water

MDPI

Article

Water and Agriculture in a Mediterranean Region: The Search for a Sustainable Water Policy Strategy

Maria Llop * and Xavier Ponce-Alifonso

Research Centre on Industrial and Public Economics (CREIP) and Department of Economics, Universitat Rovira i Virgili, Avda Universitat 1, Reus 43204, Spain; xavier.ponce@urv.cat
* Correspondence: maria.llop@urv.cat; Tel.: +34-977-759898; Fax: +34-977-758907

Academic Editors: Sharon B. Megdal, Susanna Eden and Eylon Shamir
Received: 17 November 2015; Accepted: 5 February 2016; Published: 19 February 2016

Abstract: This paper analyzes two of the main challenges facing agriculture in Europe: technological changes and the application of the principle of cost recovery to water services. Our study takes into account the economic, social, and ecological consequences associated with these measures. Specifically, we consider the effects of these two situations not only on water consumption, but also on environmental, social, and economic indicators. Our study also includes two institutional scenarios involving the possibility or impossibility of performing transactions in formal water markets. By using a computable general equilibrium (CGE) model for the economy of Catalonia, a region located in Northeastern Spain, our results suggest that institutions related with water markets matter in terms of the effects that agricultural policies cause on water resources. They also suggest that greater economic efficiency is not necessarily optimal if we consider social or environmental criteria.

Keywords: agricultural technological change; computable general equilibrium model; economic impact; water policy

1. Introduction

Water has historically been considered an abundant resource in Spain. However, there have always been considerable differences in the temporal and spatial distribution of water across the country.

In the late nineteenth century, an intellectual and political movement called regenerationism established a link between the problem of water and the Spanish economy's backwardness compared to other European countries [1]. According to this movement, water infrastructure would enable the expansion of irrigated agriculture and, thus, increased productivity, which in turn would lead to an increase in agricultural exports and an improvement in the trade balance. Furthermore, these necessary infrastructures would not only facilitate the settlement of the population throughout the territory, but would also generate the hydropower necessary to drive industrial development. Given the difficulties in obtaining the private funding needed, the idea that the public sector should take charge of planning and financing these waterworks slowly began to gain momentum [2]. Public funding would enable users to have access to water at a price below its real cost, thereby encouraging the expansion of irrigation and the modernization of the country. This new water supply policy, therefore, became a win-win game, ensuring profits for farmers, builders, hydropower companies, and financial institutions [3]. It was also seen by the political class as a way to gain legitimacy, support, and prestige. This convergence of interests explains the effort made throughout the twentieth century to transform Spain into the European country with the largest number of reservoirs.

However, over time this water supply policy has become a problem rather than a solution. In a scenario of rapid growth of water demand for non-agricultural uses, and a slowdown of investment to expand supply, the water policy has not prevented an increasing water shortage in some parts of

Spain, such as Catalonia. The main criticism of this water supply policy is that the low price of water has not created incentives to use it efficiently. As a result, despite the large volume of water used by farmers, the price they traditionally paid for this resource did not reflect its real cost, and hid a cross-subsidization between different users. This situation hindered the ability of prices to transmit shortage signals and led to mismanagement of the resource, comprising huge losses in distribution channels, the use of out-dated irrigation techniques, and the production of low-yielding crops, among other problems.

As water scarcity increased, a change in water policy became a matter of urgency. The new water policy implemented in Spain in recent decades encourages a more efficient and sustainable use of water, but also considers releasing water from agriculture to other activities with a higher economic or social value [4]. However, a more efficient use of water in agriculture does not necessarily save water but, instead, as noted by the Jevons' Paradox, may eventually lead to an increase in the amount of water consumed [5,6]. Given this possibility, the literature has considered various institutional scenarios that would help to mitigate these adverse effects.

In this paper, we analyze the impacts of technological changes in agriculture, considering different institutional frameworks. First, we consider the existence of formal water markets; second, we analyze the application of the full cost recovery principle for water services contained in the European Union Water Framework Directive [7]. These two factors are among the most important measures that have been applied in the Spanish water policy in the recent years. Our analysis considers not only how these measures contribute to saving water, but also their economic impact both at an aggregated and disaggregated level.

In order to analyze the effects of technological change in agriculture in Catalonia and to discuss the issues mentioned above, we define a static computable general equilibrium (CGE) model using a social accounting matrix (SAM) database with the most recent data available, which is for 2001. We chose Catalonia because, as a Mediterranean region, it can be regarded as a typical case in which Spanish water problems have been even more intensive than at the national level (dependency on rainfall, predominance of agriculture in water uses, high population density, high levels of economic activity, *etc.*).

Over the last 20 years, CGE models have largely been used to analyze the effects of agricultural productivity gains in areas such as poverty, food production, and trade. For instance, Lofgren and Robinson [8] presented some modifications to the specified standard CGE models to incorporate a more realistic technology in the agricultural sector. Arndt *et al.* [9] used the CGE approach to analyze both improvements in agricultural productivity and reductions in marketing costs in Mozambique. Prasada [10] studied the general equilibrium impacts of technological changes in Canadian agriculture, which were modeled as productivity rises in the use of intermediate inputs and primary factors. More recently, Belhaj *et al.* [11] investigated the influence of trade openness on both agricultural technological change and poverty in the Tunisian economy.

The CGE framework has also been extensively used to investigate water issues. In general, the CGE literature has treated water as a commodity subject to the market and, accordingly, there is a price for that commodity that is used to obtain the corresponding agents' demands. Among other contributions, Berck *et al.* [12], Seung *et al.* [13] and Goodman [14] used CGE analysis for water issues in various regions of the United States. Diao and Roe [15] studied the general equilibrium effects of some possible reforms in the water management in Morocco. Gómez *et al.* [16] presented a CGE analysis of water issues in the Balearic Islands; Letsoalo *et al.* [17] applied the CGE analysis to South Africa; Strzepek *et al.* [18] constructed a CGE model to analyze the effects of the construction of the Aswan dam in the Egyptian economy; and Lennox and Diukanova [19] applied a general equilibrium model to water reallocation in Canterbury. At the global level, Berrittella *et al.* [20] showed the potential of CGE analysis by providing a multi-regional model of the world economy that evaluated sustainable water supply uses. Most of the CGE water contributions treat water as an input used in the production system and define both the intermediate and the final usages of water. Moreover, these contributions usually focus on the impacts of an exogenously defined water reallocation and water policy in the economic system.

The structure of this paper is as follows. Section 2 describes the main features of the regional CGE model and Section 3 shows the simulation analysis undertaken and the main results. In the last section, we make some concluding remarks.

2. The Model

Computable general equilibrium techniques have advantages over other partial equilibrium models, as they provide a complete representation of the economic agents and their optimization behavior [21]. CGE models also take into account all the interactions between economic agents by completing the representation of the circular flow of income and accordingly, are not limited to the production side of the economy. Moreover, CGE models allow consideration of nonlinearities in the equations that define the optimization rules of economic agents and are, therefore, a useful method for capturing the complex interrelations within an economy.

The definition of equilibrium used in our model is based on the Walrasian notion, which has been extended to include not only producers and consumers, but also government and foreign agents. Analytically, the model is a set of equations containing the equilibrium conditions of all economic agents and all markets. The solution of the model consists of a set of endogenous variables (a vector of prices, a vector of activity levels, and other macroeconomic indicators) that clear all markets and allow all agents to reach their optimization plans.

2.1. Production

The structure of production assumes perfect competition in all markets. It shows 16 differentiated sectors (j = 1,...,16), with one representing the agricultural activity (j = 1) and one representing the production and distribution of water (j = 3).

Each sector is assumed to produce a homogeneous final good and has a nested technology that shows constant returns-to-scale in production. The first level of the production function defines the total output in each sector (Q_j), following the Armington specification [22], using a Cobb–Douglas aggregator of domestic production (X_{dj}) and imports from abroad (X_{Mj}):

$$Q_j = \delta_j X_{dj}^{\gamma_j} X_{Mj}^{1-\gamma_j} \qquad j = 1, \ldots, 16 \tag{1}$$

The second level of the production function defines the domestic production. Our analysis assumes that domestic production complies with a Cobb–Douglas combination of intermediate inputs and value added, as follows:

$$X_{dj} = \lambda_j X_{1j}^{\varphi_{1j}} X_{2j}^{\varphi_{2j}} \ldots X_{16j}^{\varphi_{16j}} VA_j^{\varphi_{vj}} \qquad j = 1, \ldots, 16 \qquad \sum_{j=1}^{16} \varphi_{kj} + \varphi_{vj} = 1 \tag{2}$$

where j = 1,...,16 represent the production activities, X_{dj} is the domestic production in j, λ_j is a scale parameter, φ_{kj} are parameters that show the response of X_{dj} when there are changes in X_{kj}, and VA_j is the value added of j.

The production function in Equation (2) allows us to analyze different institutional frameworks related to water policy. Since a Cobb–Douglas function allows a certain degree of substitutability between productive factors, this situation can be interpreted as a scenario in which there is a water market that facilitates substitutability through the buying and selling of water use rights. On the contrary, the absence of water markets is represented in the model by fixing the level of activity in the sector of water distribution (j = 3). This situation could be interpreted as a scenario of null changes in the quantities of water sold to other sectors and this would, therefore, implicitly mean that no water market to exchange water exists.

The sectoral value added, which is defined in the last (third) level of the production function, is obtained by combining labour and capital using a Cobb–Douglas function:

$$\begin{gathered} VA_j = \beta_j L_j^{1-\alpha_j} K_j^{\alpha_j} \\ j = 1, \ldots, 16 \end{gathered} \tag{3}$$

where L_j and K_j are the labor and capital, respectively, in sector j, and α_j and β_j are the parameters or exogenous variables obtained through calibration.

2.2. Consumers

Our CGE model includes a private consumer that maximizes a Cobb–Douglas utility function (in logarithms) according to Equation (4):

$$\begin{gathered} U = \sum_{h=1}^{10} \gamma_h \ln c_h + \gamma_s \ln c_s \\ \gamma_h, \gamma_s > 0; \\ \sum_{h=1}^{10} \gamma_h + \gamma_s = 1 \end{gathered} \tag{4}$$

The model differentiates two types of goods: production goods (j = 1,...,16) and consumption goods (h = 1,...,16). Consumption goods are a combination of production goods obtained through a conversion matrix of fixed and linear coefficients. In Equation (4), C_h represents the consumption of good "h" and C_S is the private saving or future consumption. The model identifies the final demand for water (h = 3) that corresponds to the amounts of water production used by the final demand of the economy.

The objective of consumers is to maximize their utility subject to the budget constraint. This constraint establishes that households' expenditure (arising from consumption and saving) cannot exceed their disposable income (arising from labor income, capital income, and public transfers net of taxation). We obtain the demand functions for consumption goods and saving from the optimization of consumers.

2.3. Public Administration

The model also includes a public agent that is assumed to produce public goods and public services. This agent also demands public services and investment goods. The public administration has a Leontief [23] utility function of public consumption (C_{16}^G) and public investment (C_I^G) in a fixed relation, which is determined by the parameter $\gamma_G > 0$:

$$U^G = \min\left[C_{16}^G, \gamma^G C_I^G\right] \tag{5}$$

The public agent maximizes Equation (5) subject to a budget constraint. In specific terms, this constraint establishes that public consumption and public investment must be equal to public revenues, which come from taxation once social transfers have been subtracted from public revenues. The model also contains a stock of public borrowing or bonds that the public agent can issue in the event of deficit. The public budget is defined as:

$$P_{16} C_{16}^G + P_1 C_1^G \leqslant I^G + \omega_I^G P_I \tag{6}$$

where ω_I^G is the debt that this agent issues if there is a situation of public deficit and I_G is the income from taxation which comes from an indirect tax on consumption, a direct tax on income, taxation on domestic production, and social security taxation. Additionally, the public administration transfers income to consumers and sectors, which have to be subtracted from taxation revenues.

The objective of the public agent is to maximize the utility function (Equation (5)) subject to the public budget constraint (Equation (6)). We obtain both the public consumption demand and the public investment from the solution to this optimization problem.

2.4. Foreign Agent

The foreign sector is assumed to produce a traded good by using regional exports through a fixed coefficients technology. The model assumes that the regional economy may receive income from abroad and may simultaneously make transfers to the external agents.

Additionally, to guarantee the macroeconomic equilibrium between investment and saving at the aggregated level, the model allows a situation of external deficit that must be used as savings by the foreign agent.

2.5. Ecological Sector

As our aim is to show the effects of agricultural technological changes on water resources, our model distinguishes between the water used by economic agents and the total water resources. By taking into account that there is an amount of water not used by the economic activity, usually referred to as the environmental or ecological flow of water, we can approximate the effects of any new situation on the water ecosystems.

In particular, to show the trade-off between the water used by the economy and the environmental flow of water, we define a level of activity in the ecological sector (*Ye*) which is residually calculated by taking into account the natural restriction between the total water endowments and total water uses in the regional economy, as follows:

$$1 = w_3 Y_3 + w_e Y_e \tag{7}$$

where w_3 is the percentage of water resources used by the economy (both by production and consumption activities), w_e is the percentage of ecological water not used in the economy and returned to nature), and, finally, Y_3 represents the level of activity in sector 3 (production and distribution of water). As *Ye* is endogenously determined by the model, Equation (7) assumes that there is no limitation in the amount of water because inter-basin transfers and seawater desalination automatically allow to cover any increase in the uses of water.

2.6. Database

Following the standard procedure in CGE modeling, all the model's parameters are obtained by applying the calibration procedure, which assumes that the initial situation of the economy is a starting equilibrium (benchmark situation). In this situation, the prices and activity levels are equal to one and consequently, the benchmark solution exactly reproduces the empirical information shown in the social accounting matrix database used to calibrate the parameters of the model.

The empirical application is based on a 2001 social accounting matrix of the Catalan economy. We use 2001 data because the regional water statistics available do not provide more recent data.

According to the agents and goods described in the model, the regional SAM shows 16 differentiated activities: one agricultural sector, one sector for the production and distribution of water, nine industrial activities, and five service sectors. The SAM also distinguishes between ten consumption goods, which are those used in the consumers' optimization problem. Our database also shows two factors of production (labor and capital), an account for the private income and expenditures of households, and a capital account containing all the saving and investment in the regional economy. The public agent's accounts involve four different taxes (on domestic production, on household income, on consumption, and on firms' social security contributions) and an account for the income flows and expenditures related to the public sector. Finally, the SAM includes a consolidated account for the foreign sector that simultaneously contains imports, exports, and foreign income transactions in the regional economy.

To calibrate the parameters of the ecological sector, we use additional information on water uses [24]. This information comprises the water resources in the natural regime, which are regulated through dams, groundwater pumping, and water reuse. Our model, therefore, accounts for the water that is used in the economy by sectors and households, and by residual; it also accounts for the ecological water that it is not used by economic activities and is returned to ecosystems.

The first solution in the model consists of calculating the reference equilibrium (the benchmark situation). We then use the model to analyze the effects of technological changes in agriculture on both the economic indicators and the ecological variables (e.g. the ecological flow of water).

As the analytical framework is based on a computable general equilibrium model, it is important to bear in mind some important features of the CGE in order to correctly understand the outcomes of the model. First, one of the model's equilibrium conditions is always redundant under CGE analysis, according to Walras's law [25]. Accordingly, we can take one price as being unitary in all of the perturbations. We assume that this fixed unitary price (the *numéraire*) corresponds to the wage, which will be always equal to one. The implication of this is that prices in all the new equilibriums are not absolute prices, but relative prices with respect to the *numéraire*. Second, the level of activity of the public agent is variable and the public deficit is fixed, whereas the foreign sector has a variable activity level and a fixed deficit.

3. Simulation Analysis

The belief that water was abundant in Spain, but irregularly distributed, meant that redistributing the water throughout the territory could easily solve water issues. However, this situation also led the public administration to pay little attention to inefficient uses of water that was considered to be a good in public ownership.

Nevertheless, the discourse in Spain has begun to change in recent years. Conflicts between territories and between water users have intensified in a context in which water is an increasingly scarce resource. There is, therefore, an increasing need to modernize irrigation and to foster technological changes in order to achieve a more efficient use of water in agriculture. However, the important questions are: (1) what will the environmental effects of this modernization process be; and (2) what institutional arrangements can help to mitigate those potential adverse environmental effects?

3.1. Technological Change in Agriculture Without Water Markets

In recent years, Spanish governments have established a framework of incentives to promote modernization in agriculture irrigation systems: the National Irrigation Plan [26], the A.G.U.A. Programme [27], the Emergency Plan for the Modernization of Irrigation [28], and the National Strategy for the Sustainable Modernization of Irrigation [29]. These supports for technological changes in agriculture are justified by the relative inability of private enterprises to undertake modernization processes, but these grants can also be understood as a compensation for the social benefit generated from the water savings obtained by using more efficient technologies. They can, therefore, be interpreted as compensation paid to farmers for creating positive externalities that contribute to the preservation of the environment.

For example, the National Strategy for the Sustainable Modernization of Irrigation [29] requires that each project for improving the distribution infrastructure of irrigation must include, along with the planned investment, an estimation of the amount of water that the project aims to save. It must also propose training activities that will expand the knowledge and professional skills of farmers, the diversification of activities and the implementation of environmentally-friendly production systems. However, this political support for technological change is not free of controversy because these subsidies are not always sufficient for farmers wishing to implement technological change: the uncertainty about the potential earnings of some innovations and the presence of high sunk costs often lead to a delay in farmers' investments in new technologies [30,31].

Our first simulation analyzes the impact of a 25% increase in the total factor productivity of agriculture by, for instance, modernizing transportation systems and the distribution and application of water. Following the idea that the government should subsidize the required investments to overcome farmers' reluctance to technological change [32], our simulations do not assume any increase in the producers' costs. In other words, technological changes are exogenously applied as a mere modification in TFP, without changing any other variable in the model.

The main results of Simulation 1 are shown in Table 1. Our results show that an increase in TFP reduces agricultural prices (−4.5%), although this is not translated into significant changes in the quantity produced (2.5%). As noted by King's Law, a reduction in agricultural prices only leads to a small variation in the quantity produced. As a result, the fact that agricultural prices plummet in this simulation means that farmers could see a negative impact on their profits.

Table 1. Simulation 1: 25% increase in TPF of agriculture (without water market).

Sectors	Changes in Prices (%)	Changes in Production (%)
1. Agriculture	−4.55%	2.50%
2. Energy	−0.19%	−0.06%
3. Water distribution	−0.28%	0.00%
4. Chemistry	−0.19%	−0.16%
5. Metals and electric equipment	−0.17%	0.04%
6. Automobiles	−0.17%	0.02%
7. Food production	−1.18%	0.07%
8. Textiles	−0.27%	0.03%
9. Paper	−0.15%	−0.02%
10. Other industries	−0.19%	0.03%
11. Construction	−0.03%	0.14%
12. Commerce	−0.10%	0.22%
13. Transports and communications	−0.03%	−0.02%
14. Finance	0.02%	−0.03%
15. Private services	0.00%	0.01%
16. Public services	−0.02%	0.11%
Water variables	**Changes in water variables (%)**	
Final water demand	0.32%	
Intermediate water demand	−0.29%	
Ecological water	0.00%	
Gross domestic production	**Changes in GDP (%)**	
Real GDP	0.31%	

At the regional level, technological change based on growth in TFP leads to a growth in real GDP (0.31%). However, the controversy surrounding incentives to technological change in agriculture is reinforced by doubts about the effect such a change would have on water consumption at the aggregate level. The results suggest that it only leads to a reduction in the level of intermediate water consumption of around 0.3%.

Since measures to improve water efficiency are not effective in reducing the economic pressure exerted on water resources they, therefore, need to be accompanied by other policy measures. We address this issue in the following simulations. Specifically, we analyze the impact of the EU Water Framework Directive and the establishment of formal water markets.

3.2. Technological Change in Agriculture and the EU Water Directive Framework

Water policy must provide suitable external incentives to farmers to use water more efficiently, but water policy must also encourage water savings in agriculture. As the European Union Water Framework Directive points out, water management should promote the sustainable exploitation of water resources so as to meet present needs without endangering the supply for future generations. To achieve this goal, the EU Water Framework Directive requires that water prices in the member countries of the European Union reflect their cost. Although applying the principle of cost recovery to water services can generate an additional cost that causes farmers to lose competitiveness, it can be also a stimulus to start the process of technological change that the state subsidizes.

However, this proposal leads to resistance in the agricultural sector. In fact, the water price for agriculture has been kept low by governments. For example, the average price paid for water in Catalonia is 1.7€/m^3. Nevertheless, if the EU Water Framework Directive's principle of cost recovery for water services was strictly applied, the price of water would increase to 3.30 €/m^3 [33]. The reason for this is that farmers would bear most of the cost of a significant increase in water price and, as the logic of collective action suggests, small distributional coalitions like farmers would have an incentive to form lobbies and influence policies in their favor and could, thus, hurt economic growth. Governments have, therefore, usually avoided applying the principle of cost recovery to water services in agriculture. This hidden subsidy has traditionally been justified by the need for food security and the need to establish equality between farmers with an unequal ability to pay.

In any case, we use our CGE model to simulate technological changes in agriculture in conjunction with a rise in water prices. In specific terms, we apply a 25% tax on the water price to the previous simulation of agricultural technological change. The results of Simulation 2 are shown in Table 2. As in the previous case, the agricultural price decrease (−4.6%) is greater than the increase in the quantity produced (3.2%). Furthermore, real GDP growth is also similar (0.3%). However, unlike the previous simulation, the increase in water price leads to a significant decrease in the level of intermediate water consumption (−8.3%) which is completely offset by an increase in final water demand (11%).

Table 2. Simulation 2: 25% increase in TPF of agriculture and 25% tax on water price (without water market).

Sectors	Changes in Prices (%)	Changes in Production (%)
1. Agriculture	−4.61%	3.22%
2. Energy	−0.44%	0.09%
3. Water distribution	−9.96%	0.00%
4. Chemistry	−0.24%	0.77%
5. Metals and electric equipment	−0.22%	0.71%
6. Automobiles	−0.21%	1.02%
7. Food production	−1.23%	0.88%
8. Textiles	−0.32%	1.03%
9. Paper	−0.20%	0.93%
10. Other industries	−0.24%	0.79%
11. Construction	−0.07%	0.06%
12. Commerce	−0.14%	0.58%
13. Transports and communications	−0.09%	0.55%
14. Finance	0.00%	0.27%
15. Private services	−0.04%	0.13%
16. Public services	−0.07%	−0.04%
Water variables	**Changes in water variables (%)**	
Final water demand	11.09%	
Intermediate water demand	−8.38%	
Ecological water	0.00%	
Gross domestic production	**Changes in GDP (%)**	
Real GDP	0.32%	

3.3. Technological Change in Agriculture and Water Markets

The water market is an institutional arrangement to allocate water among competing users that could enhance the economic efficiency of water uses. The pros and cons of water markets have been discussed widely in the literature [34–37]. Under certain circumstances, water markets could make it easier for farmers to internalize the opportunity cost of using an increasingly scarce resource and this could, therefore, encourage farmers to save water. To that end, the Spanish Water Act was reformed in 1999 by introducing the possibility of transferring water-use rights and, thus, enabling the creation of formal water markets. Additionally, the Spanish Water Act also introduced significant restrictions, such as who can participate in those formal water markets, which use is given to water, how long water rights may be transferred, how much water can be sold, *etc.* Therefore, the effect of water market in terms of improving allocative efficiency has been very limited.

Simulation 3 again shows the results of a 25% increase in the total factor productivity of agriculture, but now we allow water transactions between intersectoral users, as occurs in formal water markets. As shown in Table 3, allowing users to exchange water does not substantially affect the results compared to Simulation 1, in which water markets were not considered; the decline in agricultural prices (−4.5%) are greater than changes in the quantity produced (2.5%). However, the results between simulation 1 and 3 differ slightly at an aggregated level: although both lead to an increase in real GDP (0.3%), the existence of water markets lead to a greater reduction in the level of intermediate water consumption (−0.6%). These results could indicate that the impact of water markets is reduced. Indeed, as discussed below, what is questionable is the impact of subsidies for technological change.

Table 3. Simulation 3: 25% increase in TPF of agriculture (with water market).

SECTORS	Changes in Prices (%)	Changes in Production (%)
1. Agriculture	−4.55%	2.50%
2. Energy	−0.19%	−0.07%
3. Water distribution	0.01%	−0.30%
4. Chemistry	−0.18%	−0.16%
5. Metals and electric equipment	−0.17%	0.04%
6. Automobiles	−0.17%	0.02%
7. Food production	−1.18%	0.07%
8. Textiles	−0.27%	0.03%
9. Paper	−0.15%	−0.02%
10. Other industries	−0.19%	0.03%
11. Construction	−0.03%	0.14%
12. Commerce	−0.10%	0.22%
13. Transports and communications	−0.03%	−0.02%
14. Finance	0.02%	−0.03%
15. Private services	0.00%	0.01%
16. Public services	−0.02%	0.11%
Water variables	**Changes in water variables (%)**	
Final water demand	0.03%	
Intermediate water demand	−0.59%	
Ecological water	0.11%	
Gross domestic production	**Changes in GDP (%)**	
Real GDP	0.30%	

3.4. Designing a Win-Win Water Strategy

The challenge of water policy is to design a win-win strategy that encourages water efficiency and savings. In other words, water policy must generate better outcomes in terms of economic efficiency and environmental sustainability at the aggregated level, whilst also ensuring that this does not lead to increased political and social costs.

As we have seen before, applying the principle of cost recovery of water services may not be enough to improve economic efficiency or environment sustainability. Furthermore, farmers are the biggest consumers of water, so they will probably be reluctant to accept an increase in the price of water. The problem of political feasibility, therefore, continues to present itself, and raises the question of how to overcome farmers' reluctance and how to simultaneously improve environmental sustainability. This issue is not trivial.

However, this result may be offset. In Simulation 4, where we analyze a situation in which there is a 25% tax on the water price with the sale of water between users and uses (*i.e.*, water markets), the results differ. Table 4 shows these new results: both the price and quantity of the agricultural sector remains almost unchanged, and the real GDP decreases slightly (−0.03%). However, the results show a major impact at an aggregated level: a reduction in the level of intermediate and final water consumption (−24% and −21%, respectively). The main result is, therefore, an increase in water resources for maintenance of the environmental flow (around 8%).

Table 4. Simulation 4: 25% tax on water price (with water market).

Sectors	Changes in Prices (%)	Changes in Production (%)
1. Agriculture	0.11%	−0.07%
2. Energy	0.56%	−0.45%
3. Water distribution	27.89%	−23.43%
4. Chemistry	0.11%	−0.06%
5. Metals and electric equipment	0.07%	−0.01%
6. Automobiles	0.07%	−0.02%
7. Food production	0.08%	−0.05%
8. Textiles	0.09%	−0.04%
9. Paper	0.07%	−0.03%
10. Other industries	0.09%	−0.02%
11. Construction	0.06%	0.13%
12. Commerce	0.07%	−0.05%
13. Transports and communications	0.09%	−0.07%
14. Finance	0.02%	−0.04%
15. Private services	0.05%	0.00%
16. Public services	0.09%	0.36%
Water variables	**Changes in water variables (%)**	
Final water demand	−21.87%	
Intermediate water demand	−24.63%	
Ecological water	7.80%	
Gross domestic production	**Changes in GDP (%)**	
Real GDP	−0.03%	

The rising price of water may help to transmit signals that water is a scarce commodity. However, if buying or selling water is impossible, the incentives to internalize the opportunity cost of water use are smaller. This is why the establishment of water markets is crucial. As long as water use rights cannot be exchanged, water consumption will focus mainly on agriculture and, specifically, on farms that have historically had a larger water supply regardless of their efficiency. Without water markets, the rising price of water implies a double jeopardy for farmers: a drop in the prices of agricultural products and in the marginal value of the allocated water. This situation can be offset by the creation of water markets, allowing farmers to obtain an income from the sale of water.

4. Conclusions

In this paper, we have analyzed some challenges facing the agricultural sector, such as the process of technological change and the implementation of the EU Water Framework Directive. Furthermore, we consider how the institutional framework, such as the existence of formal water markets, modifies the effects of these measures. Our analysis involves a computable general equilibrium model that reflects all the connections and interactions between the economic agents. A unique feature of our model is that it shows the effects on the environmental flow of water, and provides information about the ecological consequences of each measure in terms of water resources. We, therefore, consider both economic variables and water uses.

The first result we obtain is that any technological change reduces farmers' expected revenue, which helps to explain their reluctance to undertake technological changes. The same results are obtained when we apply the principle of cost recovery in water services for agriculture. As suggested by the literature on public policy making, if a new policy is to be socially accepted, it not only needs to be economically rational, but also politically sensitive to social an environmental conditions during its implementation. However, in our simulations there is a divergence between farmers' preferences and the optimal social choice. In other words, there is a trade-off between economic efficiency and political viability.

The second conclusion we draw is that the debate about formal water markets not only matters in terms of efficiency, but also in terms of environmental sustainability. Our analysis shows that technological change or higher water prices are not sufficient conditions to ensure water savings. Our results suggest the need to clearly differentiate two types of measures and strategies that, as stated by Jevons' Paradox, are not always consistent: increasing technical efficiency and reducing water withdrawals.

The third conclusion is that environmental improvement depends on the institutional framework. Water markets enhance the political feasibility and environmental impact of the EU Water Framework Directive. Water markets provide an indication of the opportunity cost of water. Water markets should, therefore, be judged not only in terms of economic efficiency but also based on environmental sustainability.

Finally, there appears to be a trade-off between economic efficiency, environmental sustainability, and political viability in agricultural policies. In other words, a policy that leads to greater economic efficiency does not necessarily lead to environmental improvement, and nor is it the most likely to be accepted by farmers. In this context, the choice of an economic second-best improves the environmental impact and also creates greater consensus regarding its application. This conclusion leads us to the following future line of research: the challenge for water policy is to design other win-win strategies that encourage savings and efficient use of water and which, at the same time, have reduced political and social costs when they are implemented. Put another way, there needs to be a policy that generates a certain degree of consensus among those who believe that water should be treated as a commodity, and those who view water as a social asset that should be allocated outside the market. The European Union faces a new challenge in this respect: while the reform of the Common Agricultural Policy (CAP) and the implementation of the Water Framework Directive aim for greater economic efficiency accompanied by environmental improvement, these policies may also lead to a reduction in farmers' incomes. Our objective will be to evaluate the joint impact of the rise in the price of water proposed by the European Union Water Framework Directive and the reduction in agricultural prices resulting from the reform of the CAP. On the basis of this analysis, we aim to determine what kind of water policy would help turn this threat into a win-win situation.

We must bear in mind that, given that our CGE model is static, we can only observe the final impacts on endogenous variables without being able to reflect the temporal adaptation of those variables. Although this limitation makes it difficult to have a complete perspective of the effects of a win-win water strategy, our analysis helps to clarify its final economic and ecological consequences.

Another feature of the model that should be borne into account is that it implicitly assumes that any rise in water demand is automatically covered by the corresponding water supply. A future research, beyond the scope of this paper, will focus on the introduction of mechanisms able to reflect possible technological restrictions (e.g., the existing infrastructures and storage capacities) and risks of failures (e.g., floods and droughts) in water provision.

Acknowledgments: The authors acknowledge financial support from the Spanish Ministry of Culture (Grant ECO2013-41917-P), and the Government of Catalonia (Grant SGR2014-299, "Xarxa de Referencia d'R+D+I en Economia i Polítiques Públiques" and "Xarxa de Referencia d'R+D+I en Economia Aplicada"). Useful comments and suggestions by two anonymous referees and by the editor of the journal have substantially improved an earlier version of the manuscript.

Author Contributions: Maria Llop constructed the database, designed the CGE model and performed the simulations. Xavier Ponce-Alifonso analysed the results and interpreted the outcomes with the related literature. Both authors wrote the paper.

Conflicts of Interest: The authors declare no conflict of interest.

References

1. Costa, J. *Política Hidráulica*; Biblioteca Joaquín Costa: Madrid, Spain, 1911.
2. Embid, A. The Evolution of Water Law and Policy in Spain. *Int. J. Water Resour. Dev.* **2002**, *18*, 261–283. [CrossRef]

3. Ramos, J.L. La formulación de la política hidrológica en el siglo XX: Ideas e intereses, actores y proceso politico. *Ekonomiaz* **2001**, *47*, 126–151. (In Spanish).
4. Llop, M. Water reallocation in the input–output model. *Ecol. Econ.* **2013**, *86*, 21–27. [CrossRef]
5. Batchelora, C.H.; Ratna Reddyb, V.; Linsteadc, C.; Dhard, M.; Royd, S.; Mayc, R. Do water-saving technologies improve environmental flows? *J. Hydrol.* **2014**, *518*, 140–149. [CrossRef]
6. Berbel, J.; Gutiérrez-Martín, C.; Rodríguez-Díaz, J.A.; Camacho, E.; Montesinos, P. Literature Review on Rebound Effect of Water Saving Measures and Analysis of a Spanish Case Study. *Water Resour. Manag.* **2015**, *29*, 663–678. [CrossRef]
7. European Parliament. Directive 2000/60/EC of the European Parliament and of the Council of 23 October 2000, establishing a framework for the community action in the field of water policy. Available online: http://eur-lex.europa.eu/legal-content/EN/TXT/?uri=celex%3A32000L0060 (accessed on 5 February 2016).
8. Lofgren, H.; Robinson, S. *The Mixed Complementary Approach To Specifying Agricultural Supply in Computable General Equilibrium Models*; International Food Policy Research Institute: Washington, DC, USA, 1997.
9. Arndt, C.; Jensen, H.T.; Robinson, S. Marketing margins and agricultural technology in Mozambique. *J. Dev. Stud.* **2000**, *37*, 121–137. [CrossRef]
10. Prasada, P. General equilibrium impacts of technological change under different market structures: A comparison of supply managed and other primary agricultural markets in Canada. *Sri Lankan J. Agric. Econ.* **2007**, *9*, 1–21. [CrossRef]
11. Belhaj Hassine, N.; Robichaud, V.; Decaluwé, B. Agricultural Trade Liberalization, Productivity Gain and Poverty Alleviation: A General Equilibrium Analysis. 2010. Available online: http://papers.ssrn.com/sol3/papers.cfm?abstract_id=1687135 (accessed on 5 February 2016).
12. Berck, P.; Robinson, S.; Goldman, G. The use of computable general equilibrium models to assess water policies. In *The Economics and Management of Water and Drainage in Agriculture*; Dinar, A., Zilberman, D., Eds.; Kluwer Academic Publishers: Boston, MA, USA, 1991; pp. 489–509.
13. Seung, C.K.; Harris, T.R.; MacDiarmid, T.R.; Shaw, W.D. Economic impacts of water reallocation: A CGE analysis for the walker river basin of Nevada and California. *J. Reg. Anal. Policy* **1998**, *28*, 13–34.
14. Goodman, D.J. More reservoirs or transfers? A computable general equilibrium analysis of projected water shortages in the Arkansas River Basin. *J. Agric. Resour. Econ.* **2000**, *25*, 698–713.
15. Diao, X.; Roe, T. The win-win effect of joint and trade reform on interest groups in irrigated agriculture in Morocco. In *The Political Economy of Water Pricing Reforms*; Dinar, A., Ed.; Oxford University Press: Oxford, UK, 2000.
16. Gómez, C.M.; Tirado, D.; Rey-Maquieira, J. Water exchanges *versus* water works: Insights from a CGE model for the Balearic Islands. *Water Resour. Res.* **2004**, *4*, 1–11.
17. Letsoalo, A.; Blignaut, J.; de Wet, T.; de Wit, M.; Hess, S.; Tol, R.; van Heerden, J. Triple dividends of water consumption charges in South Africa. *Water Resour. Res.* **2007**, *43*, 1–11. [CrossRef]
18. Strzepek, K.M.; Yohe, G.W.; Tol, R.J.; Rosegrant, M.R. General equilibrium modelling of the value of the high Aswan dam to the Egyptian economy. *Ecol. Econ.* **2008**, *66*, 117–126. [CrossRef]
19. Lennox, J.; Diukanova, O. Modelling the regional general equilibrium effects of water allocation in Canterbury. *Water Policy* **2011**, *13*, 250–264. [CrossRef]
20. Berrittella, M.; Hoekstra, A.Y.; Rehdanz, K.; Roson, R.; Tol, R. The economic impact of restricted water supply: A computable general equilibrium analysis. *Water Res.* **2007**, *41*, 1799–1813. [CrossRef] [PubMed]
21. Cardenete, M.A.; Guerra, A.I.; Sancho, F. *Applied General Equilibrium. An Introduction*; Springer: Berlin/Heidelberg, Germany, 2012.
22. Armington, P. A theory of demand for products distinguished by place of production. *Int. Monet. Fund Staff Papers* **1969**, *16*, 159–178. [CrossRef]
23. Leontief, W. *Input-Output Economics*; Oxford University Press: New York, NY, USA, 1966.
24. Termes, M.; Guiu, R. Anàlisi de la tendència del consum d'aigua a Catalunya i marges d'estalvi. *Nota d'Economia* **2009**, *93–94*, 21–33.
25. Patinkin, D. *The New Palgrave: A Dictionary of Economics*, 2nd ed.; Palgrave Macmillan: Hampshire, UK, 2008.
26. Ministerio de Agricultura, Pesca y Alimentación. Real Decreto 329/2002, de 5 de abril, por el que se aprueba el Plan Nacional de Regadíos. Available online: https://www.boe.es/diario_boe/txt.php?id=BOE-A-2002-8129 (accessed on 15 February 2016).

27. Ministerio de Agricultura, Alimentación y Medio Ambiente. Programa Actuaciones para la Gestión y la Utilización del Agua (A.G.U.A.). Available online: http://www.magrama.gob.es/es/agua/planes-y-estrategias/informes-de-viabilidad-de-obras-hidraulicas/actuaciones-y-proyectos/index_agua.aspx (accessed on 15 February 2016).
28. Ministerio de la Presidencia. Real Decreto 287/2006, de 10 de marzo, por el que se regulan las obras urgentes de mejora y consolidación de regadíos, con objeto de obtener un adecuado ahorro de agua que palie los daños producidos por la sequía. Available online: https://www.boe.es/diario_boe/txt.php?id=BOE-A-2006-4415 (accessed on 15 February 2016).
29. Ministerio de Agricultura, Alimentación y Medio Ambiente. Estrategia para la Modernización Sostenible de los Regadíos. Available online: http://www.magrama.gob.es/es/calidad-y-evaluacion-ambiental/participacion-publica/PP_2009_p_019.aspx (accessed on 15 February 2016).
30. Carey, J.M.; Zilberman, D. A model of investment under uncertainty: Modern irrigation technology and emerging markets in water. *Am. J. Agric. Econ.* **2002**, *84*, 171–183. [CrossRef]
31. Koundouri, P.; Nauges, C.; Tzouvelekas, V. Technology adoption under production uncertainty: Theory and application to irrigation technology. *Am. J. Agric. Econ.* **2006**, *88*, 657–670. [CrossRef]
32. Bjornlund, H.; Nicol, L.; Klein, K.K. The adoption of improved irrigation technology and management practices. A study of two irrigation districts in Alberta, Canada. *Agric. Water Manag.* **2009**, *96*, 121–131. [CrossRef]
33. Catalan Water Agency (ACA). *Catalan Water Management*; Catalan Water Agency: Barcelona, Spain, 2010.
34. Easter, K.W.; Rosegrant, M.W.; Dinar, A. *Markets for Water: Potential and Performance*; Kluwer Academic Publishers: Boston, MA, USA, 1998.
35. Garrido, A. Water markets design and evidence from experimental economics. *Environ. Resour. Econ.* **2007**, *38*, 311–330. [CrossRef]
36. Grafton, R.Q.; Libecap, G.; McGlennon, S.; Landry, C.; O'Brien, B. An Integrated Assessment of Water Markets: A Cross-Country Comparison. *Rev. Environ. Econ. Policy* **2011**, *5*, 219–239. [CrossRef]
37. Palomo-Hierro, S.; Gómez-Limón, J.A.; Riesgo, L. Water Markets in Spain: Performance and Challenges. *Water* **2015**, *7*, 652–678. [CrossRef]