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Economy-wide gains from decentralized water allocation in a spatially heterogenous agricultural economy

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ABSTRACT. This paper analyzes the economy-wide gains obtainable from the allocation of surface irrigation water to its most productive use, and evaluates a decentralized mechanism for achieving this result in a spatially heterogeneous environment. The focus country for the analysis is Morocco. The analysis is based on a general equilibrium model that, in addition to the rest of the economy, captures 82 agricultural production activities, 66 of which are in seven separately identified water districts that span the entire country. The results suggest that a decentralized water trading mechanism could increase agricultural output by 8.3 per cent, affect the rental rates of other agricultural inputs at the national level, including labour, and have economy-wide effects that entail a decline in the cost of living, an increase in aggregate consumption, and expansion of international trade.

1. Introduction

Inventing and implementing social mechanisms for allocating irrigation water to more productive uses remains a challenge in both developed and developing countries. Part of the difficulty is due to the problem of establishing property rights to water (Dinar *et al*., 1998; Gleick *et al*., 2002). Another part is due to the relatively high fixed costs of dams and canals associated with surface water which raises the issues of who pays and should marginal cost pricing for water be abandoned (Dinar and

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Subramanian, 1997; Thoban, 1997; Tsur *et al*., 2004). Another difficulty arises from the negative externality that ground water extraction imposes on the extraction of water by others (Roe and Diao, 2000; Tsur and Zemel, 1997), and the transactions costs of water trade that can range from 2 to 11 per cent of water purchase cost (Mcann and Easter, 2004). Embodied in each of these difficulties is the heterogeneity of water availability and use within any one country. This heterogeneity makes the formulation of a uniform water policy difficult, and tends to necessitate a set of policies, each policy taking into account the particular spatial water and crop peculiarities and the historical practices that vary by region. At the same time, policies must recognize that the various regions are inter-linked, and that they compete for economy-wide resources so that a water policy in one region impacts other regions that compete for these resources.

Nevertheless, the need to overcome these difficulties is becoming evermore important. The International Water Management Institute (Sekler *et al*., 1999) for example has projected that by 2025 most regions in a broad swath from North China across Asia to North Africa and northern Sub-Saharan Africa will experience either absolute or severe water scarcity. Water as a potential source of conflict in the Middle East has been noted by Fisher and Askari (2001). In the majority of these countries, it is also the case that irrigated agriculture remains a major sector both in terms of its share in GDP and the proportion of a country's poor that reside in the sector.

The general purpose of this paper is to obtain insights into the potential economy-wide gains obtainable from irrigated water when it is allocated to its most productive use, and to evaluate the mechanism for achieving this result in an environment where considerable spatial heterogeneity in water availability and use exists. The heterogeneity encourages a more decentralized mechanism for allocating water, while also requiring that policy-makers take into account the indirect effects that policies in own and other irrigation districts have on the costs of other resources employed in agriculture, such as hired labour and capital. The intensity of water use, relative to other inputs, varies by region due to differences in climate, soil characteristics, and water availability. This variability can greatly affect the returns to water, the degree to which water policy in one region has indirect, though no less important, effects on other resources, and thus the effectiveness of water policy to allocate water to its most productive use in one region of a country in contrast to another.

The effect of water policy on other resources is an important determinant of a region's competitiveness in the production of a crop relative to other regions. Understanding the economics of the spatial diversity also helps to target those regions that are likely to gain the most from reform, thus helping to prioritize an already complex policy-making process. The mechanism for reallocating water is also important for obvious reasons, but of key importance here, is the choice of a mechanism that might best take account of heterogeneity among irrigation districts, and one that is likely to meet the least resistance to implement among farmers. Many authors (for example Young, 1986; Easter *et al*., 1998; Louw and Schalkwyk, 2002 for the case of South Africa) suggest the need to rely upon some water pricing mechanism. Tisdell and Ward (2002) conclude from their study of Northern Victoria, Australia, that auctioning surface water among farmers is successful in allocating water to more productive uses.

The country chosen for this analysis is Morocco. This choice is based on its spatial diversity, the availability of farm-level data, previous studies upon which to build (for example Doukkali, 1997; Diao and Roe 2003), and the relative lack of externalities in the allocation of surface water. Of the approximately 15.8 billion cubic meters of water mobilized in an average year, about 83 per cent is surface water that is regulated by nine regional agricultural development authorities (ORMVA) with about 498,617 hectares of land equipped for and under irrigation in 1996–97. Regional authorities assess farmers and set a fee for water that is generally lower than the water's productivity, and, consequently, water allocation must be administered. The gap between water's productivity and the fee charged implies that farmers capture a rent to their water assignment. Allowing the water authority to auction water to the highest bidder would cause farmers to forego this rent, and thus they can be expected to resist this method of allocating water. The water assignments are made at the beginning of the crop year, and sometimes adjusted during the year depending on rainfall and water supplies from snow accumulated in mountain ranges. Agriculture is relatively large, accounting for about 15 per cent of the country's total value added, and about 47 per cent of the population is classified as non-urban.

A computable general equilibrium model is developed for the entire country with particular attention given to modelling the agriculture of seven major irrigation regions and the perimeters within each region. Each of the regions is linked to up and down stream markets, and competes with the rest of the economy for economy-wide resources. The results show considerable diversity in the productivity of water both within and between irrigation perimeters and districts. The creation of a water user rights market in which farmers can rent in or out some of their water user rights has the potential to greatly increase the productivity of water. The results suggest that such a mechanism could increase agricultural output in the seven ORMVAs by 8.3 per cent, to have noticeable economy-wide effects that entail lowering the cost of living, increasing foreign trade, and internalizing rents to farmers from the re-allocation of water. A user rights market also appears to have desirable effects on equity among farmers. We do not account for the fact that such a market ignores the effects of externalities or that water may have social value above and beyond its value to users engaged in the water market, an issue discussed recently by Fisher *et al.* (2002). This important omission is discussed in the conclusions to help the reader to better qualify our main results.

The paper is organized by first laying out the conceptual framework that explains the key economic forces affecting the differences in the shadow price of water by region. It also defines a water user rights market, how such a market might affect the allocation of water, and the resulting rewards to other resources. The framework is used to guide the interpretation of the empirical results. Then, the nature of the data and the empirical model upon which it is based are discussed followed by the presentation of results.

2. The conceptual framework

The basic economic forces deriving the empirical results can be illustrated by narrowing our focus to a two-sector (indexed $j = a,\ b$) economy that only produces and consumes agricultural goods using two economy-wide factors, labour L, and capital K, given water assignments T_a and T_b that exhaust total water supplies T. We first characterize the equilibrium conditions given these assignments. This corresponds to the *base* solution of the empirical model. Next, we define the equilibrium in which farmers are given property rights to the assignment which they are then permitted to rent in or out. The second part shows the conditions determining how the resulting market prices of water depart from the shadow values associated with the assignments. Since the empirical model is far more complex, it should be kept in mind that the conceptual framework is meant to show how certain phenomena encountered in the empirical work can in fact arise.

2.1. Primitives of the model

The jth sector production function is

$$y_j = f^j(L_j, K_j; T_j), \quad j = a, b \tag{1}$$

and presumed to exhibit the typical neoclassical properties, including constant returns to scale in labour L_j, capital K_j, and water T_j.[1] However, it is presumed that water T_j is assigned to the jth sector, and because its marginal value product exceeds its cost, the total assignment T is allocated. Given perfect competition in each sector, the economy-wide GDP function can be expressed as

$$\begin{aligned} GDP &= G(p_a, p_b, L, K, T_a, T_b) \\ &\equiv \underset{(L_a,\, L_b,\, K_a,\, K_b)}{Max} \left\{ \sum_{j=a,b} p_j f^j(L_j, K_j; T_j) \middle| L \geq \sum_j L_j,\ K \geq \sum_j K_j \right\} \end{aligned} \tag{2}$$

given that the assignments of water exhausts total supplies T.

The corresponding sector GDP functions can be expressed as

$$G^j(p_j, w, r)T_j \equiv \underset{(L_j K_j)}{Max} \left\{ p_j f^j(L_j, K_j; T_j) - wL_j - rK_j \right\} \tag{3}$$

where the shadow price of water is given by

$$\pi_j = G^j(p_j, w, r) \tag{4}$$

[1] Constant returns to scale over the farmer's choice variables in production are also assumed in the empirical model, even though actual production likely entails sunk costs. However, sunk costs complicate the comparative static analysis, and the lack of farm level data preclude their specification in the empirical model. Since land and water are region specific, the regional level production functions exhibit diminishing returns to scale.

The economy-wide GDP function equals the sum of the sector GDP plus payments to labour and capital

$$GDP = G(p_a, p_b, L, K, T_a, T_b) = \sum_{j=a,b} (G^j(p_j, w, r)T_j + wL_j + rK_j) \qquad (5)$$

Properties of the GDP function are well known (Woodland, 1982; 127–131). For example the Hessian sub-matrix G_{pp} is positive semi-definite, due to convexity in prices, while the factor sub-matrix G_{vv} is negative semi-definite, due to GDP being non-decreasing in factor endowments.

The *base* solution of the empirical model is typified here by rental rate values $\{w^0, r^0\}$ such that markets for labour and capital clear. The resulting shadow prices of water are

$$\pi_j^0 = G^j(p_j, w^0, r^0) \qquad (6)$$

The experiment performed is to grant farmers user rights to their respective water assignments. They are permitted to rent in or out water, subject to the exhaustion of total water supply, T. Then, the equilibrium conditions can be written as the existence of values $\{w^*, r^*, t^*\}$ such that factor markets clear

$$\frac{\partial G^a(p_a, w, r)(T-t)}{\partial w} + \frac{\partial G^b(p_b, w, r)(t)}{\partial w} = -L$$

$$\frac{\partial G^a(p_a, w, r)(T-t)}{\partial r} + \frac{\partial G^b(p_b, w, r)t}{\partial r} = -K$$

$$G^a(p_a, w, r) - G^b(p_b, w, r) = 0$$

and trade in water t equates the marginal value product of water among sectors, that is

$$\pi_a^* = G^a(p_a, w^*, r^*) = G^b(p_b, w^*, r^*) = \pi_b^* \qquad (7)$$

The amount of water transacted must be such that $0 \le t \le T$, and shadow prices must be positive.

It now becomes apparent that the change in the shadow price of water relative to the base, that is $(\pi^*/\pi^0)_j$, has to do with, first, how the re-allocation of water causes changes the rental rates w, r, of the other resources, and, then, how the change in these rates affect π_a relative to π_b. We now turn to this task.

2.2. Comparative statics of shadow prices

First, we show the effect of changes in water allocation on the rental rates of labour and capital. Note that rental rates are given by the gradient of the economy-wide GDP function with respect to the factor endowments L and K. Differentiating these functions with respect to the water assignment, and requiring the water constraint to hold, we obtain the rate of change in factor rental rates as a function of the change in water allocation

$$\hat{w} = \varepsilon^{w}_{T_a}\hat{T}_a + \varepsilon^{w}_{T_b}\hat{T}_b \tag{8}$$

$$\hat{r} = \varepsilon^{r}_{T_a}\hat{T}_a + \varepsilon^{r}_{T_b}\hat{T}_b \tag{9}$$

The '^' notation is the rate of change in the respective variable. The elasticity is, for example $\varepsilon^{w}_{T_a} = (\partial^2 G(\cdot)/\partial L \partial T_a)(T_a/w)$ and $\hat{T}_b = -dT_a/(T - T_a)$. The Hessian of the GDP function implies

$$\varepsilon^{i}_{T_j} \geq 0,\, i = w, r,\, j = a, b$$

As (8) and (9) suggest, the signs of the change in the rental rates of labour and capital are indeterminate without knowledge of the initial water assignment, and the relative magnitude of the elasticities. Suppose that sector b was initially assigned an insufficient amount of water such that, post water market reform, water flows to sector b, that is $\hat{T}_a \leq 0$. Then, the change in both factor rental rates are positive if sector b is both labour and capital intensive *relative* to sector a. In this case

$$\varepsilon^{i}_{T_b} \geq \varepsilon^{i}_{T_a},\, i = w, r$$

The intuition, which carries over to the empirical analysis, is that sector b, now having more water, desires to also employ more labour and capital than the other sector is willing to release at the previous (pre-reform) rental rates for labour and capital. Thus, for the labour and capital markets to clear, their rental rates must rise. More generally, it can be shown that for a given re-allocation, $\hat{T}_a \leq 0$, four combinations of changes in w and r are possible, depending upon each sectors relative factor intensity.

The effect of $\hat{w}$ and $\hat{r}$ on the shadow price of water is given by expressing (4) in elasticity terms

$$\hat{\pi}_j = \varepsilon^{\pi_j}_{w}\hat{w} + \varepsilon^{\pi_j}_{r}\hat{r} \tag{10}$$

where, from Hotelling's lemma, the elasticities are

$$\varepsilon^{\pi j}_{w} = \frac{\partial G^j(\cdot)}{\partial w}\frac{w}{\pi_j} < 0, \quad \varepsilon^{\pi j}_{r} = \frac{\partial G^j(\cdot)}{\partial r}\frac{r}{\pi_j} < 0$$

Substituting (8) and (9) into (10) we obtain

$$\hat{\pi}_j = \varepsilon^{\pi j}_{w}\left(\varepsilon^{w}_{T_a}\hat{T}_a - \varepsilon^{w}_{T_b}\hat{T}_b\right) + \varepsilon^{\pi j}_{r}\left(\varepsilon^{r}_{T_a}\hat{T}_a - \varepsilon^{r}_{T_b}\hat{T}_b\right) \tag{11}$$

In summary, for an initial water assignment where, post water market reform, $\hat{T}_a \leq 0$, we have four possible cases, two of which are determinate, and two of which are indeterminate. They are

Case 1: Sector a is L intensive and K intensive	$(\hat{w}, \hat{r}) \leq 0$	$\pi_a^* \geq \pi_a^0$	$\pi_b^* \geq \pi_b^0$
Case 2: Sector a L intensive, b K intensive	$\hat{w} \leq 0, \hat{r} \geq 0$	indeterminate	indeterminate
Case 3: Sector a K intensitve, b L intensive,	$\hat{w} \geq 0, \hat{r} \leq 0$	indeterminate	indeterminate
Case 4: Sector b is L and K intensive	$(\hat{w}, \hat{r}) \geq 0$	$\pi_a^* \leq \pi_a^0$	$\pi_b^* \leq \pi_b^0$

Thus, starting with a very simple framework, we have shown that post reform the market prices of water can be greater or less than their pre-reform values, and that these effects work through the prices of factors of production whose productivities, and hence rental rates, are affected by the re-allocation of water. While this discussion identifies the major forces determining the empirical results, the empirical model is far more complicated. For instance, goods produced in the domestic economy are presumed not to be perfect substitutes for imported goods in the same category. Consequently, the presence of a water market can cause changes in the prices faced by farmers so that in some circumstance it is possible for these forces to dominate the effects discussed in this section. We now turn to a discussion of the empirical framework.

3. The applied general equilibrium model and data

The structure and parameters of the empirical model exploit two basic data sources. The national-level data on employment, trade, non-farm production, and resource flows are taken from a Moroccan social accounting matrix (SAM). The second source is detailed input–output data on crop production and water use at the perimeter level. These data include farms inside the country's major irrigation districts. The data inside the districts are obtained from each of the country's water authorities, ORMVA. The Moroccan economy is disaggregated into 88 production activities, which produce 49 commodities and employ eight primary inputs. On the demand side, there are five private household groups and one public group. The non-agricultural component of the economy is captured by six activities. Since the European Union (EU) is a major trading partner, Morocco's trade patterns between the rest of the world and the EU are identified separately. There is a government agent with five different policy instruments in the data, including producer and consumer taxes, subsidies, tariffs, and payments for water.[2]

Of the 88 production activities, 82 are in agriculture or agriculture-related, including 66 in crop production activities, five in livestock, and

[2] The government revenues (taxes and water payments) are allocated to government spending on consumption goods and investment. The government's real expenditure is fixed as a macro closure, while the difference between income and expenditure is endogenous (and transferred to households).

11 in processing agriculture, both up and down stream from the farm firm. To capture the spatial nature of irrigated agriculture, 66 crop production activities are further distinguished according to whether they are within or outside the seven ORMVAs. Among the 32 activities within the water authority perimeters, 21 are irrigated crop production and 11 are rain-fed. The 66 crop production activities produce 23 primary agricultural products, which implies that all crop products are jointly produced by different activities within or outside the ORMVAs. For instance, soft wheat is produced in both irrigated and in dry land areas, and in different regions of the country. Thus, this product is associated with a different production function (activity), depending upon where and how the crop is produced. Because water is either costly or presently impossible to transport between perimeters in a given ORMVA, the seven ORMVAs are further sub-divided into 20 perimeters. There is a representative farm type in each perimeter of each ORMVA, while only one representative farm type, engaged in 31 different production activities, is considered for the rest of non-irrigated agriculture.

Each representative farmer is assumed to maximize profit by choosing intermediate inputs, labour, capital, and land. For farmers residing in a perimeter managed by an ORMVA, they are presumed to take as given the farm–crop-level water quota that is assigned by the respective ORMVA. Output and input prices are given for individual producers but are affected by the market equilibrium within the economy. Farm-level production functions are assumed to be constant returns to scale in primary inputs (labour, capital, land, and water) with a constant elasticity substitution (CES) form. The elasticity of factor substitution cannot be calibrated from the data, and are taken from the econometric estimates of Doukkali (1997). The intensities of intermediate goods are in fixed proportion to output.

The migration of labour between rural to urban labour markets, and unemployment are notoriously difficult to model. Allocating labour to leisure, as in Diao *et al*. (1998), or to household production activities as in Gaitan (2001) are, in light of data requirements, unsatisfactory alternatives to explain unemployment, given the detail and complexity of the model. Consequently, we take the total employed labour force as given by the data, and then specify this force as either rural or urban. Rural labour can seek employment anywhere in agriculture (including primary and processing agriculture), but not in urban labour markets. Thus, the analysis does not account for any change in the level of unemployment nor the change in market wages this may imply.

Outside the ORMVA areas, capital and land are ‘mobile’ among all the agricultural sectors, in the sense that they can be allocated to the production of any of the identified crops (including livestock). Within a particular perimeter of a given ORMVA, capital and land can be allocated to any crop activity produced in the perimeter, but cannot be allocated to production activities in another perimeter. Land is distinguished as irrigated and rain fed. The supply of irrigated land is fixed.

The use of water by the urban sector and by non-crop agricultural production is omitted from the analysis. Water is mobile within a perimeter but not mobile across perimeters. There is no water mobility between

ORMVAs, or from an ORMVA to regions outside an ORMVA. Focus is placed on the water within the ORMVAs, and not on private irrigated lands outside of the water authority districts. Included in the analysis is the water charge assessed on farmers in the district by authorities as given in the database.

The water charge is presumed to be imposed by the method of volumetric pricing.[3] This rate is generally viewed as sufficient to cover operation and maintenance costs (Doukkali, 1997). As the water charge is less than the price the marginal users are willing to pay, the distribution of water must be administered. When the quota of water assigned to farmers is below the demand for water at the given water charge rate, then, implicitly, the shadow price for water is positive.

The share of government charges in water's total contribution to value-added to production at the farm level varies from 80 to 20 per cent across perimeters. The difference between the shadow price of water and the government's charge accrues as a benefit (rent) to farmers, that is this is a part of farmer's profit. For each individual farmer, as the intensity of water use varies by crop, benefits related to growing various crops vary from an estimated less than 1 per cent to more than 60 per cent of the value-added to production. Thus, considerable heterogeneity appears to exist across perimeters and regions in the intensity of water use in production.

Finally, given the above structure and data, the model's parameters are calibrated in such a way that a 'base solution' to the model reproduces exactly the data upon which the model is based. All other solutions to the model are compared with this base.[4]

4. Simulation analysis – getting water price right

Using the SAM and perimeter input–output data to calibrate the model, and then solving the model for the existing pre-water-market reform policy, yields estimates of the pre-water-market reform shadow prices. These values are referred to as the base. The next step is to grant farmers' rights to the assignment, and allow them to rent in/out some or all of their assignment. As shown in the theory section, this results in equating the marginal value product of water in its various uses within each perimeter of each ORMVA. A farmer's entitlement to a water user-right is the pre-reform water quota assigned to them by the water authority.

4.1. The re-allocation of water

Trade in water user rights within each perimeter only causes some (not all) water to be re-allocated away from crops, yielding a relatively low return (that is low shadow price in the base) to those crops whose shadow price

[3] In 1997, the water charge to farmers takes into account a minimum consumption of 3,000 cubic meters. By law (1969 Agriculture Investment Code), farmers that have more than 5 hectares are supposed to pay for the initial investment. Nevertheless, the actual pricing of water is close to a volumetric charge.

[4] The mathematical description of the CGE model is not presented for reasons of space. The description is available from the authors upon request.

Table 1. *Standard deviation in water shadow price and water re-allocation*

	Perimeter #	*Standard deviation of water shadow price**	*Water re-allocation***
Doukkala	1	5.91	31.44
	2	1.26	27.50
Gharb	1	0.35	3.47
	2	1.13	24.01
	3	0.63	39.50
Haouz	1	0.64	22.31
	2	3.97	63.94
	3	0.54	29.29
Loukkos	1	2.34	21.20
	2	0.90	20.96
	3	2.30	34.40
Moulouya	1	0.59	11.01
	2	1.11	32.35
	3	1.22	50.74
	4	0.55	17.00
Souss_Massa	1	1.53	31.80
	2	0.67	37.25
	3	0.78	13.59
Tadla	1	0.82	36.50
	2	0.92	36.94

Notes: * Standard deviation is calculated within each perimeter using base year's data.
** Percent of total water supply for each perimeter after introducing water use-rights market.

of water in the base is relatively high. The larger a perimeter's standard deviation in the base water shadow price cross crops, the larger the volume of water that tends to be re-allocated to equate shadow prices (that is to equate the marginal value product of water among activities within a perimeter).

However, as noted in the theory section, when water is re-allocated across crops, it may cause prices for other inputs, such as wage and capital rental rates, to change, as the production of different crops have different factor intensities in the use of water and other inputs.

Not considered in the theoretical section is that the prices for output may also change due to different trade dependencies across sectors. The lower the ratio of the exports to total supply in a sector, the greater is the sector's production constrained by domestic demand. These factors also affect water allocation, such that, for a region with a multiple crop-mix, water may not go to the crops with a relatively high base shadow price.

Table 1 displays two results. The first column reports the standard deviation in base water shadow prices for various crops in each perimeter. In terms of the theory section, these are the standard deviation of the estimated base shadow values π_j^0. The second column reports results from solving the model when farmers are given user-rights to their water assignment, which they can rent in or out within the perimeter of each of the seven ORMVAs. These values are the $\hat{T}_j$ appearing in equation (11). The amount of water re-allocated is expressed as a percentage of the water assignment reported in the base data for each perimeter.

The highest percentage of total perimeter water re-allocated is slightly more than 60 per cent. This result occurs in the Haouz irrigation district's Perimeter 2, where the standard deviation in shadow price of water is 3.97. This deviation is the highest of all perimeters. The lowest ratio of re-allocated water over a perimeter's total water supply is 3.5 per cent, which occurs in Gharb, Perimeter 1. The deviation in water shadow price in this case is only 0.35. With a few exceptions, the results suggest that trade in water user rights cause water to be re-allocated away from crops with a pre-reform low water shadow price and to those crops with a pre-reform high shadow price. The exceptions tend to occur when the crops produced vary by a relatively large magnitude in the intensity of water use, and one or more of these crops comprise a relatively large share of total hectares relative to the other crop.

Patterns within regions can also be observed. In most perimeters, the base year water shadow prices are relatively high in the production of vegetables and fruit crops and low in grain, sugar, and other industrial crops. The introduction of a water market causes a re-allocation of water away from the mentioned crops and towards the production vegetables and fruits, which, in turn, leads to a decline in grain and industrial crop production (table 2). However, this does not mean that producers of grain and industrial crops experience a decline in income. Instead, their income rises because they find it more profitable to 'rent out' some of their water user rights to producers of fruits and vegetables (or increase fruit and vegetable production themselves).

To what extent does the re-allocation of water in the various regions cause a change in production in the rain-fed areas? Declines in grain, sugar, and other industrial crop production mainly occur in the irrigated area, while the same crop produced in the rain-fed areas either does not fall or falls only slightly (second part of table 2). There are two reasons to explain this. First, there is only an indirect effect of the water policy reform on the production of rain-fed crops. The indirect effect mainly comes from the change in the prices for other inputs, such as wages, and capital rental rates, as well as some change in output prices. As water is allocated more efficiently within perimeters, the productivity of other resources is also affected, and most of these effects are positive. The result is an increase in the price of some – but not all – of these other resources. This increase has a negative effect on rain-fed crops that employ them intensively relative to other crops. The second reason is that choices in the cropping mix are relatively limited for the dry-land area. The negative effect of rising input prices used intensively in rain-fed areas is to cause a decline in land rental rates in some cases, but not a large decline in output. The change in the total output by crops at the national level is much smaller than the change at the ORMVA level.

Table 2. *Change in the seven ORMVAs' total supply by crop*

	Hard wheat	*Soft wheat*	*Barley*	*Other cereal*	*Pulses*	*Fodder*	*Sugar beet*
Irrigated							
Base level	495.99	1232.98	76.87	72.21	115.69	520.19	823.61
% change from base	−16.29	−15.57	−24.86	−30.04	−16.15	16.47	−14.25
	Sugar cane	*Other ind. crops*	*Tomato*	*Potato*	*Pepper*	*Green bean*	*Melon*
Base level	316.68	179.74	774.08	241.67	67.12	24.78	50.67
% change from base	−8.43	−22.13	−9.04	18.87	34.22	42.42	57.71
	Cucumber	*Zucchini*	*Other vegetables*	*Olives*	*Citrus*	*Apricots*	*Other fruit trees*
Base level	0.17	3.13	604.97	345.48	1580.87	77.43	1344.45
% change from base	100.89	15.01	72.68	93.26	3.27	3.47	−0.05
Rain-fed							
	Hard wheat	*Soft wheat*	*Barley*	*Other cereal*	*Pulses*	*Fodder*	*Sugar beet*
Base level	127.50	48.39	31.16	0.24	13.46	2.93	1.99
% change from base	−0.82	−0.39	−0.58	−2.39	0.56	−4.12	4.62
	Other ind. crops	*vegetables*	*Olives*	*Other fruit trees*			
Base level	0.22	1.31	0.00	4.92			
% change from base	3.70	−13.67	−0.58	3.61			

4.2. The price for water and changes in the prices of other inputs

We now focus attention on the price of water, by perimeter, that results after a water market in user rights is introduced. These results are reported as the percentage difference between the water market price, post reform, and the average shadow price of water pre-reform (see the Water column, table 3). The theory section noted the conditions causing the market price for water to be higher or lower than the shadow price, based on the water assignment, and the conditions whereby the market price would lie somewhere between the high and low shadow prices observed in the base. The empirical results show that, for almost all perimeters, the price of water after the introduction of a water user rights market lies within a range that is bounded by the highest and lowest shadow price for water observed in the base year. Given

Table 3. *Change in water price, capital rental rate, and returns to land: In percentage change relative to base*

	Perimeter #	Water*	Capital	Irrigated land	Rain-fed land
Doukkala	1	−24.89	4.64	−13.44	0.03
	2	18.98	−0.06	3.32	1.42
Gharb	1	2.24	1.85	2.11	0.21
	2	20.47	1.96	5.59	1.36
	3	18.54	0.08	−0.27	−6.85
Haouz	1	−2.30	5.77	−16.23	−0.62
	2	51.88	72.52	−42.54	−6.16
	3	20.50	−12.09	−2.00	3.96
Loukkos	1	−0.27	6.24	−3.00	−7.67
	2	9.79	8.03	−0.34	0.00
	3	15.68	9.18	3.61	1.20
Moulouya	1	2.78	−0.38	−8.60	0.78
	2	15.25	5.29	−5.26	0.00
	3	37.05	6.43	−6.16	0.00
	4	1.02	0.36	−6.75	0.00
Souss_Massa	1	−12.58	17.63	4.91	−4.27
	2	6.87	2.60	15.84	0.51
	3	3.65	−0.26	2.74	0.82
Tadla	1	26.51	−3.07	−1.08	0.76
	2	30.98	−6.39	11.06	1.90

Note: * Comparison between water market price post-reform with average returns pre-reform.
Source: model results.

the standard deviations reported in table 1, this implies that most farmers have an incentive to engage in water trading.

Table 3 also reports the change in the returns to capital and land. Effectively, perimeter capital and land are the perimeter's sector-specific resources and are thus components of farm profits.

Among the 20 perimeters included in the study, there are 16 in which the market price for water post reform is higher than the average returns to water pre-reform. This result implies that, at the perimeter level, water's productivity rises on average (that is the marginal value product of water rises post reform relative to the average marginal value product of water pre-reform), due to the introduction of trade in water user rights. Moreover, a cross-section regression shows that the magnitude of the rise in water productivity is closely related to the amount of water re-allocated due to the reform, that is the larger the amount of water re-allocated post reform, the larger the rise in water productivity. Table 3 shows that the two highest increases in water productivity are observed in Haouz, Perimeter 2 (52 per cent) and Moulouya, Perimeter 3 (37 per cent), where more than 60 and 50 per cent of water, respectively, is re-allocated (see table 1) post reform.

Whether the water market price post reform is higher (lower) than the average return to water pre-reform depends to a large extent on whether

Table 4. *Relationship between water market price and water-intensity of crop production – The case of Souss Massa*

	Perimeter 1	*Perimeter 2*	*Perimeter 3*
Crop with the largest decline in water demand	Fodder	Fodder	Fodder
% in total re-allocated water	89.20	37.30	47.90
Crop with the largest increase in water demand	vegetables	vegetables	Olive trees
% in total re-allocated water	68.70	93.00	42.20
Share of water in crop value-added*			
Fodder	71.55	58.42	56.61
Other vegetables	24.35	39.78	24.54
Olive trees			69.61
Water market price relative to the average return to water**	−12.58	6.87	3.65

Notes: * From data and all others from model results.
** Water market price is from post reform and average returns to water is from pre-reform.

water moves away from growing some crops that are less (more) water intensive to growing other crops that are more (less) water intensive. More intuitively, as water moves from crops that are less water intensive to crops that are more water intensive, those giving up water tend to release more non-water resources from production at the old rental rates of these resources than the water-intensive crops can profitably employ at the old rental rates. Thus, market pressures cause the rental rates of these other resources to fall, which, as shown in the theory section, tends to raise the shadow price of water.

We choose an ORMVA – Souss Massa to illustrate this important point (see table 4). In both Perimeters 1 and 2, the largest decline in water demand is in fodder production, ranging from 37 to 89 per cent of water being re-allocated from these crops. The largest increase in water demand is in the category, other vegetable production (ranging from 42 to 93 per cent of the water being re-allocated to these crops). Fodder production is more water intensive than is vegetable production (as indicated by the data, which shows water's share in total value added). Fodder production uses more water in Perimeter 1 than in Perimeter 2, and vegetables employ less water in Perimeter 1 than in Perimeter 2. Thus, as water is allocated to vegetables in Perimeter 1, vegetable producers also need to employ other resources. This need in turn causes the rental rates of other perimeter resources to rise (see table 3). This places downward pressures on the rise in water's shadow price, with the end result that the market price of water is −12.58 per cent of the average shadow price pre-water-market reform. We see this same tendency for the case of Perimeter 3, but in this case the prices of other inputs rise by relatively small amounts, so that the price of water is only slightly different (3.65 per cent) than the pre-reform average. In the case of Perimeter 2, the post-reform price of water is 6.87 per cent higher

Table 5. *Labour re-allocation by regions: percentage change from base labour supply*

	DOUK	*GHAR*	*HAOU*	*LOUK*	*MOUL*	*SOUS*	*TADL*	*Total****
Perimeter #*								
1	−2.87	−2.10	−6.72	−1.15	1.89	6.56	5.42	
2	8.70	5.57	−22.72	10.70	3.03	1.61	−1.47	
3		27.18	−3.59	14.27	−0.26	1.12		
4					−3.78			
Total**	1.73	10.53	−7.22	3.08	1.26	1.81	−0.09	1.13

Notes: * Increase/decrease in labour demand relative to the base labour supply at the perimeter level.
** Increase/decrease in labour demand relative to the base at the ORMVA level.
*** Increase in total labour demand relative to the base labour supply over all ORMVAs.

Table 6. *Change in the prices for economy-wide factors: percentage change from the base*

Capital in crop production	0.39
Capital in livestock production	0.33
Other capital	0.09
Rural wage	−0.81
Urban wage	0.04

than the average shadow price, pre-reform. We see from table 3 that the rental rate of capital rose by 2.6 per cent, and, thus, the 6.78 per cent rise is not the result we expect from the simple theory alone. However, we find that rural wages fall slightly, as do the prices of some other intermediate inputs. This case thus illustrates the point that the re-allocation of water has major impacts on the prices of other inputs, which in turn influences the resulting market price of water.

Labour flows are affected by differences in crop mix among perimeters. In general, if a perimeter's water is re-allocated away from growing more labour-intensive crops into less labour-intensive crops, then a labour outflow from the perimeter should be observed. This downward pressure on wages encourages some labour to search for employment elsewhere. The seven ORMVAs in total increase labour demand by about 1.13 per cent relative to the level observed in the data (table 5, the last column). However, not all ORMVAs nor all perimeters experience an increase in labour demand. Due to differences in cropping mix and the amount of water re-allocated post reform, there are two ORMVAs in which there are net labour outflows. At the perimeter level, only Souss Massa experiences a rise in the demand for labour in all of its perimeters. In the case of the other six ORMVAs, there is at least one perimeter in which labour demand falls (table 5). The results suggest that the net effect of water re-allocation will cause the rural labour wage rate to decline slightly (−0.81 per cent, table 6). The net change in labour employed, by crop, is shown in (table 7).

Table 7. *Labour re-allocation by crops: percentage change from labour demand by crop in the base*

Irrigated	*Hard wheat*	*Soft wheat*	*Barley*	*Other cereals*	*Pulses*	*Fodder*	*Sugar beets*
	−11.08	−15.19	−17.91	−38.19	−16.14	6.74	−7.97
	Sugar cane	*Other ind. crops*	*Tomato*	*Patoato*	*Pepper*	*Green bean*	*Melon*
	−1.96	−18.10	−5.98	0.87	15.67	16.68	20.69
	Cucumber	*Zucchini*	*Other vegetables*	*Olives*	*Citrus*	*Apricots*	*Other fruit trees*
	71.46	11.89	26.65	47.46	3.40	0.95	−3.96
Rain-fed	*Hard wheat*	*Soft wheat*	*Barley*	*Other cereals*	*Pulses*	*Fodder*	*Sugar beets*
	0.92	1.07	−0.03	−0.70	1.57	−5.23	6.83
	Other ind. crops	*Vegetables*	*Olives*	*Other fruit trees*			
	3.73	−11.77	−4.60	3.56			

Capital rental rates and returns to land are also affected by the re-allocation of water (table 3). As capital and land can only move across crops within a perimeter, the direction and magnitude of change in capital rental rates and returns to land varies across regions. Again, the driving force yielding this result is the differences in factor intensity across crops. For example, as tree crops are relatively capital intensive (but less land intensive), the re-allocation of water to these crops causes the capital rental rate to rise, while returns to irrigated land tends to decline.

4.3. Effects of water reform on equity, the rest of the economy, and foreign trade

Even though the seven ORMVAs only account for 10 per cent of agriculture's total GDP, the re-allocation of water within the perimeters has noticeable economy-wide effects. To show the basic effects, we draw upon selected aggregate economic indicators at the national level (table 8).

As farmers in the various ORMVAs become more competitive, due to the more productive use of water, and thus compete for factors of production with farmers in the rest of agriculture, the real output in the rest of agriculture declines slightly (by 0.01 per cent). As the positive impact of water reform in the irrigated regions dominates the negative impact on the rest of agriculture, economy-wide GDP increases by 0.17 per cent, and even the cost of living declines slightly, by 0.07 per cent. This aggregate welfare gain is also captured by the increase in consumer's total consumption, which rises by 0.25 per cent. In other words, water reform in a sector that comprises about 10 per cent of agricultural GDP, benefits the entire

Table 8. *Change in some macroeconomic indicators*

	Base (Million Dh)	*Percentage change from base*
All perimeters' real output	6740.72	8.27
All non-perimeters' real output	275652.84	−0.01
GDP at expenditure with base price	323781.40	0.17
Total consumption	26294.07	0.25
Real exchange rate (base is 1)		−0.02
Consumer price index (base is 1)		−0.07
Total rural income*	69594.21	0.16
Total farm non-wage income	51146.19	0.46
Rural wage income	18448.02	−0.66
Small farm total income	18313.44	0.24
Medium farm total income	20651.45	0.45
Large farm total income	16853.77	0.44
Total urban income	204659.27	0.20
Urban wage income	92145.91	0.17
Total trade deficit/surplus**	10641.40	
with EU (surplus)	−3932.45	2.76
with rest of the world (deficit)	14573.85	0.74
Total ag trade deficit/surplus	888.06	−21.27
with EU (surplus)	−3530.47	6.54
with rest of the world (deficit)	4418.53	0.95
Total nonag trade deficit/surplus	9753.34	1.94
with EU (surplus)	−401.97	−30.49
with rest of the world (deficit)	10155.31	0.65

Notes: All prices are normalized to the base level.
* Incomes are normalized by consumer price index.
** Total trade deficit holds constant in the scenario.

economy. This amounts to a 'free' gain in total welfare without the use of additional resources.

In terms of rural and urban income, the results suggest that urban income will rise, in real terms, slightly more than the increase in the total rural income (0.2 per cent v. 0.16 per cent). The main reason is due to the slight decline in the rural wage rate and in the cost of living. Incomes earned by farmers owning capital, land, and water user rights, increases by 0.46 per cent, while total wage income declines by 0.66 per cent. These results imply that a water market may not necessarily make those rural workers better off that do not own assets, other than their labour, such as land and machinery. Data show that the small farmer group (those owning less land and capital than those in the medium and large farmer groups) has to depend to a greater degree on wage income earned from employment, either in rural non-farm activities, or on the large farms. Thus, as a group, small farmers' income only rises by 0.17 per cent, while income rises by 0.39 per cent and 0.37 per cent for the medium and large farmer groups, respectively.

Water policy reform also affects the country's trade profile. Given the static property of the model, the total trade deficit is treated as given and fixed. However, trade shares with the EU and the rest of world, as well as the structure of the trade, is affected by the water policy. The results reported in table 8 suggest that the percentage change from the base in Morocco's total trade with EU rises by almost 3 per cent, especially the surplus in agricultural trade, which rises by more than 6 per cent. It is well known that the EU is a major destination for Moroccan vegetable and fruit exports in which Morocco has a comparative advantage. As more water is re-allocated to vegetable and fruit production in the irrigated regions, exports of these commodities rise.

We observed that crop exports, especially exports to the EU, increase the most (more than 3 per cent). As domestic production of wheat, sugar, and other industrial crops, in which Morocco tends not to hold a comparative advantage, declines due to water being re-allocated away from them, their imports rise. Thus, total crop and total agricultural imports rise by 0.71 and 0.85 per cent, respectively. An implication is that foreign and domestic barriers to agricultural trade are likely to be an important determinant of the shadow price of water.

Further, it is almost surely the case that changes in the other economy-wide policies will affect the structure of trade to a greater degree than water policy alone. This in turn would be expected to further affect water allocation and hence the structure of crop production, as well as the entire economy. Analysis of the relationship between water policy reform and trade liberalization is the focus of a forthcoming paper.

5. Concluding remarks

The growing scarcity of water in low-income countries places increased pressures for developing mechanisms to allocate water to its most productive uses. This paper considers water allocation in the context of a spatially heterogeneous irrigated agriculture, the benefits from establishing property rights to this water, and the sector and economy-wide effects that can potentially accrue by permitting users to rent in/out their rights to water. The design of a national water policy is made difficult by the spatial heterogeneity of agriculture. Property rights matter because they influence the motivation farmers have to use water efficiently, and to determine which farmers can use water more efficiently than others. The sector and economy-wide effects matter because changing water policies affect the prices of other economy-wide resources, such as labour and agricultural capital, while at the national level, they can affect the level of exports, imports, and even the cost of living, as measured by the consumer price index. Ignoring these influences is to greatly underestimate the economic rewards from allocating water to its most productive uses.

To provide insights into these factors, we develop a detailed economy-wide model of the Moroccan economy with major attention given to seven irrigated regions whose water supplies and distribution are managed by seven water authorities, each of which contains at least two irrigation perimeters. Of the 88 production activities modelled, 82 are in agriculture or agriculture-related activities, including 66 in crop production, five in livestock, and 11 in processing agriculture, both up and down stream from the farm firm. The 66 crop production activities are further distinguished by being within or outside the seven ORMVAs.

Given policies in place, as depicted in the data, including the water assignments made by the water authorities within each perimeter, the model is solved so as to reproduce the base data, as well as to provide estimates of the shadow price of water for each water assignment to each crop in each perimeter of each of the seven ORMVAs. The level and disparity in shadow prices provides insights into the degree to which current policy allocates water to the most productive crops.

Then, the assumption is made that farmers are given the user rights to their historic water assignments. In this case, they can choose to allocate water as they have in the past and internalize, as part of their profits, the shadow price of water. Or, they can choose to rent out to or in from other farmers in the perimeter some or all of their water, and receive as compensation the resulting market rental price of water in that perimeter. This is the mechanism by which the property rights to water is modelled, and how trade in water user rights leads to the allocation of water so as to equate the marginal value product of water in its alternative uses within each perimeter.

The results suggest that such a mechanism could increase agricultural output within the seven ORMVAs by 8.3 per cent. Most likely, this estimate is conservative because some of the higher income stream will surely be invested into new agricultural capital, and growth in trade should encourage growth in the imports of intermediate capital goods that will help foster growth in agriculture and the rest of the economy. The analysis finds that the output of fruits and vegetables increase the most, while the production of wheat and fodder tends to decline. Water reform is shown to have economy-wide effects, to place downward pressure on the cost of living, to increase net agricultural trade, and to increase rural farm income. The effect on rural wages is slightly negative, but incomes of small, medium, and larger farms increase. Thus, the creation of a water market appears to have positive implications to equity among farmers. The market price of water, relative to the average shadow price of water pre-water-market reform, rises in 16 of the 20 irrigation perimeters contained in the seven ORMVAs detailed in the model. The increase ranges from a low of 1 per cent to a high of almost 52 per cent, while the declines in the four remaining perimeters range from a -0.27 per cent to about -25 per cent. The allocation of water to its most productive use also tends to raise the productivity of other resources, and hence their rental rates, such as agricultural capital and land that is specific to a perimeter.

There are numerous technical and institutional difficulties to creating markets for water, let alone the reality that water has other social values above and beyond its value in irrigation. A water market will not produce a social optimum when its use in irrigation by one farmer imposes costs on others, whether they are other farmers or the maintaining of water stocks for purposes of electrification, scenic, or other environmental values. As others have noted (Tsur and Zemel, 1997; Roe and Diao, 2000; Fisher *et al.*, 2002, to mention a few) water is particularly prone to externalities, so that social and private benefits do not necessarily coincide. Moreover, the spatial nature of water does not ensure an environment of buyers and sellers of water which will preclude strategic behaviour from exploiting some agents.

Nevertheless, as the vast literature on political economy shows, public authority is itself influenced by special interests and not necessarily prone to act so as to maximize social welfare. Even if this influence is minimal, institutional constraints may preclude it from implementing the first-best instruments to achieve a social optimum in any case. From another perspective, the results from this analysis can be interpreted as at least providing insights into the opportunity cost of not allocating of irrigation water to its most productive use, costs that may be exceeded by the broader social benefits that are outside the domain of this study. The study does emphasize that these opportunity costs should be evaluated on an economy-wide basis.

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