We present a computable general equilibrium model (CGE) for the Balearic Islands, specifically performed to analyze the welfare gains associated with an improvement in the allocation of water rights through voluntary water exchanges (mainly between the agriculture and urban sectors). For the implementation of the empirical model we built the social accounting matrix (SAM) from the last available input-output table of the islands (for the year 1997). Water exchanges provide an important alternative to make the allocation of water flexible enough to cope with the cyclical droughts that characterize the natural water regime on the islands. The main conclusion is that the increased efficiency provided by “water markets” makes this option more advantageous than the popular alternative of building new desalinization plants. Contrary to common opinion, a “water market” can also have positive and significant impacts on the agricultural income. 


KEYWORDS: efficiency, general equilibrium analysis, water economics


1. Introduction

[2] The Balearic Islands, located east of the Iberian Peninsula in the Mediterranean Sea, present some critical environmental problems due to periodical droughts (when water reserves fall to 30% or 50% with respect to average years) and to the annual regime of water between winter (65% of rainfall) and summer when the demand for water is at its peak. (In the year 2000, a severe dry year, reserves fell to 30.7% in Mallorca, to 5.51% in Minorca and below 20% in Ibiza. Because of the lack of permanent rivers and dams 90% of the water supply is obtained from underground springs.) During the last few years there has been an increasing concern for the conflict of water uses coming from the rapid development of tourism and the traditional uses of water in the agricultural sector. Tourism has increased the stationary population of the island to 34% of the total population, and the rural sector uses still represent 60% of water demand, as can be seen in Table 1. Furthermore, according to the Hydrological Plan of the Balearic Islands, the urban demand will keep growing.

[3] To cope with increasing demand, physical scarcity and conflict of water uses the local water authorities have responded with some policy measures including: first, restrictions of water supply in drought periods, with water shortages in many towns. Second, overexploitation of underground reserves with severe consequences in irreversible salinization of some important water mills. Third, water imports from the Ebro River Basin on the continent. (This “Ship Operation,” which started in 1994 and lasted for 30 months, allowed the transfer of 17 cubic hectometers, a small quantity in relation to the local water demand at a cost of over € 2 per cubic meter, not including the 9 million invested in the infrastructure built to make the transfer possible.) Finally, since 1994, the main strategy has consisted in the building up of new desalinization facilities.

[4] All these strategies reflect the common and traditional view that water management must rely on measures toward an increased supply with little concern for reduced demand options and increased efficiency in water allocation. The prevalent opinion of the experts is that this traditional view has had a high economic cost in the short term, and has increased water scarcity in the long term. Most of the economic costs and environmental damages could have been avoided if alternative policies of demand management, such as water recycling and saving, and increased efficiency mainly through voluntary water exchanges, had been applied.

[5] In this paper we analyze the potential welfare gains associated with the development of a water market in the Balearic Islands. For this purpose we provide a computable general equilibrium model, specifically designed for the regional economy of the islands, and extended to include...
water demand and supply. The model is used to ask whether there are positive gains in reallocating water rights from the rural to the urban sector in a drought period. We also answer some questions about the way such a market will work, and provide some robust answers that show the advantages of markets over increased supply measures. The fully specified CGE model of the Balearic Islands is given by Tirado [2003].

2. General Equilibrium Models and Water Policy Analysis

[6] Although we can obtain some important insights from partial equilibrium analysis, this framework, when put into practice, is of a limited use for the analysis of the efficiency of water rights allocation. The main criticism comes from the fact that water is used in almost all production activities, being an essential input in many of them, and also from the fact that water value is highly dependent on time and location. Any change in the distribution of property rights over water will probably have consequences on the sectoral composition of the economic product, on employment, on costs and prices, and on the income distribution between the rural and urban sectors. A market of property rights will undoubtedly increase efficiency but, as partial analysis also leads to partial answers, in the case of water policy, when many effects are a matter of political concern, it is also necessary to provide a framework able to capture all the relevant economic effects of a changed structure of water property rights.

[7] Applied general equilibrium models for water management are well suited to compare alternative policy scenarios, such as that of Berck et al. [1991], who use a CGE which studies the reduction of water use in San Joaquin Valley as an efficient alternative to solve drainage problems, or the works of Dixon [1990], Horridge et al. [1993], Decaluwe et al. [1999], and Thabet et al. [1999] to analyze the impact and efficiency of water prices. Nevertheless, the use of CGE to analyze the reallocation of water rights between users is less common. Seung et al. [1998] studied the welfare gains of transferring water from agricultural to recreational uses in the Walker River Basin (located in northwestern Nevada and in California). Seung et al. [2000] combined a dynamic CGE model with a recreation demand model to analyze the temporal effects of water reallocation in Churchill County (Nevada). Diao and Roe [2000] provide a CGE model to analyze the consequences of a protectionist agricultural policy in Morocco and show how the liberalization of agricultural markets creates the necessary conditions for the implementation of efficient water pricing (particularly through the possibility of a market for water in the rural sector). By using an applied CGE, Goodman [2000] shows how temporary water exchanges provide a lower cost option than the building up of new dams or the enlargement of the existing water storage facilities.

[8] To sum up, the analysis of water allocation then requires a comprehensive view of the economy, and applied CGE methodology gives a potential framework to assess and compare policy options. For this purpose we use a CGE to analyze the implementation of a water market in the Balearic Islands. This CGE will also allow us to quantitatively and qualitatively compare the advantages of markets over other alternatives such as desalination plants.

3. Basic Model Structure

[9] We have performed a static theoretical model that tries to capture both the economic structure and the hydrological problems of the Balearic Islands. For this purpose, we distinguish ten economic sectors: two of them producing agricultural goods (with and without irrigation), a third sector with livestock, mining, fishing and the rest of primary activities, two sectors involved in the production of drinking water (the traditional one and the one based on desalination of seawater), and the sectors of energy, manufacture, construction, tourism and services.

[10] Any sector produces a particular good or service except the two water sectors. The desalination sector produces and distributes the same product as the traditional drinking water facilities, but with a different cost structure. Although irrigated and nonirrigated agriculture are different production techniques that can potentially be used to produce the same crops, given the conditions of the islands we assume that goods produced by the two agricultural sectors in our model are imperfect substitutes. In this case the overall product of the agricultural sector will be an Armington aggregate of both. When working with aggregate data, countries normally appear to import, produce and export the same kind of goods. The Armington solution consists in assuming that both export and domestic production on the one hand and imports and domestic production on the other, are imperfect substitutes.

[11] The economy uses five production factors: land, capital, labor, water and seawater. Land is only used in agriculture and is mobile among both the irrigated and nonirrigated sector. Capital is specific of any sector except in agriculture where it is mobile between irrigated and nonirrigated. Labor is mobile. Furthermore, at a first ap-
proximation, water supply is assumed to be fixed and water rights, actually distributed among agriculture and water supply firms, are not tradable.

[12] Farmers and water supply firms own some concessional water rights over some quantities of underground water that must be used for a pre-specified purpose and they are not initially allowed to buy or sell these water rights. Water is a primary nontransferable production factor; moreover, as it may be extracted there water is produced with a certain cost. Drinking water is produced and distributed by using other production factors and is used as a final good by consumers or as an intermediate good by the other sectors of the economy. The assumption of nontransferability of water property rights is removed to study the potential welfare gains of water trade between agriculture and water supply depending of the level of raw water supply that is assumed to be exogenously determined by the degree of drought. Seawater supply is assumed fixed and determined by the available desalination capacity.

[13] There are four agents in the economy: consumers, firms, government and the rest of the world. Consumers are identical and they own the initial endowments of land, labor, capital, water and seawater. There is also a representative firm in any economic sector and the only activity of the public sector consists in collecting the tax revenues and distributing them to consumers as lump-sum income transfers.

[14] The Balearic Islands are assumed to be a small open economy and, consequently, import demand and export supply of any good or service but tourism are determined by world prices. The relative importance of tourism for the Balearic economy leads us to assume a demand for tourism with a negative slope. We use an Armington assumption to cope with imperfect substitutability between domestic and foreign produced goods. Finally, construction and drinking water are assumed to produce nontradable goods.

3.1. Agricultural Technology

[15] As agriculture is the main user of raw water, the potential advantages of water exchanges are heavily dependent on the available possibilities of substitution between primary production factors in this sector. Additionally the agricultural sector may adjust itself to a shortage or a price increase in water resources by changing its composition between irrigated and nonirrigated crops. To include all these adjustment alternatives, we model both irrigated and nonirrigated crop production technologies as nested multi-level CES, as shown in Figure 1. The only difference between the two technologies is that the nonirrigated sector does not use raw water. CES (constant elasticity of substitution) functions are widely used in CGE modeling to represent both production and utility. They have the advantages of being well behaved, with a decent degree of flexibility and consistent with assumptions used in CGE models (linear homogeneity/homothecity). The standard two-variable CES production function may be written as

\[
Y = A \left[ bK^\beta + (1 - \beta)L^\gamma \right]^\frac{1}{\gamma}
\]

where \(Y\) is the output, \(K\) and \(L\) the two production factors, \(A\) is a scale parameter, \(\beta\) and \((1 - \beta)\), respectively, represent the share of factor \(K\) and factor \(L\) in total factor payments and \(\rho\) is related to the elasticity of substitution \(\sigma = 1/(1 - \rho)\).

[16] One drawback of the CES function is that the elasticity of substitution between any pair of goods or factors is constant. To specify that this elasticity between members of one subset of goods or factors is different from...
the one between members of one subset and members of another, it is necessary to combine the CES with another kind of functions.

[17] The bottom right side of Figure 1 shows the Leontief raw water extraction technology (RW) meaning that producing water for crops requires underground water and energy. The Leontief (fixed coefficients) function is a special case of the CES function when $\sigma \rightarrow 0$. This function is commonly used to model the use of intermediate (manufactured) inputs which are combined with the other factors of production to produce the final good. The CGE models available in the literature do not explicitly consider that water for agriculture is a produced input. Following Boyd and Newman [1991] and Decaluwe et al. [1999] we assume that capital and land are also CES aggregates ($KT$). First level aggregate inputs, raw water and the composite capital land are specific production factors of the agricultural sector. Similar to that of Goodman [2000], our model is more flexible than the alternatives provided by, i.e., Berck et al. [1991] and Seung et al. [1998], where land and water enter in the production function with fixed Leontief coefficients.

[18] In a second level the composite land-capital and raw water are combined in the CES composite $KDW$, which in a third aggregation level is combined with labor ($L$) to obtain a CES composite ($KLTW$) of all capital, labor and nature production factors. Finally, the combination of all these factors with an aggregate of intermediate inputs is combined with a Leontief technology to obtain the final output of the crop-irrigated sector. The nonirrigated sector is similar except that the RW nest does not apply.

[19] The overall crop production is an aggregate of irrigated and nonirrigated outputs with a constant elasticity function. This way, the overall agricultural output $Y_{agr}$ as shown in the equation below, must be in equilibrium with the internal and external demand, $D_{agr}$ and $X_{agr}$, and following the Armington methodology we assume a constant transformation elasticity of this tradable good:

$$Y_{agr} = f(Y_{reg}, Y_{sec}) = g(D_{agr}, X_{agr})$$

### 3.2. Noncrop Production Technology

[20] The water production and distribution sector $Wp$, extracts water available underground and transforms it into drinking water by using capital, labor and intermediate inputs in fixed proportions. The alternative in case of underground water shortage consists in the desalinization of seawater and in this case we assume a Leontief production function that uses capital, labor and intermediate inputs. The overall drinking water production is then the sum of traditional drinking water production $Wp$ and desalinated water $Wd$. Given the relatively high cost of desalinization, this sector will only be active when the quantity of underground water available is below a certain threshold and we assume that in the baseline scenario (when there is no drought problem) this sector is not active.

[21] Apart from crops and drinkable water production functions, all other production technologies are specified by a three level nested production functions as represented in Figure 2. This production structure is more flexible than the models presented in the literature and is justified by the empirical demonstration that water demand is rather flexible and can be substantially reduced during drought periods (i.e., by water saving campaigns or the installation of water saving devices in-households and firms).

[22] At the first level, capital and drinkable water are combined with a CES technology to obtain the $KDW$ composite. At the second level, this $KDW$ composite is combined with labor using Cobb-Douglas technology (the Cobb-Douglas function is a special case of the CES function when $\sigma \rightarrow 1$) to obtain the $VAP$ aggregate, which,
### Table 2. Input-Output Table of the Balearic Islands 1997, Aggregated in 10 Sectors

<table>
<thead>
<tr>
<th>Sector</th>
<th>Agriculture</th>
<th>Nonirrigated</th>
<th>Irrigated</th>
<th>Livestock and Fishing</th>
<th>Energy</th>
<th>Water Production</th>
<th>Manufacture</th>
<th>Construction</th>
<th>Tourism</th>
<th>Services</th>
<th>Intermediates</th>
<th>Exports</th>
<th>Investment</th>
<th>Final Consumption</th>
<th>Final Demand</th>
<th>Total Use</th>
</tr>
</thead>
<tbody>
<tr>
<td>Final Consumption</td>
<td>160.84</td>
<td>391.56</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Final Demand</td>
<td>239.88</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total Use</td>
<td>391.56</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Notes:**
- Values are in millions of euros.
- **fp** At factor prices.
- **mp** At market prices.

**Sources:**
- Elaborated from 1997 input output table of the Balearic Islands [Governs des Illes Balears, 2004].

**Additional Information:**
- Water and energy production.
- Intermediate and final demand items.
- Gross Added Value.
mixed in fixed proportions with intermediate inputs, leads to the production of the final good $Y_s$.

[23] Each sector produces two kinds of “goods”, those for the domestic market $D_s$ and those for the foreign market $X_s$, which are aggregated by the CET function $g(D_s, X_s)$. As far as algebra is concerned, constant elasticity of transformation functions (CET) are similar to CES functions, but whereas CES functions specify an output as a function of a number of inputs, CET functions specify an input as a function of a number of outputs (see section A8).

3.3. Final Demand and Macroeconomic Equilibrium

[24] There are two kinds of taxes collected by the public sector and returned to consumers as lump sum transfers. Indirect taxes over the production (independently if they are consumed domestically or exported) and a value added tax over the Armonington aggregate. 

[25] In this context the final demand is composed by investment ($INV$), consumption and imports. In the short term investment is exogenous and is defined by a Leontief aggregate of traded and nontraded goods. Import demand and export supply are determined by external prices and are both defined by using the normal Armonington assumptions. The foreign demand for tourism services presents a constant substitution elasticity.

[26] In the baseline scenario there is an external trade surplus that, since our economy does not consider external capital flows, we will regard as constant. For this purpose an artificial good is introduced [see Löfgren et al., 2001; Blake, 2000; Boyd and Newman, 1991]. The price of this good ($pfx$), equivalent to the real exchange rate, will balance the external sector. The absence of capital flows is equivalent to a certain internal saving which allows the external balance.

[27] Consumers maximize a Stone-Geary utility function. The Stone-Geary function can modify either the Cobb-Douglas (our case) or CES utility function to specify a minimum level of demand of each good (in our case only water) (see section A9). Consumer income is obtained by the sum of primary factors revenues and lump sum transfers. Consumption expenditure is obtained after deducing investment and net saving from consumer income. Drinking water is an essential consumer good and we assume that there is a minimum subsistence quantity of drinkable water that must be supplied in any case. Given the lack of data we assume that this subsistence level is equivalent to the 70 L per day recommended by the United Nations.

4. Implementation of the Empirical Model

[28] The basic data comes from the 1997 input output table of the Balearic Islands [Gover des Illes Balears, 2004] from which we built the social accounting matrix (SAM) presented in Table 2 (the 55 sectors were grouped into the eight mentioned above).

[29] Agricultural production has been disaggregated into different crops following the classification and data provided by the National Agrarian Accounting Network (Red Contable Agraria Nacional [Ministerio de Agricultura, Pesca y Alimentación. Secretaría General Técnica (MAPA), 1999]) and the Balearic Government. Finally, all crop outputs were regrouped to obtain the irrigated and nonirrigated production values that were incorporated in the F-O matrix. Labor income was obtained by adding wages and social security payments. Land rents were obtained from data provided by the land price survey of 1997. Capital gains in the agricultural sector were obtained by subtracting labor income and land rents from agricultural gross value added to factor prices.

[30] Nonresident consumption represents an important share of total consumption expenditure in the Balearic economy reflecting the relative economic importance of tourism. For simplicity, we treat tourist consumption as exports. Collective or public consumption was also assumed as part of the consumption expenditure of the representative agents.

[31] Water endowments were obtained from the hydrological plan of the Balearic Islands as the effective water applied to any crop in 1997 and the effective water consumption were obtained after considering a return flow of 22%.

[32] For the water desalinization sector we use the estimated cost of 0.58 euros in 1997 per cubic meter of drinking water (provided by the water supply authority of Palma de Mallorca (EMAYA)) with an installed capacity of producing 30 cubic hectometers (we assume this to be the endowment of seawater in the baseline scenario). The cost

---

Table 3. Parameters of the Balearic CGE Model

<table>
<thead>
<tr>
<th>Elastocities</th>
<th>Values</th>
</tr>
</thead>
<tbody>
<tr>
<td>Substitution elasticity in the irrigated agricultural sector</td>
<td>$\sigma^d_{agr} = 0.3$</td>
</tr>
<tr>
<td>Aggregate capital-land and aggregate water for crops</td>
<td>$\sigma^{agr} = 0.2$</td>
</tr>
<tr>
<td>Land and aggregate capital-land-water for crops</td>
<td>$\sigma^{kap} = 0.7$</td>
</tr>
<tr>
<td>Substitution elasticity in the nonirrigated agricultural sector</td>
<td>$\sigma^s_{agr} = 0.3$</td>
</tr>
<tr>
<td>Capital and land</td>
<td>$\sigma^s_{sec} = 0.3$</td>
</tr>
<tr>
<td>Labor and aggregate capital-land</td>
<td>$\sigma^s_{kap} = 4$</td>
</tr>
<tr>
<td>Substitution elasticity between imported and domestically produced goods</td>
<td>$\sigma^s_{reg} = 1$</td>
</tr>
<tr>
<td>Price elasticity of export demand for tourism</td>
<td>$\epsilon = -2$</td>
</tr>
<tr>
<td>Transformation elasticity of production</td>
<td>$\Omega_{imp} = \Omega_{r} = 2$</td>
</tr>
</tbody>
</table>

---

*a* Boyd and Newman [1991] and Seung et al. [1998].

*b* Goodman [2000].

*c* Blake [2000].

*d* Equal to all sectors and obtained as the average of the transformation elasticities considered by Seung et al. [1998].
distribution between the different factors intervening in the desalination process has been obtained by using the information about engineering costs for this kind of plants [see Centro de Estudios y Experimentación de Obras Públicas (CEDEX), 1995].

[33] In some cases substitution and transformation elasticities have been obtained from previous studies and in others they have been assumed. In any case, we present some elements further on to estimate the robustness of our estimates. All the remaining parameters have been obtained by calibration of the theoretical model with the social accounting matrix (see Table 3).

5. Model Calibration

[34] The model has been calibrated by using the MPSGE (mathematical program system for general equilibrium) module of the GAMS (general algebraic modeling system) programming platform [GAMS Development Corp., 2001].

[35] Except for water, we followed the usual Harberger convention of setting initial prices to the unity (with the obvious exceptions caused by the existence of indirect taxes). In the case of drinking water, as the quantity produced must be equal to the raw water used as input, the price will be higher than the unity and is calibrated by using the fact that the Leontief coefficient (relating raw and drinking water) is equal to one.

[36] The absence of a market for water in the agricultural sector implies a reference price of zero in the benchmark scenario. In this case, the only way to calibrate a CES production function is to assume that the input (underground water) is combined with another “marketed” input in fixed proportions (in our case: energy). Finally, labor price is taken as numerary (the model and data are available from authors upon request).

6. Main Results

[37] The benchmark, or the calibrated baseline scenario, in which no water exchanges are allowed, is basic to obtain the “no water market situation” (NM). The counterfactual situation where water rights are possible (WM) is obtained by assuming that raw water is not a sector specific input anymore and that water endowments can be freely sold until their marginal productivity is equated among the agricultural and the drinkable water production sectors.

[38] To show the differences between both situations (with and without water exchanges), we run eleven simulations of drought scenarios by considering sequential reductions of 5% of the initial water endowment. The base year of 1997, according to Tirado [2003], was considered an almost normal rainfall year.

[39] First, water markets will result in a better allocation of water among crops and drinking water production. Figure 3 shows the relevant water prices for different drought levels. In the nonmarket situation, represented by the bold lines traced for the price of urban raw water scenario. In this case, the only way to calibrate a CES production function is to assume that the input (underground water) is combined with another “marketed” input in fixed proportions (in our case: energy). Finally, labor price is taken as numerary (the model and data are available from authors upon request).
endowment \((P_{uw})\) and the price of raw water endowment for agriculture \((P_{aw})\), the diverging pattern of both shadow water prices shows the reduced ability of urban water demand to adapt to water shortages. As the agricultural shadow price increases smoothly with drought, the price curve of raw water for the urban sector is steeper and the price grows until the alternative of desalination seawater becomes profitable. A further increase in the shadow price of urban water will take place only when the capacity of the desalination plant if fully used in a severe drought which reduces the water supply in more than 55%.

The diverging response of shadow water prices in a period of drought allows mutually benefiting interchanges of water endowments between the agriculture and the urban sector. This is shown in Figure 3 by the intermediate price line that is obtained in the counterfactual market situation when the price of water is equalized for any economic use \((P_m)\). Figure 4 shows the water quantity that may be effectively sold by the rural sector.

Second, hypothetical water market would reduce the negative impact of drought over drinking water consumption. As shown in Figure 5, in a nonmarket situation (the lower curve) the production of drinking water needs to be severely reduced to increase water prices until its current market price of drinking water is high enough for its production from seawater to be worth it. On the contrary, with voluntary water exchanges, the baseline supply of drinking water can be maintained even with an intermediate drought that reduces the initial raw water endowment by 30%. As can be expected, the final price of drinking water paid by consumers can also be maintained if voluntary water exchanges are allowed, and no price increase would be necessary before a drought index of 30% is reached (as shown in Figure 6). In short, in a market situation, drinking water customers benefit both from higher supply and lower prices with respect to a situation when water is not voluntarily traded.

Third, the effect of drought on the irrigated crop production is necessarily negative in both institutional frameworks. In the market situation, as shown in Table 4, the output reduction in this sector is higher than when the sale of water rights is not allowed. Moreover, contrary to the nonmarket situation, the income obtained by water rights sale will guarantee that the overall factor payments in this sector would always be higher if water exchanges are allowed. Table 5 shows that in the nonmarket situation the rural income diminishes with drought contrary to the market situation when it always increases. The reduction of agricultural production resulting from the lower irrigated activity is partially compensated by the increased production from seawater.

Table 4. Drought Effects on Sectoral Output Under Different Institutional Frameworks (Percent of Variation Over Baseline Scenario)

<table>
<thead>
<tr>
<th>Drought Severity as a Percent Reduction in Water Availability Over Baseline Scenario (SB)</th>
<th>Nonmarket Scenario</th>
<th>Water Market Scenario</th>
</tr>
</thead>
<tbody>
<tr>
<td>Irrigated agriculture</td>
<td>-0.40</td>
<td>-0.61</td>
</tr>
<tr>
<td>Nonirrigated agriculture</td>
<td>0.39</td>
<td>0.51</td>
</tr>
<tr>
<td>Livestock and fishing</td>
<td>0.01</td>
<td>0.00</td>
</tr>
<tr>
<td>Energy</td>
<td>0.01</td>
<td>0.00</td>
</tr>
<tr>
<td>Water production and distribution</td>
<td>-5.00</td>
<td>-5.00</td>
</tr>
<tr>
<td>Manufactures</td>
<td>0.02</td>
<td>0.01</td>
</tr>
<tr>
<td>Construction</td>
<td>0.00</td>
<td>0.00</td>
</tr>
<tr>
<td>Services</td>
<td>0.01</td>
<td>0.00</td>
</tr>
<tr>
<td>Tourism</td>
<td>-0.02</td>
<td>-0.09</td>
</tr>
</tbody>
</table>

Table 5. Drought Effects on Agricultural Income (Percent Over Baseline Scenario) and the Hicks Equivalent Variations (Percent of Income From Baseline)

<table>
<thead>
<tr>
<th>Drought Severity as a Percent Reduction in Water Availability Over Baseline Scenario (SB)</th>
<th>Nonmarket Scenario</th>
<th>Water Market Scenario</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rural income</td>
<td>-0.184</td>
<td>0.036</td>
</tr>
<tr>
<td>Regional welfare</td>
<td>-0.012</td>
<td>-0.001</td>
</tr>
</tbody>
</table>

\(8\) of 11
of the nonirrigated crops, this increase being also higher in the market situation due to the reallocation of production factors from the irrigated sector.

[43] Fourth, higher drinking supply and lower prices associated with the water market situation can also explain a relatively higher activity level in other sectors of the economy. As shown in Table 4, these effects are lower than the ones on drinking water production and crops mentioned above. In some cases the effect is easy to understand, as it happens in the energy sector the demand of which increases with the entry of the desalinization plant. It is also worth mentioning that the effect of drought over tourism, the main economic activity of the islands, is clearly negative in the nonmarket institutional framework and, contrary to that, is systematically positive if voluntary water exchanges are allowed. Nevertheless, these general equilibrium sectoral effects must be the subject of further research.

[44] Finally, it is very important to show that the presence or absence of a water market plays a crucial role in the assessment of the convenience of maintaining the existing facilities to increase the supply of raw water (or of building new facilities for the same purpose). In the case of our model, the existing water desalinization plant represents this kind of facilities. As can be seen in Figures 3–6 and in the results presented in Appendix A, the desalinization plant is only active now when voluntary water exchanges are not allowed. In other words, water markets could be an important means to obtain substantial savings of resources actually used to maintain and increase the infrastructure for water regulation. Additionally, if water markets make some of these facilities redundant, other distortion effects produced by the operation of this infrastructure can also be avoided: in our model of the Balearic Islands the price and production of energy are both higher when the desalinization plant is operative implying higher production costs for the entire economy.

[45] In Table 5 we also show an estimate of the Hiskian equivalent variation of the representative agent as a measure to capture all the welfare effects mentioned above. In both institutional frameworks welfare is a decreasing function of drought. Nevertheless the welfare loss is higher in the nonmarket situation. The satisfactory results obtained when using the Gaussian quadrature methodology have shown the robustness of the model.

7. Conclusions

[46] We have presented a CGE of the Balearic economy that has been used to test the superiority of voluntary Water exchanges over the common situation of fixed water endowments. We argue that the potential efficiency gains are important in terms of reduced water prices, increased supply and the increased ability of society to adapt to recurrent drought situations.

[47] We showed that although agricultural production is lower when there is a market for water rights than when there is not such a market, this does not mean a lower rural or agricultural income but, on the contrary, if rural income needs to be maintained, the ownership of tradable water rights could lead to an efficient institutional setting for increasing efficiency in the overall economy.

[48] Water markets will also be the way to obtain substantial savings by avoiding the building up of some water regulation infrastructure (dams, desalinization plants, water transfer facilities) and also to eliminate the economic distortions that may be produced by the operation of this redundant infrastructure, as is the case of increased energy prices produced by the desalinization activity in the Balearic CGE Model. Before generalizing these conclusions it must be considered that the model presented is a first approximation and its results must be understood as the potential welfare benefits of water markets in a particular economy. On the other hand, the welfare benefits of water markets may be lower than expected if transaction costs are, as presumed by the authors, other than zero (which is actually one of the hidden assumption of our model). Although we do not offer an explicit treatment of transaction costs, at least our model gives a preliminary answer to the question of how high the transaction costs of water exchanges should be for water remaining a nonmarketable input to be the best option.

Appendix A: General Equilibrium Model Description

A1. Production Technology of the Irrigated Agricultural Sector

[49] \[ RW_{reg} = \min \left\{ \frac{A_{S_{reg}}}{A_{a_{reg}}} A_{a_{reg}}, \frac{A_{a_{reg}}}{e_{reg}} \right\}. \] (A1)

where \( RW_{reg} \) is the composite input water for crops, \( A_{S_{reg}} \) is the volume of underground water used, \( A_{a_{reg}} \) is the se of the Armington aggregate of the energy sector, and \( A_{a_{reg}} \) and \( e_{reg} \) are Leontief coefficients.

\[ KT_{reg} = A_{r_{reg}}^{b_{r_{reg}}} K_{reg}^{b_{r_{reg}}} + \left( 1 - b_{r_{reg}} \right) T_{reg}^{b_{r_{reg}}} \frac{A_{b_{reg}}}{e_{reg}}, \] (A2)

where \( KT_{reg} \) is composite land capital, \( K_{reg} \) is capital, \( T_{reg} \) is land, \( A_{b_{reg}} \) is the efficiency parameter, \( b_{r_{reg}} \) is the capital share parameter, \( A_{b_{reg}} \) is the substitute parameter, and \( A_{b_{reg}} \) is the substitution elasticity.

\[ KTW_{reg} = A_{r_{reg}}^{b_{r_{reg}}} K_{reg}^{b_{r_{reg}}} + \left( 1 - b_{r_{reg}} \right) RW_{reg} \frac{A_{b_{reg}}}{e_{reg}}, \] (A3)

where \( KTW_{reg} \) is composite \( K_{reg} \) and \( RW_{reg} \) \( A_{b_{reg}} \) is the efficiency parameter, \( b_{r_{reg}} \) is the share parameter, \( A_{b_{reg}} \) is the substitute parameter, and \( A_{b_{reg}} \) is the substitution elasticity.

\[ KLW_{reg} = A_{r_{reg}}^{b_{r_{reg}}} K_{reg}^{b_{r_{reg}}} + \left( 1 - b_{r_{reg}} \right) KTW_{reg} \frac{A_{b_{reg}}}{e_{reg}}, \] (A4)

where \( KLW_{reg} \) is composite \( K_{reg} \), \( L_{reg} \) is labor, \( A_{b_{reg}} \) is the efficiency parameter, \( b_{r_{reg}} \) is the share parameter, and \( A_{b_{reg}} \) is the substitute parameter, and \( A_{b_{reg}} \) is the substitution elasticity.

\[ Y_{reg} = \min \left\{ \frac{KLW_{reg}}{v_{a_{reg}}} A_{1_{reg}}, A_{2_{reg}} \ldots \right\} \] (A5)

where \( g \in BM \) is a set of traded production sectors, \( i \in BNM \) is a set of nontraded production sectors, \( Y_{reg} \) is output of
irrigated agriculture, \( I_{i,reg} \) is use of the intermediate input of the sector \( i \), \( \lambda_{g,reg} \) is use of the Armington aggregate of the sector \( g \), and \( v_{ata,reg}, \bar{i}_{ag,reg} \) and \( \bar{i}_{a,t,reg} \) are technical fixed coefficients.

### A2. Production Function of the Nonirrigated Agricultural Sector

\[
K_{T,sec} = A^{kt}_{sec} \left[ \beta^{kt}_{sec} K_{sec}^{\nu^{kt}_{sec}} + \left( 1 - \beta^{kt}_{sec} \right) T_{sec}^{\nu^{kt}_{sec}} \right]^{\sigma^{kt}_{sec}}, \tag{A6}
\]

where \( K_{T,sec} \) is composite land capital, \( K_{sec} \) is capital, \( T_{sec} \) is land, \( A^{kt}_{sec} \) is the efficiency parameter, \( \beta^{kt}_{sec} \) is the share parameter, \( \rho^{kt}_{sec} \) is the substitution parameter, and \( \sigma^{kt}_{sec} \) is substitution elasticity.

\[
LKT_{sec} = A^{lk}_{sec} \left[ \beta^{lk}_{sec} L_{sec}^{\nu^{lk}_{sec}} + \left( 1 - \beta^{lk}_{sec} \right) K_{sec}^{\nu^{lk}_{sec}} \right]^{\sigma^{lk}_{sec}}, \tag{A7}
\]

where \( LKT_{sec} \) is composite land capital labor, \( L_{sec} \) is labor, \( A^{lk}_{sec} \) is the efficiency parameter, \( \beta^{lk}_{sec} \) is the share parameter, \( \rho^{lk}_{sec} \) is the substitution parameter, and \( \sigma^{lk}_{sec} \) is substitution elasticity.

\[
Y_{sec} = \min \left\{ LKT_{sec}, \frac{A_{1,sec}}{\bar{i}_{a1,sec}} \frac{A_{2,sec}}{\bar{i}_{a2,sec}} \ldots \right\}, \tag{A8}
\]

where \( Y_{sec} \) is output of nonirrigated crops, \( I_{i,sec} \) is use of the intermediate input of the sector \( i \), \( A_{g,sec} \) is use of the Armington aggregate of the sector \( g \), \( v_{ata,sec}, \bar{i}_{ag,sec} \) and \( \bar{i}_{a,t,sec} \) are technical fixed coefficients.

### A3. Overall Agricultural Output

\[
y_{agr} = f \left( Y_{reg}, Y_{sec} \right) = A_{agr} \left[ \beta_{agr} Y_{reg}^{\nu_{agr}} + \left( 1 - \beta_{agr} \right) Y_{sec}^{\nu_{agr}} \right]^{\sigma_{agr}}, \tag{A9}
\]

where \( y_{agr} \) is agricultural output, \( A_{agr} \) is the scale parameter, \( \beta_{agr} \) is the share parameter, \( \rho_{agr} \) is the substitution parameter, and \( \sigma_{agr} \) is substitution elasticity.

### A4. Water Production and Distribution

\[
y_{wp} = \min \left\{ K_{wp}, L_{wp}, A_{wp}^{Aswp}, A_{1,wp}, A_{2,wp}, \ldots \right\}, \tag{A10}
\]

where \( y_{wp} \) is water produced, \( K_{wp} \) is capital, \( L_{wp} \) is labor, \( A_{wp}^{Aswp} \) is raw water, \( A_{1,wp}, A_{2,wp}, \ldots \) are technical fixed coefficients, \( I_{i,wp} \) is use of the intermediate input of the sector \( i \), and \( A_{g,wp} \) is use of the Armington aggregate of the sector \( g \).

### A5. Water Production From Desalination

\[
y_{d} = \min \left\{ K_{d}, L_{d}, A_{d}^{MAd}, A_{1,d}, A_{2,d}, A_{3,d}, \ldots \right\}, \tag{A11}
\]

where \( y_{d} \) is output, \( K_{d} \) is capital, \( L_{d} \) is labor, \( A_{d}^{MAd} \) is quantity of seawater, \( A_{1,d}, A_{2,d}, \ldots \) are technical fixed coefficients, and \( A_{g,d} \) is use of the Armington aggregate of the sector \( g \).

### A6. Other Products

\[
KDW_{s} = A_{s}^{kwp} \left[ \beta_{s}^{1-kwp} K_{s}^{\nu_{s}^{1-kwp}} + \left( 1 - \beta_{s}^{1-kwp} \right) D_{w,s}^{\nu_{s}^{1-kwp}} \right]^{\sigma_{s}^{1-kwp}}, \tag{A12}
\]

where \( KDW_{s} \) is composite capital-water, \( K_{s} \) is capital used by sector \( s \), \( D_{w,s} \) is water used by sector \( s \), \( \beta_{s}^{1-kwp} \) is the efficiency parameter, \( \beta_{s}^{1-kwp} \) is the share parameter, \( \rho_{s}^{1-kwp} \) is the substitution parameter, and \( \sigma_{s}^{1-kwp} \) is substitution elasticity.

\[
VAP_{s} = B_{s}^{vwp} L_{s}^{vwp} KDW_{s}^{1-\omega_{s}}, \tag{A13}
\]

where \( VAP_{s} \) is composite KDW and labor, \( L_{s} \) is labor, \( B_{s}^{vwp} \) is the efficiency parameter, and \( \omega_{s} \) is the share parameter.

\[
Y_{s} = \min \left\{ VAP_{s}, \frac{A_{1,s}}{i_{a1,s}}, \frac{A_{2,s}}{i_{a2,s}}, \ldots \right\}, \tag{A14}
\]

where \( Y_{s} \) is production of sector \( s \), \( \omega_{s} \) is the use of the intermediate input of the sector \( I \), \( A_{g,s} \) is use of the Armington aggregate of the sector \( g \), \( v_{vwa,s}, i_{a1,s}, i_{a2,s}, \ldots \) are technical fixed coefficients.

### A7. Investment

\[
INV = \min \left\{ A_{1,inv}, \frac{A_{2,inv}}{i_{n1,inv}}, \frac{A_{3,inv}}{i_{n2,inv}}, \ldots \right\}, \tag{A15}
\]

where \( INV \) is production of capital goods, \( D_{i,inv} \) is use of the domestic production of the sector \( I \), \( A_{g,inv} \) is use of the Armington aggregate of the sector \( g \), and \( i_{n1,inv}, i_{n2,inv}, \ldots \) are technical fixed coefficients.

### A8. External Trade

#### A8.1. Transformation Function

\[
g(D, X) = A_{t} \left[ \theta_{t} D^{\theta_{t}} + \left( 1 - \theta_{t} \right) X^{\theta_{t}} \right]^{\delta_{t}}, \tag{A16}
\]

where \( D_{s} \) is domestic demand for products of sector \( s \), \( X_{s} \) is export demand for goods of sector \( s \), \( A_{t} \) is the scale parameter of the sector \( s \), \( \theta_{t} \) is the share parameter, \( \eta_{t} \) is the transformation parameter, and \( \Omega_{t} \) is transformation elasticity.

#### A8.2. Armington Aggregate

\[
A_{g} = A_{g}^{A} \left[ \alpha_{g} D_{g}^{\alpha_{g}} + \left( 1 - \alpha_{g} \right) M_{g}^{\alpha_{g}} \right]^{\delta_{g}}, \tag{A17}
\]

where \( D_{g} \) is domestic output of the sector \( g \), \( M_{g} \) is import demand of sector \( g \), \( A_{g}^{A} \) is the scale parameter of the sector \( g \), \( \alpha_{g} \) is the share parameter \( g \), \( \rho_{g}^{A} \) is the substitution parameter, and \( \delta_{g} \) is the substitution elasticity.

#### A8.3. Tourism

\[
X_{nu} = X_{nu} \left( \frac{P_{EU}^{nu}}{P_{EU}^{nu}} \right)^{\phi}, \tag{A18}
\]

where \( X_{nu} \) is tourism, \( P_{EU}^{nu} \) is the price of tourism, and \( \phi \) is the elasticity parameter.
where $X_{tu}$ is export demand, $\Xi_{tu}$ is the initial export demand of tourism, $P_{EX_{tu}}$ is the price of tourism, $p_{FX}$ is the real exchange rate, and $\varepsilon$ is the demand price elasticity.

### A9. Consumption

\[
C = (C_w - \gamma_w)^{\alpha_c^{co}\varepsilon} C_{co}^{\alpha_c^{co}} \prod_{g=1}^{6} C_g^{\alpha_g^{co}}, \tag{A19}
\]

where $g \in BM$ is the set of traded goods, $C_w$ is drinking water consumption, $C_{co}$ is construction goods, $C_g$ is sector $g$ produced goods consumption, $\gamma_w$ is minimum subsistence consumption of drinking water, and $\alpha_c^{co}$, $\alpha_c^{co}$, and $\alpha_w$ are share parameters.

### References


GAMS Development Corp. (2001), GAMS version 2.5, solver PATH, software, Washington, D. C.


Gover de las Illes Balears (2004), Las Tablas Input-Output y el Sistema de Cuentas Regionales para la Comunidad Autónoma de las Islas Baleares, technical report, Palma, Spain.


C. M. Gómez, Department of Economics, Universidad de Alcalá, Plaza de la Victoria s/n, Alcalá de Henares, 28802 Madrid, Spain. (mario.gomez@uah.es)

J. Rey-Maquieira and D. Tirado, Departamento de Economía Aplicada, Universidad de Islas Baleares, Campus Universitario, Ctra de Valldemossa, Km. 7,5, E-07122 Palma de Mallorca, Spain. (javier.rey@uib.es; dolores.tirado@uib.es)