 2011 to 30,635 2011 DH in 2040. This increase amounts to an annual average rate of about 5.2 percent per annum. Capital and labor together account for over 90 percent of the rate of growth in value added; the remaining percent includes the contribution of land and water. However, in later periods, the contribution of land and water to growth in value added tend to increase.

Table 14 focuses on sector share in total value added. As we observe from figure 1 showing the transition shares of agriculture, industry and service in GDP since 1980 to be relatively stable. The model suggests a similar pattern into the future. The industrial sector experiences a small increase from 32.6 percent to 35 percent of value added. Agriculture also experiences a small increase while the service sector shows a slight decline of less than 3 percent. These relatively stable shares in total value added also imply relatively stable shares of full-time equivalent works in each sector in spite of the increase in the amount of capital employed in each sector per worker. The low share of labor in agriculture can be misleading. This is not the share of workers in the rural economy of Morocco. This is the share of full time workers in primary agriculture, and does not include those in ancillary agricultural manufacturing and service activities common to rural towns and villages.

What are the basic economic forces generating this transition of the economy over time? The basic force is capital deepening, defined as an increase in the amount of capital stock per worker, i.e., the quantity of buildings, machinery and equipment each worker works with. Table 9 reports the "factor intensity" or factor cost share in value added by crop, industry and service. This intensity indicates the amount or "importance" of capital in production. The table shows that capital, with a share of 0.89 in industry value added, is the most capital intensive sector in the economy. As the stock of household assets, and hence capital, rise on a per worker basis over time, the productivity of a given amount of labor in industry rises relative to other sectors of the economy, all else constant. This rise in labor productivity in industry allows industry to bid workers away from other sectors, an important one of which is the service sector. To compete for workers, and to increase the production of services to meet the growth in household demand for services brought about by growth in disposable income, the price of services must rise, as shown by the price index of services in third column of table 13. This rise in price acts like an implicit tax on other sectors of the economy which dampens their demand for economy-wide resources so they can be transferred to the production of service goods.

IV.1.2 Base solution: results for agriculture:

The structural transition of agriculture is shown in table 15. The model predicts that fodder, fruits and vegetables in the Souss Massa region, and agriculture in the rest of Morocco increase their respective value added to primary resources, including surface water, as capital deepening over time occurs. Cereals and pulses and other irrigated agriculture experience a decline in value added. Effectively, the increase in value added compared to crops with a decrease in value added is directly linked to changes in the structure of their cost of production. This structure is the importance (intensity) of labor, capital, and water in their production, and how the costs of these resources evolve with time.

The increase in the capital stock increases the productivity of labor in the capital intensive subsectors of agriculture, starting with the production of fodder, fruits and vegetables, other irrigated agriculture, and lastly cereals and pulses. Cereals and pulses have the lowest capital intensity. We see in table 15 that the value added by cereals and pulses in Souss Massa region declines from a high of 60 million 2011 DH in the base year 2011 to only 26 MDH (MDH) by 2040. As capital becomes more abundant in the economy, and its unit cost falls, some resources (labor in particular) transfer to fodder and, importantly, to fruits and vegetables where capital deepening has increased labor productivity the most. The result is an increase in fruit and vegetable production by a factor of 2.7 over thirty years without expanding the area planted to this crop. Other irrigated agriculture is only modestly more capital intensive than cereals and pluses (0.722, table 9), so its cost of production is not decreased with the greater abundance of capital as are fruits and vegetables. Hence, in the competition for labor and capital and other inputs, farmers choose to allocate more labor and capital to the other more capital intensive crops and away from the production of other irrigated crops.

The same forces causing the increase in the productivity of labor as capital deepening occurs explain the change in the productivity of water over time. Tables 16 and 17 show the effects on the demand, supply and economic values of water. Table 16, column 1, shows the shadow value of water for the Souss Massa region; this value corresponds to the vertical axis of figure 2.

Water plays two important "roles". First is the importance of water in production of a crop relative to the importance of labor, capital and land; that is the relative factor intensity of water in crop production. The second important effect is the level of surface water "assigned" to crop production every year. At the extreme, if a crop is assigned an abundance of surface water every year at a virtually zero or constant unit price, the farmer need not expend resources on pumping ground water. The farmer's cost of production will largely be determined by the cost of other inputs, labor, capital and land rental rates. We observe from table 4 that water is relatively important in the production of cereals and pulses, with an intensity of 0.414. The remaining crops range in intensity from 0.087 for fruits and vegetables to 0.094 for fodder. Thus, if the unit value of water increases (i.e., its shadow value rises), cereals and pulses will experience the largest rise in the cost of irrigating with ground water compared to the other subsectors. This rise in the shadow value of ground water may cause the cereals and pulses subsector to rely only on surface water which it receives at a constant nominal unit value. This result is what the model predicts in column 7, table 16. By year 2020, the prediction is that wheat and pulses production will not depend on ground water.

The total demand for (and supply of) surface water in this region is 202 million cubic meters (column 3, table 16). This quantity is assumed to be made available annually. Total ground water demand (table 16, column 4) accounts for about 77 percent of total irrigation water demand, and rises modestly to about 79 percent in 2045. The consumption of ground water to irrigate fodder rises from 150.2 mm3 in 2011 to 395.5 mm3 by 2045, while for fruits and vegetables, ground water use falls from 506.8 mm3 to 341.1 mm3 by 2045 (table 16). The fodder subsector is the only sector accounting for the growth in ground water demand (column 9, table 16). The rest of Moroccan agriculture also competes with other sectors of the economy for labor and capital resources. The rest of Moroccan agriculture's water consumption is treated as surface water and held constant at 9,194.7 mm3 (the last column of table 16).

Consider water consumption by crop, starting with the category cereals and pulses (table 16, column 6). The "assigned" amount of ground water is fixed at 24.4 mm3 for the entire period. The amount of ground water pumped is about 38.3 mm3 in 2011, falls to 13.3 mm3 in 2015 and, by 2020, this subsector is not consuming ground water. As noted above, this decline in the use of ground water to irrigate cereals and pulses also corresponds to the decline of cereals and pulses value added reported in table 15. The decline in this sector's competitiveness for economy-wide resources has caused its shadow value of surface water to be smaller (less) than the shadow value per cubic meter (m3) of water reported in column 1 of table 16. Effectively, because of the relative importance of water in cereals and pulses production, as noted above, the rise in cost from allocating resources to pump water becomes less profitable with time, eventually causing the subsector to rely on its assigned surface water only.

The growth in ground water demand exceeds the rate of recharge to the aquifer, as suggested by the water balance sheet reported in table 6. Consequently, the depth index reported in table 16, column 5 rises from unity to a depth index of 33.8. The depth index has the following interpretation. Since the depth to the water table in the Souss Massa region depends on the location where the measurement is made, as well as the time of year, for an economy-wide analysis an index is a preferred measure. If the measurement of depth to the water table at some location is 10 meters, then an index value of 1 in the year 2011 corresponds to this depth. Using this example, the depth to the water table in 2045 is predicted to be 10x33.7 = 337 meters. This presumes that the aquifer has this capacity, which is typically unknown. Notice that the total ground water demand (column 4), declines from 738 mm3 in 2040 to a predicted 736.6 in 2045. In the long run, the rate of withdrawal cannot exceed the rate of inflow. In the long run, the water remaining in the aquifer serves as a “platform”, allowing the inflow to be pumped off and used for irrigation.

Finally, the shadow value of water reported in column 1 rises as the cost of pumping water from greater depth increases. Since the pumping of water relies on pumping machinery and a distribution system, water pumping is relatively dependent on capital and energy. Over time, the accumulation of capital in terms of larger pumping equipment tends to lower the cost of pumping for a given depth of well. However, the resource cost required to pull the water from greater depths dominates this saving which causes the shadow value of a m3 of water to rise. In terms of figure 2, line A, the total demand for water shifts to the right relative to the supply of ground water, line B. This adjustment over time causes a rise in the shadow value of water over the period 2011 to 2040. After 2040, the shadow value price continues to rise but the total annual supply of ground water contracts and eventually converges to the rate of water inflow to the aquifer.

Table 17 reports the economic rents to land and water. Rent is the value that accrues to receivers’ (perhaps owner’s) of the rights to water and land. The rent to water is divided into two parts. The rent to surface water is the area d, figure 2, for those farmers engaged in the conjunctive use of water. The rent to ground water is area e. For the point in time when only surface water is used, the rent is equivalent to the area d plus c, with one exception. The exception is the case where the shadow value of ground water exceeds the shadow value of surface water. The calculation of rents appear in table 17. Land rents can be interpreted the level of rent observed from farmers renting land in or out in a free functioning land rental market. The rents can also be viewed as farm profits if farmers are owner - operators of the land and water resources.

Rent to surface water dominates the rent to ground water, which is also suggested by figure 2 where the area d exceeds the area e. Moreover, the rent accruing to surface water increase over time while the rent to ground water falls. Results suggest that surface water is an important natural resource, in large part, because the resources a farmer must expend to allocate one m3 of surface water is far less than the resource need to pump one m3 of ground water. Basically, ground water has the cost depicted in figure 2 by the area f. As the depth of the aquifer increases, area f increases as more resources are required to pump ground water from greater depths. In this region, land rent exceeds the total rent of water by a factor ranging from about 2.9 in 2011 to 2.5 in 2045. These rents are of course flows of value earned by these resources over time. In a later section of this paper we address the question: What is the stock value of these water resources as an economy-wide asset?

At the crop level of analysis, only the fodder sector shows a rise in its rent to ground water (table 17, column 7). All crops show a rise in rent to surface water. Since surface water supplies are fixed, and the cost of pumping rises as water withdrawal exceeds infiltration, irrigation water is becoming a more scarce resource over time, as reflected by the rise in its shadow value (table 16, column 1). In this case, those crops that use water intensively relative to other crops tend to loose their comparative advantage as their costs per unit of production tend to rise relative to others. The process results in spite of capital deepening in all subsectors. The rise in the shadow value of water has a negative or downward effect on the rent accrued to land. The negative effect tending to be larger the larger is water's share to total crop production cost. Land rents increase in fodder and fruit and vegetable subsectors. This results because the lower costs of capital deepening exceed the cost of a rise in the shadow value of water. In the case of fruits and vegetables, capital deepening can be interpreted as substituting some capital for ground water.

IV.1.3 Drought simulation: surface water decline:

We assume a once and for all ten percent decrease in surface water supply in the Souss Massa region only. The results can be interpreted a kin to an elasticity in the sense that a ten percent decline in surface water causes an X percent change in variables of interest. We contrast simulation results to the base solution by dividing the simulation variable by the corresponding base solution result. Since region’s irrigated agriculture is a relatively small percent of the entire Moroccan economy, changes in the macroeconomic level variables, such as total value added are relatively small. The direction of change is a decline in the country's total value added by less than 0.01 percent, a decline in household saving and a decline in the country's level of capital stock over time.

More important are the effects on the Souss Massa agriculture. The top panel of table 18 reports the results of the simulation solution divided by the base solution. For instance, the entry 0.992 in the first column of the table indicates the value added in cereals and pulses in 2011 is 99.2% of the corresponding value (60 MDH, table15, column 1) in the base solution. Thus, 0.992 x 60 equals 59.5 MDH, a decrease in the value added in 2011 of cereals and pulses of about 0.463 MDH (reported in the bottom panel of table 18). A ten percent decline in surface water available to irrigate cereals and pulses resulted in a decline in the subsector's value added of 0.463 MDH or (0.992 -1)100 = 1%. Had we decreased the surface water available by 20 percent, the percent change in cereals and pulses value added would decrease by less than two percent; this points out that the relationship is not linear.

Cereals and pulses declined proportionately the most, relative to the base solution, followed by other irrigated agriculture. This result occurs primarily because, as we see from table 9, water's share in total primary factor cost in cereals and pulses is higher than other crops at 0.099, followed by other irrigated agriculture at 0.059. Fodder and fruits and vegetables declined the least, largely because their respective share in total primary factor cost is 0.027 and 0.024, respectively. Other factors affecting these differences are the share of labor and capital in total primary factor cost, but the water share dominates these effects.

The second panel of table 18 shows simulation value less base value, in MDH. We observe that the loss in value added is the highest for fruits and vegetables followed by fodder, an annual average lose over the period of 94.3 and 11.5 MDH, respectively. The total annual average loss over all subsectors is about 106.9 MDH. Over the period 2011 to 2040, the total undiscounted loss over all irrigated crops is about 748 MDH.

Notice that the value of the loss increase over time, ranging, for the case of fruits and vegetables, ranging from 20.3 MDH in 2011 to 142.7 MDH by the year 2040. We see next that this growth in loss is due to farmers relying more on ground water initially (relative to base), As the depth of the aquifer increases and pumping costs rise, less ground water is used in later years relative to the base solution. This result highlights the well accepted observation that ground water is a buffer to surface water shocks, provided the surface water shocks are transitory and not permanent as assumed here.

Table 19 contrasts water allocation with a ten percent reduction in surface water relative to the base solution. In the top panel, the numbers 0.9 in columns 3, 6, 8, 10 and 12 reflect our simulation of the ten percent reduction in surface water supply. First, note the increase in the shadow value of water relative to base, column 1. The decrease in surface water supply makes total water more scarce; in terms of figure 2, this is equivalent to decreasing the area c and d by moving the vertical dotted line toward the vertical axis, and shifting the supply of ground water accordingly. During the period 2011 to 2015, the total ground water pumped is greater than the base, by 2 mm3 in 2011, and 1.7 mm3 in 2015 (bottom panel, column7). This causes the depth index to the water table to increase by 2.2 percent in 2015 (top panel, column 5), and to consistently be higher than the depth index of the base solution.

Farmers extract more water than the base in the first 15 years (column 4, table 19) and then extract less water than the base, the net effect of which is to increase the depth of the water table relative to the base (column 5). This behavior is largely due to the time rate of discount where a dirham today is worth more than a dirham tomorrow.

In the case of cereals and pulses and other irrigated agriculture (table 19, column 7 and 13), these subsectors stop using ground water. The results because, in spite of the reduction in surface water, the shadow value of surface water to these subsectors is less than the shadow value of ground water. It is thus not profitable for them to use ground water, which again, links to their respective high cost share of water in total primary resource cost of production. Returning to ground water, note the negative values in column 4, bottom panel for the years 2020 to 2045. These values are the simulation result, in mm3, less the base result. From the year 2020 to 2045, less water is taken from the aquifer than in the base solution, while more water is extracted up to about 2015. In the later years, the extraction of water from the aquifer is approximately equal to water inflow to the aquifer. However, the long-run sustainable extraction of water leads to a lower water table level than the base solution, i.e. water table depth is greater than the base solution.

Interestingly, the crop with the smallest water share of total primary factor cost (i.e., fruits and vegetables), increases its use of ground water relative to the base over the entire time period 2011-2040 (column 11, bottom panel). However, the increase in the level of its use of ground water (or “buffer water”) is not sufficient to account for the ten percent loss in the use of surface water. This result suggests that fruits and vegetables are the most competitive crop for water resources. Effectively, fruit and vegetable produces can profitably "pull" ground water resources from the other crops.

We conclude with the effect of a ten percent decline in surface water on monetary values, table 20. For the Souss Massa agricultural economy, the total rent (profits) to land and water decline by about 3 percent on average per year corresponding to the base solution (bottom panel, column 8, table 20). The importance of ground water, in terms of rents, increases for all crops that use both surface and ground water. With more "expensive" water (as measured by the higher shadow value of water) and hence the use of less water for irrigation, causes a reduction in rents to land for all crops. That is, a ten percent reduction in surface water leads to about a 3 percent reduction in total Souss Massa farm profits. The rents to ground water for fodder and fruits and vegetables (again, the most water competitive subsectors) rise. This again reflects the profitability of these crops and hence their competitiveness in competing for ground water with other subsectors of agriculture.

IV.1.4 Increase in water use efficiency-productivity

This analysis increases the efficiency or the effective water supply for both surface and ground water by ten percent. Effectively, less water is wasted. In economic jargon, we are considering a neutral technological change. This change increases, indirectly, the productivity of all other primary factors of production, such as capital, labor and land in crop production. This type of efficiency gain should not be confused with a change in the irrigation cost shares reported in table 9, we leave these unchanged. A change in these shares would be equivalent to non-neutral technological change in which the least cost combination of primary resources differs from the base solution. We choose the former type of technological change largely because we do not have data guiding us to the magnitude of cost share change in table 9 that would realistically capture alternative non-neutral technology.

As in the previous simulation, the change in the macroeconomic variables of the Moroccan economy from a change in the Souss - Massa water efficiency are small. Economy-wide total value added increases, albeit by less than 0.01 percent per year. Household saving increases slightly which increases the capital stock per worker, and lessens the increase in the price index of services. All of these changes at the national level are less than 0.01 percent. These small changes mask the larger changes at the Souss Massa level.

Table 21 reports the change in subsector value added. The average annual percent increase in subsector value added relative to the base solution is: 7.6 percent for cereals and pulses, about 7 percent for fodder, 8.7 percent for fruits and vegetables and 8.8 percent for other irrigated agriculture. In all cases, the change relative to the base is larger in the earlier periods than in later periods. This pattern reflects the fact that capital makes up a large share of total primary factor cost. Seeing opportunities to obtain higher returns in these subsectors in initial periods, induces the country's capital market to increase investment in early periods relative to base. In this way, households more quickly capture financial gains from the increase in water use efficiency.

The bottom panel in table 21 shows the value difference, simulation minus base, in MDH. Here, the scale or size of the subsector becomes apparent. The average annual gains in total subsector value added (i.e. payments to labor, capital, land and water rents) is about 721.5 MDH. Relative to base, the annual differences in value added grow with time for the case of fodder and fruits and vegetables. This pattern obtains because these two subsectors are relatively more capital intensive than are the other sectors (see table 9). As a result, the increase in the efficiency of water also increase the productivity of other resources, but for these crops, it increases the productivity of capital relative to the other crops. This effect "lasts" over time as capital deepening occurs in the production of these crops relative to the other crops.

Note that the rest of Moroccan agriculture suffers a decline in value added, ranging, in most years between 19.1 and 15.3 MDH. This result obtains because the Souss Massa's irrigated agricultural sector can now compete more effectively for economy wide resources. This competition, drives up slightly the prices of labor and capital in the rest of the economy with small negative effects on rest of economy value added.

The increase in the productivity of water encourages increased use of water which in turn increases shadow value of water. These results are shown in table 22. The shadow value of water averages about 5.3 percent higher than the shadow value in the base; this is also an indication that, in conjunctive use, the last m3 of water allocated is about 5.3 percent more productive in this simulation than in the base. Farmers increase the pumping of ground water relative to base. The depth index of aquifer is larger every period than the base solution.

Is this increase in the depth of the water table in some sense an increase in "over exploitation"? Our analysis does not take account of any physical damage to the aquifer, such as salt water incursion. If this were the case, then over exploitation would be likely. However, in our analysis, an increase in water productivity-efficiency means that it is profitable for farmers to incur additional water pumping costs thus lowering the water table. Eventually, a point is reached where the water withdrawn cannot exceed the level of water infiltration.

Table 23 reports the difference in rents to land, surface and ground water relative to the base solution reported in table 17. For fodder, fruits and vegetables, the rents to ground water increase the most, with annual average increase of 9.28 and 11.43 percent respectively. As noted in our earlier discussion, this increase being larger than the other crops is partially due to their respective surface water assignments. For the cases of conjunctive water use, notice that the average annual rate of increase in the simulation relative to the base is 4.82 percent, although that annual difference for each crop varies. Since an increase in the productivity of water, makes land also more productive, land rents also rise, with the extent of the increase linked to the contribution of land to production of the crop, i.e., the relative land intensity reported in table 9. For some crops, the increase in land rent exceeds the increase in rent to water.

Table 13. Base solution-Souss Massa: value added, value added by major factors of production, and capital stock, in 2011 constant millions of Dirhams (MDH)

	Total Value Added MDH	Household Saving MDH	Service Price Index DH	Wage per Worker DH	Total Wage Income MDH	Capital Stock MDH	Capital Stock per Worker MDH	Value Added per Worker DH	Value Added by Capital Stock MDH	Total Value Added by Land and Surface Water MDH
2011	769978	329398	0.996	22637	262583	5101378	439778	66378	495387	11980
2015	822399	340295	1.010	24096	279515	5587067	481648	70897	530121	12728
2020	881304	352196	1.025	25736	298531	6146705	529893	75975	569157	13572
2025	933576	362461	1.037	27191	315409	6655087	573719	80481	603788	14323
2030	979915	371335	1.048	28481	330374	7114673	613339	84476	634481	14992
2035	1020956	379008	1.057	29624	343631	7528479	649012	88014	661658	15586
2040	1057273	385664	1.065	30635	355366	7899814	681024	91145	685700	16113

Source: Model results

Table 14. Base solution-Souss Massa: Sector value added shares in total value value added and sector labor shares

	Industrial Share in Total Value Added	Service Share in Total Value Added	Total Ag-ricultural Share in Total value Added	Share of Full-Time Workers in		
				Industry	Service	Agriculture
2011	0.326	0.529	0.145	0.259	0.673	0.069
2015	0.333	0.522	0.145	0.265	0.666	0.069
2020	0.339	0.516	0.145	0.271	0.660	0.069
2025	0.343	0.511	0.146	0.275	0.656	0.069
2030	0.346	0.507	0.146	0.278	0.653	0.070
2035	0.348	0.505	0.147	0.280	0.650	0.070
2040	0.350	0.502	0.148	0.282	0.648	0.070

Source: model results

Table 15. Souss Massa-Base solution: Agricultural subsector value added, and agricultural value added in rest of Morocco, 2011 MDH

	Souss Massa				Rest of Morocco Agriculture
	Cereals and Pulses	Fodder	Fruits and Vegetables	Other Irr-igated Ag	
2011	60	313	4249	21	106049
2015	48	474	5237	17	112547
2020	39	742	6609	14	119823
2025	33	1072	7955	12	126262
2030	30	1452	9236	10	131957
2035	27	1871	10427	9	136992
2040	26	2313	11510	9	141441

Source: model results

Table 16. Souss Massa-Base solution: Irrigated water shadow value and surface and ground water allocation to cereals and pulses, fodder, fruits and vegetables, and other irrigated agriculture

Year	Shadow Value (DH) of Water per m3	Total Irrigation Water Demand mm3	Total Surface Water Demand mm3	Total Ground Water Demand mm3	Aquifer Depth Index meters[1/]	Cereals and Pulses		Fodder		Fruits and Vegetables		Other Irrigated Agriculture		Rest of Moroccan Agriculture mm3
						Surface Water Demand mm3	Ground Water Demand mm3	Surface Water Demand mm3	Ground Water Demand mm3	Surface Water Demand mm3	Ground Water Demand mm3	Surface Water Demand mm3	Ground Water Demand mm3	
2011	0.138	899.0	202.0	697.0	1.00	24.41	38.33	48.51	150.19	127.53	506.82	1.54	1.65	9194.7
2015	0.179	878.3	202.0	676.3	4.47	24.41	13.31	48.51	184.85	127.53	477.77	1.54	0.40	9194.7
2020	0.232	896.1	202.0	694.2	8.90	24.41	0.00	48.51	233.21	127.53	460.95	1.54	0.00	9194.7
2025	0.290	917.3	202.0	715.3	13.62	24.41	0.00	48.51	276.76	127.53	438.56	1.54	0.00	9194.7
2030	0.352	930.4	202.0	728.4	18.55	24.41	0.00	48.51	314.69	127.53	413.76	1.54	0.00	9194.7
2035	0.416	937.6	202.0	735.6	23.60	24.41	0.00	48.51	346.96	127.53	388.63	1.54	0.00	9194.7
2040	0.482	940.0	202.0	738.0	28.70	24.41	0.00	48.51	373.76	127.53	364.22	1.54	0.00	9194.7
2045	0.549	938.6	202.0	736.6	33.77	24.41	0.00	48.51	395.52	127.53	341.07	1.54	0.00	9194.7

[1/]The depth to the water level in the aquifer is an index. The actual depth can be estimated by multiplying the index by the actual average depth of the aquifer in 2011.

Source: Model results.

Table 17. Souss Massa-Base soultion: Surface and ground water rents by crop and for all of agriculture in the rest of Morocco, in MDH 2011

	Cereals and Pulses				Fodder				Fruits and Vegetables			
	Rents to Land	Rents to Surface Water	Rents to Ground Water	Total Rents	Rents to Land	Rents to Surface Water	Rents to Ground Water	Total Rents	Rents to Land	Rents to Surface Water	Rents to Ground Water	Total Rents
2011	5.18	3.37	0.18	8.73	7.52	6.71	0.70	14.92	75.62	17.63	2.35	95.60
2015	4.02	4.36	0.06	8.44	11.40	8.66	0.87	20.93	93.18	22.77	2.24	118.20
2020	3.12	5.65	0.00	8.77	17.87	11.24	1.06	30.16	117.56	29.55	2.09	149.20
2025	2.50	7.08	0.00	9.57	25.81	14.06	1.21	41.08	141.49	36.97	1.91	180.37
2030	2.06	8.59	0.00	10.65	34.98	17.07	1.34	53.39	164.24	44.88	1.76	210.87
2035	1.74	10.16	0.00	11.90	45.08	20.20	1.45	66.73	185.34	53.11	1.62	240.08
2040	1.50	11.77	0.00	13.27	55.76	23.40	1.54	80.71	204.54	61.52	1.50	267.57
2045	1.32	13.39	0.00	14.71	66.69	26.62	1.63	94.94	221.71	69.98	1.40	293.09

Source: Model results

Table Continued

	Other Irrigated Agriculture				Total Souss Massa				Rest of Morocco		
	Rents to Land	Rents to Surface Water	Rents to Ground Water	Total Rents	Rents to Land	Rents to Surface Water	Rents to Ground Water	Total Rents	Rents to Land	Rents to Surface Water	Total Rents
2011	0.89	0.21	0.01	1.11	89.21	27.93	3.23	120.36	7868.64	4000.93	11869.57
2015	0.70	0.28	0.00	0.98	109.31	36.06	3.18	148.55	8350.82	4246.10	12596.92
2020	0.55	0.36	0.00	0.91	139.10	46.80	3.14	189.04	8890.66	4520.59	13411.25
2025	0.44	0.45	0.00	0.89	170.25	58.56	3.12	231.92	9368.42	4763.52	14131.94
2030	0.37	0.54	0.00	0.91	201.65	71.08	3.09	275.82	9791.00	4978.38	14769.38
2035	0.31	0.64	0.00	0.96	232.48	84.12	3.07	319.67	10164.59	5168.34	15332.93
2040	0.27	0.74	0.00	1.02	262.07	97.44	3.05	362.57	10494.68	5336.18	15830.85
2045	0.24	0.85	0.00	1.09	289.95	110.84	3.03	403.82	10786.21	5484.41	16270.62

Table 18. Souss Massa-Drought: Simulation divided by base, agricultural subsector value added, and Agricultural value added in rest of Morocco, 2011 MDH

	Souss Massa				Rest of
	Cereals and Pulses	Fodder	Fruits and Vegetables	Other Irr-igated Ag	Morocco Agriculture
2011	0.9923	0.9957	0.9952	0.9930	1.0
2015	0.9832	0.9895	0.9873	0.9834	1.0
2020	0.9795	0.9895	0.9871	0.9808	1.0
2025	0.9753	0.9898	0.9873	0.9779	1.0
2030	0.9705	0.9900	0.9875	0.9745	1.0
2035	0.9654	0.9902	0.9876	0.9706	1.0
2040	0.9602	0.9903	0.9876	0.9665	1.0
Average	0.9752	0.9907	0.9885	0.9781	1.0000
	Value in MDH (simulation minus base)				
2011	-0.463	-1.353	-20.251	-0.148	-3.922
2015	-0.811	-4.997	-66.395	-0.283	0.574
2020	-0.801	-7.811	-85.102	-0.266	3.134
2025	-0.820	-10.947	-100.755	-0.257	5.345
2030	-0.871	-14.488	-115.539	-0.260	7.371
2035	-0.942	-18.362	-129.538	-0.271	9.216
2040	-1.027	-22.482	-142.732	-0.286	10.882
Average	-0.819	-11.491	-94.330	-0.253	4.657

Source: model results

Table 19.- Souss Massa-Drought: Simulation divided by base, and simulation minus base, water shadow value, surface and ground water allocations to cereals amd pulses, fodder, fruits and vegetables, and other irrigated agriculture

Year	Shadow Value (DH) of Water per m3	Total Irrigation Water Demand mm3	Total Surface Water Demand mm3	Total Ground Water Demand mm3	Aquifer Depth Index meters1/	Cereals and Pulses: Surface Water Demand mm3	Cereals and Pulses: Ground Water Demand mm3	Fodder: Surface Water Demand mm3	Fodder: Ground Water Demand mm3	Fruits and Vegetables: Surface Water Demand mm3	Fruits and Vegetables: Ground Water Demand mm3	Other Irrigated Agricultur: Surface Water Demand mm3	Other Irrigated Agricultur: Ground Water Demand mm3	Rest of Moroccan Agriculture mm3
2011	1.0028	0.9931	0.9000	1.0201	1.0000	0.9000	1.0532	0.900	1.0238	0.900	1.0163	0.900	1.0801	1.00
2015	1.0087	0.9798	0.9000	1.0037	1.0221	0.9000	1.1274	0.900	1.0027	0.900	1.0003	0.900	1.2828	1.00
2020	1.0090	0.9773	0.9000	0.9998	1.0159	0.9000	na	0.900	0.9979	0.900	1.0005	0.900	na	1.00
2025	1.0090	0.9776	0.9000	0.9995	1.0133	0.9000	na	0.900	0.9956	0.900	1.0020	0.900	na	1.00
2030	1.0089	0.9779	0.9000	0.9996	1.0120	0.9000	na	0.900	0.9942	0.900	1.0037	0.900	na	1.00
2035	1.0089	0.9781	0.9000	0.9996	1.0113	0.9000	na	0.900	0.9931	0.900	1.0054	0.900	na	1.00
2040	1.0090	0.9782	0.9000	0.9997	1.0109	0.9000	na	0.900	0.9924	0.900	1.0071	0.900	na	1.00
2045	1.0090	0.9783	0.9000	0.9997	1.0107	0.9000	na	0.900	0.9918	0.900	1.0089	0.900	na	1.00
		Difference in Quantity: Simulation Minus Base (mm3)												
2011		-6.171	-20.199	14.029	0.000	-2.441	2.040	-4.851	3.573	-12.753	8.283	-0.154	0.132	0.00
2015		-17.722	-20.199	2.477	0.099	-2.441	1.696	-4.851	0.506	-12.753	0.163	-0.154	0.113	0.00
2020		-20.354	-20.199	-0.155	0.141	-2.441	0.095	-4.851	-0.491	-12.753	0.242	-0.154	0.000	0.00
2025		-20.538	-20.199	-0.339	0.181	-2.441	0.000	-4.851	-1.217	-12.753	0.878	-0.154	0.000	0.00
2030		-20.527	-20.199	-0.328	0.223	-2.441	0.000	-4.851	-1.840	-12.753	1.512	-0.154	0.000	0.00
2035		-20.490	-20.199	-0.291	0.267	-2.441	0.000	-4.851	-2.381	-12.753	2.090	-0.154	0.000	0.00
2040		-20.447	-20.199	-0.248	0.313	-2.441	0.000	-4.851	-2.851	-12.753	2.603	-0.154	0.000	0.00
2045		-20.407	-20.199	-0.208	0.360	-2.441	0.000	-4.851	-3.260	-12.753	3.052	-0.154	0.000	0.00

Source: model results

Table 20. Souss Massa-Drought: Simulation divided by base: Surface and ground water rents by crop and for all of agricultur in the rest of Morocco

	Cereals and Pulses				Fodder				Fruits and Vegetables			
	Rents to Land	Rents to Surface Water	Rents to Ground Water	Total Rents	Rents to Land	Rents to Surface Water	Rents to Ground Water	Total Rents	Rents to Land	Rents to Surface Water	Rents to Ground Water	Total Rents
2011	0.996	0.902	1.166	0.964	0.996	0.902	1.133	0.961	0.996	0.902	1.125	0.982
2015	0.989	0.908	1.267	0.949	0.990	0.908	1.127	0.962	0.988	0.908	1.124	0.975
2020	0.988	0.908	na	0.937	0.990	0.908	1.125	0.964	0.988	0.908	1.128	0.974
2025	0.989	0.908	na	0.929	0.990	0.908	1.123	0.966	0.988	0.908	1.130	0.973
2030	0.989	0.908	na	0.924	0.990	0.908	1.121	0.967	0.988	0.908	1.132	0.972
2035	0.989	0.908	na	0.920	0.990	0.908	1.120	0.968	0.988	0.908	1.133	0.971
2040	0.989	0.908	na	0.917	0.991	0.908	1.119	0.969	0.988	0.908	1.135	0.971
2045	0.989	0.908	na	0.915	0.991	0.908	1.118	0.970	0.988	0.908	1.137	0.970

Table Continued

	Other Irrigated Agriculture				Total Souss Massa				Rest of Morocco		
	Rents to Land	Rents to Surface Water	Rents to Ground Water	Total Rents	Rents to Land	Rents to Surface Water	Rents to Ground Water	Total Rents	Rents to Land	Rents to Surface Water	Total Rents
2011	0.996	0.902	1.196	0.979	0.996	0.902	1.129	0.978	1.000	1.000	1.000
2015	0.987	0.908	1.441	0.966	0.988	0.908	1.128	0.972	1.000	1.000	1.000
2020	0.987	0.908	na	0.956	0.988	0.908	1.128	0.970	1.000	1.000	1.000
2025	0.987	0.908	na	0.947	0.988	0.908	1.127	0.970	1.000	1.000	1.000
2030	0.987	0.908	na	0.940	0.988	0.908	1.127	0.969	1.000	1.000	1.000
2035	0.987	0.908	na	0.934	0.989	0.908	1.127	0.969	1.000	1.000	1.000
2040	0.987	0.908	na	0.929	0.989	0.908	1.127	0.968	1.000	1.000	1.000
2045	0.987	0.908	na	0.925	0.989	0.908	1.127	0.968	1.000	1.000	1.000

Source: model results

Table 21. Souss Massa-Water productivity: Simulation divided by base, agricultura subsector value added and agricultural value added in rest of Morocco, 2011 MDI

	Souss Massa				Rest of
	Cereals and Pulses	Fodder	Fruits and Vegetables	Other Irr-igated Ag	Morocco Agriculture
2011	1.1355	1.1214	1.1522	1.1584	0.9996
2015	1.0699	1.0621	1.0769	1.0803	0.9998
2020	1.0670	1.0600	1.0742	1.0768	0.9999
2025	1.0666	1.0605	1.0747	1.0764	0.9999
2030	1.0661	1.0610	1.0753	1.0757	0.9999
2035	1.0653	1.0614	1.0758	1.0748	0.9999
2040	1.0645	1.0618	1.0761	1.0736	0.9999
Average	1.0764	1.0697	1.0865	1.0880	0.9998
	Value in MDH (simulation minus base)				
2011	8.2	38.0	646.9	3.4	
2015	3.4	29.4	402.7	1.4	
2020	2.6	44.5	490.1	1.1	
2025	2.2	64.8	594.4	0.9	
2030	2.0	88.6	695.6	0.8	
2035	1.8	114.9	790.1	0.7	
2040	1.7	142.8	876.3	0.6	
Mean DH /yr/Ha	136	3166	5871	1554	

Table 22. Souss Massa-Water productivity: simulation divided and minus base, water shadow value and surface and ground water allocations to to cereals and pulses, fodder, fruits and vegetables, and other irrigated agriculture

						Cereals and Pulses		Fodder		Fruits and Vegetables		Other Irrigated Agriculture	
	Shadow Value (DH) of Water per m3	Total Irrigation Water Demand mm3	Total Surface Water Demand mm3	Total Ground Water Demand mm3	Aquifer Depth Index meters	Surface Water Demand mm3	Ground Water Demand mm3	Surface Water Demand mm3	Ground Water Demand mm3	Surface Water Demand mm3	Ground Water Demand mm3	Surface Water Demand mm3	Ground Water Demand mm3
2011	1.0027	1.1424	1.0000	1.1837	1.0000	1.0000	1.2267	1.0000	1.1578	1.0000	1.1877	1.0000	1.3100
2015	1.0535	1.0183	1.0000	1.0238	1.1721	1.0000	1.0474	1.0000	1.0103	1.0000	1.0283	1.0000	1.1302
2020	1.0556	1.0130	1.0000	1.0167	1.1159	1.0000	0.0000	1.0000	1.0051	1.0000	1.0226	1.0000	na
2025	1.0552	1.0132	1.0000	1.0169	1.0936	1.0000	na	1.0000	1.0058	1.0000	1.0240	1.0000	na
2030	1.0549	1.0136	1.0000	1.0174	1.0824	1.0000	na	1.0000	1.0067	1.0000	1.0255	1.0000	na
2035	1.0546	1.0138	1.0000	1.0176	1.0757	1.0000	na	1.0000	1.0074	1.0000	1.0268	1.0000	na
2040	1.0544	1.0140	1.0000	1.0178	1.0715	1.0000	na	1.0000	1.0079	1.0000	1.0280	1.0000	na
2045	1.0543	1.0140	1.0000	1.0178	1.0686	1.0000	na	1.0000	1.0082	1.0000	1.0290	1.0000	na
						Difference in Quantity: Simulation Minus Base (mm3)							
2011		128.009	0.000	128.009	0.000	0.000	8.689	0.000	23.695	0.000	95.115	0.000	0.511
2015		33.838	0.000	13.639	0.671	0.000	0.631	0.000	1.405	0.000	13.360	0.000	0.707
2020		31.962	0.000	11.763	0.891	0.000	na	0.000	1.673	0.000	10.186	0.000	na
2025		12.121	0.000	12.121	1.275	0.000	na	0.000	1.617	0.000	10.505	0.000	na
2030		12.644	0.000	12.644	1.528	0.000	na	0.000	2.108	0.000	10.537	0.000	na
2035		12.978	0.000	12.978	1.788	0.000	na	0.000	2.558	0.000	10.420	0.000	na
2040		13.133	0.000	13.133	2.052	0.000	na	0.000	2.943	0.000	10.190	0.000	na
2045		13.138	0.000	13.138	2.317	0.000	na	0.000	3.253	0.000	9.884	0.000	na

Source: model results

Table 23. Souss Massa-Water productivity: Simulation divided by base, surface and ground water rents by crop and for all of agriculture in the rest of Morocco

	Cereals and Pulses				Fodder				Fruits and Vegetables			
	Rents to Land	Rents to Surface Water	Rents to Ground Water	Total Rents	Rents to Land	Rents to Surface Water	Rents to Ground Water	Total Rents	Rents to Land	Rents to Surface Water	Rents to Ground Water	Total Rents
2011	1.1415	1.0027	1.1618	1.0883	1.1222	1.0027	1.0965	1.0673	1.1530	1.0027	1.1248	1.1246
2015	1.0711	1.0535	1.1304	1.0625	1.0621	1.0535	1.0904	1.0597	1.0770	1.0535	1.1098	1.0731
2020	1.0684	1.0556	*/	1.0601	1.0600	1.0556	1.0915	1.0594	1.0743	1.0556	1.1106	1.0711
2025	1.0689	1.0552	0	1.0588	1.0605	1.0552	1.0920	1.0596	1.0748	1.0552	1.1116	1.0712
2030	1.0693	1.0549	0	1.0577	1.0610	1.0549	1.0924	1.0598	1.0754	1.0549	1.1128	1.0714
2035	1.0697	1.0546	0	1.0568	1.0614	1.0546	1.0928	1.0601	1.0759	1.0546	1.1139	1.0715
2040	1.0700	1.0544	0	1.0562	1.0618	1.0544	1.0932	1.0602	1.0763	1.0544	1.1150	1.0715
2045	1.0701	1.0543	0	1.0557	1.0620	1.0543	1.0935	1.0604	1.0765	1.0543	1.1160	1.0714
Average	1.0786	1.0482	1.1461	1.0620	1.0689	1.0482	1.0928	1.0608	1.0854	1.0482	1.1143	1.0782

Table Continued

	Other Irrigated Agriculture				Total Souss Massa			
	Rents to Land	Rents to Surface Water	Rents to Ground Water	Total Rents	Rents to Land	Rents to Surface Water	Rents to Ground Water	Total Rents
2011	1.1632	1.0027	1.2407	1.1329	1.1499	1.0027	1.1211	1.1149
2015	1.0817	1.0535	1.2198	1.0740	1.0753	1.0535	1.1050	1.0706
2020	1.0786	1.0556	NA	1.0695	1.0723	1.0556	1.1042	1.0687
2025	1.0791	1.0552	NA	1.0671	1.0726	1.0552	1.1040	1.0686
2030	1.0796	1.0549	NA	1.0649	1.0729	1.0549	1.1040	1.0686
2035	1.0801	1.0546	NA	1.0630	1.0731	1.0546	1.1039	1.0685
2040	1.0804	1.0544	NA	1.0614	1.0732	1.0544	1.1039	1.0684
2045	1.0806	1.0543	NA	1.0601	1.0732	1.0543	1.1039	1.0682
Average	1.0904	1.0482	1.2302	1.0741	1.0828	1.0482	1.1062	1.0746

Source; model results

IV.2 Tadla Azilal and the rest of Morocco

We proceed with the same pattern of analysis as that of Souss Massa, except we omit the discussion on the economics of the broader economy. This discussion is omitted because there is no difference in levels or rates of change in, for example, economy wide value added. In the case of Souss Mass, irrigated agriculture was about 0.7 percent of economy value added, and about 4.5 percent of economy-wide agriculture value added. Tadla Azilal accounts for slightly less, about 0.5 percent of economy-wide value added and about 3.5 percent of economy-wide agriculture value added.

The discussion of Souss Massa drew upon table 9 showing factor cost shares in production. For the case of Tadla Azilal, we draw upon the shares reported in table 12. The main difference to point out is irrigation water is "more important" (a larger share of total primary factor cost) in crop production in the Tadal Azilal region than for the case of Souss Massa. This difference was also noted in Diao et al (2005) in their static analysis of irrigation water in Morocco. They found that in regions of Morocco where water was relatively more abundant, farmers tended to plant crops that are more water intensive than in other more water scarce regions of the country. As shown in the water balance table 6, the aquifer recharge relative to withdrawal only left an imbalance of -3 mm3, compared to an imbalance of -283.5 mm3 for Souss. Another difference between the two regions is the conjunctive use of water. Table 10 shows that farmers producing cereals and pulses only use surface water, at least at this aggregate level of analysis. About 60 percent of total water allocated to the production of fodder and other irrigated agriculture relies on ground water. About 34 percent of water allocated to fruits and vegetables is ground water.

IV.2.1 Results for agriculture: base solution

Table 24 reports the base solution results for the evolution of subsector value added over the period 2011 to 2040. The results predict that all subsectors experience growth in value added, except for other irrigated crops, whose value added drops from 362 MDH to 220 MDH by 2040. Among the other three subsectors, cereals and pulses' value added grow at the slowest annual average rate of about 0.14 percent over the 2011 to 2040 period while, similar to Souss Massa, the corresponding rate for fodder and fruits and vegetables is about 1.5 and 2.2 average annual percent respectively. As a result, fruit and vegetable value added almost doubles while fodder value added increase by a factor of 1.8. The main economic forces giving rise to this evolution over time is capital accumulation in production of these crops. Capital is more important (i.,e, higher relative capital intensity) in the production of fodder and fruits and vegetables than it is in other sectors. As capital accumulates these crops benefit relatively more from more abundant quantity of machinery and equipment than do the other crops, and consequently, can better compete for labor and water resources with the other sectors of the economy. Water and surface water assignments also play a role, which we discuss next.

Note first the shadow value of water employed in conjunctive use, table 25 column 1. The value, 0.23 DH per m3 in 2011, rises to 0.38 in 2045. In contrast to table 16 for the case of Souss Massa, the corresponding shadow values are 0.14 to 0.55. The values are roughly equal between the two regions in 2025. This difference is due to two main factors. As figure 2 suggests, the surface water assignment to each crop that also uses ground water affects the shadow value; a lower assignment typically increases the shadow value of conjunctive water use, as well as the share of ground water in total irrigation water. In our analysis, this assignment is held constant (as for example we see by the unchanging quantities in table 25, column 6).

Second, note that the depth index for Tadla Azilal is lower and increases more slowly than is the case for Souss Massa. The data, table 6, suggest that properties of the Tadla Azilal aquifer have higher water infiltration rates per unit of water withdrawal than does the Souss Massa aquifer. A consequence is that a longer period of time is required for the rate of outflow to just equal the rate of inflow of water to the aquifer. This is the second feature tending to dampen the rise in the shadow value of water in conjunctive use.

Ground water demand rises the most for fruits and vegetables (column 11), growing at an annual average rate of 1.4 percent per year over the 2011 to 2045 period, followed to a much lesser degree by fodder. However, the decline in ground water allocated to the other crops tends to counter balance this growth in ground water demand for fodder, cereals and pulses such that total ground water demand stays relatively constant. The rise in waters shadow value dampens the demand for ground water in other crops. The change in crop value added does not link in a linear way to the consumption of ground water. One reason is that capital, in terms of machines and equipment, is becoming marginally cheaper per unit of capital. That is, as water's shadow value is rising, the opportunity cost of capital is falling. This induces farmers to substitute some capital for water and labor in production.

Table 26 reports the land and water rents. The amount of land and surface water employed in all crops is constant over time. In the case of cereals and pulses, the rise in land and water rents reflect the trade-off in cost of production from capital deepening and a lower cost per unit of capital, and the rise in the cost of labor. Since the cost of capital per unit of production relative to labor declines, the net effect is a modest rise in both rent (profit) to the producers' land and water resources. A different pattern results for other irrigated agriculture. This subsector is more labor and less capital intensive than the other crops (see table 12) which, over time and given the evolution of wage and capital rental rates, these factor cause upward pressures on production cost. Coupled with this pressure is the rise in the shadow value of water. Together, these effects "push" resources out of the production of other irrigated crops, causing a decline in its value added (table 24), and a decline in its total rent to land and water (column 4, second panel of table 26).

As in the case of Souss Massa, the crops that stand out in the Tadla Azilal region are fodder and fruits and vegetables. These subsectors tend to "pull" resources from the rest of the economy as the value added increases and their employment of resources increase, with one exception. In the case of fodder, its employment of ground water remains essentially unchanged (table 25, column 9), and hence the ground water rent it earns is also relatively constant. Fodder production costs, relative to fruits and vegetables, is weighted more by labor. As wages rise over time, its cost advantage relative to fruits and vegetables tends to decline.

For the region as a whole, both land and water rents rise (columns 5 to 8, second panel table 26). Water accounts for about 64 percent of total rents in 2011 and fall modestly to about 58% of total rents. Rent to surface water is greater than total rent to ground water, but ground water rents rise slowly while surface rents rise modestly over time. This results because the total level of ground water demand remains relatively constant (table 25) while the cost of pumping rises, mostly due to the cost of energy for pumping.

IV.2.2 Surface water decline: drought simulation

We perform the same analysis as we did with Souss Massa; we decrease the total availability of surface water to each crop by ten percent in the Tadla Azilal region, leaving all other parameters and variables unchanged. We neglect discussion of this effect on the total economy and instead focus on the region. The results are reported in tables 27, 28 and 29. Recall that the Tadla Azilal region is more reliant on surface water (table 10) than is the Souss Massa region (table 7). Consequently, a decrease in surface water has a more detrimental economic effect than the same reduction in the Souss Massa region. While ground water acts as a buffer to the drought, the cost of pumping and equipment to irrigate with ground water prevents an equal trade-off between water sources.

Table 27 compares value added by agricultural subsector from the drought simulation divided by the corresponding value of the base solution. It can be seen that a once and for all drought (a ten percent decline in surface water) tends to decrease, relative to base in each time period, valued added by about 4 to 5 percent overall. The least negative impact, relative to base, is on fodder followed closely by fruits and vegetable crops. Once again these two subsectors seem to be most competitive in holding resources in production relative to the other subsectors. Their average decline relative to base is less than 4 percent. This competitiveness is directly linked to its relatively higher capital intensity compared to the capital intensity of the other crops (table 12: compare column 3, last row of values, with other subsectors). Moreover, only fodder is less intensive in the use of water. These two features together allow fruits and vegetables to compete with other sectors and the rest of the economy for resources.

The bottom panel of table 27 shows the loss in value added from the drought shock. The average annual loss in irrigated crop value added in Tadla Azilal is over 38 MDH per year, with the loss increasing with time, from about 64.7 MDH to 111.2 MDH for the case of fruits and vegetables. The shock's total value added effect is larger for fruits and vegetables since only cereals and pulses exceed its total proportion of land planted to irrigated crops (table 10).

Table 28 reports the effect of the drought on irrigation water, relative to base. Cereals and pulses, at this macroeconomic level of analysis, are not reported to use ground water. Hence, this subsector, as modeled, cannot protect itself from a decline in water supply, and consequently, the not applicable (na) notation in the table. Note first the increase in the shadow value of water relative to base, ranging from about 1.1 percent in 2011 to 2.5 percent, relative to base, in 2045 (column 1). For conjunctive users of water, as figure 2 suggests, the higher value also applies to surface water. The depth index of the aquifer's water table grows slowly, about 4.4 percent per year which of course increases pumping costs per m3 as suggested by the modest rise in water's shadow value. Water table depth in 40 years is also projected to be much less than is the case for Souss Massa.

Only fruits and vegetables, and other irrigated agriculture increase their use of ground water. Otherwise, the water "lost" from the drought is only partially replaced by ground water. In the first year of the shock, 2011, the fruit and vegetable subsector is projected to increase its use of ground water by 4.9 mm3 (table 28, bottom panel, column 10). As the shadow value rises over time, the sector decreases it use of ground water, falling to only 0.7 mm3 in 2045. This result obtains because the downward pressures on production cost of capital deepening, relative to the base solution, are dominated by the rise in the cost of water pumping from greater depths. Other factors are present as well, such as the rise in the price index of the economy's service sector which tends to sustain the growth in wages over time. Other irrigated agriculture, which relies on ground water for about 61 percent of total irrigation water (table 10), decreases slightly its use of ground water during the first ten years, relative to the base, but then exceeds the base by amount ranging from .3 mm3 to 1.7 mm3. The reasons for this adjustment are the same as for fruits and vegetables, with only differences in magnitude.

The effect of these changes on rents to land and water are reported in table 29. Relative to base, the ten percent decline in surface water caused total rents to irrigated crop land to decline by 4.0 to 3.5 percent compared to base for the years 2011 to 2045, respectively (column 5, bottom panel of table 29). Of course, this implies that with less water, land productivity must also fall. For all irrigated crops, the total rent to surface water also declines. In terms of figure 2, the rectangular area d has become smaller, relative to the base solution. Stated differently, the rise in the shadow value of water, which could increase the height of area d on the vertical axis, is offset by the decrease in quantity on the vertical axis so that the area d is becomes smaller.

Rents to ground water, area e, figure 2, increase, relative to base. The increase in the shadow value of water, and the increase in the volume of ground water used, relative to base, makes area e of figure 2 to increase. Area f, cost of ground water pumping, also increases as the depth of the water table increases.

IV.2.3 Increase in water use efficiency-productivity

As for the case of Souss Massa, we increase water productivity, or in other terms, effective water supply for both surface and ground water, by ten percent. This change increases, indirectly, the productivity of all other primary factors of production, such as capital, labor and land in crop production. However, depending upon the various intensities of primary factor use reported in table 12, and surface water assignment, the effect on each subsector, relative to base, varies.

The effect of water productivity on subsector value added is reported in table 30. Other irrigated agriculture has the greatest response to an increase in its value add relative to base (column 4), ranging from about 9.5 percent in 2011 to over 8 percent in 2040. This exceeds the same case for Souss Massa. The more abundant irrigation water (relative to Souss Massa), induce farmers in the Tadla Azilal area to employ those technologies and varieties of crops to which more water per unit is allocated, than in Souss Massa. In economic jargon, this makes the farmers' derived demand for irrigation water overall more elastic (i.e., the curve A in figure 2 is more horizontal than the case for Souss Massa). Other irrigated agriculture has the largest response, relative to base, mostly because relative to other corps, the importance (intensity) of capital and water in production is greater than other crops (table 12). Thus, the positive shock to water productivity causes costs of production for the same level of output as the base to decline more than other crops. These same forces prevail for other crops, except the magnitudes vary as they are influence by relative factor intensity, and competition for labor and capital from the service and manufacturing sectors of the economy.

Changes in the shadow value of water, and volume of water allocated, relative to the base results reported table 25, are shown in table 31. The ten percent increase in water efficiency increases the shadow value of water in conjunctive use, ranging from about 5 percent in 2011 to 6 percent, relative to base, in 2045. These changes are along the lines of the increase in water's shadow value for the case of Souss Massa, table 22. The increase in water productivity encourages farmers to employ modestly more ground water than base, ranging from 0.23 percent in 2011 to slightly less that that pumped in the base solution for 2045 (column 4, top panel, table 31). More use of ground water encouraged farmers to pump water from greater depths, which cause an increase in the aquifer depth index by 6.6 percent relative to base in 2045.

Relative to base, the increase in ground water use is most pronounced for other irrigated agriculture followed by fruits and vegetables (columns 10 and 12, lower panel, table 31). This results because other irrigated agriculture is almost 37 percent more intensive in the use of water than is fruits and vegetables (tabe12). Thus, a ten percent increase in the productivity of ground water has a greater profitable impact on other irrigated agriculture than it does on fruits and vegetables, all else constant.

Fodder is about 59 percent less water intensive than other irrigated agricultural crops, with a capital intensity less than fruits and vegetables (table 12). Fodder must compete for ground water with fruits and vegetables, water that is drawn from deeper depths and hence more costly. As a consequence, less ground water is applied to fodder production (column 8, bottom panel, table 31).

Table 32 shows the effects of these adjustment on land and water rents. For all crops, the more productive use of water increase rents to land relative to base. Relative to base for respective years 2011 to 2045, the rise in total land rent is about 5.5 percent higher (column 5, bottom panel, table 32). The rise in rents to surface water (area c plus d, figure 2) are about the same magnitude (column 6) as land. The rise in rents to ground water is about 6 percent higher for each respective year of the base analysis (column 7). The last three columns in the bottom panel of table 32 indicate how the rest of the economy is affected by the Tadla Azilal simulation. These values are less than unity for the most part. This result shows that the increase in water productivity in the Tadla Azilal area, although a relatively small component of the country's total value added, tends to pull some resources away from the rest of the economy due to an increase in water's productivity.

Table 24. Tadla Azilal-Base solution : Agricultural subsector value added, and Agricultural value added in rest of Morocco, 2011 MDH

	Tadla Azilal				Rest of
	Cereals and Pulses	Fodder	Fruits and Vegetables	Other Irr-igated Ag	Morocco Agriculture
2011	736	820	1850	362	105842
2015	742	905	2111	328	113365
2020	749	1001	2419	294	121895
2025	755	1087	2705	269	129528
2030	760	1164	2969	249	136343
2035	764	1233	3209	233	142416
2040	767	1294	3428	220	147818

Source: model results

Table 25. Tadla Azilal-Base solution: Irrigated water shadow value and surface and ground water allocation to cereals and pulses, fodder, fruits and vegetables, and other irrigated agriculture

						Cereals and Pulses		Fodder		Fruits and Vegetables		Other Irrigated Agriculture		
Year	Shadow Value (DH) of Water per m3	Total Irrigation Water Demand mm3	Total Surface Water Demand mm3	Total Ground Water Demand mm3	Aquifer Depth Index meters	Surface Water Demand mm3	Ground Water Demand mm3	Surface Water Demand mm3	Ground Water Demand mm3	Surface Water Demand mm3	Ground Water Demand mm3	Surface Water Demand mm3	Ground Water Demand mm3	Rest of Moroccan Agriculture mm3
2011	0.2329	1053.1	649.6	403.5	1.0	233.9	0.0	135.4	206.0	234.0	115.3	46.3	82.2	7465.5
2015	0.2539	1052.2	649.6	402.6	2.0	233.9	0.0	135.4	210.2	234.0	132.6	46.3	59.8	7465.5
2020	0.2788	1051.2	649.6	401.7	3.0	233.9	0.0	135.4	212.7	234.0	149.3	46.3	39.6	7465.5
2025	0.3021	1050.4	649.6	400.9	4.0	233.9	0.0	135.4	213.4	234.0	162.1	46.3	25.4	7465.5
2030	0.3238	1049.7	649.6	400.1	4.9	233.9	0.0	135.4	213.2	234.0	172.0	46.3	15.0	7465.5
2035	0.3437	1049.0	649.6	399.4	5.7	233.9	0.0	135.4	212.4	234.0	179.8	46.3	7.2	7465.5
2040	0.3618	1048.3	649.6	398.7	6.4	233.9	0.0	135.4	211.4	234.0	186.1	46.3	1.3	7465.5
2045	0.3783	1051.0	649.6	401.4	7.1	233.9	0.0	135.4	210.2	234.0	191.2	46.3	0.0	7465.5

Source: model results

Table 26. Tadla Azilal-Base solution: Surface and ground water rents by crop and for all of agriculture in the rest of Morocco, in MDH 2011

	Cereals and Pulses			Fodder				Fruits and Vegetables			
	Rents to Land	Rents to Surface Water	Total Rents	Rents to Land	Rents to Surface Water	Rents to Ground Water	Total Rents	Rents to Land	Rents to Surface Water	Rents to Ground Water	Total Rents
2011	139.72	125.75	265.47	49.34	31.54	5.77	86.65	95.68	54.50	3.23	153.41
2015	140.93	126.84	267.76	54.43	34.38	5.83	94.64	109.45	59.39	3.68	172.52
2020	142.21	127.99	270.20	60.22	37.75	5.84	103.80	125.67	65.23	4.10	194.99
2025	143.30	128.97	272.26	65.40	40.92	5.80	112.12	140.71	70.69	4.41	215.81
2030	144.22	129.80	274.02	70.03	43.85	5.76	119.63	154.56	75.75	4.64	234.95
2035	145.01	130.51	275.51	74.16	46.54	5.70	126.40	167.21	80.40	4.82	252.44
2040	145.68	131.12	276.80	77.84	48.99	5.64	132.48	178.71	84.65	4.97	268.32
2045	146.27	131.64	277.91	81.12	51.22	5.54	137.88	189.11	88.50	5.04	282.65

Source: model results

Table Continued

	Other Irrigated Agriculture				Total Tadla Azilal				Rest of Morocco		
	Rents to Land	Rents to Surface Water	Rents to Ground Water	Total Rents	Rents to Land	Rents to Surface Water	Rents to Ground Water	Total Rents	Rents to Land	Rents to Surface Water	Total Rents
2011	20.54	10.78	2.30	33.62	305.28	236.55	137.05	678.89	7632.54	2770.39	10402.93
2015	18.48	11.75	1.66	31.88	323.28	246.45	138.00	707.73	8175.03	2967.29	11142.33
2020	16.44	12.91	1.09	30.43	344.53	258.10	139.01	741.64	8790.14	3190.56	11980.70
2025	14.86	13.99	0.69	29.53	364.26	268.89	139.87	773.02	9340.60	3390.36	12730.96
2030	13.61	14.99	0.40	29.00	382.41	278.80	140.60	801.82	9832.06	3568.75	13400.81
2035	12.62	15.91	0.19	28.72	398.99	287.86	141.23	828.07	10270.01	3727.71	13997.71
2040	11.82	16.75	0.03	28.60	414.05	296.07	141.76	851.88	10659.55	3869.10	14528.64
2045	11.16	17.51	0.00	28.67	427.66	303.49	142.23	873.38	11005.51	3994.68	15000.19

Source: Model results

Table 27. Tadla Azilal: Drought simulation divided by base, agricultural subsector value added, and agricultural value added in rest of Morocco, in 2011 MDH

	Tadla Azilal				Rest of
	Cereals and Pulses	Fodder	Fruits and Vegetables	Other Irr-igated Ag	Morocco Agriculture
2011	0.9511	0.9738	0.9650	0.9623	0.9984
2015	0.9512	0.9742	0.9657	0.9611	0.9989
2020	0.9512	0.9746	0.9663	0.9599	0.9993
2025	0.9513	0.9749	0.9668	0.9589	0.9996
2030	0.9513	0.9751	0.9671	0.9581	0.9998
2035	0.9513	0.9753	0.9674	0.9574	0.9999
2040	0.9513	0.9754	0.9675	0.9568	1.0000
Average	0.9512	0.9747	0.9666	0.9592	0.9994
	Value in MDH (simulation minus base)				
2011	-35.9702	-21.5330	-64.7086	-13.6457	-166.9280
2015	-36.2424	-23.3533	-72.4270	-12.7612	-129.9074
2020	-36.5368	-25.4049	-81.4230	-11.8157	-90.5879
2025	-36.7890	-27.2632	-89.7845	-11.0497	-58.0797
2030	-37.0061	-28.9547	-97.5423	-10.4333	-31.4925
2035	-37.1938	-30.4932	-104.7079	-9.9353	-10.0101
2040	-37.3566	-31.8875	-111.2880	-9.5297	7.0876
Average	-36.728	-26.984	-88.840	-11.310	-68.560

Table 28. Tadla Azilal: Drought simulation divided by base, and simulation minus base, water shadow value and surface and ground water allocations to cereals and pulses, fodder, fruits and vegetables, and other irrigated agriculture

						Cereals and Pulses		Fodder		Fruits and Vegetables		Other Irrigated Agriculture		Rest of
Year	Shadow Value (DH) of Water per m3	Total Irrigation Water Demand mm3	Total Surface Water Demand mm3	Total Ground Water Demand mm3	Aquifer Depth Index meters	Surface Water Demand mm3	Ground Water Demand mm3	Surface Water Demand mm3	Ground Water Demand mm3	Surface Water Demand mm3	Ground Water Demand mm3	Surface Water Demand mm3	Ground Water Demand mm3	Moroccan Agriculture mm3
2011	1.021	0.939	0.900	1.001	1.000	0.900	na	0.900	0.991	0.900	1.043	0.900	0.969	1
2015	1.022	0.939	0.900	1.001	1.015	0.900	na	0.900	0.990	0.900	1.030	0.900	0.975	1
2020	1.023	0.938	0.900	1.001	1.020	0.900	na	0.900	0.989	0.900	1.020	0.900	0.988	1
2025	1.023	0.938	0.900	1.001	1.023	0.900	na	0.900	0.988	0.900	1.015	0.900	1.012	1
2030	1.024	0.938	0.900	1.000	1.024	0.900	na	0.900	0.988	0.900	1.010	0.900	1.059	1
2035	1.024	0.938	0.900	1.000	1.024	0.900	na	0.900	0.988	0.900	1.007	0.900	1.183	1
2040	1.024	0.938	0.900	1.000	1.025	0.900	na	0.900	0.988	0.900	1.005	0.900	2.270	1
2045	1.024	0.936	0.900	0.995	1.025	0.900	na	0.900	0.988	0.900	1.003	0.900	0.000	1
		Difference in Quantity: Simulation Minus Base (mm3)												
2011		-64.486	-64.956	0.470	0.000	-23.389	na	-13.542	-1.873	-23.396	4.931	-4.629	-2.589	0
2015		-64.654	-64.956	0.302	0.029	-23.389	na	-13.542	-2.164	-23.396	3.967	-4.629	-1.501	0
2020		-64.723	-64.956	0.233	0.062	-23.389	na	-13.542	-2.358	-23.396	3.054	-4.629	-0.463	0
2025		-64.755	-64.956	0.201	0.091	-23.389	na	-13.542	-2.455	-23.396	2.352	-4.629	0.304	0
2030		-64.780	-64.956	0.176	0.117	-23.389	na	-13.542	-2.498	-23.396	1.793	-4.629	0.881	0
2035		-64.804	-64.956	0.152	0.139	-23.389	na	-13.542	-2.511	-23.396	1.342	-4.629	1.321	0
2040		-64.823	-64.956	0.133	0.160	-23.389	na	-13.542	-2.503	-23.396	0.974	-4.629	1.663	0
2045		-66.773	-64.956	-1.817	0.177	-23.389	na	-13.542	-2.486	-23.396	0.669	-4.629	0.000	0

Source: model results

Table 29. Tadla Azilal: Drought, simulation divided by base: surface and ground water rents by crop and for all of agriculture in the rest of Morocco, in MDH 2011

	Cereals and Pulses			Fodder				Fruits and Vegetables			
	Rents to Land	Rents to Surface Water	Total Rents	Rents to Land	Rents to Surface Water	Rents to Ground Water	Total Rents	Rents to Land	Rents to Surface Water	Rents to Ground Water	Total Rents
2011	0.9511	0.9511	0.9511	0.9751	0.9191	2.5063	1.0566	0.9672	0.9191	2.6374	0.9853
2015	0.9512	0.9512	0.9512	0.9755	0.9198	2.5042	1.0494	0.9678	0.9198	2.6059	0.9862
2020	0.9512	0.9512	0.9512	0.9759	0.9204	2.5026	1.0415	0.9684	0.9204	2.5824	0.9862
2025	0.9513	0.9513	0.9513	0.9762	0.9208	2.5017	1.0350	0.9688	0.9208	2.5676	0.9857
2030	0.9513	0.9513	0.9513	0.9764	0.9212	2.5014	1.0295	0.9690	0.9212	2.5574	0.9850
2035	0.9513	0.9513	0.9513	0.9766	0.9214	2.5013	1.0250	0.9692	0.9214	2.5501	0.9842
2040	0.9513	0.9513	0.9513	0.9766	0.9216	2.5014	1.0212	0.9694	0.9216	2.5446	0.9835
2045	0.9513	0.9513	0.9513	0.9767	0.9218	2.5137	1.0181	0.9694	0.9218	2.5527	0.9828

Source: model results

Table Continued

	Other Irrigated Agriculture				Total Tadla Azilal				Rest of Morocco		
	Rents to Land	Rents to Surface Water	Rents to Ground Water	Total Rents	Rents to Land	Rents to Surface Water	Rents to Ground Water	Total Rents	Rents to Land	Rents to Surface Water	Total Rents
2011	0.9638	0.9191	2.4496	1.0512	0.9609	0.9380	1.0815	0.9773	0.9984	0.9984	0.9984
2015	0.9629	0.9198	2.4667	1.0251	0.9616	0.9377	1.0791	0.9762	0.9989	0.9989	0.9989
2020	0.9620	0.9204	2.5010	0.9993	0.9623	0.9374	1.0765	0.9750	0.9993	0.9993	0.9993
2025	0.9614	0.9208	2.5612	0.9795	0.9629	0.9370	1.0745	0.9741	0.9996	0.9996	0.9996
2030	0.9609	0.9212	2.6798	0.9643	0.9634	0.9367	1.0727	0.9733	0.9998	0.9998	0.9998
2035	0.9605	0.9214	2.9942	0.9526	0.9638	0.9365	1.0713	0.9726	0.9999	0.9999	0.9999
2040	0.9602	0.9216	5.7459	0.9435	0.9641	0.9362	1.0700	0.9721	1.0000	1.0000	1.0000
2045	0.9600	0.9218	na	0.9367	0.9644	0.9360	1.0690	0.9716	1.0001	1.0001	1.0001

Table 30. Tadla Azilal: Simulation water efficiency, simulation divided by base, agricultural subsector value addedand agricultural value added in rest of Morocco, 2011 MDH

	Tadla Azilal				Rest of
	Cereals and Pulses	Fodder	Fruits and Vegetables	Other Irr-igated Ag	Morocco Agriculture
2011	1.0501	1.0368	1.0478	1.0955	0.9921
2015	1.0504	1.0404	1.0527	1.0928	0.9942
2020	1.0507	1.0436	1.0571	1.0899	0.9962
2025	1.0509	1.0459	1.0602	1.0876	0.9976
2030	1.0510	1.0475	1.0624	1.0857	0.9987
2035	1.0511	1.0487	1.0640	1.0842	0.9995
2040	1.0512	1.0495	1.0651	1.0831	1.0001

Source: model results

Table 31. Tadla Azilal: Simulation water efficiency, simulation divided by base, water shadow value and surface and ground water allocation to cereals and pulses, fodder, fruits and vegetables, and other irrigated agriculture

	Shadow Value (DH) of Water per m3	Total Irrigation Water Demand mm3	Total Surface Water Demand mm3	Total Ground Water Demand mm3	Aquifer Depth Index meters1/	Cereals and Pulses: Surface Water Demand mm3	Cereals and Pulses: Ground Water Demand mm3	Fodder: Surface Water Demand mm3	Fodder: Ground Water Demand mm3	Fruits and Vegetables: Surface Water Demand mm3	Fruits and Vegetables: Ground Water Demand mm3	Other Irrigated Agriculture: Surface Water Demand mm3	Other Irrigated Agriculture: Ground Water Demand mm3	Rest of Moroccan Agriculture mm3
2011	1.0496	1.0009	1	1.0023	1.0000	1	na	1	0.9793	1	0.9945	1	1.0709	1
2015	1.0518	1.0007	1	1.0019	1.0390	1	na	1	0.9817	1	1.0024	1	1.0721	1
2020	1.0541	1.0006	1	1.0017	1.0533	1	na	1	0.9834	1	1.0076	1	1.0776	1
2025	1.0559	1.0006	1	1.0015	1.0593	1	na	1	0.9842	1	1.0104	1	1.0903	1
2030	1.0573	1.0005	1	1.0013	1.0625	1	na	1	0.9845	1	1.0119	1	1.1184	1
2035	1.0583	1.0004	1	1.0012	1.0643	1	na	1	0.9847	1	1.0128	1	1.1972	1
2040	1.0592	1.0004	1	1.0010	1.0653	1	na	1	0.9847	1	1.0133	1	1.9023	1
2045	1.0598	0.9994	1	0.9984	1.0660	1	na	1	0.9846	1	1.0135	1	na	1
						Difference in Quantity: Simulation Minus Base (mm3)								
2011		0.9184	0.0000	0.9184	0.0000	0.0000	na	0.0000	-4.2727	0.0000	-0.6344	0.0000	5.8255	0.0000
2015		0.7735	0.0000	0.7735	0.0761	0.0000	na	0.0000	-3.8482	0.0000	0.3120	0.0000	4.3097	0.0000
2020		0.6748	0.0000	0.6748	0.1622	0.0000	na	0.0000	-3.5395	0.0000	1.1378	0.0000	3.0765	0.0000
2025		0.5983	0.0000	0.5983	0.2390	0.0000	na	0.0000	-3.3781	0.0000	1.6862	0.0000	2.2902	0.0000
2030		0.5281	0.0000	0.5281	0.5281	0.0000	na	0.0000	-3.2971	0.0000	2.0520	2.0520	1.7732	0.0000
2035		0.4643	0.0000	0.4643	0.3676	0.0000	na	0.0000	-3.2584	0.0000	2.2990	0.0000	1.4237	0.0000
2040		0.4066	0.0000	0.4066	0.4206	0.0000	na	0.0000	-3.2416	0.0000	2.4667	0.0000	1.1814	0.0000
2045		-0.6553	0.0000	-0.6553	0.4670	0.0000	na	0.0000	-3.2359	0.0000	2.5806	0.0000	0.0000	0.0000

Source: Model results

Table 32 Tadla Azilal: Simulation water efficiency, simulation divided by base: Tadla Azilal surface and ground water rents by crop and for all of agriculture in the rest of Morocco, MDH 2011

	Cereals and Pulses: Rents to Land	Cereals and Pulses: Rents to Surface Water	Cereals and Pulses: Total Rents	Fodder: Rents to Land	Fodder: Rents to Surface Water	Fodder: Rents to Ground Water	Fodder: Total Rents	Fruits and Vegetables: Rents to Land	Fruits and Vegetables: Rents to Surface Water	Fruits and Vegetables: Rents to Ground Water	Fruits and Vegetables: Total Rents
2011	1.0501	1.0501	1.0501	1.0364	1.0496	8.0933	1.5110	1.0477	1.0496	8.2193	1.1993
2015	1.0504	1.0504	1.0504	1.0401	1.0518	8.1140	1.4800	1.0527	1.0518	8.2847	1.2066
2020	1.0507	1.0507	1.0507	1.0434	1.0541	8.1276	1.4455	1.0572	1.0541	8.3281	1.2089
2025	1.0509	1.0509	1.0509	1.0456	1.0559	8.1343	1.4163	1.0604	1.0559	8.3511	1.2078
2030	1.0510	1.0510	1.0510	1.0473	1.0573	8.1378	1.3920	1.0626	1.0573	8.3642	1.2051
2035	1.0511	1.0511	1.0511	1.0484	1.0583	8.1394	1.3718	1.0642	1.0583	8.3720	1.2020
2040	1.0512	1.0512	1.0512	1.0493	1.0592	8.1403	1.3550	1.0654	1.0592	8.3767	1.1988
2045	1.0512	1.0512	1.0512	1.0498	1.0598	8.1613	1.3394	1.0662	1.0598	8.4008	1.1950

Table Continued

	Other Irrigated Agriculture: Rents to Land	Other Irrigated Agriculture: Rents to Surface Water	Other Irrigated Agriculture: Rents to Ground Water	Other Irrigated Agriculture: Total Rents	Total Tadla Azilal: Rents to Land	Total Tadla Azilal: Rents to Surface Water	Total Tadla Azilal: Rents to Ground Water	Total Tadla Azilal: Total Rents	Rest of Morocco: Rents to Land	Rest of Morocco: Rents to Surface Water	Rest of Morocco: Total Rents
2011	1.0972	1.0496	8.8506	1.6127	1.0503	1.0499	1.6466	1.1705	0.9921	0.9921	0.9921
2015	1.0946	1.0518	8.8614	1.4825	1.0520	1.0510	1.6353	1.1654	0.9942	0.9942	0.9942
2020	1.0918	1.0541	8.9066	1.3550	1.0537	1.0522	1.6237	1.1600	0.9962	0.9962	0.9962
2025	1.0896	1.0559	9.0113	1.2587	1.0552	1.0532	1.6141	1.1556	0.9976	0.9976	0.9976
2030	1.0879	1.0573	9.2443	1.1857	1.0563	1.0540	1.6061	1.1519	0.9987	0.9987	0.9987
2035	1.0865	1.0583	9.8963	1.1303	1.0572	1.0547	1.5994	1.1488	0.9995	0.9995	0.9995
2040	1.0854	1.0592	15.7262	1.0879	1.0579	1.0552	1.5937	1.1461	1.0001	1.0001	1.0001
2045	1.0846	1.0598	na	1.0695	1.0585	1.0557	1.5889	1.1439	1.0005	1.0005	1.0005

Source: Model results

IV.3 The economics of Morocco's ecosystem services of land and water

We present first an intuitive notion of the economics of ecosystem services from the land and water resources of focus here. The appendix provides the analytical structure of the model.

Land and water are natural resources that yield a flow of services to the production of crops, thus providing opportunities for employment, growth in total value added and consequently raising a country's standard of living. In the context of our analysis, the flow of water services from the Souss Massa and the Tadla Azilal aquifers are causing a decline in their respective water tables, thus decreasing in the volume of water that can be profitably withdrawn over time. As the depth of water table increases a point is reached where water withdrawal cannot profitably exceed water inflows, causing the growth in production of some crops to be curtailed and others to decline in value added. This is the result for Souss Massa's production of cereals and pulses, and other irrigated crops (table 15), and for the other irrigated crops category in the Tadla Azilal region (table 24). The increasing cost of extracting ground water can also slow the production of the more profitable crops such as fodder and fruits and vegetables.

This section reports our models' projection of the "stock" value of land and water resources in each region over time. The basic notion of stock value is the following. What is the value in year 2011 a farmer would be willing to pay to have the property right to land planted to cereals and pulses? Purchasing the right to this property allows the farmer to earn rent from the land for as long as he desires, as well as any appreciation or depreciation in the land's price (or stock value). The farmer contrasts the discounted present value of earnings from purchasing the land to the discounted present value of same investment if placed in savings that earns a risk free rate of return. The equation capturing this decision making process appears in the appendix.

The same logic applies to the property rights to an aquifer. Only in this case we may conceptualize the property right to the aquifer as a public resource belonging to the citizens of Morocco. What is the value in year 2011 "society" would be willing to pay to have the property right to the aquifer? This property right allows society to earn rents from the aquifer (in the amount given by area e, figure 2) for as long as it desires. A difference with land, is that the aquifer slowly loses its capacity to supply water in excess of water infiltration. This equation is also given in the appendix. Both the land and water equations amount to discounting the value of the service flows to their net present value, using as an opportunity cost, the risk free rate of return on savings The land rent for cereals and pluses production in Souss Massa is reported in table 17, column 1.[4].

IV.3.1 Souss Massa: Land and water stock value analysis, the base case

The stock values for the base analysis of Souss Massa appear in table 33. The total stock value of land planted to various crops are divided by Ha irrigated (table 7). For example, table 33 column 1, shows the land planted to cereals and pulses is "valued" at 3,559 DH per hectare in 2011 (or approximately 150 US$ per acre). This is the value for which the farmer is indifferent between placing his savings in a bank account which earns a riskless but varying rate of return over time, and paying for the property right to land planted to cereals and pulses. Land planted to Fodder, and fruits and vegetables is shown to have a higher stock value per Ha. The value of this land in 2011 is more than ten times the value of land in cereals and pulses. The most important reason for the difference in land values is that the land rental rate for fruits and vegetables increases over time, (see table 17, columns 5 and 10), while that planted to cereals and pulses declines. A profit maximizing farmer, facing a decline in the future flow of rents to land producing cereals and pulses, is unwilling to pay a price for the land that is higher than a price of land for which rents are rising over time.

The relatively low initial price (3,559) is closely linked to the decline in cereals and pulses land rents. Our model, "stand in" farmer has perfect foresight to the future decline in land rents to cereal and pulses production, and knowledge that the price of this land will also decline. Hence, the 3,559 price in 2011 is the price that he would be indifferent between paying and earning a risk free rate of return on saving. In reality, the farmer would likely convert some of the cereal and pulses land into other crops. A weakness with our analysis is that land reallocation among crops over time is not taken into account

Land values planted to fodder, and fruits and vegetables, table 33, columns 2 and 3, show appreciation in their respective values. In 2011, the value of one Ha planted to fodder is 48,471 DH. In the long run (about 150 years), this value converges to a constant value per Ha of about 254,940 DH. The reason for this appreciation is the same as the explanation given for growth in the sectors value added with time. Capital deepening increases the productivity of water. The sector does not use water intensively per unit of production as other sectors. This sector can thus profitably

[4] Effectively, this analysis resembles an analysis of an agent calculating the price to pay for an apartment building that yields a flow of rents over time, it may appreciate or depreciate in value, and the building incurs costs of depreciation, where the opportunity cost of investment is a savings account yielding a risk free but variable rate of return over time.

"compete for" ground water from other subsectors, namely cereals and pulses, causing the rent to fodder land to increase. An implication is, for those crops that cannot compete for water, and have declining land rental values, policy should seek to help farmers transfer the land resource to those crops that are more capital intensive and the less water intensive. The reason is that falling per unit rental rates of capital and rising shadow value of water places the least upward cost pressures on producing these types of crops. Increasing the area planted to crops that use water less intensively than other crops is, effectively, "saving" water per unit value of production. .

The stock value of the Souss Massa aquifer is shown in column 6, table 33. The value ranges from 416 MDH in 2011 to 472 MDH in the long run. This value rises as the shadow value of water rises (table 16, column 1) and the depth of the water table increases (table 16, column 5). The rise in this value suggests ground water is becoming scarce. Since the shadow value of water is increasing (table 16, column 1), water productivity, in terms of the additional value added to irrigated crops from an additional m3 of water withdrawn from the aquifer, is also increasing. The rise in productivity during 2011 -2045 comes about because capital deepening in irrigated agriculture occurs at a faster rate per unit of production than is the withdrawal of water per unit of production. In other words, the capital to water ratio is increasing. This result implies that farmers are substituting machinery and irrigation equipment to save on the use of water per unit of production.

It is useful to divide the stock value of the aquifer by the stock of water remaining to be harvested, and to divide the stock value by the area irrigated. In the first case, we sum the total water the model predicts will be withdrawn from the aquifer over the period 2011 to 2061 and divide this value into 416 MDH for the year 2011. For year 2015, we sum the total water *left to be withdrawn*, i.e., from 2015 to 2061, and divide this value into 424 MDH, and so on. The resulting values are reported in column 7. For example, 4,294 DH in 2011 is the value per mm3 of the water *remaining* to be withdrawn (harvested) from the aquifer of the period 2011 to 2061. Another more recognizable value is the total stock value of the aquifer divided by Ha irrigated, column 8. The stock value per Ha can be viewed as follows. The 3,727 DH is what "society" in 2011 would be indifferent between acquiring the property right to ground water that can supplement surface water in irrigating the crops listed in table 33, and placing the same amount of saving in a risk free asset (or saving account) earning a risk free rate of return r(t), t = 1,…T.

Surface water stock values are shown in the last column, table 33. These values exceed the value of ground water mainly because, in our analysis, virtually no cost is incurred by farmers for surface water. The stock value of using surface water only for irrigation is closely linked to the discounted present value of the area c plus d, figure 2. If surface and ground water are used conjunctively, then the stock value of surface water is closely linked to the discounted present value of area d. While the cost of withdrawing ground water increases with depth of the water table and quantity of water withdrawn, surface water does not incur these costs in our analysis. These features of surface water make it a relatively more valuable natural resources per mm3 than ground water. The rise in the shadow value of water in conjunctive use, makes surface water ever more valuable. In addition, surface water rents rise in greater proportion to the rise in ground water rents. The value per Ha that would make society indifferent between acquiring the rental flows to surface water, and placing the same investment in a riskless account earning competitive rate of return are the values shown in the last column of table 33.

A policy implication is that the rents to surface water could be taxed. This amounts to transferring some of the rents that farmers receive each year from surface water (areas c plus d), to reinvest in water saving technologies that farmers, as individuals, have no incentive to invest in. This includes new crop varieties that are less water intensive, improvement in canals transferring water to farmers, and water application technologies that better target the water to plants. It can be shown that, in principle, a tax on surface water rent that is less than the shadow value of water will not affect the quantity of surface water a farmer desires to acquire.

IV.3.2. Souss Massa: Effect of drought and water efficiency on Land and water stock values

We follow the pattern of simulations presented in the previous sections. We evaluate a ten percent decline in surface water for each crop, and a water productivity – water efficiency gain of ten percent on the stock values of land and water. The results, in terms of the simulation divided by the base results, appear in tables 34 and 35.

The basic pattern of stock values over time remains unchanged from the base solution. A ten percent decline in surface water assignments to each crop leads to a decline in land stock values by subsector of about one percent (table 34, column 2 to 4).

The stock value of the aquifer rises by more than 12 percent from the ten percent drought shock (table 34, column 6). In long-run equilibrium, the stock value remains about 13 percent higher. As shown in table 19, column 5, the depth to the water table is about 1 percent deeper than the same year of the base solution, and the shadow value is about 0.9 percent higher than the base solution. Water withdrawal under this draught scenario is higher than the base through 2015, and then it remains unchanged (table 19, column4). Thus, the aquifer served as a "buffer stock of water" in the earlier periods of drought, which in turn increases the rents to ground water resources. The higher rents are sustained over time, and thus yielding a higher stock value to society. The higher shadow value of water helped to dampen the exploitation of the aquifer, which nevertheless, resulted in a lower water table than the base. With more limited supplies of surface water, the stock value of this resource increased by about 12 percent on average (table 34).

The effect of a ten percent increase in water productivity – efficiency is reported in table 35. The greater "abundance" of effective water increases the productivity and hence the stock value of land by similar percentage, relative to base, for all irrigated crops. More productive – efficient irrigation water, also increases the stock values of both surface and ground water. That is, the stock value of both ground and surface water are increased as the services provided by these natural resources now make a larger contribution, per m3, to value added by irrigated crops.

Relative to base, the increase in the stock value of ground water (table 35, column 8) is greater than the increase in stock value of surface water (column 9). Aquifer depth increases, ranging from 6 to 17 percent (table 22, column 5), relative to base. The key effect causing the difference in the stock value of ground water relative to the stock value of surface water is the rent (area e, figure 2) increases over time in greater proportion than the increase in water withdrawal costs, (area f), over time. Hence, the ecosystem services provided by the aquifer is increased.

A caveat to these results, as noted earlier, is that we are not analyzing a water saving type of technological change. It is the case that over time, capital is substituted for water for each level of production, which saves water as it becomes increasingly scarce relative to capital. The water productivity - efficiency gain we studied is neutral, so change is not of a direct water saving type. A water saving technological change would be one that lowers the cost share of water in total cost (i.e., the values 0.099, 0.027, etc., table 9). Moreover, no account has been taken of deterioration in water quality with water table depth, salt water incursion, or degradation of water holding capacity of the aquifer.

IV.3.3 Tadla Azilal: Land and water stock value analysis, the base case

Land and water stock values for Tadla Azilal are reported in table 36. The base solution (table 24) shows value added over time increasing for all subsectors except other irrigated agriculture which falls from 362 MDH in 2011 to 220 in 2040. An important difference in crop production between Tadla Azilal and Souss Massa is the following. Capital tends to make up a larger proportion of total production costs in Souss Massa than in Tadla Azilal, while water makes up a smaller proportion of total production costs in Souss Massa than it does in Tadla Azilal. It can be said that technology in crop production in Souss Mass is relatively more capital using and water saving than in Tadla Azilal.

The results suggest a stock price of land planted to cereals and pulses of 38,558 DH per Ha in 2011, (or approximately 1,400 US dollars per acre) rising to 45,658 DH in 2040. This stands in stark contrast to Souss Massa where land planted to cereals and pulses is 3,559 DH per Ha in 2011, and falling to 1,482 DH in 2045 (table 33, column 1). The difference in magnitude arises in part because cereals and pulses production in Souss Massa experiences a rise in production costs relative to other crops grown in that region. This difference causes land rents in cereals and pulses in Souss Massa to decline with time, as dose its total value added. While the rise in value added of this crop is modest in Tadla Azilal, land rents over time increase. Consequently, the appreciated value of land rents makes land in cereals and pulses in Tadla Azilal a more attractive asset than in Souss Massa.

In contrast, the stock value of land planted to fruits and vegetables in the two regions are very similar. For Tadla Azilal, they range from 42,775 DH per Ha in 2011 to 71,331 DH in 2045; the corresponding value for Souss Massa in 2045 is 76,791 DH per Ha. The rest of Morocco stock values for land are also similar between the two analyses. The rise is land values shows the value of the ecosystem services provided by land is rising for all land except land planted to other irrigated crops. To the extent that this land is adaptable to producing other crops, some land may transition out of this subsector over time.

The stock value of the Tadla Azilal aquifer (table 36, column 6) is about twice the stock value of the Souss Massa aquifer. Between 2011 and 2045, the Souss Massa aquifer appreciates by 10 percent in total stock value, while the Tadal Azilal aquifer appreciates by 11 percent, from 901 MDH in 2011 to 996 MDH in 2045. The annual water withdrawal from the Souss Massa aquifer is in the vicinity of 700 mm3 per annum (table16) while for Tadla Azilal withdrawal is about 400 mm3 per annum (table 26). This difference reflects, in part, the higher percentage of surface water used in irrigation, and the higher recharge rate per unit of water extracted from the aquifer in Tadla Azilal than for Souss Massa. As pointed out above, the difference in net recharge in turn gives rise to an initially higher shadow value of water in Tadla Azilal, but a shadow value that rises more slowly and eventually becomes less than the water shadow value for Souss Massa. The depth index of the Tadla Azilal is only 7.1 in 2045 compared to that of Souss Massa which is 33.8 in 2045 (table 26).

The stock values of the aquifer per Ha irrigated per annum vary much less between the two regions. For Tadla Azilal it ranges from 4,436 DH per Ha in 2011 to 4,906 DH per Ha in 2045 (table 36, column 8) which is about 19 percent higher than for Souss Massa. Contrasting table 36, last column, for Tadla Azilal, to the last column of table 33 for Souss Massa, we see that the stock value of surface water, in DH per Ha, is roughly equal, on a per annum bases, but the value for Souss Massa rises above Tadla Azilal in later years. This results because the Souss Massa depth index implies a water depth much greater than for Tadla Azilal.

IV.3.4. Tadla Azilal: Effect of drought and water efficiency on Land and water stock values

Results from a presumed permanent ten percent decline in the volume of surface water appear in table 37. Recall that the Tadla Azilal region uses virtually no ground water for the production of cereals and pulses and, overall, draws a smaller percent of total irrigation water from the ground compared to Souss Massa. The effect on decreasing land stock values, relative to the base, is almost 5 percent of base land stock values for cereals and pulses, to as little as 2.3 percent of base for land planted to fodder. These relative declines in land value are linked to the percentage reliance on ground water for each crop. The amount of extra ground water withdrawn to accommodate the decline in surface water, relative to base, is only about 0.1 percent more than base, table 28, column 4. Consequently, irrigation water allocated declines by about 64 mm3 of surface water per annum. This is water "lost" due to a presumed ten percent decline in total surface water, and a decline in the amount of water infiltration to the aquifer. Thus, the depth of the water table is effected by the increase in withdrawal, as well as less surface water infiltrating the aquifer (see the depth index, table 28).

The 0.1 replacement of "lost" surface water with ground water amounts to only about 477 thousand m3 of water being replaced in the first year, 2011, falling to about 133 thousand m3 replacement in 2035. Despite the relatively small increase in water withdrawal, the total stock value of the aquifer increases by a factor of 2.5 relative to the base solution (table 37, column 6). Similar magnitudes of difference relative to base are reported for the stock value of water divided by the profitably harvestable water (see footnote 2, table 33 for definition of the quantity of profitably harvestable water), and the stock value divided be Ha irrigated (excluding cereals and pulses). The stock value of surface water in conjunctive use rises by about 2.4 percent relative to base (table 37, last column). This increase contrasts to the roughly 1 percent increase for the case of Souss Massa.

We turn attention next to our analysis of a presumed once and for all time ten percent increase in the productivity-efficiency of both surface and ground water used for irrigation in the Tadla Azilal region. Comparison of the simulation with the base solution appears in table 38. For the case of cereals and pluses, fodder, and fruits and vegetables, the positive effect on Tadla Azilal land values are positive and roughly one percent less than corresponding values for Souss Massa. Otherwise these values follow a similar pattern over time. The roughly one percent higher value in Souss Massa obtains due to the relatively more capital intensive nature of crops produced in Souss Massa compared to Tadla Azilal. More fundamentally, because capital in the production of Souss Mass crops accounts for a larger share in total primary resource cost of production, and capital rental rates decline with time, Souss Massa farmers find it profitable to employ more capital for a given increase in water productivity than farmers in Tadla Azilal. As a consequence, land productivity rises to a marginally greater degree in Souss Massa than it does in Tadla Azilal, thus increasing the stock value of land in Souss Massa relative to the increase in land values in Tadla Azilal.

The stock value of ground water is more responsive to the ten percent increase in water productivity-efficiency than to the ten percent decline in surface water. Recall that Tadla Azilal uses more water per unit of value added for cereals and pulses, fodder, and fruits and vegetables than do Souss Massa farmers. Thus, Tadla Azilal farmers' response to an increase in the productivity of water is to employ proportionately more water per unit of production than the typical Souss Massa farmer. As a consequence, the stock value of irrigation water exceeds base values by a factor of eight (table 38, columns 6, 7, and 8) in Tadla Azilal.

Table 33. Souss Massa: base solution stock - asset value of land and water resources

	Souss Massa land value per Ha planted to irrigated				Rest of Moroccan stock value of land per Ha	Stock value of Souss Massa aquifer in MDH[1/]	Stock value of aquifer in DH / mm3 of water remaing to harvest, 2011 to 2160[2/]	Stock value of aquifer in DH /Ha irrigated[3/]	Stock value of surface water in conjunctive use, DH/Ha.[4/]
	Cereals & Pulses	Fodder	Fruits & Vegetables	Other Irrigated crops					
2011	3,559	48,471	40,171	17,813	20,308	416	4,294	3,727	13,562
2015	3,041	58,236	45,522	15,367	21,567	424	4,501	3,798	15,726
2020	2,571	71,428	51,963	13,109	22,995	432	4,766	3,875	18,526
2025	2,227	85,381	57,982	11,426	24,272	440	5,043	3,939	21,394
2030	1,967	99,735	63,500	10,140	25,413	446	5,334	3,994	24,284
2035	1,767	114,146	68,477	9,138	26,430	451	5,642	4,039	27,157
2040	1,609	128,307	72,903	8,340	27,335	455	5,970	4,077	29,980
2045	1,482	141,965	76,791	7,696	28,139	458	6,322	4,108	32,725
Long-run	825	254,940	95,824	4,249	33,710	472	na	4,231	62,018

1/ This value is closely linked to the discounted present value of area e, figure 2

2/The stock value (e.g. year 2015, value 424) divided by the total volume of water over the period remaining to harvest, which is the sum of water pumped from, for example, 2015 to 2161, an end point where the outflow of water is just balanced by water inflow to the aquifer.

3/ The area irrigated appears in table 10

4/ This value is closely linked to the discounted present value of area c plus d, figure 2.

Table 34. Sourss Massa: drought affects on stock - asset value of land and water resources, simulation divided by base

	Souss Massa land value per Ha planted to irrigated				Rest of Moroccan stock value of land per Ha	Stock value of Souss Massa aquifer in MDH	Stock value of aquifer in DH / mm3 of water remaing to harvest, 2011 to 2160	Stock value of aquifer in DH /Ha irrigated	Stock value of surface water in conjunctive use, DH/Ha.
	Cereals & Pulses	Fodder	Fruits & Vegetables	Other Irrigated crops					
2011	0.989	0.990	0.988	0.988	1.000	1.128	1.128	1.128	1.009
2015	0.989	0.990	0.988	0.987	1.000	1.127	1.128	1.127	1.009
2020	0.989	0.990	0.988	0.987	1.000	1.127	1.128	1.127	1.009
2025	0.989	0.990	0.988	0.987	1.000	1.127	1.128	1.127	1.010
2030	0.988	0.990	0.988	0.987	1.000	1.127	1.128	1.127	1.010
2035	0.988	0.990	0.988	0.987	1.000	1.128	1.128	1.128	1.010
2040	0.988	0.990	0.988	0.987	1.000	1.128	1.129	1.128	1.010
2045	0.988	0.990	0.987	0.986	1.000	1.128	1.129	1.128	1.010
Long-run	0.984	0.987	0.983	0.982	1.000	1.131	na	1.131	1.013

See footnotes to table 33.

Table 35. Sourss Massa: water productivity-efficiency affects on stock - asset value of land and water resources, simulation divided by base

	Souss Massa land value per Ha planted to irrigated				Rest of Moroccan stock value of land per Ha	Stock value of Souss Massa aquifer in MDH	Stock value of aquifer in DH / mm3 of water remaing to harvest, 2011 to 2160	Stock value of aquifer in DH /Ha irrigated	Stock value of surface water in conjunctive use, DH/Ha.
	Cereals & Pulses	Fodder	Fruits & Vegetables	Other rigated crop					
2011	1.08	1.06	1.08	1.09	1.00	1.11	1.09	1.11	1.05
2015	1.069	1.061	1.076	1.079	1.000	1.104	1.088	1.104	1.055
2020	1.069	1.062	1.076	1.079	1.000	1.104	1.088	1.104	1.055
2025	1.070	1.062	1.076	1.080	1.000	1.104	1.089	1.104	1.055
2030	1.070	1.062	1.076	1.080	1.000	1.104	1.089	1.104	1.055
2035	1.070	1.062	1.076	1.080	1.000	1.104	1.089	1.104	1.055
2040	1.070	1.062	1.076	1.080	1.000	1.104	1.089	1.104	1.055
2045	1.070	1.062	1.076	1.080	1.000	1.104	1.090	1.104	1.055
Long-run	1.065	1.059	1.072	1.075	1.000	1.105	na	1.105	1.059

See footnotes to table 33.

Table 36. Tadla Azilal: base solution stock - asset value of land and water resources

	Tadla Azilal land value per Ha planted to irrigated				Rest of Moroccan stock value of land per Ha	Stock value of Tadla Azilal aquifer in MDH	Stock value of aquifer in DH / mm3 of water remaing to harvest, 2011 to 2160	Stock value of aquifer in DH /Ha irrigated	Stock value of surface water in conjunctive use, DH/Ha.
	Cereals & Pulses	Fodder	Fruits & Vegetables	Other Irrigated crops					
2011	38,558	32,291	42,775	18,492	20,563	901	15,163	4,436	15,728
2015	39,775	34,908	47,023	17,591	21,949	917	15,874	4,518	16,988
2020	41,117	37,911	52,005	16,665	23,533	936	16,772	4,608	18,464
2025	42,285	40,631	56,608	15,918	24,961	951	17,690	4,685	19,825
2030	43,305	43,084	60,832	15,309	26,243	965	18,638	4,752	21,073
2035	44,196	45,289	64,682	14,809	27,391	977	19,625	4,811	22,209
2040	44,976	47,264	68,176	14,394	28,417	987	20,661	4,862	23,239
2045	45,658	49,029	71,331	14,048	29,331	996	21,756	4,906	24,168
Long-run	50,158	61,514	94,478	12,118	35,736	1,055	na	5,195	30,960

See footnotes, table 33.

Table 37. Tadla Azilal: drought affects on stock - asset value of land and water resources, simulation divided by base

	Tadla Azilal land value per Ha planted to irrigated				Rest of Morocco stock value of land per Ha	Stock value of Tadla Azilal aquifer in MDH	Stock value of aquifer in DH / mm3 of water remaing to harvest, 2011 to 2160	Stock value of aquifer in DH /Ha irrigated	Stock value of surface water in conjunctive use, DH/Ha.
	Cereals & Pulses	Fodder	Fruits & Vegetables	Other Irrigated crops					
2011	0.951	0.976	0.968	0.961	0.999	2.531	2.452	2.531	1.023
2015	0.951	0.976	0.969	0.961	1.000	2.532	2.451	2.532	1.023
2020	0.951	0.976	0.969	0.961	1.000	2.532	2.448	2.532	1.024
2025	0.951	0.977	0.969	0.960	1.000	2.532	2.445	2.532	1.024
2030	0.951	0.977	0.969	0.960	1.000	2.533	2.442	2.533	1.024
2035	0.951	0.977	0.970	0.960	1.000	2.533	2.439	2.533	1.024
2040	0.951	0.977	0.970	0.960	1.000	2.533	2.436	2.533	1.025
2045	0.951	0.977	0.970	0.960	1.000	2.533	2.432	2.533	1.025
Long-run	0.951	0.976	0.969	0.960	1.000	2.533	na	2.533	1.025

See footnote to table 33.

Table 38. Tadla Azilal: water productivity-efficiency affects on stock - asset value of land and water resources, simulation divided by base

	Tadla Azilal land value per Ha planted to irrigated				Rest of Morocco stock value of land per Ha	Stock value of Tadla Azilal aquifer in MDH	Stock value of aquifer in DH / mm3 of water remaing to harvest, 2011 to 2160	Stock value of aquifer in DH /Ha irrigated	Stock value of surface water in conjunctive use, DH/Ha.
	Cereals & Pulses	Fodder	Fruits & Vegetables	Other Irrigated crops					
2011	1.049	1.044	1.059	1.089	0.996	8.265	7.969	8.265	1.055
2015	1.050	1.046	1.062	1.088	0.998	8.269	7.965	8.269	1.056
2020	1.051	1.048	1.064	1.087	0.999	8.273	7.959	8.273	1.058
2025	1.051	1.049	1.065	1.086	1.000	8.276	7.951	8.276	1.059
2030	1.051	1.050	1.066	1.085	1.001	8.278	7.941	8.278	1.060
2035	1.052	1.051	1.067	1.085	1.001	8.279	7.930	8.279	1.061
2040	1.052	1.051	1.068	1.084	1.002	8.281	7.918	8.281	1.061
2045	1.052	1.051	1.068	1.084	1.002	8.282	7.905	8.282	1.061
Long-run	1.052	1.050	1.066	1.085	1.001	8.282	ns	8.282	1.060

See footnotes to table 33.

V. Summary and Policy Implications

This project implemented an economic analysis of the economy-wide effects over time of surface and ground water used for irrigation in two regions of Morocco. The two regions are Souss Massa and Tadla Azilal. Together, these regions account for about 23 percent of the country's value added by irrigated crops. With a semiarid climate and variable rainfall, but blessed by water harnessed from snow melt in mountainous regions, agriculture's 15 percent share in total value added underestimates the importance of agriculture and water to the national economy. The contribution of surface and ground water to gross domestic product do not appear in official product accounts, and consequently the degradation of this resource over time and how degradation affects the country's natural resource wealth may not receive the attention it warrants in policy analyses.

About 80 percent of total water allocated to the production of fodder and fruits and vegetables in Souss Massa is ground water, with cereals and pulses and other irrigated agriculture ranging from 45 to 55 percent ground water. In the case of Tadla Azilal, the services of land and water account for about 17 percent of this regions value added in 2011. It can be said that Tadla Azilal, which is more endowed with surface water per Ha than is Souss Massa, employs agricultural technologies and methods that use the services of these natural resources in abundance relative to Souss Massa. The aquifers in both regions have experienced a decline in the water table.

The methodology is to fit to data two almost analytically identical but empirically different models. One model empirically focuses on the region of Souss Massa and the rest of Morocco, while the other focuses on the Tadla Azilal region and the rest of Morocco. Following a base analysis with each model, we perform two simulations. One simulation focuses on the effect of a ten percent decline is surface water on each of these regional economies, in the context of the broader Moroccan economy. The other simulation considers a ten percent increase in the productivity – efficiency of irrigated water. These analyses provide insights and policy implications with regard to the natural resource services provided by land and more importantly water in these two major regions.

Major findings

In the case of Souss Mass, the results suggest the unit value of water (i.e. the shadow value of water) in conjunctive use (surface and ground) will rise by almost 300 percent over the next 40 years, as the percent of ground water used in irrigation rises by about 6 percent, and the water table declines rather precipitously, from a depth index of 1 to 33.8. The cost of pumping water from greater depths dampens ground water use, and particularly so in the production of cereals and pulses. This crop, per unit of production, uses water relative intensely compared to other crops. The less water intensive using crops, such as fruits and vegetables, tend to “out-compete” cereals and pulses for aquifer water. The Fodder subsector also competes favorably for ground water.

A ten percent decline in the volume of surface water, which we refer to as a drought shock, decreases Souss Massa sector value added for crops that use water intensively per unit of production; these are cereals and pulses and other irrigated agriculture. The ten percent shock lowered their value added by about 2.0 to 3.0 percent per year over the 2011 – 2040 period compared to corresponding years of the base solution. The more “water competitive” corps, fodder and fruits and vegetables, experienced a decline of only about 1.0 percent per year relative to base. Relative to corresponding years of the base solution, the shadow value of water rises, reflecting increase water scarcity, and depth to the water table increases surprisingly modestly, by about 2.2 percent in 2015, with an increase in depth per year declining to about 1.0 percent in year 2040. Eventually, the rate of water outflow cannot exceed the rate of water infiltration. A relatively small amount of the surface water lost to drought is replaced by ground water.

The water productivity/efficiency analysis increased water productivity - efficiency by ten percent. In Souss Massa, the increase in value added was the highest for the water-competitive crops, fodder and fruits and vegetables. Their value added increased the most in early periods, and averaged per year over 8.0 percent for the 2011 to 2040 period, relative to base. Other irrigated agriculture and cereals and pulses also increased their value added, ranging from 6.0 to almost 8 percent per year. Increasing the productivity - efficiency of water increased the volume of its use, and also increased the productivity and employment of more labor and capital in irrigated crop production. These resources, relative to the base solution, must be “pulled” from other activities and consequently, the value added in the rest of Moroccan agriculture declines by a small amount.

In the case of Tadla Azilal, the results of the base analysis suggests the unit value of water in conjunctive use will rise by about 62 percent, (or only about 20 percent of the rise experienced for Souss Massa) over the 2011 to 2045 period. Moreover, the depth index of the water table only falls to 7.1 in 2045. Total ground water pumped remains relatively constant at about 400 mm3 per year over the entire period. Nevertheless, the out flow of water exceeds inflow to the aquifer, but at a relatively constant amount over time. The data suggest one reason for this result is that water inflow per unit of water withdrawn from the aquifer in the Tadal Azilal region is higher than is the case for the Souss Massa aquifer. Value added of fodder and fruits and vegetables almost double over the 30 year period. The value added by cereals and pulses only increase by about 4 percent. The value added by other irrigated agriculture declines.

We perform the same kind of analysis as we performed for the case of Souss Massa; we decrease surface water by ten percent (a once and forever drought) and, in the second simulation, we increase water productivity – efficiency by ten percent. Since surface water is a larger percentage of total irrigation water in the Tadla Azilal region than in the Souss Massa region, a drought tends to have larger absolute effects on production than a drought in the Souss Massa region. Otherwise, we obtain almost the same pattern of results as obtained for Souss Massa. While value added for all irrigated subsectors decline relative to the base analysis, the declines are greatest for those employing water relatively intensively per unit of value added; these are cereals and pulses, and other irrigated agriculture. In contrast to Souss Massa, the cereal and pulses sector tend not to use ground water. Hence in our analysis, this subsector does not buffer the negative surface water shock by pumping water. Its value added drops the most, almost 5 percent relative to every year of the base solution. The average value added lost per year for cereals and pulses is about 36 MDH. Since fruits and vegetables comprise larger area planted, its average annual loss is about 88 MDH.

The increase in value added from a ten percent increase in water productivity – efficiency, tends to increase the Tadla Azilal’s irrigated crop value added, relative to base, for crops with a relatively large surface water assignment relative to ground water in total irrigation water, and those crops that are relatively water intensive (cereals and pulses, and other irrigated agriculture) relative to the base analysis. Other irrigated agriculture increased value added (almost 9 percent per annum per year over base), followed by fruits and vegetables (about 6 percent), cereals and pulses (about 5 percent), and lastly fodder (abour 4.5 percent).

The shadow value of water increases ranged from about 5 percent higher than base in 2011 to almost 6 percent higher than base by 2045. The depth index increased by 3 percent above base index, in 2015 and by 6.6 percent compared to base by 2045. Increasing the productivity - efficiency of water increased ground water use, and also increased the productivity of other resources employed in crop production. The increase in ground water use is also accompanied by increased use of labor and capital in irrigated crop production. These resources, relative to the base solution, must be "pulled" from other activities and consequently, the value added in the rest of Moroccan agriculture declines by a small amount.

The last part of our analysis focuses on the stock value of land and water in both regions, and for each of the simulations discussed above. Our analysis hold's land in each crop fixed over time. Thus, land is not permitted to be allocated to other crops where it might be more productive.

With this caveat in mind, the stock value of land in the base solution tends to fall for crops whose value added is declining over time, e.g., cereals and pulses in Souss Massa, and rising for other crops. The stock value of land planted to fruits and vegetables in Souss Massa rises from about 40,171 DH per Ha. in 2011 to about 76,800 in 2045. These values are the price of a hectare of land that a farmer would be indifferent between putting his resources in an account earning a riskless rate of return, and holding the property rights to the land which allow the farmer to earn a stream of land rents over time as well as the appreciation in land prices. The fundamental result is land in the competitive crops of fodder and fruits and vegetables appreciates in value relative to other crops.

In the Souss Massa region, the stock value of the aquifer, and the stock value of surface water both increase over time. The stock value of the Souss Massa aquifer increases from 3,727 DH per Ha irrigated in 2011 to 4,108 per Ha irrigated in 2045. In total value terms, the stock value increased from 416 MDH in 2011 to 458 MDH in 2045. The stock value of surface water used conjunctively with ground water increases from 13,562 DH per Ha. in 2011 to 32,725 DH per Ha in 2045. On a mm3 bases, the stock value of surface water is more valuable than the stock value of ground water due to the cost of pumping.

The drought simulation and the water productivity – efficiency simulations show an increase in the stock value of both surface and ground water in Souss Massa. Thus, whether a drought which causes farmers to draw more heavily on ground water, or a productivity shock, both of which induce an increases in the use of ground water, results in an increase in water's stock value, relative to the base solution. The drought simulation impacts land values negatively relative to base.

The results for the region of Tadla Azilal follow the same general pattern of Souss Massa, but differ substantially in magnitude, particularly land producing cereals and pulses. Land planted to cereals and pulses is predicted to have a stock value of 38,558 DH per Ha in 2011 rising to 45,958 DH per ha in 2045. Land planted to Fodder tends to have a higher stock value in Souss Massa than in Tadla Azilal where land in this category ranges in stock price of 42,775 DH per Ha in 2011 to 49,029 DH per Ha in 2045.

The stock value of the Tadla Azilal aquifer is about twice the stock value of the Souss Massa aquifer. The value ranges from 901 MDH in 2011 to 996 MDH in 2045. The stock value in terms of Ha irrigated ranges from 4,436 per Ha irrigated in 2011 to 4,906 in 2045. The stock value of surface water is also higher initially in this region than in Souss Massa. The value ranges from 15,728 DH per Ha irrigated in 2011 to 24,168 DH per Ha irrigated in 2045, whereas Souss Massa ranges from 13,562 to 32,725 DH per Ha irrigated.

The drought simulation increases the stock value of the Tadla Azilal aquifer by a factor of 2.5 for each year of the base, in contrast to Souss Massa which averaged factor increase of about 1.13 for each year of the base. In the case of the water productivity- efficiency simulation, the stock value of the Tadla Azilal aquifer, relative to the base, increases by a factor of almost 8.3 on average over the period. The explanation for this difference lies in the "higher importance" (larger share in primary resource cost) of land and water in producing value added from irrigated crops in Tadla Azilal than it is in Souss Massa, all relative to other resources such as labor and capital.

Policy Implications

The services of land, surface and ground water in irrigated crop production account for about 5 percent of value added by primary resources in the Souss Massa region, and for about 17 percent of value added in Tadla Azilal. This difference indicates that crop technology is more land and water intensive in Tadla Azilal than it is in Souss Massa. That is, in the less arid and more water abundant region of Tadla Azilal, farming methods are more reliant on land and water resources, relative to labor and capital, than are farmers in the Souss Massa region. This difference is consistent with the induced innovation hypothesis verified empirically for Japan and the U.S, see Binswanger et al. (1978). Roughly, the hypothesis states that farmers choose the technology that saves the relatively most scares resource. The technology farmers employ in Souss Massa is more water saving (and closely linked land saving) than the technology farmers use in Tadla Azilal. A policy implication is for public authorities and private organizations is to help farmers find and adopt those technologies that save the relatively most scares resources, in this case, water and land, both of which are in relatively fixed supply over time. This strategy is also consistent with the World Bank (200b) findings that the proportion of natural resource value in total national asset values falls with the level of GDP per capita. That is, the stock value of capital, labor services and institutional services rise in proportion to the stock value of natural resources over time as GDP per capita increase on a relatively persistent basis.

Our analysis shows that in the process of economic growth, capital in production grows per unit of labor, and per unit of water resources. This results largely because capital rental rates fall with time while wages rise, and the shadow value of water increases. The substitution of cheaper capital for labor and water over time lowers production costs, while increasing the productivity of the natural resource services of land and water. Policy that places downward pressures on the costs farmers face in substituting capital for other resources, such as lower cost banking and credit market structures, and introducing farmers to new farming methods that make substitution more profitable should be encouraged. This substitution for water amounts to water saving per unit of irrigated crop production.

Cereals and pulses are often viewed as food staples and important in food security considerations. At the same time, this crop category is a relatively intensive user of water per unit of value added. In periods of drought, cost of cereal and pulses production tends to rise relative to other crops as the shadow value of irrigation water increases. Effectively, other crops, particularly the use of ground water to produce fruits and vegetables, places pressures on cereal and pulses producers since fruit and vegetable producers draw more heavily on ground water causing water's shadow price to rise. Food security might be better achieved by decreasing the amount of surface water assigned to produce cereals and pulses and increasing the amount assigned to more water competitive crops, such as fruits and vegetables. By exporting the crops for which Morocco has a comparative advantage and importing cereals, more reliance is placed on surface water in producing competitive crops which will lessen pressures on lowering the ground water table and lessen the increase in pumping costs. Of course, for Morocco to important cereals, domestic and foreign trade barriers to Morocco's exports of fruit and vegetables need to be addressed as well.

Our analysis suggests the economic rent to land and water resources per irrigated Ha are lower in the Souss Massa region than in the Tadla Azilal region. This is largely caused by the mentioned differences in land and water intensity in irrigated crop production being higher in the Tadla Azilal region. Rents to surface water per Ha in irrigated crops rises be almost 300 percent in Souss Massa, as does the shadow price of water, while ground water rent rises by only 7 percent (compared to 4 percent in Tadla Azilal). Thus, relative to Tadla Azilal, the flow of services, especially from water, in irrigated crop production in Souss Massa is becoming a more limiting resource (or limiting at a faster pace) than are these same services from crop production in the Tadla Azilal region. The policy implication is that attention should be given to water saving technologies in the Souss Massa region to reduce pressures of water as a limiting resource to expanding production of irrigated crops. This action may entail decreasing water assignments in the less competitive crops, such as cereals and pulses, and increasing assignment in the more competitive crops such as fodder, and fruits and vegetables.

In the case of surface water shortages, our drought analysis shows that crops using water more intensively than other crops experienced the largest decline in value added as their costs increased from using ground water to partially replace surface water lost to drought. The more competitive crops, i.e., those that are less water intensive, such as fodder and fruits and vegetables, experienced the least decline in value added. Effectively, the latter crops could "pull" ground water away from the less water competitive crops as the water shadow value, relative to the base analysis, increased over time. The surface water shortage decreased land rents, but increased water rents. The Souss Massa aquifer served as a buffer for the first 5 to 8 years, increasing the depth to the water table, but then withdrawals were unchanged from base withdrawals thereafter. These results suggest the aquifer can only be relied upon for replacing surface water in the short run. A similar result, but less extreme, is predicted for ground water as a buffer stock in the Tadla Azilal. This result places pressures on policy makers and advisers to allocate surface water particularly efficiently among crops, with the likelihood that the most water competitive crops receiving a somewhat higher allocation of water during a drought than the less water competitive crops, such as cereals and pulses.

A ten percent increase in water productivity – efficiency increased value added in both regions, and by the greatest percentage per Ha. planted to fruits and vegetables in Souss Massa. In the case of cereals and pulses the average annual gain (2011 to 2040) in value added per Ha was higher Tadla Azilal, otherwise the gains per Ha of the other irrigated crops are predicted to be higher in Souss Massa. These average annual gains per Ha are a guide to the gross value of gains to research and farm extension expenditure that seek to increase the productivity – efficiency of irrigation water. The increase in the type of water productivity – efficiency considered here increase the depth of the water table in both regions relative to the base. The differences in water table depth between the two regions link to features of the aquifers captured by our data, the most important of which is the larger ground water recharge per unit of water extracted in the Tadla Azilal region. The ten percent increase in efficiency increased the water table depth by a greater percentage, relative to base, in Souss Massa relative to Tadla Azilal. Another type of technological change, which is not investigated in this study, would be to decrease the "importance" of water in crop production for the same amount of value added as the base solution. This type of technological change would tend to lower, rather than raise, the shadow value of water and lessen the depth of the water table relative to base.

Our analysis shows the shadow value of water in both regions rising with time. This value is beyond the nominal value farmers currently pay for surface water. Ground water too earns rents, albeit much less than surface water due to the cost of pumping. A policy implication is imposing a tax that is some fraction of water's unit shadow value to generate proceeds used to encourage farmers to employ more water saving technologies and to covert land from crops that are water intensive to crops that are less water intensive. This also includes crop varieties that are less water intensive, improvement in canals transferring water to farmers, and water application technologies that better target the water to plants.

Our assumption that farmers do not take into account that their individual withdrawal of water has no effect on the depth of the aquifer almost surely leads our modeling results to "over extract" water in yearly years and under extract ground water in later years. A policy implication is that public authority or a farmers water association might be delegated with convincing farmers of this possible consequence of their behavior. Changing behavior would likely serve to conserve the profitable extraction of ground water over a longer period of time as well as serve as an insurance to buffer periodic if not long-term trends in surface water declines

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APPENDEX: Overview of the Analytical Model

The fundamental analytical structure underpinning the two empirical models is presented below.

Environment

Households are assumed to choose their path of consumption and savings over time to maximize the discounted present value of utility of their current and future generations. In the background, institutions are presumed to assemble the savings of households and lend to firms and other households at competitive rates of return. Each period, the economy produces agricultural, industrial and service goods. Agriculture in a region of the country produces four irrigated crops: cereals and pluses, fodder, fruits and vegetables, and other irrigated crops. The remaining agricultural production in the region and agricultural production in the rest of the economy is aggregated into a single aggregated agricultural sector. All production except service goods is traded internationally. Firms producing final goods are assumed to maximize returns to resources: labor and capital and, in addition for agriculture, water and intermediate service input in a competitive market environment. In the region of interest, the country is endowed with an aquifer. Each period, firms producing water employ labor, capital and some of the service good to pump ground water for irrigation. Pumping can cause an increase in the depth of the water table which in turn requires more resources per unit of water pumped. Surface water is also employed in production. Surface water is a perfect substitute for ground water, but it is assigned by government to irrigated crops in the region. The assignment affects the shadow value of water. The economy thus produces seven final goods, five of which are agricultural, and one intermediate good, ground water.

Production

Industry and service: Represent the manufacturing and service sector technology by the Cobb-Douglas production function

$$Y_j = \psi_j K_j^{\alpha_{j1}} L_j^{\alpha_{j2}},\ j = m(\text{industry}), s(\text{service}) \qquad (1)$$

The variables in this function are the input levels of capital $K_j(t)$ and the share of the total work force $L_j(t)$ employed in the $j-th$ sector, while the parameters are ψ_j, α_{j1}, α_{j2} (each being strictly positive). The α_{j1} and α_{j2} are the respective factor cost-shares (elasticities) of capital and labor employed in manufacturing and services.

The cost function corresponding to technology (1) is defined as

$$C^j(r^k, w)Y_j \equiv K_j, L_j \min \left\{ r^k K_j + wL_j:\ Y_j \le \psi_j K_j^{\alpha_{j1}} L_j^{\alpha_{j2}} \right\},\ j = m, s \qquad (2)$$

The function is the minimum cost of producing Y_j units of output given factor prices r^k and w. Given the properties of the Cobb-Douglas function (1), the cost function is homogeneous of degree one in factor prices, twice (continuously) differentiable, non-decreasing and strictly concave in factor prices and increasing in output.

Agriculture: Represent the neoclassical technology for agriculture in the rest of the Moroccan economy as a function of capital, labor and land (Z_j)

$$Y_j = \psi_j K_j^{\alpha_{j1}} L_j^{\alpha_{j2}} Z_j^{\alpha_{j3}},\ j = 5(\text{rest of agriculture}) \qquad (3)$$

where Greek letters are coefficients. The value added function of this technology is

$$\Pi^j(p_j, r^k, w)Z_j \equiv K_j, L_j \max \left\{ p_j \psi_j K_j^{\alpha_{j1}} L_j^{\alpha_{j2}} Z_j^{\alpha_{j3}} - r^k K_j - wL_j \right\} \qquad (4)$$

For a given technology, the value added function is the maximum land rent that can be generated for a given land endowment and prices p_j, r^k and w. Given the technology, the value added function $\Pi^j(\cdot)Z_j$ is homogeneous of degree one in prices, and degree one in land endowment Z_j, twice continuously differentiable in prices, increasing in p_j, decreasing in r^k and w, and satisfies Hotelling's lemma. Land, Z_j, planted to crop $j = 5$, is not a choice variable.

Irrigated agricultural in the region of interest depends on capital, labor, land and water (H_j), and employs the neoclassical production technologies:

$$Y_j = \psi_j K_j^{\alpha_{j1}} L_j^{\alpha_{j2}} Z_j^{\alpha_{j3}} H_j^{\alpha_{j4}},\ j = 1(\text{cereals and pulses}),\ 2(\text{fodder}),\ 3(\text{fruits and vegetables}),\ 4(\text{other irrigated crops}) \tag{5}$$

yielding, in a competitive environment, the value added functions

$$\Pi^j\left(p_j, r^k, w, p_h\right)Z_j + p_h\bar{H}_j \equiv \tag{6}$$

$$K_j, L_j, H_j \max \left\{p_j\psi_j K_j^{\alpha_{j1}} L_j^{\alpha_{j2}} Z_j^{\alpha_{j3}} H_j^{\alpha_{j4}} - r^k K_j - wL_j - p_h H_j\right\} \tag{7}$$

where the total volume of irrigation water, H_j, equals the sum of surface $\bar{H}_j$, and ground water H_{gj},

$$H_j = \bar{H}_j + H_{gj}$$

We treat these as perfect substitutes.

The volume of surface water $\bar{H}_j$ is assigned by the water authority at no cost to the farmer, causing rent to include the shadow value $p_h\bar{H}_j$ of the surface water. The volume of ground water H_{gj} is chosen by farmers. Hence, the price p_h is the ßhadow" price per m3 of water (see figure 2). For purposes here, we assume an interior solution so that $H_{gj} > 0\ \forall\ j$. In the empirical analysis, $H_{gj}(t)$ is zero for some crops for some t, in which case p_h is calculated differently.

Groundwater extraction: We view groundwater extraction as a separate, intermediate input to agricultural production, an activity that is separable from the process of planting and producing a crop. Hence, without loss of generality, we treat this activity as a separate sector. We further assume the groundwater sector behaves in a competitive and myopic fashion. Farmers extract water from the aquifer to the point where the cost of extracting an additional m3 of water is equal to the return to the m3 water in producing a crop. Farmers do not take into account when deciding how much water to extract that their action, and the action of other farmers, lowers the water table. If farmers behaved in this manner, and they chose to cooperate, then they could be viewed as taking into account the effect of their actions on the ground water table. In this case, they would almost surely decide to withdraw water at a slower pace in earlier periods compared to their modeled behavior here.

Ground water extraction is represented by the "pumping-delivery of water" technology

$$Y_j = \min \left\{\psi_j K_j^{\alpha_{j1}} L_j^{\alpha_{j2}}; H_g\right\},\ H_g = \frac{Y_{sj}}{\kappa D},\ \alpha_{j1} + \alpha_{j2} < 1,\ j = 6 \tag{8}$$

where coefficients are positive. We assume diminishing returns to scale, $\alpha_{j1} + \alpha_{j2} < 1$. Profit maximization yields

$$\Pi_j = \Pi^j(p_{vh}, r^k, w)$$
$$\equiv K_j, L_j, Y_{sj} \max \left\{\min \left\{p_{vh}\psi_j K_j^{\alpha_{j1}} L_j^{\alpha_{j2}}; \frac{Y_{sj}}{\kappa D}\right\} - r^k K_j - wL_j\right\} \quad (9)$$

where the value added price is

$$p_{vh} = p_h - p_s\kappa D, \quad j = 6 \quad (10)$$

and p_h is the shadow value of water implicitly paid by producers of final agricultural goods, $j = 1,\cdots,4$ in the region of interest, and of course, in the region where the aquifer is present. The total amount of water pumped from the aquifer H_g

$$H_g = \sum_{j=1}^{4} H_{gj} = Y_j \quad (11)$$

equals the amount of ground water distributed to production of irrigated crops, Y_j. The Leontief component of the technology, $Y_{sj}/\kappa D$, D denotes the depth from the surface, in meters, of the aquifer's water table at time t, Y_{sj} is the amount of the service good (e.g., energy and other services) required to operate the pumping process, and κ is a parameter that converts the ratio Y_{sj}/D into units of water.

As water is withdrawn from the aquifer over time, the depth of the water table can increase if withdrawal $Y_j(t)$ exceeds inflows $I(t)$ to the aquifer. This "physical correspondence" is represented by the the reduced form hydrological equation

$$\dot{D}(t) = \frac{Y_j(t) - \phi_1 I(t)}{\phi_2} \quad (12)$$

where ϕ_1 and ϕ_2 are positive coefficients, and $I(t)$ is the volume of inflow. In the empirical model, inflow is affected by exogenous factors (e.g., precipitation) and by a fraction of irrigation water that percolates back to the aquifer.

Household preferences, savings and consumption

Represent instantaneous utility $Q(t)$ as a Cobb-Douglas function

$$Q = \left(\Pi_{j\in(1,3,4,5)} Q_j^{\gamma_j}\right) Q_m^{\gamma_m} Q_s^{\gamma_s}, \quad \sum_{j\in(1,3,4,5,m,s)} \gamma_j = 1, \ \gamma_j > 0 \ \forall j \quad (13)$$

The γ_j represent the share of household disposable income spent on Q_j, which includes: cereals and pulses ($j = 1$), fruits and vegetables ($j = 3$), other irrigated agricultural goods ($j = 4$), all of which are produced within the region of interest, and the aggregate of agricultural goods produced in the rest of the country ($j = 5$). The expenditure function associated with utility is derived in the normal manner. We express it as

$$\epsilon = E(p_1, p_3, p_4, p_5, p_m, p_s)Q \tag{14}$$

We assume no growth in the work force - population to simplify notation, and we normalize the total work force, L to unity. Households' optimal savings decision solves the following dynamic optimization problem:

$$\mu = Q(t) \max \int_0 \frac{Q(t)^{1-\theta} - 1}{1-\theta} e^{-\rho t} dt \tag{15}$$

subject to initial conditions

$$K(0),\ D(0),\ p_s(0)$$

the flow budget constraint

$$\begin{aligned}\dot{K} = w(t) + r(t)K(t) + \sum_{j\in(1,\cdots,5)} \Pi_j\,(t)Z_j + \Pi_6(t) \\ + p_h(t) \sum_{j\in(1,\cdots,5)} \bar{H}_j - \epsilon(t)\end{aligned} \tag{16}$$

and the traversality condition

$$t \to \infty \lim \left\{K(t)e^{-\int_0^t r^k(v)dv}\right\} = 0$$

The coefficient θ is the inverse of the inter-temporal elasticity of substitution. Note the term $p_h \sum_{j\in(1,\cdots,5)} \bar{H}_j$. This term is the value of the country's regional endowment of surface water, evaluated at the shadow price p_h. We are assuming that each of the regional crops, $j = 1,\cdots,5$ employ both surface and ground water. The numerical model does not impose this restriction, so that in the numerical model a common shadow value does not necessarily result (see figure 2).

The solution to this optimization problem gives the basic condition for choosing consumption over time

$$\dot{\epsilon} = \frac{\epsilon}{\theta}\left[r - \rho - (1-\theta)\lambda_s \frac{\dot{p}_s}{p_s}\right] \tag{17}$$

For the typical case where $K(0) < t \to \infty \lim\ K\,(t)$, and convergence is monotonic, the rate of change in expenditure is positive and declining, which indicates that the household is forgoing less consumption as the economy reaches long-run equilibrium. In long run equilibrium, $\dot{p}_s/p_s \cong 0$, the households return $r(t)$ to a risk free asset equals its rate of time preference ρ.

Equilibrium

As in Roe, Smith and Saracoğlu, it is convenient to distinguish between intra-temporal and inter-temporal equilibrium.

Intra-temporal equilibrium: Intra-temporal equilibrium must satisfy the following six equations in six unknowns, $\Omega \in \{r^k, w, p_s, p_h, Y_m, Y_s\}_{t\in[0,\infty)} \in \mathbb{R}_{++}$ taking as given $K(t)$, $\epsilon(t)$, and $D(t)$:

zero industry and service sector profits

$$C^j(r^k, w)Y_j = p_j,\ \ j = m, s$$

factor market clearing for

labor

$$\sum_{j\in(m,s)} C_w^j\,(r^k, w)Y_j - \sum_{j\in(1,\cdots,5)} \Pi_w^j\,(p_j, r^k, w, p_h)Z_j - \Pi_w^j(p_{vh}, r^k, w) = 1$$

capital

$$\sum_{j\in(m,s)} C_{r^k}^j\,(r^k, w)Y_j - \sum_{j\in(1,\cdots,5)} \Pi_{r^k}^j\,(p_j, r^k, w, p_h)Z_j - \Pi_{r^k}^j(p_{vh}, r^k, w) = K$$

the water "market"

$$\sum_{j\in(1,\cdots,5)} \left(-\Pi_{p_h}^j(p_j, r^k, w, p_h)Z_j - \bar{H}_j\right) = \Pi_{p_{vh}}^j(p_{vh}, r^k, w)$$

and clearing of the service good market

$$\gamma_s \frac{\epsilon}{p_s} = Y_s - \Pi_{p_{vh}}^j(p_{vh}, r^k, w)\kappa D$$

where the intermediate factor demand for the service good in ground water pumping is $\Pi_{p_{vh}}^j(p_{vh}, r^k, w)\kappa D$.

Inter-temporal equilibrium: The intra-temporal equilibrium suggests that if we solve for the sequence $\{K(t), \epsilon(t), D(t)\}_{t\in[0,\infty)}$ we can return to the intra-temporal conditions and solve for $\Omega(t)_{t\in[0,\infty)}$.

We utilize the hydrological equation (12), the budget constraint (16) and the Euler equation (17) along with reduced forms for r^k and w from the zero profit conditions. Substituting these reduced forms into the factor market clearing conditions we solve for the supply functions Y_j, $j = m, s$. We obtain $\dot{p}_h$ from the water market clearing condition.

These derivations are too awkward to present here. The reader is referred to Roe, Smith and Saracoğlu for the general procedure. The result is four autonomous differential equations

$$\dot{K} = \bar{K}(K, p_s, p_h, D)$$

$$\dot{p}_s = \bar{P}^s(K, p_s, p_h, D)$$

$$\dot{p}_h = \bar{P}^h(K, p_s, p_h, D)$$

$$\dot{D} = \bar{D}(K, p_s, p_h, D)$$

the solution to which yield $\{K(t), p_s(t), p_h(t), D(t)\}_{t\in[0,\infty)}$ which allows for obtaining $\epsilon(t)_{t\in[0,\infty)}$, and hence $\Omega(t)_{t\in[0,\infty)}$.

Comparative statics: Sufficient to point out that the zero profit conditions allow us to derive the factor rental rate equations as a function of industrial and service sector prices. These equations have the same Stopler-Samuelson properties as the classical two sector static model. Supply functions are homogeneous of degree zero in prices and unity in endowments and hence inferences can be obtained from the Rybczynski theorem. The reader is referred to Roe, Smith and Saracoğlu.

Resource stock values, welfare and sustainability

The empirical results report the evolution of stock values of all agricultural land, and of water resources in each region, Souss Massa and Tadla Azilal. A brief discussion of the analytical structure of these values and their linkage to the sustainability of ecosystem services is provided here.

In the context of this framework, sustainability obtains when the rate of growth in felicity $Q(t)$, equation (13), remains non-negative, i.e.,

$$\frac{\dot{Q}(t)}{Q(t)} \geq 0 \ \forall t \qquad (18)$$

Since our framework includes at least one[5] source of market failure caused by the myopic behavior of farmers' water withdrawals, μ, (15) is not likely to be the maximum attainable discounted present value. This caveat aside, (18) can obtain even though an aquifer is depleted. We thus suggest the sustainability of a resource such as land planted to crop j, and the

[5]Other failures are the assignment of surface water which is unlikely to equate the shadow value of water across crops at least for those crops not using ground water.

sustainability of an aquifer to yield a flow of rents $\forall t$ such that its stock value does not decline $\forall t,$ and thus contribute positively to (18)

Assets $A(t)$ in this framework are

$$A(t) = K(t) + \sum_{j \in (1,\cdots,5} P^j\,(t)Z_j + P^h(t)$$

where $P^j(t)$ and $P^h(t)$ are the stock prices of land Z_j planted to various crops and the stock price of the aquifer $P^h(t),$ all of which evolve with time. It can be shown (Roe, Smith and Saracoğlu, page 163-164) that these prices must evolve over time such that the following no-arbitrage condition holds for land Z_j planted to the various crops

$$r(t) = \frac{\Pi_j(t)}{P^j(t)} + \frac{\dot{P}^j}{P^j(t)},\ \forall t,\ j = 1,\cdots,5 \tag{19}$$

and for ground water

$$r(t) = \frac{\Pi_6(t)}{P^6(t)} + \frac{\dot{P}^6}{P^6(t)} \tag{20}$$

where $P^6(t)$ is the stock price of the aquifer.

Condition (19) implies that $P^j(t)$ must evolve such that an agent has no incentives, over time, to exchange one unit of land for another asset. This result obtains when, for each t, the risk free rate of return $r(t)$ to one unit of income would also buy $1/P^j(t)$ units of land planted to the $j - th$ crop that earns a rental income of $\Pi_6(t) \times \left(1/P^j(t)\right)$ as well as capital gains (losses) in the amount of $\dot{P}^j/P^j(t)$.

Note that (19) and (20) are first order differential equations. The solution to the stock price of land at time t, is given by the discounted value of rents accruing to that resource, i.e.,

$$P^j(t) = \int_t^\infty e^{-\int_t^v r(v)dv}\, \Pi_j(t)dt,\quad j = 1,\cdots,5 \tag{21}$$

For the case of property rights to the aquifer, (20), its stock value evolves according to

$$P^6(t) = \int_t^\infty e^{-\int_t^v r(v)dv}\, \Pi_6(t)dt \tag{22}$$

Effectively, $P^6(t)$ is the discounted present value of the triangle e for each t, figure 2. These values for land and water appear in tables 33-38.

How do the evolution of these values relate to welfare? The rents $\Pi_j(t)$ to the services of land and the aquifer appear in the budget constraint (16) as an income stream. If the stream $\Pi_j(t)$ increases with time, all else constant, intuitively, utility must increase. However, the evolution of $\Pi_j(t)$ is not necessarily monotonic since, in (9) for example, the rate of return to capital tends to fall $dr^k/dt \leq 0_j$, causing $\Pi_6(t)$ to increase while $dw/dt \geq 0$ causes $\Pi_6(t)$ to decrease. An additional negative effect is the increase in water table depth, $dD/dt \geq 0$ which lowers the value added price (10). Exploitation of the aquifer may thus cause $\Pi_6(t)$ to fall over time. In this case, it is likely that $\dot{P}^6/P^6(t) \leq 0$.

We index the stock value of land and water resources to welfare by expenditure, $\epsilon(t)$, which is linked to felicity by (14)

$$Q(t) = \frac{\epsilon(t)}{E\big(p_1, p_3, p_4, p_5, p_m, p_s(t)\big)}$$

Setting $\theta = 1$, the relationship of stock values to expenditure is given by deriving the household's expenditure *function*

$$\epsilon(t) = (\rho - n)(k(t) + \int_t^{\infty} e^{-\int_t^{\tau} r(v)dv}\, w(\tau)d\tau + \sum_{j\in(1,\cdots,5)} \int_t^{\infty} e^{-\int_t^{\tau} r(v)dv}\, \Pi_j(\tau)Z_j d\tau +$$

$$\int_t^{\infty} e^{-\int_t^{\tau} r(v)ds}\, \Pi_6(\tau)d\tau)$$

Note that the terms in integrals are the stock prices (21) and (22). Sustainability of the natural resource, including the aquifer, requires

$$\dot{P}^j/P_j(t) \geq 0,\ \forall t,\ j = 1,\cdots,6$$