Policy strategies face with future water availability using a dynamic CGE approach

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ABSTRACT: The real evolution of water supply in the last years in the province of Huesca in north-eastern Spain is taken into account to make a forecast with a 2030 time horizon. The main aim of this work is to find policy strategies to apply to water management to cope with future water availability integrating extreme events like droughts.

For this purpose, we develop a dynamic computable general equilibrium (CGE) model with water as an explicit factor of production. The main core of these strategies is focused on smoothing impacts of water constraints through an improvement in resources management of Irrigated agriculture. Alternative technological improvements in Irrigated agriculture are considered. In addition to technological change, we take into account Water Framework Directive (EC 2000/60) that sets up the recovery of costs of water as a central target. In a context of limits on natural resources, finding new designs for the implementation of water pricing policies could be a challenge. Thus, we assess strategies that combine water pricing and improved technology. The results show that it would be possible to deal with future water availability, even in presence of droughts, to reverse the long-term economy trend through policy strategies which would involve technical progress. The way to introduce technical progress in agriculture is significant. Moreover, this study confirms lower price volatility can improve optimal water use.

KEY WORDS: Computable general equilibrium model, Dynamic, Policy strategies, Water scarcity, Technical progress.
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1. Introduction

Since the Dublin conference on Water and the Environment (ICWE, 1992), it has become generally accepted that water should be considered an economic good. It is due to competing water use resulting in resource scarcity (Brower and Hofkes, 2008). However, what this entails can cause confusion depending on the interpretation. We can distinguish 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 as a process of integrated decision making on the allocation of scarce resources (Savenije and van der Zaag, 2002; Llop and Ponce-Alifonso, 2012). In this context, finding new strategies for the implementation of water policies can be a challenge. On the other hand, specific river basins in arid areas with growing water scarcity and cyclical droughts demand immediate analysis on policy interventions that could provide an incentive for adaptation responses to climate change and mitigate the longer-term economic effects of environmental change.

In this line, the main objective of this paper is to find policy strategies to apply to water management to cope with future water availability integrating extreme events like droughts. The core of our policies is to mitigate the economic-wide impacts of water constraints, even in drought years, through an improvement in resources management of Irrigated agriculture in the long-term. We take into account agriculture resources (both water and land) are limited. To do it, we use the methodological approach of a dynamic computable general equilibrium (CGE) model. These models consider the various inter-linkages between economic sectors and are particularly useful for the evaluation of water pricing policies (Brower and Hofkes, 2008). Therefore, an additional objective of this paper is to contribute to a growing literature that uses CGE models as a tool for the analysis of water management due to the majority of the studies are usually focused on energy and climate change. Since the challenge of water is a long-term matter, dynamic CGE models can help us to analyze water management providing insights into future economic impacts. A dynamic framework is essential to capture the adjustment path during the transition towards some sustainable development targets in the future for such exogenous policy changes (Böhringer and Löschel, 2006). These models present a wide range of possibilities that let us use different approach in line with the objectives, even a structuralist approach (Taylor, 1990).

Specific river basin models can help to evaluate and predict the impact of policy interventions on both economic and water systems. Thus, the model is used to address future water availability through policy strategies in a Spanish River basin, specifically the Ebro River basin, which is dominated by a relevant irrigation scheme. Indeed, both Spain and this river basin are characterized as a semi-arid area with significant cyclical water shortages.

The demanding situation in this area with the international institutional framework of water leads us to consider several assumptions. These policy strategies are designed to improve technology in Irrigated agriculture. We assess alternative types of improved technology. First, technological change is associated with the use of factors. We observe the effects of an improvement in irrigation water efficiency since Irrigated agriculture sector accounts for more than 80% of the water uses in this area. Second, we consider technical change in facility structure. It means a land transformation of rainfed land into irrigated land. This analysis allows us to assess the effects on cropping patterns and to analyze the impacts on land use change. Third, technical change takes places in the efficiency of technology. This shows the result of farmer´s reactions to increasing costs. Productivity gains depend on multiple factors such as irrigation knowhow, agricultural research or product marketing. The availability of advanced technology depends on collected amount set aside to pay for investment on Irrigated agriculture. This assumption focuses on tax policies can generate enough public revenue to cover the full costs of technology adoption (López-Morales and Duchin, 2011).

In addition to technological change, the institutional framework can play an essential role facing water constraints. Agriculture sector is the largest consumer of water while the price paid for this resource has long been lower than its cost. In this line, the Water Framework Directive (WFD) (EC 2000/60) sets up the recovery of costs of water as a central target, so as water prices reflect their costs to encourage users to use resources efficiently. This assumption leads us to consider strategies that combine water pricing and improved technology. Finally, we are conscious of many current decisions about the allocation of water resources in Spain are made outside the market. This implies a high preference for industrial and urban uses against irrigation uses.

With these policy strategies, we are interested in answering to the following questions: Would it be possible to reach a growth path after future water constraints through policy strategies that combine technical progress in an economy with limited natural resources? How should it be technological change in Irrigated agriculture? Could water pricing be decisive facing water scarcity?

In addition, we focus our study on the substitution in production and consumption at the sectoral level to observe the effects of the reallocation of water. The novelty of this paper is threefold. First, this study proves and obtains that policy strategies can be effective to mitigate the impacts of water constraints in a context with cyclical droughts, showing the effects of alternative technological improvements. Second, strategies also take into account the institutional framework of water. Finally, the model is built to suit a specific river basin which is a wide irrigation scheme although geographically small with a hard situation to solve. The rest of the paper is organized as follows. In Section 2 we provide a brief background about water situation in the province of Huesca in north-eastern Spain. Section 3 describes the model and calibration. Section 4 addresses policy scenarios and results. Finally, Section 5 discusses and concludes.

2. Background: Water situation in the province of Huesca

The Ebro River Basin is the Spain´s largest river basin, occupying 17 per cent of its territory. Within the Ebro River basin, the irrigation of the province of Huesca has over 200,000 hectares. The rationale for choosing the province of Huesca in Spain is based on various aspects. First, the major irrigation scheme of Spain is located in this region, which covers over 127,000 hectares, in particular, the Upper Aragon Irrigation System (CGRAA in Spanish acronyms) which includes 58 irrigation communities. This irrigation scheme also supplies water to several towns and cities, as well as ten industrial estates, and it is highly representative of irrigation in the Ebro valley. Second, the ready availability of data and collaboration in previous studies with this scheme has provided relevant information on water uses, levels of efficiency, cropping patterns and crop yields from 2001 to 2010, that means that the CGRAA is ideally suited for the purposes of this study.

In addition to these assumptions, the main reason is that this irrigation scheme faces with a downward trend of water supply and some cyclical restrictions in water resource availability in last ten years. See Figure B1 in Appendix B. The volume of water supply in some years is insufficient for crops such as corn, rice, alfalfa, fruit or almonds, which are the most profitable and with a high interest for agri-food industry, livestock and imports. These water constraints are provoking shocking changes in the cropping pattern moving towards less water demanding crops with lower profitability instead of the expected evolution (more weight of fruits, vegetables, corn,…). Latter studies demand more regulation and encourage land consolidation instead of an expansion of land and land-use changes towards less profitable crops. The current levels of water use efficiency in this irrigation scheme are very significant and suppose an efficient use if we compare with the lower levels three decades ago. They could thus be enhanced if they continue with the process of modernization (Sánchez-Chóliz and Sarasa, 2013).

Finally, the water situation in this irrigation scheme could have a wider international application as a reflection in other arid areas with water constraints and/or downward trends in the volume of water in the latter years. Furthermore, it could be relevant due to the current situation is tricky and there are some uncertainties for the preservation of the agricultural activity. In these areas maintaining the most profitable and demanding crops could be rather tricky due to the lack and insecurity of water supply.

3. The model

In this paper, we develop a multi-sector, recursive dynamic computable general equilibrium (CGE) model. Dynamic CGE models can be classified as forward-looking dynamic ("intertemporal") or recursive dynamic models. A recursive dynamic model is basically a series of static CGE models that are linked between periods by exogenous and endogenous variables that let be updated, whereas a forward-looking dynamic model is based on the Ramsey growth model and economic agents are characterized as having perfect foresights. We work with a recursive model because it allows us to handle investment easier in line with the aim of the study. Indeed, we think that perfect foresights approach, despite its wide use, can be unrealistic in the medium and long term. This recursive model takes in a specific time horizon to include the forecast projection of the evolution of water. In this section, we lay out an overview of the model.

3. 1. Overview of the model

This model characterizes the economy of the province of Huesca where CGRAA is located. We break down the economy in 18 sectors, taking a special interest in Agropecuarian (farm and cattle) sectors that are disaggregated in Irrigated agriculture, Non-irrigated agriculture and Livestock. In addition, Irrigated agriculture is captured by 4 sectors: Cereals and legumes, Industrial crops, Fruits and vegetables and Olive and vineyard. This allows us to gain wider insights into the implications of different policy strategies. Sectors are groups of homogeneous units of production. The model is written down as a mixed complementarity problem (MCP) following Mathiesen (1985) and Rutherford (1999). This implies that the equilibrium is determined by positive income level, production activity and prices level, both non-negatives, where three classes of equilibrium conditions and inequalities are satisfied: zero profit conditions, market clearance and income balance. In last years, CGE models are more and more solved as a MCP approach due to it simplifies the coding model and does not require specifying the equations. This enables to solve easily cases that include water or energy as input, increasing returns or dynamic models.

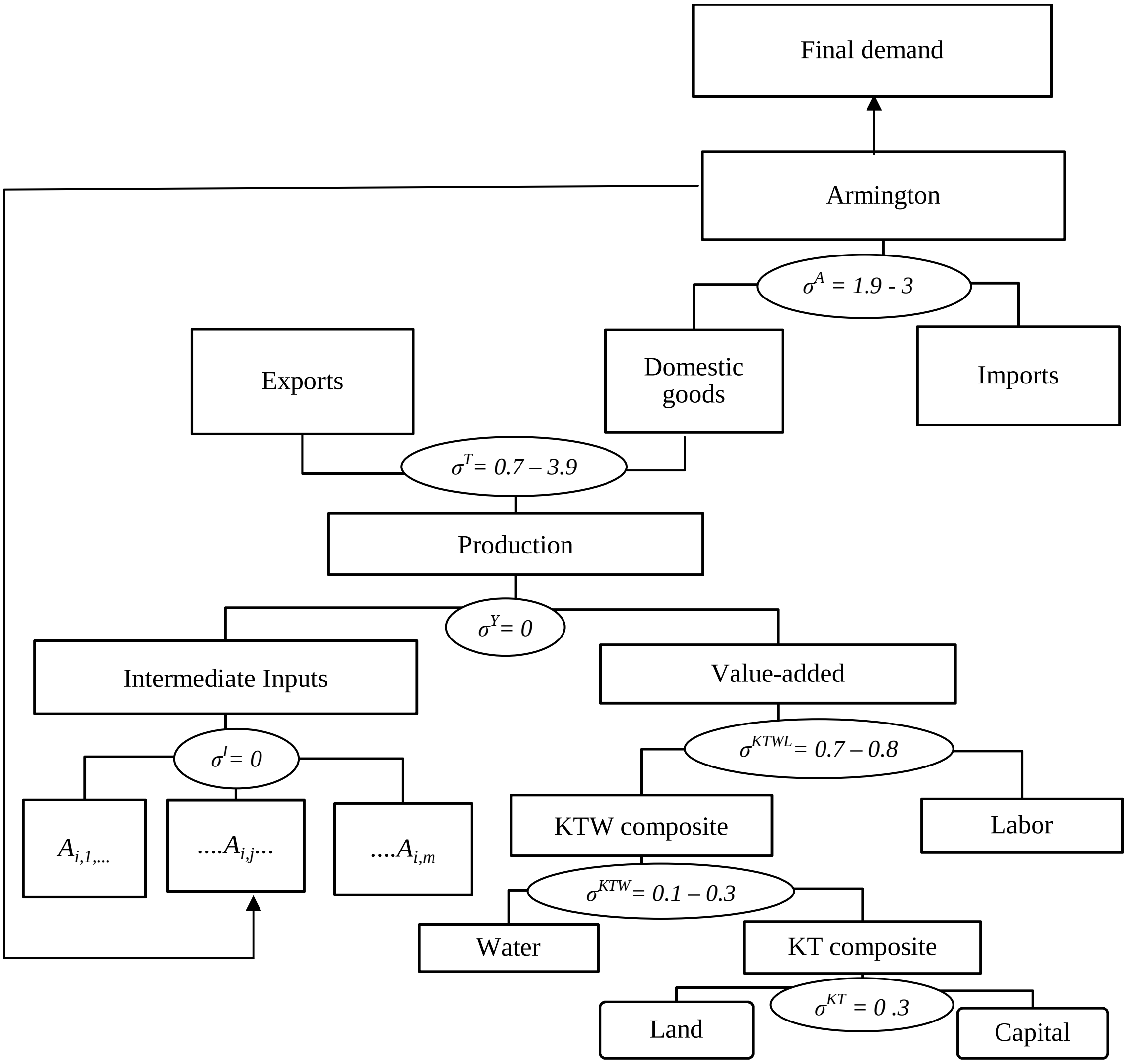

Fig. 1. Production function structure

Figure 1 provides an overview of the production technology. Producer behavior is specified through a four-stage nested constant elasticity of substitution (CES) production function and through a zero-profit condition. The level of production (output) for each economic activity is obtained through a combination of intermediate inputs and value-added according to a Leontief function. Each sector produces a single homogeneous good which is differentiated from any other good in the economy. Aggregate value-added is a CES function of factors (labor and capital composite) whereas the aggregate of intermediate inputs follows a Leontief function. Water is an intermediate input[1] and a factor of production. Water and capital-land composite are substituted to produce KTW composite through a CES function. Facing water constraints, resources (capital and land) would be reassigned. The elasticity of substitution between water

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[1] It takes into account the collection, purification and distribution of water as well as sanitation activities, waste management and water pollution. Water factor reflects the consumption of water of each sector.

and capital plays an essential role. We consider that the ability to adapt facing water constraints depends on irrigation techniques. Crops with sprinkler irrigation techniques have more ability to adapt than crops with drip irrigation due to it is trickier to find another technique to save more water[2]. The substitution between capital and land follows previous literature Boyd and Newman (1991), Decaluwé et al. (1999) and Gómez et al. (2004), (see Table 1).

In the case of the Non-irrigated agricultural sector that does not use water, labor factor is combined only with capital-land composite. Labor and capital are considered perfectly mobile across industries. However, water factor is use specific in two blocks: Irrigated agriculture sectors and the rest of sectors. It is due to water prices are considerably different between Irrigated agriculture sectors and the rest of sectors. It also allows us to design specific irrigation water pricing policies. Inside these blocks, they are mobile. The land mobility is modeled through a constant elasticity of transformation (CET) frontier. We adopt a nested CET function which allocates land in two tiers: an optimal allocation of a given parcel of land under types of land (rainfed and irrigated land) in the first stage, while the choice of crops is made in the second stage (Figure B2, Appendix B). This allows us to observe the trend in cropping patterns.

Output of each sector can be earmarked to domestic or foreign demand through a CET function. We also assume Armington approach in which domestic and import goods are imperfect substitutes. There are two consumer groups: a representative agent and the government. The representative agent maximizes the total utility through subject to the budgetary constraint. Their incomes come from the sale of their endowments of factors and direct transfers from the government and foreign sector, that they are spent on consumption, tax payments, savings and transfers to the rest of the world. The government receives taxes from the representative agent and transfers from the rest of the world. It spends them on consumption, savings and transfers to the representative agent. Total public expenditure is modeled through a fixed coefficients structure. An additional agent is included to collect the markup on the cost of water and sets aside for investing in Irrigated agriculture. This agent could work similar to a Water Confederation or in this region, the CGRAA.

The production function of Irrigated agriculture integrates two technological improvements. The first one is associated with the use of factors, specifically water. It involves that water is an effective resource, in other words, the improvement occurs in effective water. Efficiency parameter (φ_t) follows a logistic evolution that we capture with a Gompertz function, see

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[2] We consider that the substitution elasticity between capital and water is 0.3 in all sectors. In the case of Irrigated agriculture, this value is the same in Cereals and industrial crops due to they use sprinkler irrigation. On the other hand, we consider 0.2 in Fruits and vegetables and 0.1 in Olive and vineyard because they use drip irrigation in line with Gómez et al. (2004).

Appendix A, which also depends endogenously on collected amount and a static cost index for technology, specifically for modernization costs. It implies two assumptions: getting improvements in efficiency when the level is closer to the ceiling of the function is more difficult[3] (currents levels of efficiency are taken in the slowdown phase of the function); efficiency level does not increase at the same level of collection (γ is an exogenous scale exponent lower than 1). Figure B3 in Appendix B shows the evolution of irrigation water efficiency that we assess afterwards. The second technological improvement tackles the efficiency of the technology, which is captured by the efficiency parameter of the CES function for Irrigated agriculture.

The economy of Huesca requires the small open economy assumption, in other words, it is a price taker with no influence on world market prices in both imports and exports markets. The difference between revenue and payments with the rest of the world is exogenously given. Finally, total investment equals total saving, where savings are composed of savings from all institutions. The market balance conditions are satisfied by adjusting relative prices. Homogeneity of degree zero in prices is assumed for all supply and demand functions in the model. In line with the general equilibrium framework, only relative prices are relevant for the specification of the quantities of goods supplied and demanded. This requires the determination of a numéraire price in the model. The index price of the representative agent is used as the numéraire price level against which all relative prices in the model are measured. Concerning to dynamic model, the economy grows at a constant rate and capital formation is based on an exogenous interest rate and endogenous capital stock.

3.2. Calibration and Data

A base scenario is a prerequisite for the application of any CGE model. We use the 2002 SAM for the province of Huesca obtained from Cazcarro et al. (2010) as our base scenario. This SAM has been worked later in Cazcarro et al. (2011) to include water as an explicit factor of production. The aim of this work leads us to use the 2002 SAM as the benchmark due to 2002 year saw average rainfall in Huesca. This also enables to include real water supply evolution for the first decade. We suppose that the future evolution of water supply will follow the trend observed from our database what allow us to observe the effects on cyclical water shortages. The selection of the elasticity parameters is realized according to the region of study through a review of the literature and some studies in this area (Table 1).

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[3] We assume the ceiling level of the Gompertz function is equal to 90%. There are water losses during transport and use which are tricky to avoid.

Table 1: Elasticity parameters used in the model

Substitution elasicity between:	
Intermediate inputs and value-added	$\sigma^{Y} = 0$
Intermediate inputs	$\sigma^{I} = 0$
Irrigated and Non-irrigated agriculture production (a)	$\sigma^{RS} = 1$
Labor and KTW aggregate	(b) σ^{KTWL} = 0.7 (Farming sectors)
	(c) σ^{KTWL}= 0.8
Capital and water (KTW aggregate) (d)	σ^{KTW}= 0.3
	σ^{KTW}= 0.2 (Fruits and vegetables)
	σ^{KTW}= 0.1 (Olive and vineyard)
Domestic and import goods (e)	σ^{A}= 1.9 - 3
CET (f)	σ^{T}= 0.7 - 3.9
Demand elasticity coefficients (g)	σ^{C}= 0.51-1.45
Land transformation (h)	σ^{TT} = 0.1 and 0.3 (Appendix B)

(a) Land and climate characteristics and different technique provoke that final goods produced by irrigated and non-irrigated agricultural sectors are considered as imperfect substitute following Gómez et al. (2004).

(b) The substitution between KTW aggregate and labor is lower in Farming sector due to the relevance of the KTW aggregate for this sector (Jomini et al., 1991).

(c) Seung et al. (1998).

(d) We suppose economy has ability to adapt according to irrigation technology as we explained before.

(e) As we assume that policies are specifically applied in the area of study, we aggregate foreign trade instead of considering different values of trade elasticity by regions. This last case could be more suitable for a national policy. Instead of it, we distinguish among sectors following Hertel (1997).

(f) See de Melo and Tarr (1992).

(g) All demand elasticity coefficients by sectors taken from Mainar (2010).

(h) OECD (2003).

Concerning to the dynamic model, the value of the main parameters are obtained from real data of the region from 2002-2010 (INE, 2002-2010). The level of the annual interest rate is 4.31% and growth rate is 2.01%. The relationship between capital and investment in the steady-state is obtained from the calibration of the model using SAM data. The model is programmed as MCP using GAMS/MPSGE (Rutherford, 1999), and is solved with the PATH algorithm.

4. Scenarios and Results

As we explained, policy strategies are focused in two main assumptions. Firstly, they are designed to include technological change to tackle future water constraints. Secondly, we take into account WFD targets to combine water pricing and improved technology.

4.1. Description of Scenarios

The four scenarios described below simulate a reference scenario, a forecast over future water availability and two policy strategies, with a 2030 time horizon. Both policies include the forecast projection and are designed to smooth the impacts of water availability to reach a growth path, or at least to reduce the gap with the reference scenario.

I. *Benchmark scenario*: Results are laid out in a steady state reference scenario with a 2030 time horizon. This projection is used for comparing the results of the rest of scenarios. We have in mind that the steady-state path is far for being real since all variables grow at the same level. In the following scenarios, we consider that agriculture resources (both water and land) do not follow this same path.

II. *Water damage scenario:* The real evolution of irrigation water supply in the last years (2001-2010) in this region is taken into account to make a forecast projection with two decades until 2030. The evolution of water supply is based on a slightly downward trend of water supply and some drought years integrating cyclical shortages (Figure B1, Appendix B) [4]. In addition, since land presents limits to be expanded in the long-term, growth rate is not applied in land factor. This allows us to observe the transformation process between rainfed and irrigated land with constrains in the expansion of total land. This scenario does not consider any policy strategies.

Next following scenarios take into account *Water damage scenario*. The challenge of these policies is to design a strategy to improve technology in Irrigated agriculture sectors in the long-term to tackle water constraints. To do it, a markup (25%) of water consumption costs is collected by the new agent (i.e. CGRAA) to set aside to pay for innovation in Irrigated agriculture.

III. *Policy1:* This endogenous policy presents the results of a policy designed to enhance efficiency in Irrigated agriculture considering three technology improvements. However, we also present the effects of the three technology changes separately[5]:
    a. *Water:* Irrigation water efficiency follows the Gompertz function.
    b. *Land:* Transforming rainfed land into irrigated land[6].
    c. *Productivity gains:* The level of gains in Irrigated agriculture sectors is 10%.

IV. *Policy2*: In addition to the previous policy, we include in the model a structuralist approach to keep the control of the evolution of irrigation water prices. We assess different growth paths of irrigation water prices: a linear trend of water pricing, a two-

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[4] The trend followed by the water for industrial uses is completely different, even increases in drought years. This is the reason we consider only irrigation water uses. However, it does not change significantly the results due to the weight of industrial uses is low.

[5] When the three improvements are considered separately, collection is reduced by a third.

[6] Irrigated land increases by 10% and this area is subtracted from rainfed land.

tiered[7] trend of water pricing and high water pricing from the beginning. To do it, government applies an endogenous tax on value-added in Irrigated agriculture sectors and transfer them to invest in Irrigated agriculture[8]. The aim is to observe the substitution between irrigated products to handle the growth path of irrigation water prices.

Finally, we focus our study on the substitution in production and consumption at the sectoral level to observe the effects of the reallocation of water.

4.2. Results

This subsection presents the results of our simulations. Given real water supply is based on a cyclical evolution, it involves us to sum up the results showing the average on two periods: short-term (2011-2020) and long-term (2021-2030) in Table 2, and results in specific drought years in Table 3[9]. We begin with few macroeconomic results of some key indicators for the different scenarios to observe the influence of Irrigated agriculture in the economy. These results are shown as a comparison to benchmark scenario. Then, we study the results at sectoral level.

4.2.1. Main results

Water damage scenario takes into account the downward trend of water supply and water constraints without applying policies. As expected, Table 2 presents negative impacts on average with falls in macroeconomic results although these falls in the economy are limited but larger in the long-term and in drought years (Table 3). The highest negative impact occurs in total production which falls by 2.01% in a drought year in the long-term. This fall can be due to a drop in productivity in irrigated industries when there is no way of buying more water on the markets (see Berrittella et al., 2007). We should take into account that Irrigated agriculture accounts for 3.32% of the total sectors in the calibration year. In line with literature results, high variations are also observed in irrigation water price which increase on average 209% in the short-term (2011-2020) and 320% in the long-term (2021-2030). They are much more inflationary in drought years. Standard deviation of irrigation water price is very large that shows high variations among years as a consequence of cyclical evolution of water supply. Tables 2

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[7] The average of each decade is the price chosen. There are three decades since 2002 but we show the results of the last two.

[8] The lump sum transfers between government and *farmer* agent are endogenously adjusted to ensure budget balance for the government.

[9] There are three relevant drought years that characterize years with the highest falls of water supply. The first one is in 2005 which occurred really. The second ones (2014 and 2023) are estimations following the previous trend. Note that these years are only approximations to future drought years. Any resemblance to reality would be a coincidence.

and 3 also show land allocation. The downward trend of water supply leads to reduce total irrigated land to increase total rainfed land in the long-term. We can think that irrigated land earmarked for cereals and legumes is reduced mainly due to a reduction of corn and rice, crops which need more water. Slight increases of land are observed in Fruits and vegetables and Olive and vineyard. Nevertheless, we should not forget that in the calibration year, cereals in irrigated land stretches around 60% of total irrigated land, while 30% belongs to industrial crops. Moreover, in spite of the increase of rainfed land area in drought years, total land area is reduced. It shows the abandonment of land by farmers which is currently discussed (see Figure B4 in Appendix B). This situation could involve in the future the extinction of irrigated land.

Tables 2 and 3 also sum up the results on production on the main groups of sectors. The sharpest falls are found in Irrigated agriculture sectors, as we expected. These falls are not limited (22.36% on average in the short-term and 36.06% in the long-term). It is followed by falls in the rest of farming sector due to this depends on Irrigated agriculture. The slight increase in Industrial sectors is linked up with substitution between capital and water that manages to adapt capital resource facing water constraints. The small fall in services is provoked mainly in Hotel and restaurants (see subsection 4.2.2).

Figure 2 shows results in total irrigated production and irrigation water prices to observe the effects of this cyclical evolution of water supply. It suggests that negative impacts in drought years are far for being limited and are larger in the long-term because a downward trend of water supply over time. Variations in water prices are higher in drought years than on average. Note that water prices are more inflationary in the long-term.

The results under the first policy (*Policy1*) present the effects of a policy strategy designed to enhance technology in Irrigated agriculture. This policy lets obtain significant positive results even both in Irrigated agriculture sectors and the whole economy in the long-term. As private consumption is a function of disposable income, if disposable income decreases (by increasing markups in this case), consumption will also decreases. In addition, consumption decreases due to an increase in investment and, in turn, in savings.

Nevertheless, we can observe different characteristics of the types of technical change. The improvement in water efficiency *("Water")* shows a greater efficiency to mitigate the falls in the economy in the long-term (see Figure 2 and Table 2). This improvement also leads to an efficient use of land allocation due to the most profitable crops (fruits and vegetables and olive and vineyard) are stimulated. The land transformation into irrigated land (*"Land"*) reduces hardly negative impacts although it is not enough. Finally, productivity gains in Irrigated agriculture let obtain efficiency in the process and obtain results almost closer to the benchmark scenario through an optimal use of land. However, this improvement loses effectiveness over time and in drought years in the whole economy, unlike irrigation water efficiency.

Thus, reducing negative impacts in the economy becomes really tricky specifically in the long-term and in drought years. A water policy that manages to reverse the dramatic trend in Irrigated agriculture sectors in the long-term requires an improvement of irrigation water efficiency through modernization, encouraging farmers to make a good use of the opportunities presented to get productivity gains and an optimal use of the resources available after the investment in agriculture to focus on the most profitable crops which requires a land transformation into irrigated land. In this regard, Figure 2 confirms that this policy avoids wider impacts observed in the long-term and in drought years through improved technologies.

To sum up, a policy strategy that involves improved technologies in Irrigated agriculture facing future water constraints enables to mitigate the economic-wide effects in the economy and to reverse the long-term trend in Irrigated agriculture sector. Indeed, the evolution of cropping patterns would be changed towards the most profitable crops.

Concerning to the second policy scenario (*Policy2*), in conjunction with improved technology, this scenario aims at designing the evolution of irrigation water prices and reducing price volatility of *Policy 1*. This scenario is focused in EU targets which propose the recovery of costs of water. It suppose that the evolution of irrigation water prices, both in extreme water constraints and lower water constraints, assures a high price to recover costs. This policy let us assess the sensibility of the variability of prices facing water use. Figure 2 can be useful to have an idea of the different evolutions of water prices that are simulated.

Firstly, a gradual rise of irrigation water prices following the trend (*"Linear"*) manages to incentive farmers to earmark their resources for the most profitable crops (Fruits and vegetables) showing larger positive results in production in Irrigated agriculture sectors than *Policy 1*, even in the long-term. However, mitigating negative impacts in drought years becomes tricky due to a high price should be required in these years (Table 3). Secondly, a two-tiered trend of irrigation water prices (*"Tiered"*) avoids price volatility and to enhance natural resources use to grow the most profitable crops such as Fruits and vegetables again. This policy provides training facing water constraints that let obtain larger positive results in the long-term. Thirdly, a high rise of irrigation water prices from the beginning ("*High*") through a policy that ensures a price higher than costs lets again obtain positive results in Irrigated agriculture and mitigate the economic-wide impacts of constraints. Nevertheless, this high price could involve fictitious incentives to other agents in the short-term. In this regard, Table 2 shows larger negative impacts in industrial and services production.

Table 2

Main results on average in each period

% change compared to benchmark scenario	**2011-2020**								**2021-2030**							
		Policy 1				**Policy 2**				**Policy 1**				**Policy 2**		
	Water Damage	**3 TC#**	**TC**			**Linear**	**Tiered**	**High**	**Water Damage**	**3 TC**	**TC**			**Linear**	**Tiered**	**High**
			Water	**Land**	**Prod. gains**						**Water**	**Land**	**Prod. gains**			
Total production	**-0.89**	**0.33**	-0.43	-0.82	-0.29	0.32	0.31	0.27	**-1.49**	**0.02**	-0.83	-1.36	-0.87	0.00	0.01	0.03
Total Private consumption	**-0.37**	**-0.34**	-0.42	-0.59	-0.19	-0.36	-0.37	-0.73	**-0.70**	**-0.30**	-0.54	-0.83	-0.42	-0.24	-0.27	-0.24
Capital investment	**-0.30**	**3.07**	0.90	0.76	1.19	3.10	3.08	3.31	**-0.56**	**3.11**	0.79	0.54	0.97	3.09	3.14	3.17
Total production Irrigated agriculture	**-22.36**	**20.48**	-10.30	-19.72	0.23	30.54	30.56	84.31	**-36.06**	**5.97**	-21.17	-33.74	-18.37	7.11	13.25	13.21
Total production Rest of farming	**-11.16**	**-8.90**	-7.45	-13.19	-10.49	-11.32	-11.43	-22.64	**-20.82**	**-14.01**	-13.94	-22.70	-18.85	-14.68	-15.81	-15.70
Total production Industrial sectors	**0.75**	**0.17**	0.57	0.97	0.38	-0.18	-0.18	-2.24	**1.39**	**0.83**	1.06	1.68	1.17	0.81	0.58	0.60
Total production Services	**0.00**	**-0.01**	-0.06	-0.05	0.05	-0.12	-0.13	-0.69	**-0.01**	**0.19**	0.01	0.01	0.14	0.16	0.11	0.13
% land change compared to 2002																
Total rainfed land	**2.75**	**-16.20**	0.75	-14.23	2.43	-16.62	-16.63	-16.62	**4.26**	**-15.42**	1.68	-13.19	4.20	-15.48	-15.69	-15.48
Total irrigated land	**-1.96**	**7.77**	-0.53	5.51	-1.72	7.90	7.87	9.24	**-3.41**	**6.99**	-1.13	3.79	-3.36	6.85	7.04	7.03
Irrigated land Cereals and legumes	**-5.23**	**4.70**	-1.58	2.50	-6.94	3.66	3.77	-4.22	**-11.62**	**1.25**	-4.79	-4.76	-13.25	1.45	0.41	0.40
Industrials crops	**1.87**	**0.65**	-1.53	7.12	-2.16	-0.95	-1.13	-6.72	**8.96**	**3.36**	1.61	14.91	4.62	2.50	2.06	2.08
Fruits and vegetables	**8.14**	**63.28**	11.41	22.26	43.48	80.87	80.17	191.97	**11.94**	**69.68**	16.48	26.95	45.41	69.63	83.20	83.03
Olive and vineyard	**16.69**	**13.38**	10.37	25.72	12.43	13.03	12.99	11.36	**30.59**	**23.42**	20.00	40.84	25.83	23.30	23.16	23.17
Prices (baseline index = 1.00)																
User cost of irrigation water factor	**2.09**	**2.34**	1.96	2.19	2.44	2.39	2.34	3.57	**3.20**	**3.57**	2.97	3.35	3.71	3.36	3.57	3.57
Standard deviation of irrigation water prices (%)	***60.33***	***70.60***	*60.55*	*62.47*	*68.44*	*29.41*	*0.00*	*0.00*	***77.52***	***92.52***	*79.93*	*80.17*	*86.28*	*29.41*	*0.00*	*0.00*

*Notes: *Benchmark scenario column is 0.00%*

It includes the three technology improvements.

TC: Technology change

Table 3

Results on specific drought years

% change compared to benchmark scenario	**2014**								**2023**							
		Policy 1				**Policy 2**				**Policy 1**				**Policy 2**		
			TC								**TC**					
	Water Damage	**3 TC**	**Water**	**Land**	**Prod. gains**	**Linear**	**Tiered**	**High**	**Water Damage**	**3 TC**	**Water**	**Land**	**Prod. gains**	**Linear**	**Tiered**	**High**
Total production	**-1.51**	**-0.47**	-1.09	-1.44	-1.00	-0.71	-0.68	-0.48	**-2.01**	**-0.70**	-1.41	-1.88	-1.47	-0.91	-0.84	-0.82
Total Private consumption	**-0.67**	**-0.74**	-0.73	-0.91	-0.56	-0.61	-0.60	-0.62	**-0.99**	**-0.70**	-0.85	-1.15	-0.79	-0.53	-0.52	-0.49
Capital investment	**-0.53**	**2.73**	0.65	0.49	0.87	2.26	2.30	2.68	**-0.79**	**2.72**	0.53	0.26	0.64	2.25	2.37	2.40
Total production Irrigated agriculture	**-38.14**	**-4.54**	-27.91	-36.01	-21.62	-33.09	-31.59	-11.15	**-48.84**	**-16.19**	-36.41	-46.97	-36.15	-41.42	-37.04	-37.05
Total production Rest of farming	**-19.52**	**-15.51**	-15.13	-21.79	-17.91	-13.09	-13.00	-14.41	**-29.42**	**-21.15**	-21.88	-31.49	-26.93	-19.51	-19.25	-19.14
Total production Industrial sectors	**1.38**	**0.89**	1.16	1.63	1.11	1.89	1.85	1.15	**2.05**	**1.58**	1.68	2.37	1.93	2.51	2.36	2.37
Total production Services	**0.01**	**-0.04**	-0.06	-0.05	0.05	0.15	0.14	0.01	**-0.01**	**0.16**	0.00	0.00	0.12	0.31	0.29	0.31
% land change compared to 2002																
Total rainfed land	**5.77**	**-13.34**	4.30	-12.08	5.69	-12.34	-12.41	-12.34	**6.79**	**-12.80**	5.00	-11.41	6.83	-11.98	-12.15	-11.98
Total irrigated land	**-5.20**	**4.28**	-3.28	1.52	-5.08	2.19	2.35	3.90	**-7.03**	**3.24**	-4.11	-0.56	-7.12	1.23	1.71	1.69
Irrigated land																
Cereals and legumes	**-13.72**	**-2.36**	-8.16	-7.32	-15.02	3.24	2.97	-0.97	**-22.23**	**-7.46**	-13.00	-16.76	-23.29	-0.91	-1.94	-1.97
Industrials crops	**7.83**	**2.90**	1.65	13.31	3.43	0.87	1.13	2.82	**18.60**	**9.20**	7.93	24.94	13.76	5.76	6.78	6.79
Fruits and vegetables	**9.84**	**64.66**	15.13	24.20	41.72	-4.42	-1.09	47.79	**11.46**	**66.88**	18.11	26.46	40.25	-3.58	7.86	7.77
Olive and vineyard	**30.23**	**26.70**	23.45	40.08	25.51	26.71	26.67	26.65	**45.06**	**36.89**	33.45	56.24	39.51	36.78	36.69	36.70
Prices (baseline index = 1.00)																
User cost of irrigation water factor	**3.42**	**3.94**	3.35	3.56	3.94	2.25	2.34	3.57	**4.87**	**5.59**	4.75	5.07	5.55	3.12	3.57	3.57

TC: Technology change

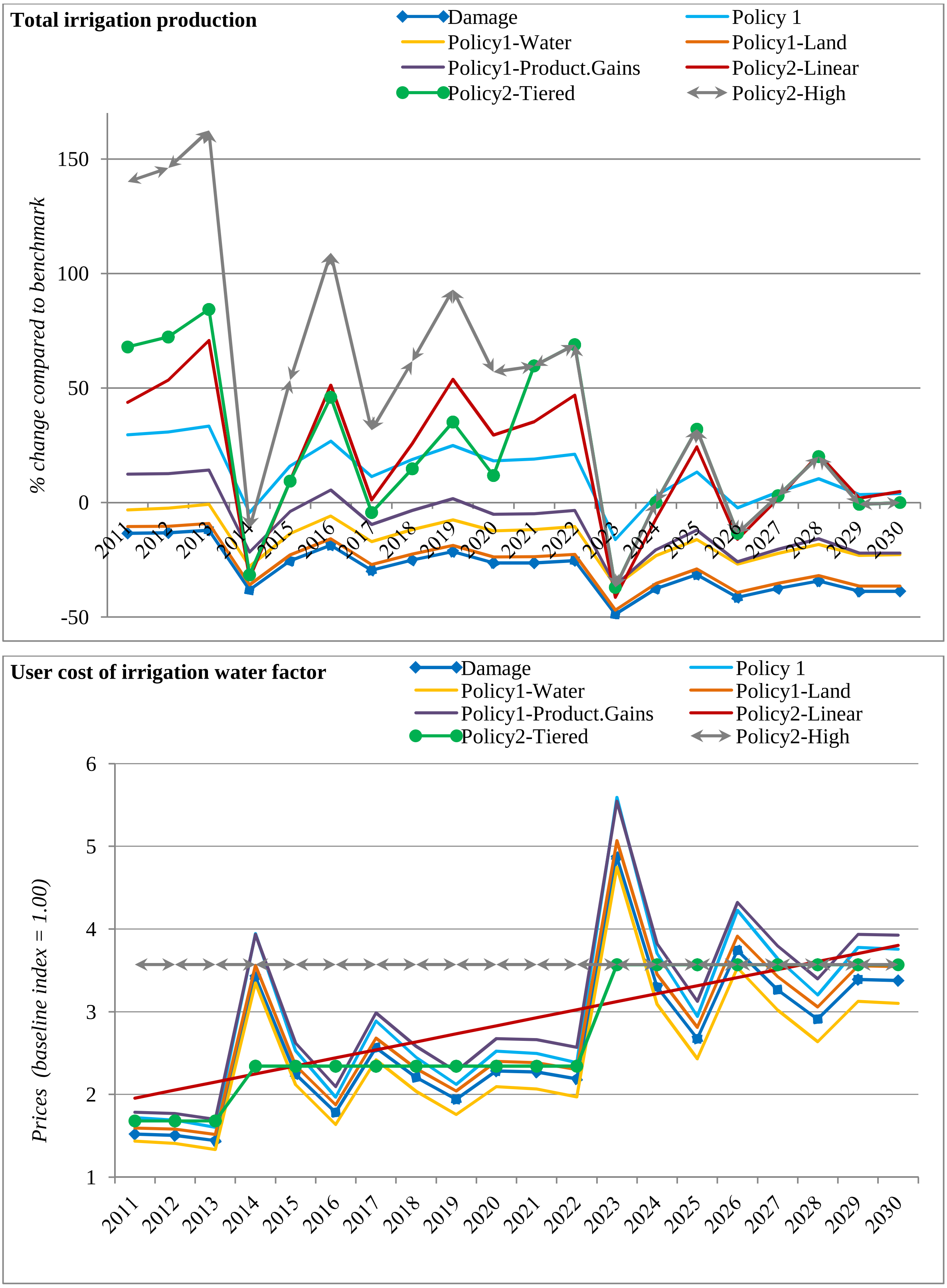

Fig. 2. Results in total production and irrigation water prices

On the other hand, a high price could reduce impacts in Irrigated agriculture production on average ensuring a high investment in irrigated agriculture from the beginning to make up for falls in drought years. As irrigation water efficiency depends on collected amount, a high rise of irrigation water prices implies a high level of collection in the short-term. In general, combining prices policy and improved technology assures high collection and as a consequence a slight high level of water efficiency in the long-term.

The three trends of irrigation water prices show an optimal use of land factor. It is due to the substitution process among Irrigated agriculture accounts as a consequence of the aim of the policy at stimulating profitable cropping patterns improving the use of factors. However, this policy reaches hardly the benchmark scenario in drought years due to irrigation water price should be higher.

To sum up, in the second policy scenario that involves a planning of irrigation water prices in addition to technical progress to avoid price volatility, the benchmark scenario would be reached on average, and positive impacts are found specifically in Irrigated agriculture sectors. This policy lets obtain significant positive results in Irrigated agriculture as a consequence of a better resources management. The main conclusion of this policy is that facing uncertainty in water shortages that we have tried to simulate with a cyclical evolution of water, a price planning could be significant and provide training for a fast adjustment. The timing to apply a specific policy in extreme events could not be enough to reduce the effects of water shortages. Specifically, a linear growing trend of irrigation water prices could tackle water constraints and avoid unrealistic expectations among agents that could provoke negative effects in the rest of sectors.

4.2.2. Sectoral results

Differences are larger between sectors as shown Table 4 in outputs results. In *Water damage scenario*, the bigger falls on output in descending order are in Irrigated agriculture (specifically Cereals and legumes), Agri-food industry, Livestock, Non-irrigated agriculture and Water. The reason is that Irrigated sectors, Livestock and Water utilities have a significant share of water factor production as a consequence of their high consume of water. The falls in Agri-food industry is due to this sector depends on Irrigated agriculture and the falls in Non-irrigated agriculture is a consequence of limited extension of land introduced in the model. These falls are larger in the long-term. On the contrary, the account with the largest increase in output is Mineral products, machinery and transport material which could be due to the substitution between capital and water provokes largest efforts in capital and machinery facing water constraints.

Table 4

Impacts on sectoral output *(% change compared to benchmark)*

Sectors\Scenarios	**2011-2020**					**2021-2030**				
	Water damage	**Policy1**	**Policy2**			**Water damage**	**Policy 1**	**Policy 2**		
			Linear	**Tiered**	**High**			**Linear**	**Tiered**	**High**
Cereals and legumes (irrigated land)	**-36.42**	-13.75	-15.56	-15.55	-26.79	**-56.20**	-33.06	-33.18	-34.48	-34.47
Industrial crops (irrigated land)	**-28.40**	-13.32	-14.94	-15.23	-22.65	**-41.78**	-26.72	-27.36	-27.99	-27.96
Fruits and vegetables (irrigated land)	**-18.05**	49.27	70.17	70.42	181.76	**-31.46**	33.74	36.42	48.97	48.86
Olive and vineyard (irrigated land)	**-11.61**	3.52	3.59	3.29	4.21	**-19.91**	-2.71	-3.25	-2.87	-2.83
Non-irrigated agriculture	**-10.39**	-17.96	-19.60	-19.79	-27.87	**-19.50**	-25.07	-25.43	-26.14	-26.05
Livestock	**-11.42**	-5.82	-8.51	-8.60	-20.87	**-21.27**	-10.25	-11.03	-12.31	-12.18
Energy products	**3.58**	1.31	1.17	1.19	0.02	**6.36**	3.60	3.70	3.55	3.59
Water utilities	**-10.35**	7.74	12.21	12.21	36.17	**-16.88**	1.05	1.56	4.32	4.32
Minerals and metals	**5.19**	0.92	0.10	0.15	-4.23	**8.75**	4.40	4.41	3.88	3.92
Minerales and non-metals products	**2.76**	0.42	-0.21	-0.20	-3.36	**4.45**	2.45	2.41	2.05	2.09
Chemicals	**1.18**	1.69	2.66	2.67	7.79	**2.18**	1.63	1.79	2.35	2.30
Mineral products, machinery and transport material	**18.06**	2.77	0.87	1.18	-10.15	**31.71**	13.50	13.91	12.33	12.35
Agri-food industry	**-13.88**	-2.74	-2.84	-3.12	-3.60	**-23.72**	-10.11	-10.59	-10.39	-10.35
Manufactures	**4.87**	0.46	-0.89	-0.90	-7.18	**7.23**	3.87	3.62	2.94	2.98
Rubber, plastics and others	**5.74**	0.76	0.32	0.35	-2.28	**9.90**	3.82	3.92	3.59	3.57
Construction and engineering	**-0.29**	-0.06	-0.06	-0.06	-0.17	**-0.53**	-0.01	0.00	0.00	0.03
Hotels and restaurants	**-0.21**	-0.27	-0.32	-0.32	-0.81	**-0.41**	-0.13	-0.08	-0.12	-0.09
Rest of services	**0.04**	0.03	-0.09	-0.09	-0.67	**0.06**	0.25	0.20	0.15	0.17
Standard deviation (%)	***13.31***	*13.79*	*18.76*	*18.84*	*46.35*	***21.46***	*15.25*	*15.81*	*17.99*	*17.96*

**Benchmark scenario column is 0.00%*

Policy 1 lets reduce falls in Irrigated agriculture sectors even showing positive results in the most profitable crops (Fruits and vegetables and Olive and vineyard). Indeed, it also reduces spillover effects in the rest of economy reducing the falls in Agri-food industry, Livestock and Water utilities even in the long-term. On the other hand, positive results in industrial accounts are reduced. This policy thus leads less difference between sectors, that it is observed through a reducing standard deviation between sectors, specifically in the long-term. Fruits and vegetables production has a considerable enhance, as well as Olive and vineyard. Thus, technology change provides a better optimal water use since the most profitable crops grow.

Policy 2 also involves a planning of irrigation water prices as we explained before. Since this policy avoids price volatility through a substitution between goods within Irrigated agriculture, the effects in crops are relevant. This has significant effects in Irrigated agriculture sectors than the previous policy. Specifically, Fruits and vegetables achieve larger positive output results even in the long-term. Note that it would be advisable to reach a medium situation to avoid negative losses in the rest of sectors in the short-term. These findings reveal an additional conclusion: lower price volatility can easily enhance natural resources use in irrigated agriculture in a context of cyclical droughts.

Table 5 shows results on sectoral prices in each period (short and long term). After taking into account the downward trend of water supply, *Water damage scenario* shows significant rise in prices in Irrigated agriculture sectors, specifically in Industrial crops (18.42%) and Cereals and legumes (8.37%) in the short-term that are even larger in the long-term. They are followed by rise of prices in the rest of Irrigated agriculture sectors and Agri-food industry.

Table 5

Impacts on sectoral prices on average 2011-2020 *(% change compared to benchmark)*

	2011-2020					**2021-2030**				
			Policy2					**Policy 2**		
Sectors\Scenarios	**Water damage scenario**	**Policy1**	Linear	Tiered	High	**Water damage scenario**	**Policy 1**	Linear	Tiered	High
Cereals and legumes (irrigated land)	**8.37**	5.70	6.68	5.23	8.88	**14.37**	10.27	10.70	9.55	10.69
Industrial crops (irrigated land)	**18.42**	11.56	11.69	9.41	16.12	**33.62**	21.80	21.08	19.27	21.07
Fruits and vegetables (irrigated land)	**1.77**	0.99	-10.16	-5.52	-15.61	**3.45**	1.96	-5.91	-2.59	-5.92
Olive and vineyard (irrigated land)	**1.94**	1.21	-2.19	-1.06	-3.18	**3.63**	2.28	-0.36	0.59	-0.36
Non-irrigated agriculture	**0.38**	0.51	0.57	0.55	0.56	**0.65**	0.88	1.07	1.06	1.08
Livestock	**0.21**	0.16	0.82	0.47	1.34	**0.46**	0.24	0.66	0.41	0.66
Energy products	**-0.69**	-0.35	-0.33	-0.22	-0.56	**-1.31**	-0.73	-0.55	-0.52	-0.55
Water utilities	**-0.49**	-0.08	-0.89	-0.30	-1.82	**-0.98**	-0.22	-0.42	-0.14	-0.43
Minerals and metals	**-0.29**	-0.18	-0.14	-0.09	-0.25	**-0.53**	-0.33	-0.24	-0.24	-0.24
Minerales and non-metals products	**-0.14**	-0.08	-0.20	-0.09	-0.41	**-0.29**	-0.14	-0.15	-0.11	-0.15
Chemicals	**0.16**	0.22	-0.64	-0.17	-1.37	**0.16**	0.36	-0.01	0.22	-0.02
Mineral products, machinery and transport material	**-0.31**	-0.19	-0.16	-0.08	-0.35	**-0.57**	-0.33	-0.20	-0.19	-0.20
Agri-food industry	**1.71**	1.14	0.01	0.27	-0.15	**3.00**	2.07	1.22	1.41	1.22
Manufactures	**-0.01**	0.01	-0.16	-0.05	-0.35	**-0.02**	0.03	-0.04	0.02	-0.04
Rubber, plastics and others	**-0.14**	0.00	-0.44	-0.13	-0.95	**-0.30**	0.00	-0.13	0.02	-0.13
Construction and engineering	**-0.22**	-0.14	-0.12	-0.07	-0.23	**-0.39**	-0.24	-0.19	-0.17	-0.19
Hotels and restaurants	**-0.25**	-0.21	0.31	0.03	0.76	**-0.41**	-0.41	-0.16	-0.31	-0.16
Rest of services	**-0.31**	-0.21	-0.03	-0.06	-0.02	**-0.54**	-0.37	-0.23	-0.26	-0.23
Standard deviation (%)	***4.67***	*2.95*	*4.14*	*2.92*	*5.95*	***8.45***	*5.53*	*5.74*	*5.03*	*5.74*

**Benchmark scenario column is 0.00%*

Technological improvements in Irrigated agriculture lead to reduce agricultural prices as a consequence of a better use of natural resources and larger irrigation knowhow or marketing process. It provides less difference between sectors (standard deviation is reduced). Prices results are closer to the benchmark scenario. However, as rises in prices in Irrigated agriculture are larger in the long-term, the incorporation of improved technologies reduce them although hardly in the long-term. As we have seen, these results are translated into significant changes in the quantity produce, specifically Fruits and vegetables sector.

In addition, reducing price volatility in irrigation water prices provides an increase in Fruits and vegetables production. Table 5 shows larger reductions in the most profitable crops (Fruits and vegetables) that confirm that the greater efficiency generated by combining water pricing and technological changes let enhance production. This policy shows larger reduction in other accounts such as Agri-food industry. To sum up, a planning of the evolution of irrigation water prices can help to reduce the impacts specifically of the most profitable crops due to a better use of irrigated resources.

5. Discussion and conclusion

The use of CGE models is a distinctive new approach to integrated hydro economic modelling (Brower and Hofkes, 2008). In this line there is a growing literature that uses these models as a tool for the analysis of water management through different economic policies. Majority works tackle difference issues as the reallocation of water (Seung et al., 1998; Gómez et al., 2004), water pricing policies (Decaluwé et al., 1999; Velázquez et al., 2006) or reductions in water demand (Van Heerden et al., 2008) among another relevant studies.

This paper addresses the issue of future water availability changes to achieve that a policy strategy may mitigate the longer-term effects of downward trends of water supply even in drought years. This policy should be able to cope with water constraints that could be imminent in the future, specifically in some arid-countries and in some drought years.

We simulate four scenarios that are used for different purposes. First, a benchmark scenario replicates a steady state growth path that enables to compare the results of the rest of scenarios. The irrigation area, on which the paper is focused, is characterized by a downward trend of water supply and some restrictions in water resource availability, and limits to increase total land area. This real evolution of water supply is taken into account to make a forecast with a 2030 time horizon that integrates extreme events like droughts. These results are shown in a *Water damage* scenario that allows us to observe the impacts of water availability changes and involves us to look for mitigation strategies. The two previous scenarios do not include any type of policy. After it, we develop two strategies that take into account the forecast of the evolution of water and land constraints. The policy strategies are focused on avoiding possible negative effects of natural resources constraints and reducing them through technology improvements.

The main insights of this paper are based on wide features. Firstly, *Water damage scenario* reveals negative impacts on average with falls in macroeconomic results. These falls are limited in the economy but larger in the long-term and in drought years. However, negative impacts are far for being limited in farming sectors, which even fall on average over than 30% compared to benchmark scenario. Indeed, spillover effects are shown in other accounts, mainly Livestock and Agri-food industry. Variations in water prices are significant and they tend to be higher in the long-term. This situation shows the abandonment of land by farmers in drought years that could involve the extinction of Irrigated land in the future.

Secondly, it is possible to manage future water availability, even in presence of droughts, to reverse the long-term economy trend, specifically in Irrigated agriculture sectors, induced by a policy strategy designed to improve technology. Alternative types of technological change are analyzed. The improvement in irrigation water efficiency shows a greater efficiency to mitigate the negative impacts. However, as well as water efficiency, reversing the trend requires to encourage farmers to make a good use of the opportunities presented to get productivity gains and an optimal use of the resources available after the investment in agriculture sectors to focus on the most profitable crops which requires a land transformation into irrigated land. Increasing innovation in Irrigated agriculture implies a change in the evolution of cropping patterns towards the most profitable crops.

Thirdly, the results show that a planning of irrigation water prices could be more efficient in Irrigated agriculture sectors in the long-term. Combining water pricing and technical progress provide an extra-incentive for optimal water use. Lower water price volatility enables to further reduce the impacts of water constraints on Irrigated agriculture sectors. It could provide training for faster adjustment facing uncertainty changes in climate change.

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Appendix A – Some equations

Water and capital-land aggregate (Irrigated agriculture sectors, $ireg$)

$$KTW_{i,t} = CES\left(KT_{i,t}; W_{i,t} \cdot \varphi; \sigma^{KTW}\right) =$$

$$\alpha_i (a_{iKTW} \cdot KT_{i,t}{}^{\frac{\sigma^{KTW}-1}{\sigma^{KTW}}} + (1 - a_{iKTW}) \cdot (\varphi \cdot W_{i,t})^{\frac{\sigma^{KTW}-1}{\sigma^{KTW}}})^{\frac{\sigma^{KTW}}{\sigma^{KTW}-1}}, \forall(i = ireg, t) \qquad \text{Eq.(A1)}$$

where KT= capital and land composite; W= water factor; σ^{KTW}= Elasticity of substitution; α_i= scale in the production function; a_i= share in the functions; φ = efficiency parameter;

Level of irrigation water efficiency (Gompertz function)

$$\varphi_t = a \cdot e^{(-e^{b-c\cdot\lambda_t\cdot t})}, \forall(t) \qquad \text{Eq.(A.2)}$$

where $a = 90\%\ (upper\ asymptote);\ b = \ln\left(-\ln\left(\frac{54\%}{90\%}\right)\right); c = \frac{\ln\left(-\ln\left(\frac{60\%}{90\%}\right)\right) - b}{-8}$

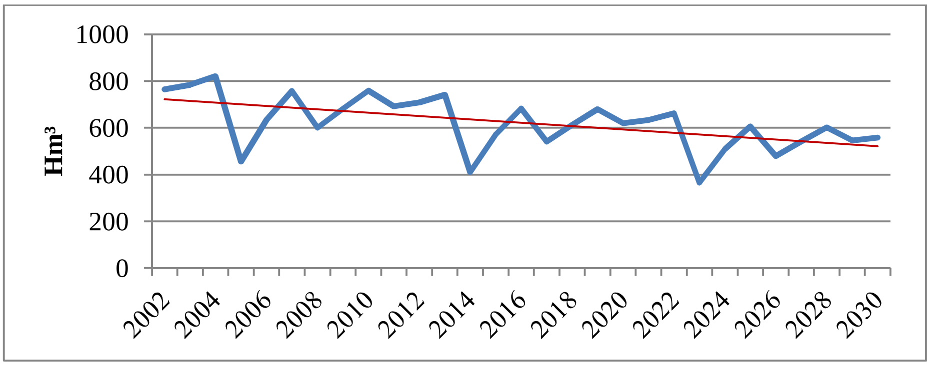
And parameter λ_t:

$$\lambda_t = \left(\frac{Z_t}{\bar{C}}\right)^{\gamma} \qquad \text{Eq.(A.3)}$$

where $\bar{C}$ = static cost index for technology; γ = an exogenous scale exponent; Z_t= collected amount

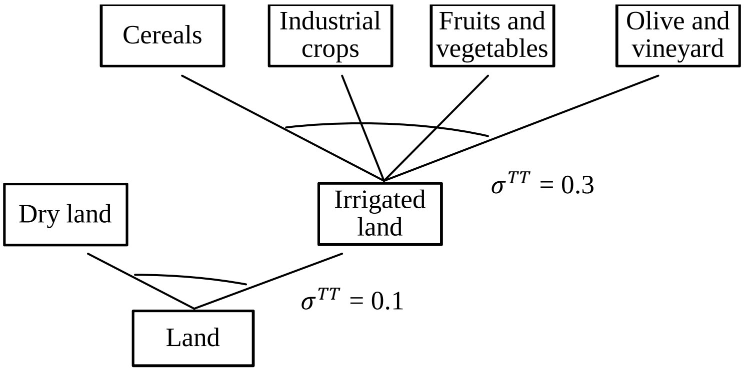
Appendix B - Complements

Figure B1. Evolution of water supply in CGRAA



Source: Own elaboration following the first decade from Sánchez-Chóliz and Sarasa (2013)

Figure B2. Land allocation



Source: Own elaboration

Figure B3. Evolution of irrigation water efficiency

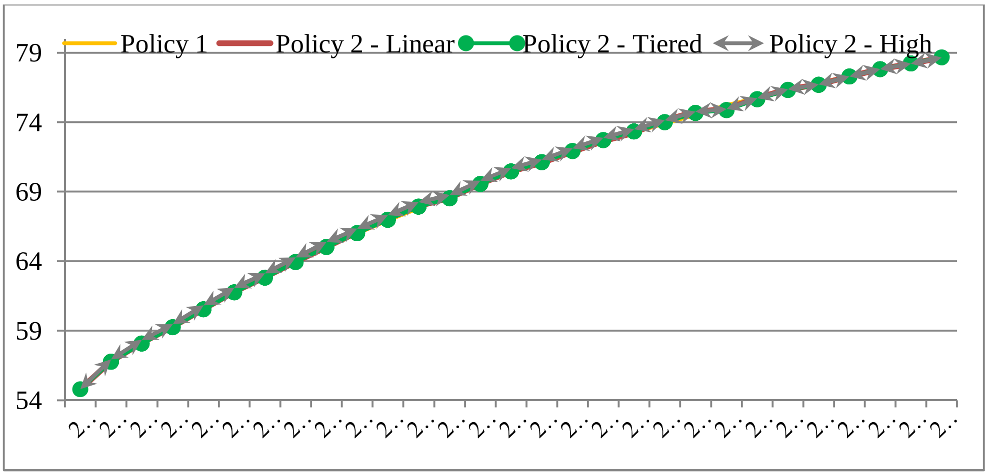


Figure B4. Evolution of total land area