General Equilibrium Analysis and Policy Evaluation in the Context of the Water Framework Directive

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ABSTRACT
Using a model for the Balearic Islands in Spain we show how general equilibrium models are useful tools for policy analysis in the context of the implementation of the EU Water Framework Directive. We show that, contrary to partial equilibrium approach, general equilibrium models may predict that water saving policies could be ineffective in terms of improvements in water ecosystems. Consequently, we also show the need for ancillary measures, such us price incentives, to meet the ecological targets of the water saving measures. As it is illustrated, AGEMs also provide information about side social benefits of water efficiency measures that should be considered to determine the maximum acceptable cost of implementing water saving programs to reduce pressures on water ecosystems. Finally, the usefulness of AGEMs to compare different institutional arrangements for water allocation is also illustrated with the Balearic Islands case.

I. Introduction

Partial and general equilibrium analyses are distinct methodological frameworks to obtain relevant information about the desirability of a certain measure or a certain combination of measures performed to improve the ecological quality of a water body or a river basin. Partial equilibrium analysis, for example, may be useful to determine the technical effectiveness and the associated marginal cost of a policy measure by assuming that other things do not change in the economy; this way, any economic activity affected by a water efficiency measure is analysed without taking into account the interactions with other markets in the economy. Contrary to that, the main purpose of a general equilibrium methodology is to determine how the entire economy adapts after a policy shock and in this framework the interactions between the different economic activities are of paramount importance. By focusing on one market or on the entire economy both frameworks may provide different pieces of relevant information for the decision taking process and sometimes may also lead to different conclusions for the same policy evaluation problem.

Applied general equilibrium models (AGEMs) are well suited to compare alternative policy scenarios for water management[1].In this paper we use a general

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[1] The following are the most relevant applications of this analysis tool: Berck, Robinson and Goldman (1991) who use a CGEM which studies the reduction of water use in San Joaquim Valley as an efficient alternative to solve drainage problems. Dixon (1990), Horridge *et al.* (1993), Decaluwé *et al.*(1999) and Thabet *et al.* (1999) analyse the impact and efficiency of water prices. Seung *et al.*

equilibrium model of the Balearic Islands (Gómez, Tirado and Rey, 2004) to illustrate how this methodology can be converted into a useful analysis tool in the implementation process of the WFD.

Although general equilibrium analysis allows us to obtain a more complete and detailed information over the welfare effects of a policy option, this method is also more information and skills demanding and its results may be less precise and more difficult to communicate to stakeholders and decision takers. In many cases partial analysis may provide enough information to conduct a policy evaluation and the gains from using a more sophisticated, information demanding and sometimes less transparent analysis tool may not be worth the effort.

For example, the costs and benefits associated to a change in the irrigation system of a reduced number of farms or of a limited leakage reduction program in the water distribution network may be accurately measured and compared in a partial equilibrium framework. This is so because these measures will probably not have an important effect over the market for agricultural products or over the price of drinking water in the economy. However these interaction effects may become more relevant as the coverage of the water policy measures increases leading, for example, to noticeable improvements in the productivity of water services in agriculture or to a significant reduction in the marginal cost of providing drinking water. Then, the convenience of using one method or the other depends on the relevance of crossed effects between the different markets in the economy, so AGEMs may be useful tools to analyse the policy options affecting the productivity and the market conditions of services that are used by most of the production activities in the economy and demanded as a final good by any consumer.

Apart from its potential as information source to test the technical effectiveness and the costs and benefits of water management policy measures, by analysing how the entire economy adapts itself to a water policy shock, AGEMs may provide some additional and relevant information to the decision taking process. This information refers, for example, to how water policy options may affect the competitiveness of one

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(1998) study the welfare gains of transferring water from agricultural to recreational uses in the Walker River Basin. Seung *et al.* (2000) combine a dynamic CGE model with a recreation demand model to analyse the temporal effects of water reallocation in Churchill County (Nevada). Diao and Roe (2000) provide a CGE model to analyse 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). 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. Finally Gomez, Tirado and Rey-M. (2004) develop the model in which the applications presented in this paper are based.

sector with respect to others or may increase or reduce the equilibrium production levels of the different economic activities directly or not directly affected by the water policy. In the same line, AGEMs may give us an idea of the possible effects of water policy measures over employment in different sectors of the economy.

Another important advantage of AGEMs is that they allow us to appreciate the different value of water services in the many significant water uses in the economy providing information, for example, on how valuable water is as an input for crop production with respect, for example, to the provision of drinking water services. This way AGEMs are relevant to analyze the possibility of increasing efficiency by redistributing water property rights or, more exactly, to compare some institutional arrangements to allocate the available water services among the different water uses in the economy.

The purpose of this paper is to illustrate how applied general equilibrium models may provide important pieces of information on water management options in the context of the implementation process of the Water Framework Directive. In particular we will present some general discussions and illustrations about the following aspects. First we want to stress that in some relevant cases, partial and general equilibrium results may differ importantly in terms of the evaluation of water saving policy measures. Second, we want to show why water saving measures need to be accompanied by properly designed price incentives measures in order to guarantee that water saved in particular economic uses would result in effective improvements of water ecosystems. Third, we want to show how general equilibrium models can be used to obtain information about the potential benefits and the maximum cost the economy may be willing to pay for a water saving program that reduces the pressures over the water ecosystem. Finally, we will also try to illustrate how AGEMs may be used to test different institutional arrangements to allocate scarce water property rights in the economy. The way general equilibrium models contribute to the decision process on the design of river basin management plans is illustrated by some general results obtained from a model developed to study water policy issues in the economy of the Balearic Islands in Spain. The model may be consulted in Gómez, Tirado and Rey-M. (2004) and its main characteristics and data are in the technical annex.

II. Partial and General Equilibrium Analysis of Water Efficiency Measures

An important number of the measures available to improve the quality of water ecosystems in Europe consist in reducing the water services requirements of the different economic activities by somehow improving the efficiency with which water is used. By efficiency measures we must understand any action allowing to reduce the minimum quantity of water uses needed to provide society with a certain quantity of water services including, for example, improvements of irrigation systems that reduce the water needed to obtain a given level of agricultural output, the recirculation of waste water for some particular uses or the substitution of water-using domestic appliances. Efficiency measures may be effective ways to obtain the same level of water services with lower water abstractions and a better ecological quality of the water sources. The same will happen if an extended waste water treatment system is installed in order to reduce the impact on the river basin chemical quality of domestic water uses.

We will now discuss how efficiency measures are assessed in the context of partial and general equilibrium frameworks. Assuming that we have already identified a desired ecological status of the water ecosystem, we proceed by conducting a cost effectiveness analysis of the whole set of water efficiency measures that may contribute to our policy target. From a partial equilibrium analysis perspective the kind of measures mentioned above are considered as water saving policy options that may be ordered according to their respective marginal cost so as to obtain the least cost combination of measures to reach a target reduction in water pressures over the ecosystem. This analysis requires the implicit assumption that any quantity of water saved by the economy will be translated into a reduction of water abstractions and then into an improvement in the relevant parameters measuring the ecological quality of the water source (for example into an increased water flow or a lower contaminant concentration).

For example, let us say, a 10% reduction in the drinking water needed to provide the current activity level of the tourist sector in the Balearic Islands, where tourism uses represents 30% of total drinking water consumption, will represent a final 3.9 cubic hectometres reduction in water requirements. Adding the 75% efficiency in the water transport, treatment and distribution system this would mean a reduction in water abstractions of 5.3 cubic hectometres every year. If implementing this measure costs 53,000€ in annual equivalent units we would say that the increase of the water available in the ecosystem comes to an average annual cost of one euro cent per cubic meter. This information is of course relevant both to judge the technical effectiveness of the water saving measures and to obtain the least cost combination of measures that may be included in the river basin management plan.

These conclusions may substantially change if we analyse the same problem in a general equilibrium framework. In this case the answer on whether or not and by how much a water efficiency measure will improve the ecological status of a water body depends on how the economy will adapt to the water policy shock. From general equilibrium perspective a water efficiency action is conceived as one of the many possible resource saving technical changes that may occur in the economy. In other words, once the saving measures are applied, the economy will be able to produce a better combination of final goods with the same endowment of inputs as before the technical change.

From a welfare perspective an efficiency improvement is a way to reduce water scarcity and not necessarily to save water or to reduce economic pressures over the environment. In this framework it is not appropriate to identify a water efficiency increase with water savings or water abstraction reductions. Contrary to that, water is now a more productive input to provide tourism services and this is the source of two opposite effects over tourism firms' water demand. Water requirements are reduced and the quantity of water demanded at any price in now lower than in the baseline situation. Figure 1 shows this effect in the particular case of the Balearic economy when a 10% efficiency increase in water efficiency in the tourism sector is applied as a shift down on the industry water demand function.

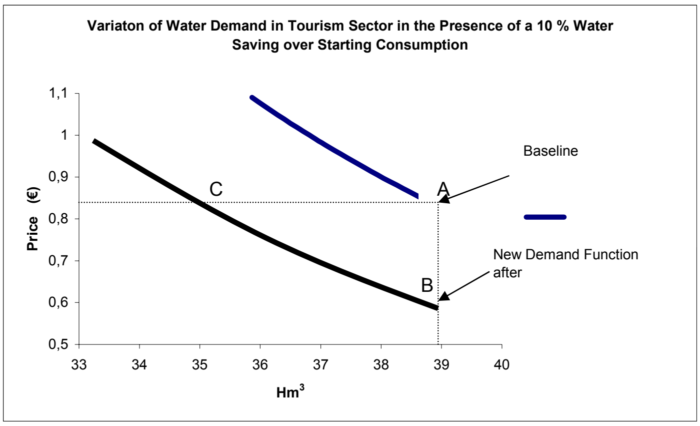

Figure 1: Efficiency improvements shifts water demand down in the tourism sector.

Additionally, water efficiency improvements in one activity may have consequences over other markets of the economy. This is so because efficiency measures may modify the equilibrium conditions of the drinking water market. After the technical change the overall water demand in the economy is reduced (because water is a more abundant input in the economy); see Figure 2.

Assuming that water supply remains unchanged the market adjustment will necessarily lead to a reduction in the market equilibrium price and to an increase in water consumption in tourism as well as in other water uses in the economy. In other words, if water supply is not reduced somehow or, alternatively, effects over water demand are not compensated by any other water management policy, water efficiency measures will not have any impact on the ecological quality of water sources. Figure 3 shows the economic effects of a water efficiency increase in the tourism sector of the Balearic economy, when water supply remains constant. The initial 10% reduction in the tourism sector is partially compensated by the price adjustments and once the new market equilibrium is reached the sector only saves 7,5% of its initial water requirements. Other sectors in the economy receive the benefits of the price reduction and the water effectively saved by tourism is now consumed by residents (whose water consumption increases by 5,3%) and productive activities (whose water consumption increases by 2,7%) without any positive effect over the ecological quality of water ecosystems.

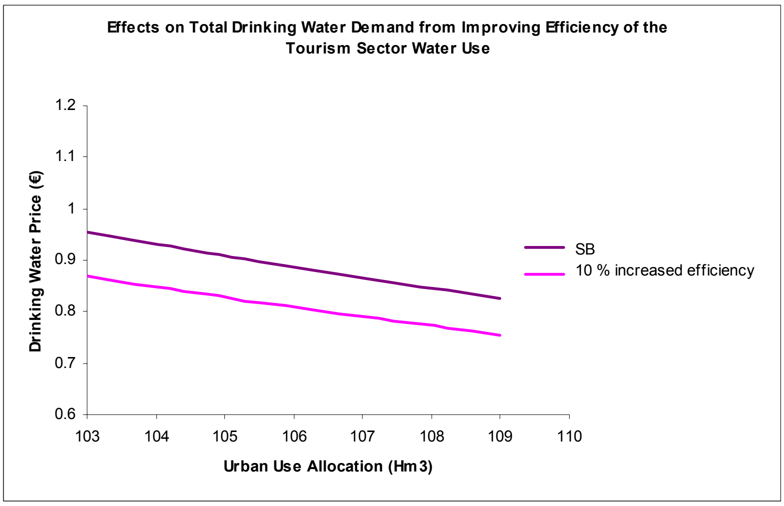

Figure 2: Improvements in water efficiency in the tourism sectors shifts the total drinking water demand.

Surprisingly, partial and general equilibrium analysis lead to opposite answers on the effectiveness of water management policy measures as a means to improve the ecological status of water sources. This result is one example of the paradox discovered by Stanley Jevons in 1865 and has been documented in many studies on the costs and benefits of energy efficiency programs in Europe and the United States[2].

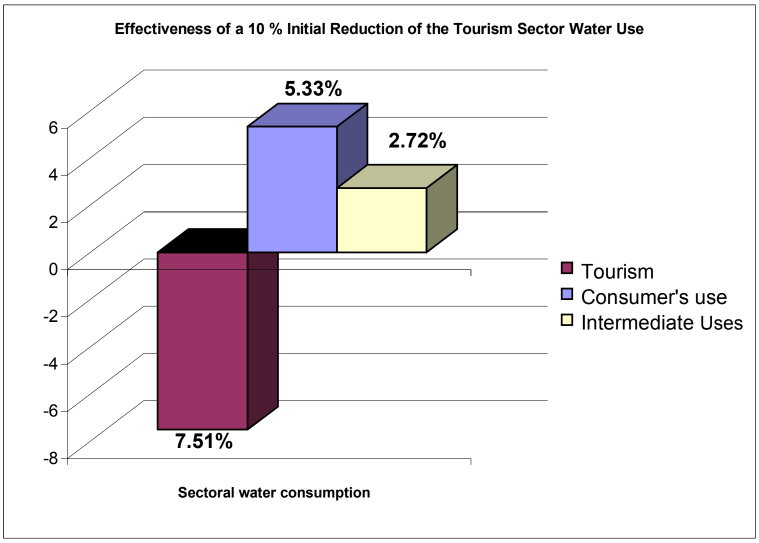

Figure 3: Water demand reductions in one sector creates an excess capacity in the water supplying sector that will necessarily lead to a reduction in the market equilibrium price and an increase in the other uses.

III. Policy Packages vs Policy Measures

Probably the most important corollary of the previous discussion is that in an economy where drinking water is rationed by the market, improvements in water efficiency will not lead to improvements in water ecosystems. This is so because water savings obtained this way are equivalent to making water more productive or equivalently to increasing the availability of water services in the economy. The market economy will take advantage of these new conditions to create more wealth through the production of a better set of market goods, a category in which ecological quality of water sources is not obviously included.

Apart from taking the needed actions to increase water efficiency in a market economy something more is needed to guarantee the transfer of water savings to the environment. The way to solve the "Jevons paradox" is to reduce water consumption in the economy and this can be obtained in two ways. First by increasing water prices through an environmental tax and second by reducing the endowment of water of the rinking water supply industry. The water authority may increase prices to reduce equilibrium demand or it may reduce quantity to increase equilibrium prices in the drinking water market. In both cases the effect would be the same.

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[2] In *The Coal Question:Can Britain Survive* first published in 1865. Jevons wrote: "it is a confusion to suppose that the economical use of fuel is equivalent to diminished consumption. The very contrary is the truth". For examples of the Jevons Paradox see, for example: Saunders (1992), Brookes (1979) and Khazzoom (1980) and Herring (1999).

As we can see in Figure 2 above, water saving shifts water demand and reduces water equilibrium prices. Water taxes may then be used to reduce water demand effectively and transfer water savings from the market into the environment. The problem of water savings and environmental improvement can now be viewed from a social choice perspective. An improvement in the technical efficiency of water use is an opportunity to improve economic welfare through the provision of both market goods and better environmental quality. Society then has the opportunity to choose what combination of both kind of goods to obtain as a final result. We have already seen how, if no action is taken over water markets prices or quantities, all water saved will be used by the economy to increase the provision of final market goods and the ecological quality of water will remain unchanged (see point C in Figure 4). However, if water prices are increased through an environmental tax, the quantity of water demanded will be reduced and environmental quality will thus be improved. In each case, the resulting welfare changes may be valued through the Hicksian equivalent variation or the quantity of money that will produce the same welfare improvement in the baseline conditions. Figure 4 plots different possible combinations of market welfare and environmental improvements for the example of a water saving measure in the tourism activity in the Balearic economy.

As shown in the figure, there is a clear trade off between market gains (measured by their equivalent variation in the vertical axis) and environmental quality improvements (measured by reductions in water abstractions). Point A is the baseline situation, where no water efficiency action is taken. Point B shows the effect of a water saving program without further actions to translate its effects to the environment. The rest of the frontier shows the combinations available for the society to choose. If prices are properly set there is an intermediate price that will guarantee that the total water saved in some economic activity will be converted into an equivalent water abstraction saving. (see point C in the Figure).

As we can see in the figure, once the water saved initially saved by the tourism activity is completely transferred to the environment there is still some remaining welfare improvement through the provision of market goods. This benefit that cannot be appreciated in a partial equilibrium analysis has a simple explanation in a general equilibrium framework. An input efficiency increase has two different sources of welfare improvements. The first one, a quantitative effect, comes from the reduction of the input requirements to obtain a given production level (because of this we can define efficiency measures as input saved technical changes). The second, a reallocation effect, comes from the redistribution of the inputs between the different economic activities. Transferring water savings to the environment eliminates the first effect from the market but not the second. Provided a proper combination of water management measures is taken, interaction between technical efficiency improvements and water prices may be a powerful way of enhancing the environmental improvements. As we see in Figure 4, the maximum reduction in water abstractions that guarantees the preservation of the previous welfare level is higher than the quantity of water initially saved in the tourism sector. In the Balearic Islands example, the efficiency improvement that initially reduces the current water requirements in the tourism sector in 3.9 Hm^3, if properly combined with a water price increase may be converted in a reduction of nearly 10 Hm^3 without reducing the market income of the overall economy.

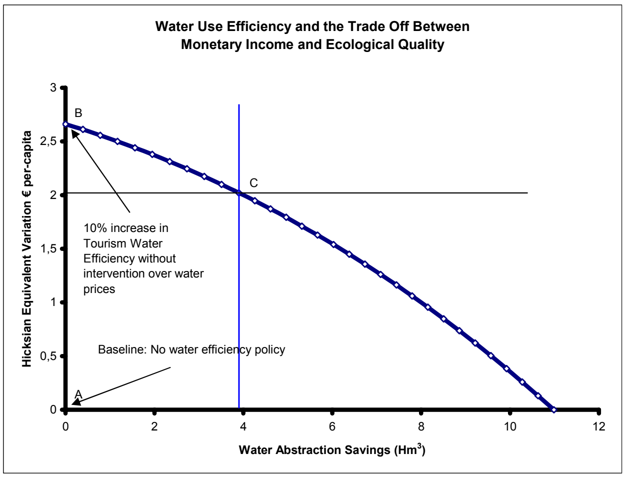

Figure 4: The combination of market goods and water ecosystem quality improvements that results from a water efficiency action form a frontier.

General equilibrium models offer important information about the gains that society may obtain from water policy options both through increases in the market production and environmental improvements. The proper combination between market and non-market goods and services that must result from the water management plan can only be determined by public participation and stakeholder involvement.

IV. A Note on Water Policy and Incentives

Water efficiency policies are subject to a well known incentive problem that can easily be analyzed in the context of our general equilibrium model. Firms and households will only invest in them provided the private benefits are enough to compensate for the opportunity cost of putting water efficiency measures in practice. But this kind of private benefits does not exist at all if any water saved by improving efficiency is transferred to the environment. This incentive problem needs to be solved some how to make water policy feasible If water savings are desirable from a social welfare perspective and some of these savings are to be transferred into reduced economic pressures on the environment, the opportunity cost of water efficiency measures needs to be at least partially financed by the government. For this reason price instruments may be considered a better option than quantity instruments as long as they provide the public revenue needed to finance the water policy measures and to compensate private activities for leaving water savings in the environment instead of using them to increase market welfare.

Our general equilibrium approach shows that a properly designed policy package could meet the ecological targets and produce an income increase that would at least partially compensate for the social costs of implementing those measures. This is the case of point A in figure 4 where the water policy translates into a reduction in water consumption of 3,9 Hm^3 and an increase of per capita income of 2,02€. This monetary figure could be interpreted as the maximum per capita cost of the efficiency measures that could be financed with no social net cost.

More broadly, Figure 5 shows market gains of several water efficiency measures in the tourism sector. A particularity of this figure is that in every case the water savings in the tourism sector results in an equivalent reduction in water abstractions thanks to a proper increase in water price. This market gain determines how much of the costs of implementing the efficiency measures could be financed by the income increases resulting from the same water policy. For the policy maker it would be interesting to devise water policy instruments to capture this additional income in order to finance the efficiency measures.

These examples show how a win-win water policy strategy can be built to use water efficiency gains in a way that improves the environment without reducing the market driven welfare and using those gains to make private incentives compatible with the objectives of the water management plan.

V. Distributional effects of water savings measures.

An additional merit of a general equilibrium approach compared to partial equilibrium is that it allows an analysis of the specific effects of water policy options on the different production sectors as well as a calculation of distributional effects.

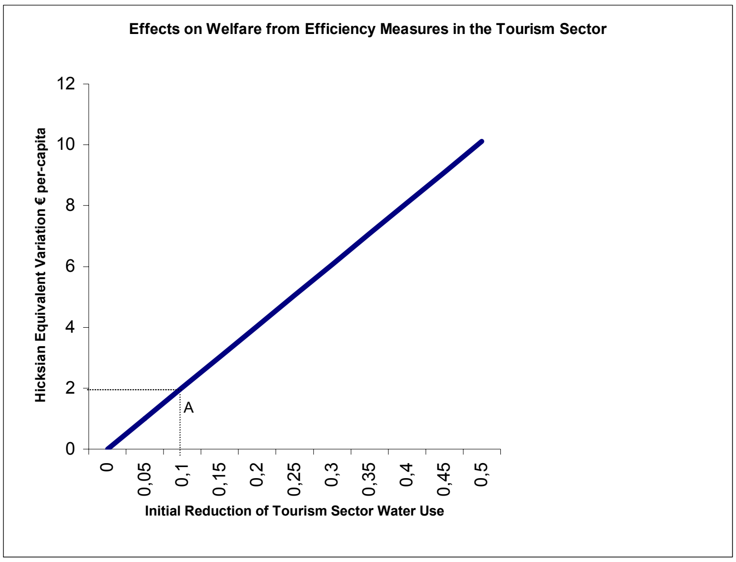

Figure 5: More ambitious water efficiency measures in the tourism sector imply higher market gains even if water savings fully translate into lower water abstraction.

As an illustration, Figure 6 shows changes in Gross Value Added of several production sectors in the Balearic Islands that result from the combination of a 10% increase in water use efficiency by the tourism sector and water price policy measures.

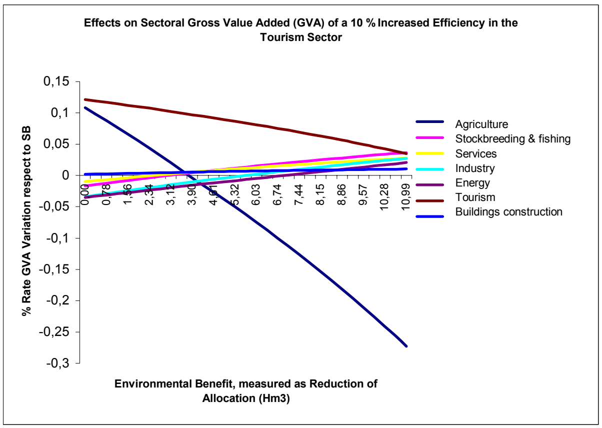

Figure 6. Water policy measures may have quite diverging effects on the different productive sectors.

Market effects are more important in tourism and agriculture. On the one hand, given that tourism benefits directly from the water efficiency policy, this is the only sector that increases GVA in any of the possible scenario. On the other hand, the agriculture benefits from the policy package for the cases of low ecological improvement, but it is very negatively affected by price increases associated to more ambitious ecological targets. This large sensitivity of agriculture is due to low substitution possibilities between water and other inputs in the agriculture technology.

The behaviour of the rest of sectors is determined by the reallocation of other production factors from or to tourism and agriculture. Thus, most of the productive sectors contract at low levels of ecological improvement to provide for factors demanded by the expansion of agriculture and tourism, whilst they increase their activity at high levels of ecological improvement to absorb those inputs released by the agriculture.

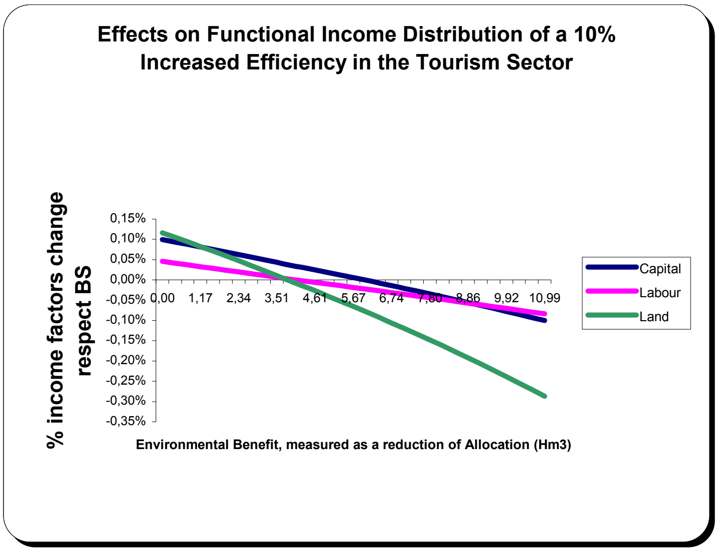

Figure 7. Functional income distribution may be affected by water saving policy.

Regarding functional income distribution, in Figure 7 the impacts on labour, capital and land income of the aforementioned policy package are shown as a function of the degree of ecological benefits.[3] Consistently with figure Z, agricultural land income is the most affected by the water policy measures, while labour income is the less sensitive one due to high labour mobility between different sectors.

VI. Markets vs Prescription

As an illustration on how applied general equilibrium models allow us to compare different institutional settings to allocate raw water property rights in the economy we analyse the potential welfare gains associated with the development of a water market between the rural and the drinking supply sector during drought periods.

The benchmark, or the calibrated baseline scenario, in which no water exchanges are allowed, is basic in order to obtain the “no water market situation” (*NM*). The counterfactual situation where water rights are possible (*WM*) is obtained by assuming that water endowments can be freely sold until their marginal productivity is equated among the agricultural and the drinkable water production.

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.

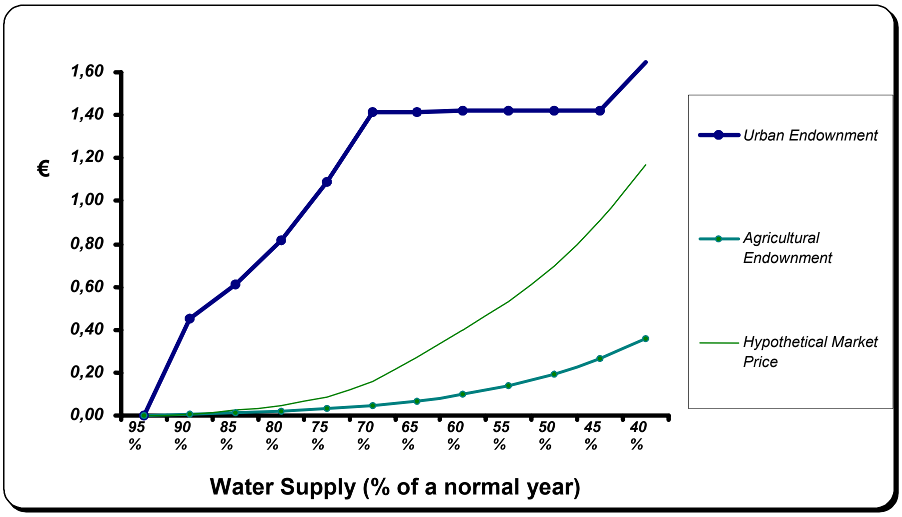

Figure 8. Shadow prices and market prices of raw water

Figure 8 shows the relevant water prices for different drought levels. In the non-market situation, represented by the bold lines traced for the price of urban raw water endowment (*Puw*) and the price of raw water endowment for agriculture (*Paw*), 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 desalinisating seawater becomes profitable. A further increase in the shadow price of urban water will take place only when the capacity of the desalinisation plant if fully used in a severe drought which reduces the water supply in more than 55 per cent.

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 8 by the intermediate price line that is obtained in the counterfactual market situation when the price of water is equalised for any

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[3] Land only refers to agricultural land. Income of urban land is considered to be a part of capital income.

economic use (*Pm*). Figure 9 shows the water quantity that may be effectively sold by the rural sector.

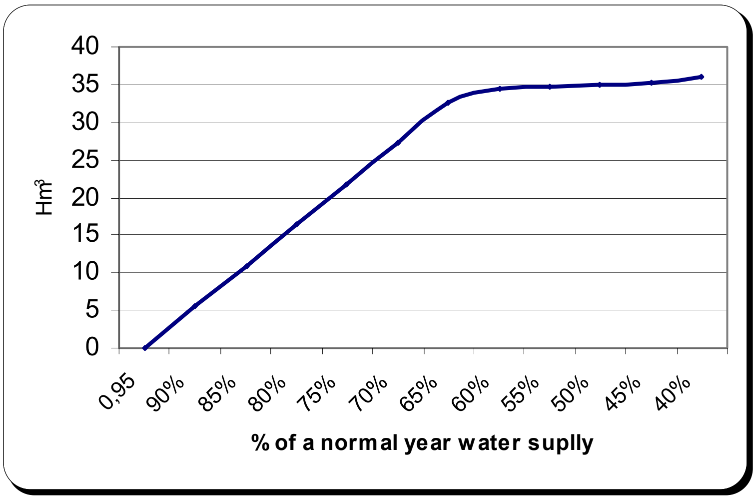

Figure 9. Total transferred water

A hypothetical water market would reduce the negative impact of drought over drinking water consumption. As shown in Figure 10, in a non-market situation (the lower curve) the production of drinking water needs to be severely reduced to increase water prices until the 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 per cent. 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 per cent is reached (as shown in figure 11). 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.

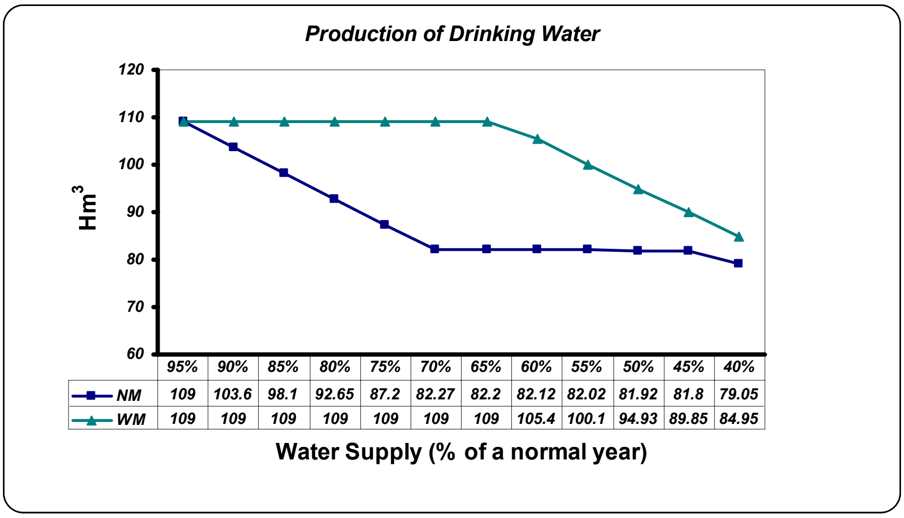

Figure 10. Production of drinking water

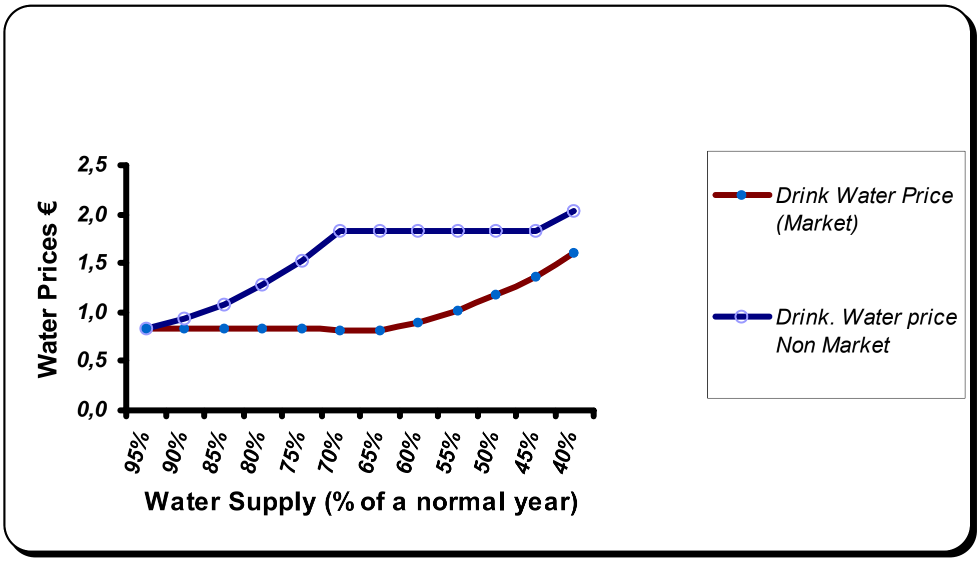

Figure 11. Drinking water equilibrium prices and drought severity

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 desalinisation plant represents this kind of facilities. As can be seen in Figures 8 to 11, the desalinisation plant is only active now when voluntary water exchanges are not allowed. In other words, water markets could be an important means of obtaining 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 desalinisation plant is operative implying higher production costs for the entire economy.

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Technical Annex

The General Equilibrium Model of the Balearic Economy

Economic Activities:

The model considers ten economic activities, rain fed agriculture, irrigated agriculture, the rest of primary activities (livestock, mining, fishing, etc.), two complementary sectors of drinking water (the traditional one and the one based on desalinisation of sea water), and the sectors of energy, manufacture, construction, tourism and services.

Production Factors

The economy uses five production factors: land, capital, labour, water and seawater. Land is only used in agriculture and is mobile among both the irrigated and rain fed crops. Capital is specific of any sector except in between agricultural activities. Labour is mobile. Farmers and water supply firms own some water rights over underground water and they are not initially allowed to buy or sell these water rights. Raw water is a primary non-transferable production factor that may be extracted where water is produced with a certain cost using energy. Drinking water is produced and distributed by using raw water, capital, labour and intermediates. Sea water supply is assumed fixed and determined by the available desalinisation capacity.

Economic Agents

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, labour, 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.

External Trade

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.

Macroeconomic Equilibrium

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 non-traded goods. Import demand and export supply are determined by external prices and are both defined by using the normal Armington assumptions. The foreign demand for tourism services presents constant substitution elasticity.

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[4].

Model Data

The basic data comes from the 1997 Input Output table of the Balearic Islands (TIOB/1997) from which we built the social accounting matrix (*SAM*) presented in Table A.3.

Agricultural data comes from the National Agrarian Accounting Network (Red Contable Agraria Nacional- MAPA, 1999) and the Balearic Labour income was obtained by adding wages and social security payments. Land rents were obtained from data provided by the land price survey of 1997. For simplicity, we treat tourist consumption as exports[5].

Water endowments were obtained from the *Hydrological Plan of the Balearic Island*s, Govern de les Illes Balears, 1999, (see table 1 in the appendix 2). The agricultural endowment has been calculated from the effective water consumption data of *Plan National of Irrigated Land* (MAPA, 2001), considering a return flow of 22%, and from data of hectares irrigated for the differents corps in 1997.

For the water desalinisation 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 sea water in the baseline scenario) and capital and supplies costs provided by CEDEX, 1995 and Torres, 2001.

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 2 in Appendix 2).

Model Calibration

The model has been calibrated by using the MPSGE (*Mathematical Program System for General Equilibrium*) module of the GAMS (*General Algebraic Modelling System*) programming platform (*GAMS*, 2001).

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[4] Given the lack of data we assume that this subsistence level is equivalent to the 70 litres per day recommended by the United Nations, see SCEA (1999).

[5] Also collective or public consumption was assumed as part of the consumption expenditure of the representative agents.

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.

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, labour price is taken as numerary[6].

Mathematical Description of the Model

I. Production Technology of the Irrigated Agricultural Sector

$$RW_{reg} = min\left\{\frac{AS_{reg}}{aa_{reg}}, \frac{A_{en,reg}}{ee_{reg}}\right\} \qquad (1)$$

RW_{reg}	Composite input –water for crops
AS_{reg}	Volume of underground water used
$A_{en,\,reg}$	Use of the Armington aggregate of the energy sector
aa_{reg} ee_{reg}	Leontief coefficients

$$KT_{reg} = A_{reg}^{kt}\left[\beta_{reg}^{kt} K_{reg}^{\rho_{reg}^{kt}} + \left(1-\beta_{reg}^{kt}\right) T_{reg}^{\rho_{reg}^{kt}}\right]^{\frac{1}{\rho_{reg}^{kt}}} \qquad (2)$$

KT_{reg}	Composite Land Capital
K_{reg}	Capital
T_{reg}	Land
A_{reg}^{kt}	Efficiency parameter
β_{reg}^{kt}	Capital share parameter
ρ_{reg}^{kt}	Substitution parameter
σ_{reg}^{kt}	Substitution Elasticity

$$KTW_{reg} = A_{reg}^{ka}\left[\beta_{reg}^{ka} KT_{reg}^{\rho_{reg}^{ka}} + \left(1-\beta_{reg}^{ka}\right) RW_{reg}^{\rho_{reg}^{ka}}\right]^{\frac{1}{\rho_{reg}^{ka}}} \qquad (3)$$

KTW_{reg}	Composite KT_{reg} y RW_{reg}
A_{reg}^{ka}	Efficiency parameter
β_{reg}^{ka}	Share parameter.
ρ_{reg}^{ka}	Substitution parameter

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[6] The model and data are available from authors upon request.

σ^{ka}_{reg}	Substitution elasticity

$$KLTW_{reg} = A^{la}_{reg}\left[\beta^{la}_{reg} L_{reg}^{\rho^{la}_{reg}} + \left(1-\beta^{la}_{reg}\right) KTW_{reg}^{\rho^{la}_{reg}}\right]^{\frac{1}{\rho^{la}_{reg}}} \tag{4}$$

$KLTW_{reg}$	Composite KTW_{reg} and labour.
L_{reg}	Labour
A^{la}_{reg}	Efficiency parameter.
β^{la}_{reg}	Share parameter.
ρ^{la}_{reg}	Substitution parameter.
σ^{la}_{reg}	Substitution elasticity.

$$Y_{reg} = min\left\{\frac{KLTW_{reg}}{vaa_{reg}}, \frac{A_{1,reg}}{iia_{1,reg}}, \frac{A_{2,reg}}{iia_{2,reg}}, \dots, \frac{A_{g,reg}}{iia_{g,reg}}, \frac{II_{1,reg}}{iia_{1,reg}}, \frac{II_{2,reg}}{iia_{2,reg}}, \dots, \frac{II_{i,reg}}{iia_{i,reg}}\right\} \tag{5}$$

$g \in BM$	Set of traded production sectors.
$i \in BNM$	Set of non-traded production sectors
Y_{reg}	Output of irrigated agriculture
$II_{i,reg}$	Use of the Intermediate Input of the sector *i*
$A_{g,reg}$	Use of the Armington aggregate of the sector *g*
vaa_{reg} $iia_{g,reg}$ $iia_{i,reg}$	Technical fixed coefficients

II. Production Function of the non-irrigated agricultural sector

$$KT_{\sec} = A^{kt}_{\sec}\left[\beta^{kt}_{\sec} K_{\sec}^{\rho^{kt}_{\sec}} + \left(1-\beta^{kt}_{\sec}\right) T_{\sec}^{\rho^{kt}_{\sec}}\right]^{\frac{1}{\rho^{kt}_{\sec}}} \tag{6}$$

KT_{sec}	Composite Land Capital
K_{sec}	Capital
T_{sec}	Land
$A^{kt}_{\sec}$	Efficiency parameter
$\beta^{kt}_{\sec}$	Share parameter
$\rho^{kt}_{\sec}$	Substitution parameter
$\sigma^{kt}_{\sec}$	Substitution elasticity.

$$LKT_{\sec} = A^{lk}_{\sec}\left[\beta^{lk}_{\sec} L_{\sec}^{\rho^{lk}_{\sec}} + \left(1-\beta^{lk}_{\sec}\right) KT_{\sec}^{\rho^{lk}_{\sec}}\right]^{\frac{1}{\rho^{lk}_{\sec}}} \tag{7}$$

LKT_{sec}	Composite Land Capital Labour
L_{sec}	Labour
$A^{lk}_{\sec}$	Efficiency parameter
$\beta^{lk}_{\sec}$	Share parameter

$\rho_{\sec}^{lk}$	Substitution parameter
$\sigma_{\sec}^{lk}$	Substitution elasticity.

$$Y_{\sec} = min\left\{\frac{LKT_{\sec}}{vaa_{\sec}}, \frac{A_{1,\sec}}{iia_{1,\sec}}, \frac{A_{2,\sec}}{iia_{2,\sec}}, \ldots, \frac{A_{g,\sec}}{iia_{g,\sec}}, \frac{II_{1,\sec}}{iia_{1,\sec}}, \frac{II_{2,\sec}}{iia_{2,\sec}}, \ldots, \frac{II_{i,\sec}}{iia_{i,\sec}}\right\} \tag{8}$$

Y_{sec}	Output of non-irrigated crops
$II_{i,sec}$	Use of the Intermediate Input of the sector *i*
$A_{g,sec}$	Use of the Armington aggregate of the sector *g*
vaa_{sec}, $iia_{g,\ sec}$, $iia_{i,\ sec}$	Technical fixed coefficients

III. Overall agricultural output

$$Y_{agr} = f\left(Y_{reg}, Y_{\sec}\right) = A_{agr}\left[\beta_{agr} Y_{reg}^{\rho_{agr}} + \left(1-\beta_{agr}\right) Y_{\sec}^{\rho_{agr}}\right]^{\frac{1}{\rho_{agr}}} \tag{9}$$

Y_{agr}	Agricultural output
A_{agr}	Scale parameter
β_{agr}	Share parameter
ρ_{agr}	Substitution parameter
σ_{agr}	Substitution elasticity

IV. Water production and distribution

$$Y_{wp} = min\left\{\frac{K_{wp}}{ka_{wp}}, \frac{L_{wp}}{la_{wp}}, \frac{AS_{wp}}{au_{wp}}, \frac{A_{1,wp}}{iia_{1,wp}}, \frac{A_{2,wp}}{iia_{2,wp}}, \ldots, \frac{A_{g,wp}}{iia_{g,wp}}, \frac{II_{1,wp}}{iia_{1,wp}}, \frac{II_{2,wp}}{iia_{2,wp}}, \ldots, \frac{II_{i,wp}}{iia_{i,wp}}\right\} \tag{10}$$

Y_{wp}	Water produced
K_{wp}	Capital
L_{wp}	Labour
AS_{wp}	Raw water
ka_{wp} la_{wp} au_{wp} $iia_{g,wp}$ $iia_{i,wp}$	Technical fixed coefficients
$II_{i,wp}$	Use of the Intermediate Input of the sector *i*
$A_{g,wp}$	Use of the Armington aggregate of the sector *g*

V. Water production from desalinisation

$$Y_{d} = min\left\{\frac{K_{d}}{ka_{d}}, \frac{L_{d}}{la_{d}}, \frac{AM_{d}}{ma_{d}}, \frac{A_{1,d}}{iia_{1,d}}, \frac{A_{2,d}}{iia_{2,d}}, \ldots, \frac{A_{g,d}}{iia_{g,d}}\right\} \tag{11}$$

Y_{d}	Output
K_{d}	Capital
L_{d}	Labour
AM_{d}	Quantity of sea water
ka_{d} la_{d} ma_{d} $iia_{g,d}$	Technical fixed coefficients

$A_{g,d}$	Use of the Armington aggregate of the sector *g*

VI. Other products

$$KDW_s = A_s^{kap}\left[\beta_s^{kap} K_s^{\rho_s^{kap}} + \left(1-\beta_s^{kap}\right) D_{w,s}^{\rho_s^{kap}}\right]^{\frac{1}{\rho_s^{kap}}} \tag{12}$$

KDW_s	Composite Capital-water
K_s	Capital used by sector *s*
$D_{w,s}$	Water used by sector *s*
A_s^{kap}	Efficiency parameters
β_s^{kap}	Share parameters
ρ_s^{kap}	Substitution parameter
σ_s^{kap}	Substitution elasticity.

$$VAP_s = B_s^{vap} L_s^{\alpha_s^{vap}} KDW_s^{\left(1-\alpha_s^{vap}\right)} \tag{13}$$

VAP_S	Composite *KDW* and Labour
L_s	Labour
B_s^{vap}	Efficiency parameter
α_s^{vap}	Share parameter

$$Y_s = min\left\{\frac{VAP_s}{vva_s}, \frac{A_{1,s}}{iia_{1,s}}, \frac{A_{2,s}}{iia_{2,s}}, \ldots, \frac{A_{g,s}}{iia_{g,s}}, \frac{II_{co,s}}{iia_{co,s}}\right\} \tag{14}$$

Y_s	Production of sector *s*
$II_{co,s}$	Use of the Intermediate Input of the sector *i*
$A_{g,s}$	Use of the Armington aggregate of the sector *g*
vva_s $iia_{g,s}$ $iia_{co,s}$	Technical fixed coefficients

VII. Investment

$$INV = min\left\{\frac{A_{1,inv}}{in_{1,inv}}, \frac{A_{2,inv}}{in_{2,inv}}, \ldots, \frac{A_{g,inv}}{in_{g,inv}}, \frac{D_{1,inv}}{in_{1,inv}}, \frac{D_{2,inv}}{in_{2,inv}}, \ldots, \frac{D_{i,inv}}{in_{i,inv}}\right\} \tag{15}$$

INV	Production of capital goods
$D_{i,inv}$	Use of the domestic production of the sector *i*
$A_{g,inv}$	Use of the Armington aggregate of the sector *g*
$in_{g,inv}$ $in_{i,inv}$	Technical fixed coefficients

VIII. External trade

Transformation function

$$g\left(D_s, X_s\right) = A_s^t\left[\theta_s D_s^{\eta_s} + \left(1-\theta_s\right) X_s^{\eta_s}\right]^{\frac{1}{\eta_{sr}}} \tag{16}$$

D_s	Domestic demand for products of sector s
X_s	Export demand for goods of sector s
A_s^t	Scale parameters of the sector s
θ_s	Share parameters
η_s	Transformation parameter
Ω_s	Transformation elasticity.

Armington aggregate

$$A_g = A_g^{ar}\left[\alpha_g D_g^{\rho_g^{ar}} + \left(1-\alpha_g\right) M_g^{\rho_g^{ar}}\right]^{\frac{1}{\rho_g^{ar}}} \qquad \forall g \qquad (17)$$

D_g	Domestic output of the sector g
M_g	Import demand of sector *g*
A_g^{ar}	Scale parameter of the sector g
α_g	Share parameters *g*
ρ_g^{ar}	Substitution parameters
σ_g^{ar}	Substitution elasticities.

Tourism

$$X_{tu} = \overline{X}_{tu}\left(\frac{PEX_{tu}}{pfx}\right)^{\varepsilon} \qquad (18)$$

X_{tu}	Export demand
$\overline{X}_{tu}$	Initial export demand of tourism.
PEX_{tu}	Price of tourism.
pfx	Real exchange rate
ε	Demand price elasticity

IX. Consumption

$$C = \left(C_w - \gamma_w\right)^{\alpha_w^c} C_{co}^{\alpha_{co}^c} \prod_{g=1}^{6} C_g^{\alpha_g^c} \qquad (19)$$

$g \in BM$	set of traded goods
C_w	drinking water consumption
C_{co}	construction goods consumption
C_g	Sector g produced goods consumption
γ_w	Minimum subsistence consumption of drinking water
$\alpha_g^c \;\; \alpha_{co}^c \;\; \alpha_w^c$	Share parameters

Table A.1. Baseline Water Demand and Water Sources per Sector (hm^3/year)

	Underground	Desalinisation	Water Reservoirs	Waste water	Total	Consumption share (%)
Public Consumption	100.7	3.73	7.2	1.8**	113.43	38.8
Irrigation	159.5	-	-	15.03	174.53	59.7
Industry*	0.7	-	-	-	0.7	0.2
Golf irrigation	0.8	-	-	2.94	3.74	1.3
Total	261.7	3.73	7.2	19.77	292.4	100
Supply share (%)	89.5	1.3	2.5	6.7	100	

Source: elaborated from data of the PHIB, Govern de les Illes Balears (1999).
*Private uses not connected to the public water network.
**Used to irrigate public gardens and parks.

Table A.2. Parameters of the Balearic CGE Model

Elasticities	Values
Substitution Elasticity in the Irrigated Agricultural sector	
Capital and Land [a]	$\sigma_{reg}^{kt} = 0.3$
Aggregate Capital-Land and aggregate Water *for crops*	$\sigma_{reg}^{ka} = 0.2$
Land and aggregate Capital-Land-Water for crops [a]	$\sigma_{reg}^{va} = 0.7$
Substitution Elasticity in the Non-irrigated Agricultural sector	
Capital and Land	$\sigma_{\sec}^{kt} = 0.3$
Labour and aggregate Capital-Land	$\sigma_{\sec}^{va} = 0.7$
Substitution Elasticity in Other Sectors	
Capital and Water	$\sigma_{s}^{kap} = 0.3$
Substitution Elasticity Between Imported and Domestically Produced Goods [b]	$\sigma_{g}^{ar} = 4$
Substitution Elasticity between irrigated and non-irrigated agricultural products	$\sigma_{agr} = 1$
Price Elasticity of Export demand for Tourism [c]	$\varepsilon = -2$
Transformation Elasticity of production [d]	$\Omega_{agr} = \Omega_{s} = 2$

[a] Boyd and Newman (1991) and Seung *et al.* (1998).
[b] Rutherford and Paltsev (1999) y Goodman (2000).
[c] Blake (2000).
[D] Equal to all sectors and obtained as the average of the transformation elasticities considered in Seung ET. al. (1998)

Table A.3. Input-Output of the Balearic Islands 1997, aggregated in 10 sectors (millions of euros.)

		AGRIC.	Non-Irrig.	Irrig.	LIVEST.	ENERGY	WATER PRODUCTION	MANUF.	CONST.	TOURISM	SERVICES	INTERM.	EXPORTS	INVESTM.	FINAL CONSUMP.	FINAL DEMAND	TOTAL USE
		1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**
AGRICULTURE	**1**		0.46	5.58	18.15			66.15	0.17	57.83	3.33	151.68	77.11	1.93	160.84	239.88	391.56
Non-irrigated	**2**																
Irrigated	**3**																
LIVESTOCK and FISHING	**4**		0.01	0.72	0.06			136.19		60.05	1.17	198.22	9.24	1.08	88.36	98.68	296.90
ENERGY	**5**		1.16	10.08	13.09	98.17	6.40	42.03	18.98	140.22	328.46	658.58		4.46	349.33	353.79	1,012.37
WATER PRODUCTION	**6**		0.00	1.69	0.21	0.10	0.51	2.04	0.07	32.81	13.51	50.94		2.61	38.13	40.74	91.67
MANUFACTURE	**7**		3.99	8.34	42.97	1.72	1.10	622.38	502.19	599.73	371.82	2,154.25	989.87	449.61	2,339.56	3,779.03	5,933.28
CONSTRUCTION	**8**		0.00	1.81	0.60	0.90	0.26	10.04	1.68	118.25	210.98	344.51		1,980.01	167.02	2,147.02	2,491.53
TOURISM	**9**		0.01	0.19	0.29	0.41	0.28	6.87	6.86	72.55	66.12	153.58	4,642.22		880.65	5,522.87	5,676.45
SERVICES	**10**		2.79	15.57	14.41	25.89	13.98	256.97	565.63	703.23	1,789.37	3,387.84	999.32	306.68	5,069.41	6,375.42	9,763.26
INTERMEDIATES	**11**		8.42	43.98	89.78	127.19	22.52	1,142.68	1,095.58	1,784.68	2,784.77	7,099.60	6,717.76	2,746.37	9,093.30	18,557.43	25,657.03
Labor	**12**		10.47	16.81	40.38	88.47	42.23	374.53	632.27	1,401.35	3,313.54	5,920.06					
Land	**13**		4.95	10.27								15.22					
Capital	**14**		18.99	60.33	54.83	92.54	35.97	295.87	662.47	2,100.77	3,085.81	6,407.57					
Gross Value Added fp*	**15**	121.82	34.41	87.41	95.21	181.00	78.19	670.40	1,294.74	3,502.12	6,399.35	12,342.85					
Indirect Taxes	**16**	0.80	0.70	0.10	0.68	0.93	1.02	7.06	7.56	19.57	63.35	100.97					
Subsidies	**17**	13.47	11.22	2.25	10.93	4.12	17.11	6.92	0.47	16.79	294.98	364.79					
Gross Value Added mp*	**18**	109.16	23.90	85.26	84.96	177.82	62.10	670.53	1,301.84	3,504.90	6,167.72	12,079.03					
TOTAL OUTPUT	**19**	161.56	32.32	129.24	174.74	305.01	84.62	1,813.21	2,397.41	5,289.58	8,952.50	19,178.63					
IMPORTS	**20**	221.90			115.37	698.04		4,034.48		112.76	178.85	5,361.40					
VAT	**21**	8.10			6.79	9.32	7.06	85.59	94.12	274.11	631.91	1,117.00					
TOTAL SUPPLY	**22**	391.56			296.90	1,012.37	91.67	5,933.28	2,491.53	5,676.45	9,763.26	25,657.03					

Source: Elaborated from 1997 input-output table of the Balearic Islands (Govern de les Illes Balears, 2004).
*At factor prices
** At market prices

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