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Document de treball n.17 - 2012

DEPARTAMENT D'ECONOMIA – CREIP
Facultat d'Economia i Empresa

UNIVERSITAT
ROVIRA I VIRGILI
DEPARTAMENT D'ECONOMIA

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CENTRE DE RECERCA EN ECONOMIA
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Edita:

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Adreçar comentaris al Departament d'Economia / CREIP

Dipòsit Legal: T - 887 - 2012

ISSN edició en paper: 1576 - 3382
ISSN edició electrònica: 1988 - 0820

Agriculture, technological change and environmental sustainability: Looking for a win-win water policy strategy

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Abstract

This paper analyses the effects that technological changes in agriculture would have on environmental, social and economic indicators. Specifically, our study is focused on two alternative technological improvements: the modernization of water transportation systems versus the increase in the total factor productivity of agriculture. Using a computable general equilibrium model for the Catalan economy, our results suggest that a water policy that leads to greater economic efficiency is not necessarily optimal if we consider social or environmental criteria. Moreover, improving environmental sustainability depends less on the type of technological change than on the institutional framework in which technological change occurs.

Keywords: agricultural technological changes, computable general equilibrium model, economic impact, water policy

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Acknowledgements

The first author acknowledges the financial support of the Spanish Ministry of Culture (grant ECO2010-17728), the Catalan Government (grant SGR2009-322 and “Xarxa de Referencia d’R+D+I en Economia i Polítiques Públiques”) and the Chair for Local and Regional Economy of the Rovira i Virgili University. The second author acknowledges the “Xarxa de Referencia d’R+D+I en Economia Aplicada” and the Chair for Local and Regional Economy of the Rovira i Virgili University.

1. Introduction

Historically, water was considered an abundant resource in Spain, but there were significant differences in the spatial and temporal distribution of water throughout the territory. The solution would have been to develop a water supply policy in order to create the water infrastructures required to distribute the water between uses, users and locations. However, the high cost of this made it difficult to find the private funding needed.

In the late nineteenth century, an intellectual and political movement called regenerationism (Costa, 1911) established a link between the water problem and the backwardness of the Spanish economy compared to other European countries. They stated that water infrastructures would permit the expansion of irrigated agriculture and thus increase productivity, which would in turn allow an increase in agricultural exports and an improvement in the trade balance. Furthermore, these infrastructures would not only facilitate the settlement of the population throughout the territory, but also would 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 in planning and financing these waterworks slowly began to gain momentum. This way, users would have access to water at a price below its true cost, thereby encouraging the expansion of irrigation and the modernization of the country. Beyond the general interest, it was also seen by the political class as a way to gain legitimacy, support and prestige. Therefore, this new water supply policy became a win-win game, which made profits for farmers, builders, hydropower companies, financial institutions, politicians, etc. This convergence of interests explains the effort made throughout the 20th Century to transform Spain into the country with the highest percentage of land covered by reservoirs.[1]

However, over time this water supply policy became a problem rather than a solution. In a scenario of rapid growth in water demand for non-agricultural uses, slowdown and rising investment to expand supply, the water policy did not prevent an increasing water shortage from being generated in certain parts of Spain, as is the case in Catalonia.[2] The main criticism of this water supply policy is that the low price of water did not create incentives to use it efficiently. Thus, despite the large volume of water used by farmers, the price they traditionally paid for this resource did not reflect its true cost, but hid a cross subsidy between the different users. This situation hindered the transmission of shortage price signals and led to mismanagement of the resource resulting in huge losses in distribution channels, the use of outdated irrigation techniques, and the production of low-yielding crops, among other problems.

Therefore, in a scenario of increasing water scarcity, where the development of new water resources was

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[1] The importance given to water policy in Spain throughout the 20th century is reflected in the successive plans for waterworks which started with the National Water Resources Exploitation Plan (Gasset Plan, 1902), which was applied during the dictatorship of Primo de Rivera (1923-1930). During the Second Republic (1931-1939) a Water Works General Plan was adopted (Pardo Plan, 1933), whose guidelines were resumed after the Civil War in a New Hydraulic Works General Plan (Peña Plan, 1940), in which water policy became the main development policy during the dictatorship of General Franco (1939-1975). The establishment of democracy in the late 1970s brought new momentum, as is evidenced by the Borrell Plan (1993) and the National Hydrological Plan (2001) (Garrido and Llamas, 2010).

[2] Catalonia is a Mediterranean region located in the north-east of Spain. With a small surface area (32,000 kilometres^2), it covers approximately 16% of the Spanish territory and it has over 7,500,000 citizens. Catalonia is a highly industrialized region that represents around 20% of the total Spanish GDP. 72% of its available water is used for agriculture, 19% goes to urban uses and the remaining 9% goes to industrial uses (ACA, 2008); however, it is a region that suffers water shortages periodically.

increasingly expensive and complex, it was inevitable that changes in water policy should have been considered in order to release water from agriculture to other activities with a higher economic or social value, and also to encourage a more efficient and sustainable use of water.

In this regard, 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. Above all, in recent years an effort has been made to promote innovation and technological modernization in irrigation by establishing a framework of incentives in the National Irrigation Plan (MAPA, 2002), the A.G.U.A. programme (MMA, 2004), the Emergency Plan for the Modernization of Irrigation (MAPA, 2006) and the National Strategy for the Sustainable Modernization of Irrigation, Horizon 2015 (MARM, 2010).[3]

However, this political support for technological change is not exempt from controversy. First, these subsidies are not always sufficient for farmers wishing to implement technological change. In fact, empirical evidence suggests that the process of adopting new technologies in agriculture is slower than the traditional criteria of economic rationality would suggest (Caswell and Lichtenberg, 1990; Carey and Zilberman, 2002).

Second, there is a debate about what kind of innovation the public administration should support. The Government may choose to promote a more standardized approach, such as reducing intermediate consumption of water in agriculture through the modernization of transportation systems, water distribution and applications. However, the administration could also opt for a higher degree of flexibility by promoting an increase in total factor productivity through research into new technologies, enhancing energy efficiency, improving the training of farmers, encouraging land consolidation, etc. (Karagozoglu and Lindell, 2000; Gabel and Sinclair-Desgagné, 2001).[4]

Finally, a more efficient use of water in agriculture does not necessarily save water, but as noted by the "Jevons paradox" may eventually lead to an increase in the amount of water consumed. Given this possibility, the literature has debated whether or not to implement other measures such as creating water markets or efficient pricing signals of water scarcity (Caswell and Zilberman, 1985; Dinar and Letey, 1991).

To analyze the effects of technological change to agriculture in Catalonia and to discuss the issues mentioned above we apply a general equilibrium model using a social accounting matrix (SAM) database with 2001 data. During the last 20 years, computable general equilibrium (CGE) models have largely been used to analyse the effects of agricultural productivity gains on areas such as poverty, food production and trade. For instance, Lofgren and Robinson (1997) presented some modifications to the specified standard CGE models to incorporate more realistic technology in the agricultural sector. Arndt

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[3] These aids to technological change in agriculture are justified by the relative inability of private enterprises to undertake these processes of modernization, but also by the social benefit generated from the water savings obtained through using more efficient technology. They can therefore be interpreted as compensation paid to farmers for creating positive externalities that contribute to the preservation of the environment.

[4] For example, the National Strategy for the Sustainable Modernization of Irrigation, Horizon 2015 (MARM, 2010) requires that each project for improving the distribution infrastructure of irrigation includes, along with the planned investment, an estimation of the amount of water which the project intends 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 production systems that respect the environment.

et al. (1999) used the CGE approach to analyse both improvements in agricultural productivity and reductions in marketing costs in Mozambique. Dorosh *et al*. (2003) used a CGE model of the Ugandan economy to examine the implications on welfare of regional variation in agricultural production, changes in agricultural productivity and shifts in world prices of agricultural products. Prasada (2007) studied the general equilibrium impacts of technological changes in Canadian agriculture, which were modelled as productivity rises in the use of intermediate inputs and primary factors. More recently, Belhaj *et al*. (2010) 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. Among others, Berck *et al*. (1991) used the CGE approach to study the effects of reducing water inputs on sectorial output, gross domestic production, employment and land use in the San Joaquin Valley. Seung *et al*. (1998) used CGE techniques to analyse the economic effects of water transfers in the Walker River Basin of Nevada and California. Goodman (2000) compared the economic impacts of an increase in water storage with temporary water transfers between rural and urban communities in the Arkansas River Basin. Hewings *et al*. (2005) evaluated the impact of water reallocation from agriculture to other productive sectors in a model that fully captured the feedback effects between sectors. Berrittella *et al*. (2007) showed the potential of CGE analysis by applying a global multi-regional model that defined water as a differentiated factor of production to the analysis of sustainable water supply uses. More recently, Lennox and Diukanova (2011) have used the general equilibrium framework to determine the regional effects of water reallocation in Canterbury. Finally, Llop and Ponce-Alifonso (2012) have applied a CGE model to the Catalan economy to analyse the regional impacts of alternative water policies on both economic indicators and water variables.

The structure of the present 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 of the paper we give some concluding remarks.

2. The model

Computable general equilibrium techniques have advantages over other partial equilibrium models in that they provide a complete representation of the economic agents and their optimisation behaviour. CGE models also take into account all the interactions existing between economic agents by giving a complete representation of the circular flow of income.

The definition of equilibrium in our general equilibrium model follows 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 models consists of a set of endogenous variables made up of 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.[5]

In the following sections, we describe the main features of the agents and markets defined in the computable general equilibrium model used to simulate technological changes in agriculture.

2.1. Production

The structure of production assumes perfect competition in all markets. It shows 16 sectors including one which represents agricultural activity and one which represents the production and distribution of water.

Each production sector obtains a homogeneous good and has a nested technology that shows constant returns-to-scale. The first level of the production function defines the total output in each sector following the Armington specification, and is a Cobb-Douglas aggregator of domestic production and imports from abroad.

The second level of the production function defines the domestic production. Our analysis follows two alternative definitions of the domestic production: one definition assumes that the domestic production responds to a Leontief function containing fixed proportions of intermediate inputs and value added in each sector, and the other definition uses a Cobb-Douglas combination of intermediate inputs and value added. Expressions (1) and (2) show these two alternative representations:

$$X_{dj} = min\left[\frac{X_{1j}}{a_{1j}},\ldots,\frac{X_{16j}}{a_{16j}},\frac{VA_j}{v_j}\right], \qquad j = 1,....,16\,, \tag{1}$$

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

where $j = 1,...,16$ represents the production activities, X_{dj} is the domestic production in j, λ_j is a scale parameter, and a_{kj} are the nonnegative input-output technical coefficients. In the expressions above, VA_j is the value added of j, and v_j is the coefficient of value added per unit of domestic production.

The features associated with each production function allow us to analyse different institutional frameworks related to water policy. Since there is an initial endowment of water allocated to each farmer, the use of a Leontief function (expression (1)) implies the non-substitutability of production factors and this situation could be interpreted as the absence of water markets that facilitate the sale of water (see table 2 and 3). In contrast, a Cobb-Douglas function (expression (2)) allows a certain degree of substitutability between productive factors, which means that this situation can be interpreted as a water market that facilitates substitutability through buying and selling water use rights (see table 4).

The sectorial value added, which is defined in the last (third) level of the production function, is obtained by combining labour and capital through a Cobb-Douglas function.

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[5] Alternatively, we could have defined an equilibrium for some markets that had insufficient demand to absorb all the supply (that is, an excess of surplus).

2.2. Consumers

The model shows a generic household with a logarithmic Cobb-Douglas utility function that combines consumption and saving (or future consumption). The model distinguishes between production goods (16) and consumption goods (10) that are obtained through a conversion matrix of fixed coefficients. This conversion matrix shows a linear distribution of the production goods to the final consumption goods. The utility function is defined in terms of the consumption goods.

Consumer budget restrictions mean that their expenditure cannot exceed household disposable income. The private income comes from the endowments of labour and capital and transfers from government and from abroad. To obtain the net disposable income of consumers, we have to subtract the social security contributions of workers and the direct taxation on the amount of private revenues.

The optimisation of consumers consists of maximising their utility subject to their budget constraints. From this behaviour, we can obtain the demands for consumption goods and private saving.

2.3. Government

In the model, the government or public agent is assumed to produce public goods and public services and to demand public services and investment goods. This public agent has a Leontief utility function, and it combines public consumption and public investment in a fixed proportion.

The government budget restriction establishes that public consumption and public investment must be equal to total public revenues, which come from taxation once social transfers have been subtracted from government revenues. The model also contains a stock of public borrowing or government bonds that the public agent can emit in case of deficit.

The government maximises the Leontief utility function subject to the public budget constraint. From this optimisation, we obtain both the public consumption demand and the public investment.

2.4. Foreign Agent

The foreign sector is assumed to produce a trade good by using regional exports through a fixed coefficients technology. At the same time, the region can both receive income transfers from abroad and make income transfers to the external agents.

Additionally, the model allows a situation of external deficit that must be used as savings of the foreign agent. This preserves the macroeconomic equilibrium between the total savings and total investments of the economy.

2.5. Ecological Sector

Finally, as our aim is to show the effects of agricultural technological changes on water resources, our regional CGE model distinguishes between the water used by economic agents and the total water resources. Specifically, it shows the changes in the water not used by the economic activity, which can also be interpreted as the amount of water needed to maintain healthy ecosystems (environmental flow).

To show the trade-off between the water used by the economic activity and the environmental flow of water, the level of activity in the ecological sector is residually calculated by taking into account the natural restriction between the total water endowments and total water uses in the regional economy.

2.6. Database

All the exogenous variables of the model are obtained by applying the standard calibration procedure, which allows an initial equilibrium (benchmark situation) to be reproduced. In this situation, all the prices and activity levels are unitary and the solution of the model reproduces the empirical information shown in the social accounting matrix (or SAM) database used to calibrate the parameters of the model. Table 1 shows the list of accounts in the 2001 SAM of the Catalan economy.

Table 1. List of accounts in the SAMCAT

Production Sectors	1. Agriculture
	2. Energy
	3. Water distribution
	4. Chemistry
	5. Metals and electric equipment
	6. Automobiles
	7. Food production
	8. Textiles
	9. Paper
	10. Other industries
	11. Construction
	12. Commerce
	13. Transports and communications
	14. Finance
	15. Private services
	16. Public services
Consumption Goods	17. Food
	18. Water
	19. Tobacco and alcohol
	20. Clothes and shoes
	21. Housing
	22. Furniture
	23. Medical assistance
	24. Transports and communications
	25. Culture and education
	26. Other consumption goods
Factors of production	27. Labour
	28. Capital
Consumers	29. Consumers
Saving-investment	30. Capital account
Public sector	31. Production taxes
	32. Social Security taxes on employers
	33. Direct taxes on income
	34. Consumption taxes
	35. Government
Sector exterior	36. Foreign sector

Given the information deficiencies at the regional level, the SAM for the Catalan economy (SAMCAT) has a very simple structure. The production system is divided into 16 sectors, one of which shows agricultural production and one of which shows the production and distribution of water. Additionally, the SAMCAT shows ten consumption goods, which are the ones used in the consumers' optimisation problem. The regional database also shows two production factors, labour and capital, and a generic account containing the income relations of private consumers. The capital account shows all the sources of saving and investment in the regional economy, and the government accounts involve four different taxes (on production, on income, on consumption, and firms' social security contributions) and an account that contains the income flows of the public administration. Finally, the foreign agent is aggregated into a consolidated account that shows imports, exports and foreign income transactions of the regional economy.

The first solution of the model consists of calculating the reference equilibrium (benchmark situation). Afterwards, we use the model to analyse the effects of technological changes in agriculture.

Before showing the outcomes of the simulations, some additional aspects of the analytical context used should be considered. First, given that Walras law implies that one of the equations in the model is redundant, in the computation of the model we have assumed that wage is the *numéraire* (that is, the price of labour is unitary in all the simulations undertaken).[6] Second, the model defines a variable activity level of government and a fixed public deficit, and a variable activity level of foreign agents and a fixed trade deficit.

3. Simulation analysis

The belief that water was abundant in Spain, but irregularly distributed, meant that water policy was based on a model that aimed to expand the water supply. But this belief in an abundant supply of water also led the Public Administration to pay little attention to inefficient uses of water that was considered to be a public ownership good. Moreover, there was also the belief that there was no need to implement a policy to modernize irrigation.

In recent years, however, the discourse in Spain has begun to change. In a context where water is an increasingly scarce resource, conflicts between territories and between water users have intensified. Thus, there is an increasing need to modernize irrigation and promote technological change to achieve a more efficient use of water in agriculture. However, the important questions are: 1) what will be the effect of this modernization process? And 2) will public subsidies be sufficient to overcome the reluctance of farmers to make the necessary technological changes?

3.1. Reluctance to undertake technological change in agriculture

Although the economic literature does not provide conclusive results on the variables that influence farmers' decisions to invest in new technologies, risk has often been regarded as one of the factors

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[6] Therefore, the prices in the new equilibriums have to be interpreted as being relative prices with respect to the numéraire.

affecting any kind of agricultural innovation. This risk takes the form of uncertainty regarding the expected return of investment, which in turn depends on such factors as the level of production that will be achieved, or the expected price of the product (Mohr, 2002; Koundouri *et al*., 2006).

This uncertainty about the potential earnings of some innovations and the presence of high sunk costs explains why farmers feel the need to accumulate experience and information before investing in new technologies. That is, the decision to delay investments in new technologies to see what other farmers do can be understood as part of a learning process. All these factors lead farmers to demand a high rate of return for their investment and explain the delays in the adoption of new technologies that are characteristic of this sector (Carey and Zilberman, 2002; Isik, 2004; Odening *et al.*, 2005).

The public administration can play an important role in overcoming the reluctance to undertake technological change by subsidizing the costs involved. However, this also poses a dilemma: what kind of technological change should be encouraged? Our first simulation represents a standardized technology that allows a 25% reduction in agricultural water consumption by, for instance, modernizing transportation systems and the distribution and application of water. The second simulation analyses the impact of a 25% increase in the total factor productivity (TFP) of agriculture resulting from a non-centralised technological change whereby producers react to the external incentives by increasing their productivity.[7] The main results of these simulations are shown in table 2.[8]

Table 2. Simulation 1 and 2. Production prices, water variables and other indicators

	Simulation 1[a]		**Simulation 2**[b]	
SECTORS	Changes in prices (%)	Changes in production (%)	Changes in prices (%)	Changes in production (%)
1. Agriculture	-0.10%	0.01	-9.78%	-0.05
2. Energy	-0.00%	0.00	-0.06%	-0.25
3. Water distribution	-0.00%	-0.46	-0.05%	-0.38
4. Chemistry	-0.00%	0.00	-0.26%	-0.42
5. Metals and electric equipment	-0.00%	0.00	-0.10%	-0.10
6. Automobiles	-0.00%	0.00	-0.11%	-0.15
7. Food production	-0.04%	0.01	-3.65%	0.02
8. Textiles	-0.01%	0.00	-0.64%	-0.14
9. Paper	-0.00%	0.00	-0.19%	-0.15
10. Other industries	-0.00%	0.00	-0.30%	-0.10
11. Construction	-0.00%	0.00	-0.11%	0.21
12. Commerce	-0.00%	0.01	-0.37%	0.51
13. Transports and communications	-0.00%	0.00	-0.05%	-0.06
14. Finance	-0.00%	0.00	-0.02%	-0.03
15. Private services	-0.00%	0.00	-0.07%	0.04
16. Public services	-0.00%	0.00	-0.07%	0.19
	Changes in water variables (%)			
Water final demand	-0.06%		-0.03%	
Water intermediate demand	-0.79%		-0.70%	
Water production	-0.46%		-0.38%	
Ecological water	0.20%		0.10%	
	Changes in prices, GDP and household welfare (%)			

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[7] Agriculture is the leading water user in Catalonia, accounting for over 70% of the total water demand. One attempt to release water to other users is the Catalan Irrigation Plan, which involves upgrading more than 150,000 hectares of traditional irrigation systems to pressurized irrigation systems, thus reducing water consumption by nearly 35% (ACA, 2008). Based on this figure and in order to make comparisons, we have assumed an improvement of 25% in both types of technological change.

[8] In simulations 1 and 2, we use a Leontief production function that assumes a null substitution between factors. In fact, this is a realistic assumption in the agricultural sector, given the difficulty of exchanging factors that are qualitatively different. When comparing both simulations, we assume the same percentage of 25% which we chose to make the results clearer.

CPI	-0.01%	-0.74%
Real GDP	0.00%	0.55%
Equivalent Variation (million Euros)	51.26	628.99

[a] Simulation 1: 25% reduction in water consumption of agriculture (without water market).

[b] Simulation 2: 25% increase in total factor productivity of agriculture (without water market).

Our results show that an increase in TFP reduces agricultural prices much more than it reduces the intermediate consumption of water (-9.78% vs. -0.1%), although this is not translated into significant changes in the quantity produced. Thus, despite the greater efficiency generated by this technological change, production remains practically constant because of the non-substitutability of factors and the presence of diminishing marginal returns in agriculture. As noted by King's law, the lowering of agricultural product prices leads to only a small variation in the quantity produced.[9]

Beyond this coincidence between the patterns of prices and quantities, there are significant differences between the two simulations. Technological change based on growth in TFP leads to a further drop in prices in the agricultural sector. This fact is reflected at the aggregated level, with a greater reduction in the consumption price index (CPI, that is -0.74% vs -0.01%), higher consumer welfare (629 vs 51 million euros in terms of equivalent variation) and higher GDP growth (0.55% vs 0%). However, although these positive effects trigger an increase in TFP at the aggregate level, the fact that agricultural prices plummet in this simulation means that farmers prefer the option of reducing their intermediate consumption of water (simulation 1) as this not only reduces information costs and risk aversion, but also lowers the negative impact on their profits.

In fact, the controversy surrounding incentives to technological change in agriculture is reinforced by doubts about the effect such change would have on water consumption at the aggregate level. The results from both simulations suggest that it only leads to a reduction in the level of water consumption of around 0.7% and to a slight improvement in ecological flow of less than 0.2%. Therefore, although the modernization of irrigation is often defended as one of the keys to solving the growing demands for water in water-stressed areas, it can actually generate the so-called Jevons paradox in which increased water efficiency reduces the marginal cost of water and increases the marginal willingness to pay, which in turn generates greater demand for water. This is especially true in scenarios such as those that we have simulated, where water transactions are not allowed and the price of water does not reflect its true opportunity cost.

Therefore, since measures to improve water efficiency are not effective in reducing the economic pressure exerted on water resources, they need to be accompanied by other policy measures, and we address this

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[9] One of the earliest attempts at quantitative economic analysis was made by Gregory King in the 17th century. He developed a price-quantity schedule that showed how prices changes in the agricultural markets are proportionately greater than changes in the quantity demanded.

issue in the following sections.

3.2. The Design of a Win-Win Strategy

The challenge of water policy is to design a win-win strategy that encourages water efficiency and saving, whilst also ensuring that this does not lead to increased political and social costs. That is, water policy must not only provide suitable external incentives to farmers, but must also encourage them to recognize and seize the opportunities presented.

In this regard, one method that has been proposed to encourage water saving in agriculture is to establish a water price that can transmit scarcity signals and the true cost of water use,[10] thus providing the incentives to encourage a more efficient use. Although applying the principle of cost recovery of water services can generate an additional cost that causes farmers to lose competitiveness, it can also be a stimulus for innovation, process reengineering, improving a product's public image, etc. In this way, competitive advantages could be developed through more stringent environmental policies (Porter, 1991; Porter and van der Linde, 1995).

In this regard, we use our CGE model to simulate technological changes in agriculture in conjunction with a rise in water prices. Specifically, we add a 25% increase in water prices to the previous simulations of agricultural technological changes.[11] The results of these new simulations are shown in table 3.

Table 3. Simulation 3 and 4. Production prices, water variables and other indicators.

	Simulation 3[c]		**Simulation 4[d]**	
SECTORS	Changes in prices (%)	Changes in production (%)	Changes in prices (%)	Changes in production (%)
1. Agriculture	0.10%	-0.01	-9.61%	-0.07
2. Energy	1.86%	-0.11	1.80%	-0.35
3. Water distribution	28.53%	-11.02	28.46%	-10.95
4. Chemistry	0.31%	0.06	0.05%	-0.35
5. Metals and electric equipment	0.11%	0.09	0.02%	-0.01
6. Automobiles	0.12%	0.05	0.01%	-0.10
7. Food production	0.12%	0.00	-3.49%	0.01
8. Textiles	0.18%	0.03	-0.46%	-0.11
9. Paper	0.15%	0.05	-0.04%	-0.10
10. Other industries	0.23%	0.07	-0.07%	-0.02
11. Construction	0.13%	0.18	0.02%	0.38
12. Commerce	0.14%	-0.06	-0.23%	0.45
13. Transports and communications	0.24%	-0.04	0.19%	-0.10
14. Finance	0.05%	-0.03	0.03%	-0.06
15. Private services	0.10%	0.04	0.03%	0.08
16. Public services	0.16%	0.51	0.09%	0.70
		Changes in water variables (%)		

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[10] According to the European Union Water Framework Directive (2000), 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 Water Framework Directive requires that water prices in the member countries of the European Union reflect their cost, so as to encourage users to use resources efficiently. It also notes that the public administration should not only promote water conservation, but must also set and monitor compliance with rigorous quality objectives.

[11] The average price paid for water in Catalonia is 1.7€/m^3. Recent studies suggest that if the Water Framework Directive's principle of cost recovery of water services was strictly applied, the price of water would increase to 3.30€/m^3 (ACA, 2010). However, such a proposal generates resistance in the agricultural sector because differences in the price of water and hidden subsidy have traditionally been justified on the basis of criteria such as the need for food security or the need to establish equality between farmers with an unequal ability to pay.

Water final demand	-22.24%	-22.21%
Water intermediate demand	-2.62%	-2.52%
Water production	-11.02%	-10.95%
Ecological water	3.70%	3.70%
	Changes in prices, GDP and household welfare (%)	
CPI	0.34%	-0.40%
Real GDP	-0,04%	0.51%
Equivalent Variation (million Euros)	-278.10	344.38

[c] Simulation 3: 25% reduction in water consumption of agriculture and 25% tax on water price (without water market).

[d] Simulation 4: 25% increase in total factor productivity of agriculture and 25% tax on water price (without water market).

As in table 2, table 3 shows that technological change based on an increase in TFP generates better outcomes in terms of economic efficiency at the aggregate level; that is, inflation is further reduced, thus generating a greater increase in both GDP and consumer welfare in terms of equivalent variation. Similarly, the technological change preferred by farmers is again to reduce intermediate consumption of water because this does not cause agricultural prices to fall in the way that an increase in TFP does (-9.61%), and ensures that production levels remain nearly constant.

The most important change in the results is in the amount of water saved. Simulations 3 and 4 show that technological change in agriculture, when accompanied by an appropriate water pricing policy, improves ecological flow by nearly 4%. Consequently, applying the principle of cost recovery of water services as an accompanying measure to aid technological change can generate both an environmental improvement and increased economic efficiency. However, given that simulation 4 significantly reduces agricultural prices, the problem of political feasibility continues to present itself and raises the question of how to overcome farmers' reluctance to undertake technological change.[12]

How can farmers be compensated to ensure the viability of these policy reforms? Water policy should not only provide suitable incentives for farmers to save water, but must also play a role in encouraging them to recognize and seize the opportunities presented by the new technologies. In this sense, the creation of water markets makes it easier for farmers to internalize the opportunity cost of using an increasingly scarce resource and thus understand the rising price of water as a win-win situation that encourages technological change.

In order to analyze the effects of a water market, in the following we modify the production function of the model. Specifically, we consider a Cobb-Douglas function in the definition of sectorial domestic production (expression (1) of the model) so that it reflects a flexible situation in the water uses. In other words, this situation corresponds to a market consequence through which water has some degree of substitution within the production costs according to changes in relative prices of intermediate costs.

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[12] This issue is not trivial. A cost recovery policy, especially in the agricultural sector, will only be effective when prices rise above a certain price threshold, since below this threshold water demand is completely inelastic and there is no change in the pattern of water consumption or the type of crop cultivated. In this scenario of a significant increase in water price, the group that would bear most of the cost of this measure would be farmers. As noted by Olson (1982), small distributional coalitions like farmers would have an incentive to form lobby groups and influence policies in their favour and could thus hurt economic growth. However, although the benefits of these inefficient policies would be concentrated amongst a small number of coalitions members, as long as the costs are distributed throughout the whole population, the logic of collective action dictates that there will be little public resistance to them.

Table 4 shows the results of implementing the two proposed types of technological change in agriculture in a context where the public administration is raising the price of water and there are formal water markets.

Table 4. Simulation 5 and 6. Production prices, water variables and other indicators.

	Simulation 5[e]		**Simulation 6**[f]	
SECTORS	Changes in prices (%)	Changes in production (%)	Changes in prices (%)	Changes in production (%)
1. Agriculture	-0.96%	0.66	-4.45%	2.43
2. Energy	0.49%	-0.40	0.37%	-0.52
3. Water distribution	27.86%	-23.48	27.90%	-23.66
4. Chemistry	0.04%	-0.02	-0.07%	-0.23
5. Metals and electric equipment	0.01%	0.04	-0.10%	0.03
6. Automobiles	0.01%	0.03	-0.10%	0.00
7. Food production	-0.21%	0.09	-1.09%	0.01
8. Textiles	0.01%	0.04	-0.18%	-0.02
9. Paper	0.02%	0.01	-0.08%	-0.06
10. Other industries	0.02%	0.03	-0.10%	0.00
11. Construction	0.03%	0.18	0.02%	0.27
12. Commerce	0.02%	0.02	-0.03%	0.16
13. Transports and communications	0.05%	-0.03	0.05%	-0.09
14. Finance	0.00%	-0.01	0.04%	-0.08
15. Private services	0.02%	0.04	0.05%	0.01
16. Public services	0.08%	0.38	0.07%	0.47
	Changes in water variables (%)			
Water final demand	-21.85%		-21.79%	
Water intermediate demand	-24.72%		-25.08%	
Water production	-23.48%		-23.66%	
Ecological water	7.80%		7.89%	
	Changes in prices, GDP and household welfare (%)			
CPI	0.14%		-0.04%	
Real GDP	0.04%		0.28%	
Equivalent Variation (million Euros)	-120.46		146.91	

[e] Simulation 5: 25% reduction in water consumption of agriculture and 25% tax on water price (with water market).

[f] Simulation 6: 25% increase in total productivity of agriculture and 25% tax on water price (with water market).

As in the previous simulations, the results suggest that the technological change that leads to the greatest economic efficiency is the increase in TFP (simulation 6). However, the smaller reduction in inflation (-0.04%) and the lower GDP growth (0.28%) compared with simulations 2 or 4 suggest that, when there are water markets, an increase in TFP generates poorer results in terms of economic efficiency.

However, this negative result may be offset by two factors. First, table 4 shows that water market enhances political feasibility and potential implementation of technological change in agriculture: that is, the increase in the TFP of agriculture causes a drop of almost 4.5% in agricultural prices that can be partially offset by an increase of around 2.5% in the corresponding production. This is a better result in terms of the expected profitability for farmers compared with simulations 2 or 4. That is, if farmers perceive water policy as an aid to reducing costs and improving efficiency in order to compete in increasingly open markets, this could increase the likelihood of them applying a technological change. Second, both simulations 5 and 6 show that, whatever the type of technological change, the possibility of selling water rights helps to reduce the amount of water consumed and to increase ecological flow by nearly 8%.

4. Conclusions

In this paper, we have analysed the effects that technological changes in the agricultural sector have on both economic variables and water uses. Our analysis involves a computable general equilibrium model that reflects all the connections and interactions between the economic agents. An interesting characteristic of the model used is that it shows the effects of technological change on the environmental flow of water, and provides information about the ecological consequences of each technological change in terms of water resources. To gain deeper knowledge about the effects of technological changes in agriculture, we have used two production functions for the activities (Cobb-Douglas and Leontief) that allow us to test the degree of reliability of the results.

The first result we obtain is that any technological change reduces farmers' expected profits, which helps to explain their reluctance to undertake technological change. 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.

The second result is that technological change in agriculture generates a positive-sum game where there are winners and losers. In fact, there is a divergence between farmers' preferences and the optimal social choice; that is, between technological change that increases TFP and thus produces better results at the aggregate level, or technological change that reduces intermediate consumption of water in agriculture. However, this latter option is associated with a better expected return on investment for farmers. Therefore, we find that there is a trade-off between efficiency and political viability.

The third conclusion we draw is that the debate about technological change not only matters in terms of efficiency, but also in terms of sustainability. Our analysis shows that technological change is not a sufficient condition to ensure water savings and that it must be accompanied by a policy that manages to transmit signals of water scarcity. Our results suggest the need to clearly differentiate two types of measures and strategies that, as stated by the Jevons paradox, are not always consistent: increasing technical efficiency and reducing water withdrawals. Therefore, environmental improvement depends less on the type of technological change and more on the institutional framework in which such technological change occurs; for example, when such a framework includes water markets.

Finally, when technological change is implemented in agriculture, there seems to be a trade-off between economic efficiency, environmental sustainability and political viability. That is, a policy that leads to greater economic efficiency does not necessarily lead to environmental improvement nor it is 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 the saving and efficient use of water and that at the same time have reduced political and social costs when implemented. That is, it 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. In this regard, the European Union faces a new challenge: while reform of the Common Agricultural Policy (CAP) and the implementation of the Water Framework Directive (WFD) 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 WFD 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.

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