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Farm waters run deep: a coupled positive multi-attribute utility programming and computable general equilibrium model to assess the economy-wide impacts of water buyback

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ABSTRACT

Little is known about the economy-wide repercussions of water buyback, which may include relevant feedbacks on the output of economic sectors at a regional and supra-regional scale. Limited studies available rely on stand-alone Computable General Equilibrium (CGE) models that represent competition for water explicitly, but this approach presents significant data and methodological challenges in areas where mature water markets are not in place –the case of most regions worldwide. To bridge this gap, this paper couples a microeconomic Positive Multi-Attribute Utility Programming (PMAUP) model that elicits the value and price share to water with a macroeconomic, regionally-calibrated CGE model for Spain. Methods are illustrated with a case study in the Murcia Region in southeastern Spain. Economy-wide feedbacks amplify income losses in Murcia's agriculture from −20.5% in the PMAUP model up to −33% in the coupled PMAUP-CGE model. Compensations paid to irrigators enhance demand in the region, but supply contraction in agriculture and related sectors lead to overall GDP losses (up to −2.1%) in most scenarios. The supply gap is partially filled in by other Spanish regions, which experience a GDP gain through a substitution effect (up to +.034%). In all scenarios, aggregate GDP for Spain decreases (up to −.023%).

1. Introduction

Water institutions are increasingly reliant on the reacquisition or *buyback* of water rights to restore the balance in overexploited basins. Buyback programmes are operated through purchase tenders that compensate farmers who choose to relinquish their rights to withdraw water, complemented with flanking measures to address negative feedbacks on agriculture and related economic sectors at a regional and supra-regional scale (DSEWPAC, 2016; GRBA, 2008; Hanak and Stryjewski, 2012). An expanding research analyses the interaction between user-level choices and tender design to limit information rents and prevent overcompensation (Iftekhar et al., 2013; Qureshi et al., 2009; Wheeler et al., 2013; Zuo et al., 2015). Less is known, however, about the economy-wide impacts of buyback –despite the large amount of resources committed to mitigate them. For example, the buyback programme of the Upper Guadiana River Basin in Spain projected an investment of EUR 3 billion along a 20-year transition period, of which only 33% addressed purchase tenders directly; while the remaining 67% envisaged flanking measures to compensate for negative feedbacks, including subsidies for economic diversification and new transportation, communication and energy infrastructures (GRBA, 2008). In Australia's Murray-Darling Basin, an investment of AUD 3.1 billion for the reacquisition of 1500 million m^3 from irrigators was complemented with an irrigation modernization programme worth AUD 7.36 billion aiming to i) compensate for negative feedbacks through enhanced productivity and ii) limit water use by another 1900 million m^3 (Department of the Environment, 2015; DSEWPAC, 2016), although the achievement of the latter target has been questioned (Australian Parliament, 2017).

Research available on the topic relies on theoretical models (Marchiori et al., 2012), or Computable General Equilibrium (CGE) models applied to the Australian case. Dixon et al. (2012a, 2011) use a dynamic CGE model containing water accounts to analyze the effects of an illustrative buyback scheme in the Southern Murray-Darling Basin. Simulation results show that, contrary to what could be expected, buyback has a positive impact on the regional economy, and a negative albeit marginal one at a national level. This is explained by supply-demand interaction in water markets, which lead to higher prices that i)

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increase net exports of water and consumption and ii) cause a reallocation of farm production factors that partially compensates for the negative impact on agricultural output. Notably, the adjustment dynamics of the model relies on the existence of full-fledged water markets, a prerequisite that holds only in Australia, Chile and the semi-arid states of Western US. In most regions and countries today, allocation rules are still conditioned by historical rights and queuing, and prices represent administrative charges to (partially) recover the cost of conveying water to users (OECD, 2015). In this context, attempts to model competition for water explicitly in a CGE environment must rely on estimations that assign a price and value share to water (see e.g. Darwin et al., 1995), which is challenging due to the limited information available. More importantly, recent research rightly claims that the shadow price of water must correspond to the gap between irrigated and rainfed production to pay for the returns to water, which is often not reflected in value and price estimations (Hertel and Liu, 2016). Addressing this methodological challenge in a CGE environment calls for an alternative approach that models water competition implicitly, e.g. through irrigated land (Calzadilla et al., 2011; Taheripour et al., 2013) or virtual water (Cazcarro et al., 2014), which however is inadequate to model and inform water purchase tenders and thus the economy-wide impact of buyback programmes.

In the absence of water markets or data sources with equivalent information, an economy-wide assessment of buyback programmes may require the macroeconomic model to be simulated in concert with a complementary bottom-up model that supplies the missing information. This makes possible to bridge the scale gap and adapt the analysis on the varied and asymmetric welfare impacts to the more convenient scale or decision unit. A wide range of applications coupling bottom-up with macroeconomic models can be found in the literature, and not only related to water issues. Bottom-up models can be bio-physical (Carrera et al., 2015) or microeconomic, such as agent-based (Husby, 2016, chap. 7) or mathematical programming methods (Baghersad and Zobel, 2015); while macroeconomic approaches typically include CGE or Input-Output (IO) models. The choice of bottom-up and macroeconomic model varies depending on the research focus, data availability and policy experiment. CGE models are preferred over IO where price dynamics are expected to be relevant, as happens with policies involving large reallocations of physical and financial resources such as buyback, and to examine the medium and long run effects (Dudu and Chumi, 2008). On the other hand, microeconomic mathematical programming methods are the approach typically used to model agents' motives and behavior in agricultural economics (Graveline, 2016).

One straightforward way to combine the complementary outputs of micro- and macro-economic models is to solve both models independently, where available, and use results to inform water policy. However, the different foundations of both approaches (individual behavior in narrowly-defined markets in microeconomic models v. structure and behavior of a whole economy in macroeconomic ones) can lead to conflicting outcomes and raise consistency issues (Pindyck, 2015). Using a holistic approach that solves both models together allows a detailed representation of causal relationships and interdependencies and ensures consistency, but making the complex internal optimization procedures of micro- and macro-economic models compatible will demand oversimplification, as happens with holistic hydroeconomic models that represent farmers' behavior through piecewise exogenous benefit functions that relate water use to profit (Harou et al., 2009). Modular approaches run the two models independently in a recursive or sequential fashion, which increases the probability of convergence on an optimal solution and the level of detail in each subfield, at the expense of a less thorough representation of causality and interdependencies between models (Singh, 2012). While the use of both holistic and modular approaches is widely reported in hybrid models literature, the coupling of computationally demanding macroeconomic models with bottom-up models is typically conducted using a modular approach (Carrera et al., 2015; Grames et al., 2016).

This paper presents a methodological framework that utilizes a modular approach to connect, in a sequential fashion, a microeconomic Positive Multi-Attribute Utility Programming (PMAUP) model with a macroeconomic CGE model to assess the local and economy-wide impacts of agricultural water buyback. The microeconomic PMAUP model makes possible a realistic representation of intricate water allocation mechanisms based on queuing and historical rights charged by the administration, and a detailed assessment of farmers' motives and behavior, bringing positivism and high spatial resolution to the design of buyback scenarios; while the CGE model feeds on the simulation outputs from the PMUAP model to assess the spread and intensity of the policy shock throughout spatial units, economic sectors and macroeconomic agents. Methods are illustrated with an application to the Region of Murcia in southeastern Spain. The PMAUP model is calibrated at an Agricultural Water Demand Unit (AWDU) scale, a basic agricultural unit in Spain that encompasses irrigation communities with a common source of water and similar administrative and hydrological characteristics (SRBA, 2015a). On the other hand, CGE models typically work at a national or supranational scale, although some examples considering the sub-national regions within a country or a group of countries can be found in Australia (Wittwer and Horridge, 2010), Europe (Brandsma et al., 2015), US (Dixon et al., 2012a), Russia (Bohringer et al., 2014) and China (Horridge and Wittwer, 2008). This work relies on the Intertemporal Computable Equilibrium System (ICES), a global CGE model that has been used extensively to assess the macro-economic impacts of climate change and to evaluate different environmental and climate policies (see e.g. Parrado and De Cian, 2014). For the purpose of this research, the model has been calibrated for 17 sub-national units at a NUTS2[1] level in Spain. This bridges the scale gap and makes feasible the coupling between both models, which is resolved in two steps. In the *first step*, the water constraint is progressively strengthened in the PMAUP model to assess agents' (AWDUs) responses to buyback and reveal: i) the foregone income; and ii) the compensating variation that addresses foregone utility, or shadow price of water. This step relies on previous work by Pérez-Blanco and Gutiérrez-Martín (2017). In *the second step*, the foregone income and compensating variation obtained for every agent are aggregated at a regional level and reproduced in a macroeconomic context through two shocks: i) a shock on production based on the foregone income; and ii) a shock on the income of the representative agent in the CGE model resulting from the water sales –a function of the compensating variation. The economy-wide repercussions of water buyback are estimated as the difference between the economic output of the economic sectors and regions under selected water reacquisition targets and that of the baseline without buyback.

The paper is structured as follows. Sections 2,3 and 4 constitute the methodological part of the paper and introduce the PMAUP model, the CGE model and the coupling approach, respectively. Section 5 presents the case study area, the Region of Murcia in Spain. Section 6 illustrates the methods with an application to the case study area. Section 7 discusses the results, and Section 8 concludes.

2. The microeconomic module: positive multi-attribute utility programming

The microeconomic model used in this paper builds on the axioms of revealed preference (Houthakker, 1950; Samuelson, 1938) to elicit an objective function that is both consistent with an observed (and finite) set of choices and prices (Afriat, 1967) and suitable as a basis for empirical analysis in agricultural water management (Gutiérrez-Martín

[1] The *Nomenclature of Units for Territorial Statistics* (NUTS) is a EU standard that refers to the subdivisions of countries. In Spain, NUTS 1 refers to groups of autonomous communities; NUTS 2 to Autonomous communities and cities; and NUTS 3 to provinces (Eurostat, 2016).

and Gómez, 2011). The theory of revealed preference originates in Samuelson's (1938) "pure theory of consumer behavior", which derived testable implications of rational consumption behavior and demand for two different budget sets without the need to postulate a utility function to represent agent's preferences, giving rise to the Weak Axiom of Revealed Preference (Samuelson, 1948, 1938). Later on, Houthakker (1950) introduced the Strong Axiom of Revealed Preference (SARP), which uses transitivity to derive testable implications of rational consumption for any budget sets. Houthakker also established a close link between the axioms about demand and those about preferences by showing that, in order to satisfy SARP, demand functions must be the observable result of the optimization of preferences subject to agent's budgetary constraint.

The theoretical foundation for revealed preference theory provided by Houthakker (1950) and Samuelson (1948, 1938) assumes a *complete* description of a demand system that gives quantities as a function of every possible budget and price. The key development in applied revealed preference research is offered by Afriat (1967), who develops a utility function consistent with agent's choices from an observed finite dataset of prices and choices, providing the basis to estimate aggregate consumer demand functions (Christensen et al., 1975). Although the first revealed preference applications date from the 1970s (Battalio et al., 1973), the large computational power and hard micro-data necessary to implement revealed preference models have limited empirical analyses (Vermeulen, 2012). Yet, these barriers appear to be subsiding: in 2005, Varian (2006) conducted a search on "revealed preference" in JSTOR business and economics journals and found 997 results; in early 2018, the same search found 8866 results. Revealed preference is becoming an increasingly relevant applied economics tool in areas as disparate as public goods research (Cherchye et al., 2011), information costs (Caplin and Dean, 2015), monetary economics (Swofford, 1995), citation analysis (Tahai and Meyer, 1999), health economics (Demuynck and Verriest, 2013), network economics (Ellickson et al., 2013), environmental goods (Getz and Huang, 1978), climate change (Stavins, 1999) or agricultural economics (Gutiérrez-Martín and Gómez, 2011).

In the area of water resources management and farm modeling, revealed preference has been relevant in the calibration of multi-attribute utility models. Positive Multi-Attribute Utility Programming (PMAUP) models that build on the axioms of revealed preference have been used to elicit farmers' objective function (Gómez-Limón et al., 2016; Gutiérrez-Martín and Gómez, 2011) and assess their responses to price volatility (Gutiérrez-Martín et al., 2014), insurance policies (Pérez-Blanco et al., 2016a) and water charges (Pérez-Blanco et al., 2016b). In a recent application, Pérez-Blanco and Gutiérrez-Martín (2017) run a series of simulations in the Region of Murcia in Spain in which the water allocation constraint in the model is progressively strengthened to estimate: i) the foregone income; and ii) the compensating variation that addresses foregone utility, or *shadow price* of water. The price and value share to water thus revealed were found consistent with those observed in previous reacquisitions (Garrido et al., 2013) and other works in the area using Positive Mathematical Programming (Martínez-Granados and Calatrava, 2014). This paper relies on the estimations by Pérez-Blanco and Gutiérrez-Martín (2017) to feed a series of simulations in a CGE environment through the development of a coupled PMAUP-CGE model in order to assess the economy-wide repercussions of agricultural water buyback.

2.1. Objective function

In irrigated agriculture, agent observed choices are a combination of crop mix and timing, water application and capital stock (Just, 1975). Literature often simplifies this complex decision process by representing each possible combination of crops, timing, water application and capital as a separate crop with unique features, so that the optimization problem is reduced to a choice on the crop portfolio x within a domain $F(x)$, where the crop portfolio x is a vector representing the land share devoted to each individual crop x_i such that:

$$x \in F(x), \quad 0 \le x_i \le 1, \quad \sum_{i=1}^{n} x_i = 1 \tag{1}$$

The agent does not have direct preferences over the crop portfolio itself, but over the utility this crop portfolio will return in terms of the provision of valuable attributes. Applied models to simulate farmer's behavior often assume that farmers are rational profit maximizers and therefore utility equals profit ($U = \pi$), although this approach usually leads to significant divergence between observed and simulated behavior. More robust theoretical frameworks assume agent's behavior can be modeled by means of maximizing a utility function where profits are the relevant attribute, as in Expected Utility (von Neumann and Morgenstern, 1953) and Positive Mathematical Programming (Howitt, 1995). Since the 1970s a growing research body known as the Theory of Planned Behavior (TPB) has disputed that farmers' behavior can be modeled maximizing profits or a utility function where profits are the single relevant attribute (Ajzen, 1991; Harman et al., 1972); instead, these authors argue that farmers' behavior is driven by multiple (and often conflicting) attributes related to socioeconomic, cultural and natural features, including but not limited to profit. Recent empirical evidence shows that the variance in farmers' intentions and observed strategic and entrepreneurial conduct are largely explained by farmers' attitudes towards their behavior (Basarir and Gillespie, 2006; Berkhout et al., 2010). Attitudes can be seen as "a summary of psychological evaluations based on agent's beliefs about the "goodness" or "badness" of an object, normally associated with a particular attribute" (Gómez-Limón et al., 2016). If farmers' beliefs concerning multiple attributes govern decision making, modeling farmers' behavior requires the consideration of more than one attribute through a multi-attribute utility function where relevant attributes are included (Keeney and Raiffa, 1993). Rational economic agents will choose the crop portfolio x that maximizes the utility from the provision of relevant attributes $z(x)$ within a domain $F(x)$:

$$\max_{x} U(x) = U(z_1(x);\ z_2(x);\ z_3(x) \ldots z_m(x)) \tag{2}$$

$$\text{s.t.}: 0 \le x_i \le 1 \tag{3}$$

$$\sum_{i=1}^{n} x_i = 1 \tag{4}$$

$$x \in F(x) \tag{5}$$

$$z = z(x) \in R^m \tag{6}$$

Attributes are quantities of dimension one, the result of dividing observed attribute values by the maximum feasible value they can attain; and are defined so that "more is better", i.e. increasing the provision of one attribute improves agent's utility provided the remaining attributes are kept constant. Assuming attributes are measurable, alternative crop portfolios can be ranked in accordance to the utility they yield. There is no risk of correlation among attributes, since the outcome of the utility function is an ordinal value (Edgeworth, 1881). This means that the model is not concerned about total utility or levels of utility, but rather about ranking alternative decisions so that they are coherent with observed choices. Rational agents will then cultivate the crop portfolio that maximizes utility within a domain defined by a set of quantifiable restrictions, notably agronomic features, land constraints, know-how, policy restrictions (e.g. Common Agricultural Policy) and water allocation. The latter can be represented as:

$$\sum_{i=1}^{n} w_i x_i \le W \tag{7}$$

Where water availability per hectare is denoted by W. w_i is the water required by crop x_i, per hectare.

In revealing agent's preferences the PMAUP model follows a positive approach, implying that the optimal solution to the problem above should be as closed as possible to the observed choice or crop portfolio x^0 (Afriat, 1967). The PMAUP model thus aims to recover an objective function that is consistent with x^0 and the choice domain F(x), so that it can be used to forecast future behavior (Varian, 2006). Following standard microeconomic theory, the parameters of a utility function can be elicited for a given set of attributes equalizing the Marginal Rate of Transformation (MRT_{kp}), which represents the opportunity cost between two attributes z_p, z_k and is obtained as the slope of the efficient frontier β_{kp}; and the Marginal Rate of Substitution (MRS_{kp}), which represents the willingness to sacrifice one unit of attribute z_p for one unit of attribute z_k:

$$MRT_{kp} = \beta_{kp} = MRS_{kp} = -\frac{\partial U/\partial z_p}{\partial U/\partial z_k};\ \forall\ p \neq k \tag{8}$$

The utility function is parameterized in three steps, which are explained in detail in the next sections:

i *Efficient frontiers* are elicited for each pair of attributes using numerical methods, and the tangency point that serves as a landing point for the utility function's indifference curve is obtained.
ii Given a tangency point and a functional form, the *utility function* parameters are calibrated for every possible combination of attributes equalizing the MRT_{kp} and the MRS_{kp}.
iii Error terms are obtained as the distance between observed and simulated choices. The utility function with the lowest error contains the *relevant attributes* and is the one used in the simulations.

2.2. Marginal rate of transformation

Observed decisions of rational agents must be efficient, i.e. they must belong to the Pareto efficient set or efficient frontier. Therefore, among all feasible choices we are only interested in revealing those along the efficient frontier, where the agent maximizes utility. In a multi-attribute context, the efficient frontier represents the maximum value of attribute z_p rational agents can attain for a given value of attribute z_k within the domain. Real-life efficient frontiers cannot be analytically defined using a closed function (André, 2009). Instead, numerical methods through an optimization procedure are typically used, as follows:

$$\underset{x}{\text{Max}}\, z_p(x) \tag{9}$$

$$\text{s.t.}: z_k\ (x) = c\ \ \forall\ k \neq p\ c = (0,\ \ldots,1) \tag{10}$$

$$0 \leq x_i \leq 1 \tag{11}$$

$$\sum_{i=1}^{n} x_i = 1 \tag{12}$$

$$x \in F(x) \tag{13}$$

where c= (0, ...,1) is a finite set that determines the values of attribute z_k for which the values of attribute z_p are projected to the frontier (recall attributes are values of dimension one). Solving the optimization problem above we obtain an efficient frontier in the two-dimensional space $\tau_{z_p,z_k}(X^{**})$, where X^{**} is the set of crop choices delivering a provision of attributes z_p, z_k *along* the frontier.

Literature offers a number of alternatives to estimate the tangency or "landing point" for the utility function. Sumpsi et al. (1997) maximize each attribute (z_k, z_p) separately within the domain to calculate the pay-off matrix (i.e. the maximum value each attribute can attain within the domain), and approximate the efficient frontier through a hyper-plane connecting two efficient points included in the pay-off matrix (segment formed by points A and B in two dimensions in Fig. 1-case 1). André and Riesgo (2007) project the observed choice to the closest efficient point x^{**} (i.e. along the efficiency frontier), which is then used as a reference point to obtain a "compromise set" consisting of a set of efficient points in the vicinity. The compromise set is interpreted as the piece of the efficient frontier where the utility function is maximized. Then the tangency point for the indifference curve is obtained regressing a hyper-plane from the compromise set (segment formed by points A and B in Fig. 1-case 2). Finally, Gutiérrez-Martín and Gómez (2011) obtain the maximum feasible value of attribute z_p for the *observed* value of z_k (i.e. c= z_k^o in Eq. (10)), and vice versa, and again use a hyper-plane connecting the two points to approximate the efficient frontier (segment formed by points A and B in Fig. 1-case 3). All these methods obtain the efficient frontier and tangency points from linear combinations of two efficient points. Admittedly, efficient frontiers are convex –otherwise there is no tradeoff and the choice between the two attributes becomes irrelevant. This means that the hyper-planes connecting efficient points will not belong to the actual efficient set X^{**} and will lead to approximation errors (distance between the segment AB and X^{**} in Fig. 1).

Positive multi-attribute models typically rely on the methods described in cases 1–3 to reveal the tangency points. Consistent with Pérez-Blanco and Gutiérrez-Martín (2017) this paper follows the method by Gutiérrez-Martín and Gómez (2011), which minimizes the approximation error for the database used. Solving the optimization problem in Eqs (9)–(13) for the observed values of each pair of attributes z_k and z_p (i.e. z_k^o and z_p^o) yields two efficient points, namely τ_{z_p,z_k^o} and $\tau_{z_p^o,z_k}$ (points A and B in Fig. 1-case 3). The slope in any intermediate point τ between the two projected efficient points, or MRT_{kp}, is obtained as follows:

$$MRT_{kp}^{\tau} = \beta_{kp}^{\tau} = \frac{z_p - z_p^o}{z_k - z_k^o} \tag{14}$$

β_{kp}^{τ} provides a "reliable estimate" (Gutiérrez-Martín et al., 2014) for the tangency point, which is used for the calibration of the utility function.

2.3. Marginal rate of substitution

The Marginal Rate of Substitution MRS_{kp} measures the willingness to sacrifice one unit of attribute z_p for one unit of attribute z_k, which graphically corresponds to the slope of the indifference or isoutility curve ($MRS_{kp} = -\frac{\partial U/\partial z_p}{\partial U/\partial z_k}$, see Eq. (8)). Rational economic agents will choose the crop portfolio where the MRS_{kp} over the indifference curve equals the MRT_{kp} over the efficient frontier for any pair of attributes (see Eq. (8)).

Similarly to Afriat's (1967) model for the case of single-attribute utility functions, the methodology presented here can be used to calibrate a utility function consistent with observed choices and the domain. Typically, there will be several utility functions available. For the case of single-attribute utility functions, Varian (1982) presented a way to describe the entire set of utility functions consistent with observed preferences, while Varian (1983) obtained bounds on specific functional forms. For the case of multi-attribute utility functions, the information provided by the MRT_{kp} and MRS_{kp} makes feasible the elicitation of the function parameters consistent with observed choices within the domain F(x), *for a given functional form considered*. For the application presented here it is assumed that the multi-attribute utility function adopts a Cobb-Douglas specification, which offers a sensible approximation to actual farmers' behavior (Sampson, 1999). As compared to alternative additive or multiplicative-additive specifications, a Cobb-Douglas function offers the advantages of decreasing marginal utility for each attribute and the existence of a global optimum (Inada, 1963). Following a Cobb-Douglas specification, the objective function in Eq. (2) can now be represented as:

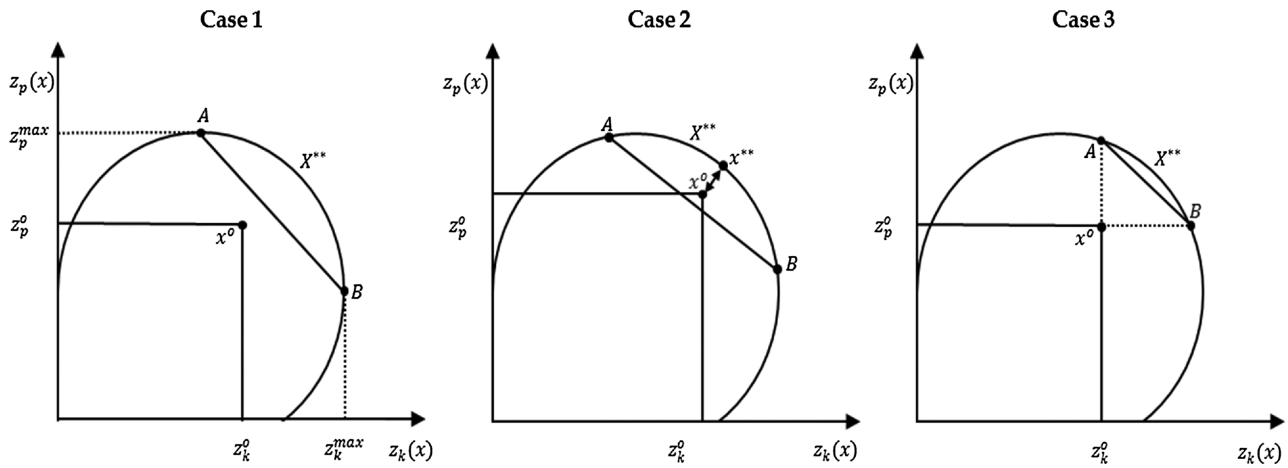

Fig. 1. Potential errors caused by projecting observed points onto linear approximations of the efficient set.
Source: Own elaboration.

$$U\left(\prod_{p=1}^{m} z_p^{\alpha_p}(x)\right);\ \sum_{p=1}^{m} \alpha_p = 1 \quad (15)$$

Where α_p are the objective function parameters or alpha values. By means of equalizing the MRS_{kp} of a Cobb-Douglas function and the MRT_{kp} obtained in the previous section, the objective function parameters can be estimated solving the following system of equations:

$$MRS_{kp} = -\frac{\alpha_p}{\alpha_k}\frac{z_k}{z_p} = \beta_{kp} = MRT_{kp};\ \forall\ p \neq k \quad (16)$$

$$\sum_{p=1}^{m} \alpha_p = 1 \quad (17)$$

The values of the parameters obtained resolving the system of equations above for alternative attribute combinations within the set z(x) are used in Eqs. (2)–(6) to simulate the optimal crop portfolio choice (x^*) and obtain the corresponding attribute values (z_p^*; p= 1, ...,m) and utility (U^*).

2.4. Relevant attributes and utility function parameters

Rational agents cultivate the portfolio of crops that maximizes the utility obtained from the attributes they value. Therefore, the relevant attributes are those that minimize the distance between observed and calibrated behavior, which is measured through a calibration residual obtained as the ordinary arithmetic mean of two errors. The first error captures the distance between the observed (x^o) and simulated (x^*) crop portfolio:

$$e_x = \frac{1}{n}\sqrt{\sum_{i=1}^{n}\left(\frac{x_i^o - x_i^*}{x_i^o}\right)^2} \quad (18)$$

The second error captures the distance between observed (z^o) and calibrated (z^*) attributes:

$$e_\tau = \frac{1}{m}\sqrt{\sum_{p=1}^{m}\left(\frac{z_p^o - z_p^*}{z_p^o}\right)^2} \quad (19)$$

The relevant set of attributes minimizes the average calibration residual, which is obtained as follows:

$$e = \frac{e_x + e_\tau}{2} \quad (20)$$

The set of attributes and corresponding parameter values that minimize the average calibration residual is the one used in the simulations.

2.5. Data

Agents in the PMAUP model are the 55 Agricultural Water Demand Units (AWDUs) of the Segura River Basin located within the boundaries of the Region of Murcia. Aggregation of individual farmers to conform representative economic agents is well documented in the literature, also through the use of AWDUs (Martínez-Granados and Calatrava, 2014; Pérez-Blanco and Gutiérrez-Martín, 2017). The calibration year (observed crop portfolio x^o) is 2013. Data used in the PMAUP model depends on the finite attributes set considered in the model calibration. We explore five attributes, based on a literature review on multi-attribute utility functions (see Pérez-Blanco and Gutiérrez-Martín, 2017). These attributes include: profit (z_1, quantified through the gross variable margin), risk avoidance (z_2, obtained as the difference between the standard deviation of the crop portfolio that maximizes profit and that of an alternative portfolio x), direct costs avoidance (z_3, the difference between the per unit of revenue direct costs incurred in the management of the crop portfolio that maximizes profit and those of an alternative portfolio x), hired labor avoidance (z_4, the difference between the hired labor necessary to implement the crop portfolio that maximizes profit and that of an alternative portfolio x) and family labor avoidance (z_5, the difference between the hired labor necessary to implement the crop portfolio that maximizes profit and that of an alternative portfolio x).

Data collection aims at supplying the necessary information to quantify the attributes listed above. Land use data per crop is obtained at a municipal level for the calibration year from Región de Murcia (2015), and disaggregated at an AWDU level crossing this information with the land use data per crop category[2] available for AWDUs in the basin plan (SRBA, 2014), using georeferenced data (SRBA, 2015b). Data on water sources, withdrawals and distribution and irrigation efficiency in 2013 are obtained for every relevant AWDU from SRBA (2014). Crop yields and prices are available for every Spanish province (NUTS 3) in MAGRAMA (2015b) for the period 2003–2013. Information on other revenues such as subsidies, family labor and variable costs (namely hired labor, contracts, fertilizers, phytosanitaries, water, fuel, replacement parts, repairs, lubricant, seeds plants and other supplies) are obtained at a provincial level for the period 2003–2013 from MAGRAMA (2015a). Monetary values are expressed in constant prices of 2007, which is also the CGE's reference year.

[2] Including: forage, winter cereal, summer cereal, spring cereal, industrial crop, legume, horticulture –bulb, horticulture –root, horticulture –flower, horticulture –leaf, horticulture –fruit, horticulture –greenhouse, horticulture –tuber, citrus tree, stone fruit, seed fruit, almond tree, vineyard (grape), vineyard (wine), olive grove.

3. The macroeconomic module: computable general equilibrium model

3.1. Theoretical structure

From a general point of view a CGE model is a market-based tool which captures the economic interactions taking place between sectors, regions and factors. Prices are flexible and adjust to the different impacts and policies to clear the markets and achieve a new equilibrium in which supply equals demand. The regionalized ICES is a neoclassical model: perfect competition is assumed in all sectors of the economy, factors are fully employed and investments are saving-driven. In this experiment we use a regionalized version of the model that includes the 17 NUTS2 regions of Spain, the rest of Europe and the rest of the world; and seven economic sectors, namely agriculture, extraction, food industry, other industry, utilities sector, construction and services. The main characteristics of demand and supply are described in the following sub-sections.

3.1.1. Supply

A representative firm in every region and sector minimizes costs subject to a Leontief technology production function for output (y) considering the Gross Value Added (GVA) (va) and intermediate inputs (in):

$$\min_{va_{j,s},\, in_{j,s}} \left(pva_{j,s} va_{j,s} + pin_{j,s} in_{j,s} \right) \tag{21}$$

$$\text{s.t.}: y_{j,s} = \min\{va_{j,s}, in_{j,s}\} \tag{22}$$

where $pva_{j,s}$ and $pin_{j,s}$ are respectively the price of the value added composite and the price of intermediate inputs in sector j of region s. GVA in sector j is produced with a Constant Elasticity of Substitution (CES) function that depends on v_f primary factors (f = capital, land, labor, and natural resources), with sector-specific elasticity of substitution σ_j. Input augmenting or biased technical change is represented with the parameter $\gamma_{f,j,s}$ for each primary factor f in sector j and region s.

$$va_{j,s} = F(\gamma_{f,j,s}, v_{f,j,s}, \sigma_j)\ ;\ \sigma_j > 0 \tag{23}$$

The regionally-calibrated CGE model assumes endogenous labor and capital supply at the regional level, allowing to some extent the spatial mobility of workers and capital within the national territory. Production factors are immobile with respect to the rest of Europe and the rest of the world. Within each Spanish region, labor and capital can move across sectors, while land is used in the agricultural sector only and natural resources in mining, forestry and fishing sectors. A Constant Elasticity of Transformation (CET) function is implemented for the purpose of modelling regional labor and capital supply given the national constraint. The First Order Conditions are obtained from the following maximization problem:

$$\max_{w_{f,s}} \sum_{s}^{Spain} w_{f,s} q_{f,s};\ f = \text{labor, capital};\ s \in \text{Spain} \tag{24}$$

$$q_{f,Spain} = \left(\sum q_{f,d}^{\frac{\eta_f - 1}{\eta_f}} \right)^{\frac{\eta_f}{\eta_f - 1}};\ \eta_f \le 0 \tag{25}$$

where q_f represents the supply in the sub-country region s and in Spain, and w_f their corresponding prices. The elasticity of substitution η_f falls within the interval [0, -∞]. A higher absolute value indicates a higher interregional mobility, while a null value denotes perfect immobility at the regional level. Consistently with previous studies (Carrera et al., 2015; Koks et al., 2015) we set an intermediate value of minus two.

3.1.2. Demand

Final and intermediate goods can be traded in the domestic, national and international market. The *demand* side includes an upper and a lower bundle. Both thresholds postulate imperfect substitution between products coming from different spatial units (countries and/or regions) according to the standard Armington assumption (Armington, 1969). In the upper level, this is done by breaking agents' demand for any commodity in two parts using a CES function, $dd_{j,s}$ and $dm_{j,s}$, which are the domestic demand and the aggregate demand for imported products in region s and sector j, respectively. The representative agent in each region includes the household and the government. For each economic sector, the representative agent minimizes the total expenditure under the CES constraint on domestic and imported goods.

$$\min_{dd_{j,s},\, dm_{j,s}} \left(pdd_{j,s} dd_{j,s} + pdm_{j,s} dm_{j,s} \right) \tag{26}$$

$$\text{s.t.}: dtot_{j,s} = G_1(dd_{j,s}, dm_{j,s}, \sigma_j^{Up})\ ;\ \sigma_j^{Up} > 0 \tag{27}$$

Where $dtot_{j,s}$ is the total demand and $pdd_{j,s}$ and $pdm_{j,s}$ are the prices associated with domestic and aggregate demand for imported goods, respectively. The Armington elasticity in the upper level (σ_j^{Up}) captures the imperfect substitution between domestic and imported commodities.

In the lower level the aggregate amount of imports ($dm_{j,s}$) are sourced from the country or the sub-country region of origin. The representative agent in each region and sector minimizes the expenditure for imports under a Constant Ratios of Elasticities of Substitution and Homothetic (CRESH) constraint (Cai and Arora, 2015; Hanoch, 1971; Pant, 2007).

$$\min_{imp_{j,s',s}} \sum_{s'} pimp_{j,s',s} imp_{j,s',s} \tag{28}$$

$$\text{s.t.}: dm_{j,s} = G_2(imp_{j,s},\ \sigma_{j,s}^{Lo})\ ;\ imp_{j,s} \in R^S, \sigma_{j,s}^{Lo} \in R^S \tag{29}$$

Where $imp_{j,s',s}$ is the bi-lateral trade flow from region/country s' to region/country s in sector j and $pimp_{j,s',s}$ is the associated price; $imp_{j,s}$ and $\sigma_{j,s,}^{Lo}$ are two S-dimensional vectors (S being the number of country/regions in the CGE) representing respectively all the bi-lateral imports and elasticities of substitution of region/country s in sector j. Price Indexes for the aggregate import composite is weighted by the three-dimensional elasticity following the minimization problem in the two equations above. The advantage to use the CRESH function in the lower level consists in having a three dimensional elasticity ($\sigma_{j,s,s}^{Lo,} > 0$), which allows for more flexibility than CES to model the product substitutability for each couple of spatial units. Since theoretical and empirical evidence shows that trade is larger within national borders than across them, given the same distance (Anderson et al., 2003; McCallum, 1995), intra-national trade flows should be more fluid than international trade ones, and this is guaranteed by setting a higher value of the CRESH elasticity involving two Spanish regions.

The income (Inc_s) of the representative agent in each sub-national region or country is allocated in fixed proportions to private final consumption ($Cons_s$), government consumption (Gov_s) and saving ($Save_s$).

$$Inc_s = Cons_s + Gov_s + Save_s \tag{30}$$

The macro-economic closure assumes that the investments are mobile at the international level; global investments are equal to global savings; and trade balance in each country/region is given by the difference between regional/country savings and investments.

3.2. Data

The model uses information from the GTAP 8 database (Narayanan et al., 2012). The 8.1 version consists in a collection of Social Accounting Matrices (SAMs) for 57 economic sectors and 134 countries (or groups of countries) in the world. The reference year is 2007. We split the national SAM of Spain in the GTAP database into 17 regions using information from Spanish Regional Accounting (INE, 2017) and Economic Accounts for Agriculture and Structural Business Statistics (Eurostat, 2016). To do this, first we match the sectors of the GTAP database with those of our data sources. Then, for each sector, the regional shares of value added, and accordingly of labor, capital, land and natural resources are computed using the sub-national data. Finally, these shares are used to distribute original country-level data across sub-national units. A detailed description of the methodology is available in Bosello and Standardi (2015).

INE (2017) provides information on both capital and labor at the sectoral level. For some manufacturing activities we referred to Structural Business Statistics (Eurostat, 2016) because they have a more detailed description of these sectors. To regionalize the agricultural economic components of value added we mainly rely on the Economic Accounts for Agriculture (Eurostat, 2016) because of the rich and already standardized information across EU regions.

One of the most challenging tasks to achieve in the database construction is the derivation of the sub-national domestic demand and trade among regions within the country. This is because these data are often missing and need to be computed using different techniques. In our case we rely on the so-called Simple Locations Quotients (SLQs) (Miller and Blair, 2009). SLQs give a measure of the regional specialization in the economic activity compared to the national average and allow us to determine the domestic demand and aggregate demand for imports. Then we follow the gravitational approach to obtain the bilateral trade flows across sub-national regions in line with Dixon et al. (2012b) and Wittwer and Horridge (2010).

4. Coupling the PMAUP and CGE models

Once the multi-attribute objective function is calibrated in the PMAUP model, the water allocation constraint W_g is progressively strengthened to comply with alternative water reacquisition targets (g), and the resulting crop portfolio x^*_g, utility U^*_g and GVA va^*_g (a function of the gross margin $z^*_{1,g}$, and hired labor $z^*_{4,g}$) are estimated. These variables contain the necessary information to reveal: i) the foregone income; and ii) the compensating variation that addresses the foregone utility. These two measures serve as a basis to assess the economy-wide repercussions of water buyback in a CGE environment. The foregone income is used to estimate the consequences on the *supply* side through a productivity shock in the representative agricultural firm; while the compensating variation is used to assess the consequences on the *demand* side through a money transfer to the representative agent in Murcia.

4.1. The supply shock

In the microeconomic model, the GVA (va^*_g) in Murcia for every reacquisition target g is obtained aggregating the simulated gross margin ($z^*_{1,g}$) and labor income (a function of hired labor, $z^*_{4,g}$):

$$va^*_g = f(z^*_{1,g}, z^*_{4,g}) \quad (31)$$

The foregone income in Murcia for a given reacquisition target, as compared to the baseline (g= 0), can be transformed using simple calculations into a productivity shock (γ_g) (Carrera et al., 2015):

$$\gamma_g = \frac{va^*_g}{va^*_0} \quad (32)$$

The negative productivity shock is homogeneously distributed among the production factors (f, including labor, capital and land) of the representative agricultural firm (j= agr) of Murcia (s= MUR) in the macroeconomic model through Eq. (23). The productivity shock reproduces the impact on GVA estimated by the PMAUP model in a CGE context, for every water reacquisition target considered.

$$va_{g,agr,MUR} = F(\gamma_g, v_{f,agr,MUR}, \sigma_{agr}) \quad f = \text{land, labor, capital} \quad (33)$$

4.2. The demand shock

The compensating variation is the amount of money that keeps the utility equal to that of the baseline scenario without buyback (g= 0). Although the foregone income is in principle more easily observable to the buyer (principal) than foregone utility, using a method that accounts for changes in utility instead of changes in income yields more accurate, and typically lower, compensation estimates. This is explained by the tradeoff between risk and management complexity aversion on the one hand, and profit on the other, in the multi-attribute microeconomic model. As a result, water uses displaying high income, but high risk and management complexity, can yield a relatively low marginal utility (and compensating variation); and vice-versa, uses with low income but low risk and management complexity attached can still yield a high marginal utility (and compensating variation). For a detailed discussion on the compensation estimation method choice, the reader may refer to Pérez-Blanco and Gutiérrez-Martín (2017).

The compensating variation for a given reacquisition target CV_g is obtained in the microeconomic model as follows:

$$CV_g = e(U^*_0, W_g) - e(U^*_0, W_0) \quad (34)$$

Where *e* represents an expenditure function, i.e. the minimum amount of money agents would need to attain the initial utility (U^*_0) given a water constraint W_g. In the baseline scenario (g= 0), the expenditure function equals 0.

For consistency, the compensating variation stemming from the PMAUP model is divided by the baseline GVA in the PMAUP model, and the resulting percentage is multiplied by the baseline GVA in the CGE model to estimate the equivalent compensating variation in the macroeconomic context (δ_g).

$$\delta_g = \frac{CV_g}{va^*_0} va_{g,agr,MUR} \quad (35)$$

Compensations to irrigators are represented in the CGE macroeconomic context through an income transfer to the representative agent in Murcia (T_g). Income transfers can be operated through an annuity payment or a lump sum transfer. Since the capitalization rate that applies to agricultural assets in Spain has been volatile during the financial crisis (BOE, 2015), an annuity payment that removes discount rate uncertainty was preferred in this case. Note that the marginal cost of the public funds scheme and the corresponding distortion of resource allocation is endogenous in the CGE model and is captured by the adjustment in the relative prices. Once the transfer from the rest of Spain to the Murcia region is set, economic agents change their decision according to their new income budget constraint.

When *ex-ante* designing the policy, an analyst may be tempted to equalize income transfers to *expected* compensating variations. However, CGE models work on realized values, which typically do not match expected compensating variations due to information asymmetry. This leads to some degree of agency costs $\theta \geq 1$ (Iftekhar et al., 2013).

$$T_g = \theta * \delta_g \quad (36)$$

The potential for rent extraction is conditional on the information asymmetries present and on the ability of the principal to address them (e.g. through auction design).

Next the income transfer is introduced in the CGE model through the equation representing regional income (see Eq. (30)). First, each Spanish region pays its share of the income transfer (Tr_s) based on the GDP share of the region in the national economy ($GDPsh_s$).

$$Tr_s = GDPsh_s * T_g \quad (37)$$

$$Inc_s = Cons_s + Gov_s + Save_s - Tr_s \;;\; Tr > 0, s \in \text{Spain except Murcia} \quad (38)$$

The Region of Murcia receives the total amount of the annuity for the implementation of the water buyback policy, minus its share of the income transfer payment.

$$Inc_{Murcia} = Cons_{Murcia} + Gov_{Murcia} + Save_{Murcia} + T_g - Tr_{Murcia} \quad (39)$$

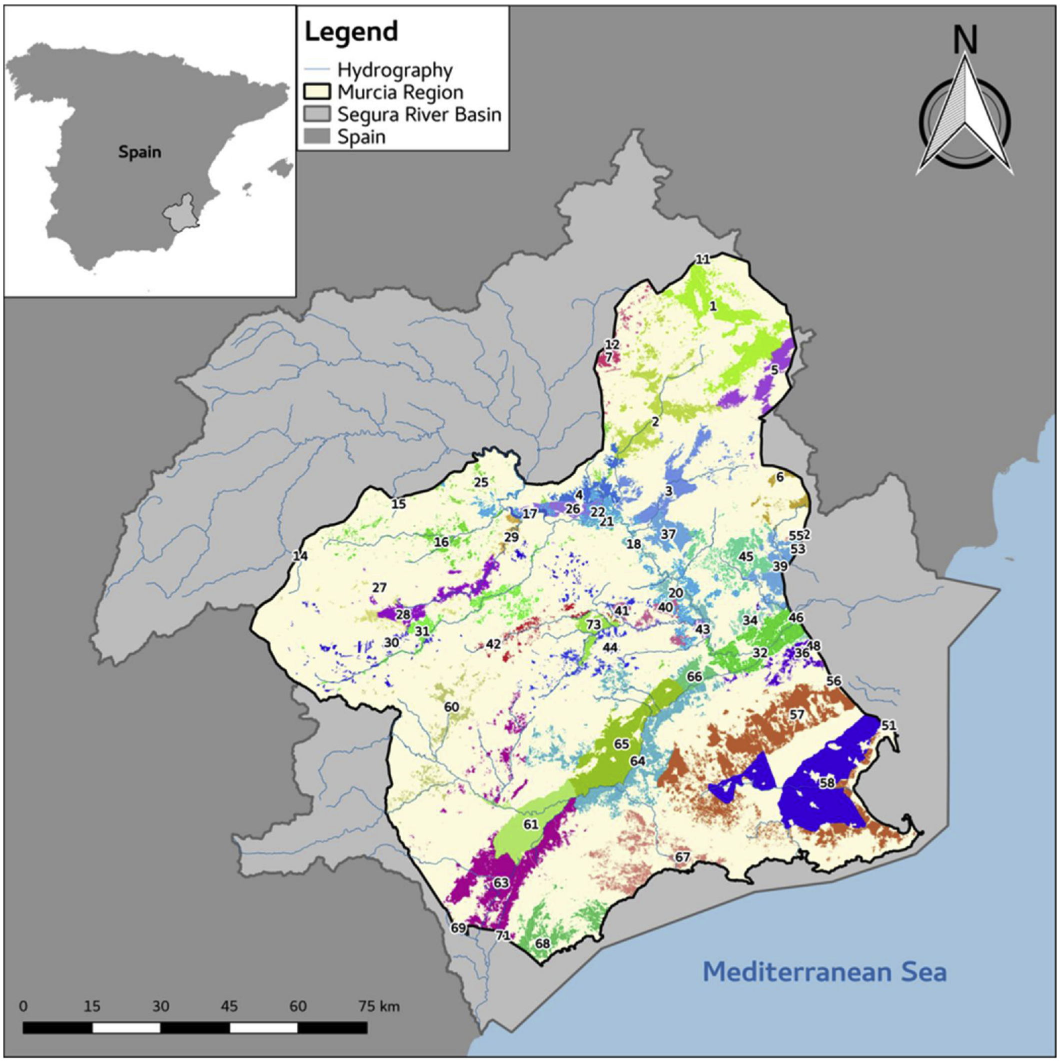

Fig. 2. Location of the Murcia Region and detail of the AWDUs.
Source: Own elaboration.

The regionally-calibrated CGE model reproduces the productivity shock in the representative agricultural firm and the income transfer to the representative agent in a macroeconomic context and finds a new equilibrium. The economy-wide impacts of water buyback are estimated as the difference between the GVA of the economic sectors and regions in Spain for each water reacquisition target and that of the baseline without water buyback.

5. Case study area: the Region of Murcia in Spain

The Region of Murcia is located in southeastern Spain, within the boundaries of the absolute water scarce Segura River Basin. Murcia has a surface of 11,313 km^2, a population of 1.5 million inhabitants and a GDP per capita of EUR 19,089 (Eurostat, 2016). Historically located along the middle stretches of the Segura River (*Huerta Murciana*), Murcia's irrigated agriculture sprawled towards coastal areas from the 50 s. This resulted in an increasing number of AWDUs (the *agent* in the PMAUP model), which now total 55, and water use (SRBA, 2015a). Fig. 2[3] displays the AWDUs in the Murcia region.

[3] *1. Yecla-Corral Rubio; 2. Jumilla; 3. Regadíos sobre Ascoy-Sopalmo; 4. Regadíos del Ascoy Sopalmo sobre el Sinclinal de Calasparra; 5. Acuífero de Serral-Salinas; 6. Acuífero de Quibas; 7. Subterráneas Hellín-Tobarra; 12. Superficiales Tobarra-Albatana-Agramón; 14. Regadíos aguas arriba de Taibilla; 15. Regadíos aguas*

(*footnote continued*)
arriba de Cenajo; 16. Moratalla; 17. Tradicional Vega Alta, Calasparra; 18. Tradicional Vega Alta, Abarán-Blanca; 20. Tradicional Vega Alta, Ojós-Contraparada; 21. Tradicional Vega Alta, Cieza; 22. Vega Alta, posteriores al 33 y ampliación del 53; 25. Regadíos de acuíferos en la Vega Alta; 26. Nuevos regadíos Zona I Vega Alta-Media; 27. Cabecera del Argos, pozos; 28. Cabecera del Argos, mixto; 29. Embalse del Argos; 30. Cabecera del Quípar, pozos; 31. Cabecera del Quípar, mixto; 32. Tradicional Vega Media; 34. Vega Media, posterior al 33 y ampliación del 53; 36. Regadíos de acuíferos en la Vega Media; 37. Nuevos regadíos Zona II Vega Alta-Media; 39. Nuevos regadíos Zona IV Vega Alta-Media; 40. Nuevos regadíos Zona V Vega Alta-Media; 41. Nuevos Regadíos Yéchar; 42. Tradicionales de Mula; 43. Mula, manantial de los Baños; 44. Pliego; 45. Regadíos del Ascoy-Sopalmo, Fortuna-Abanilla-Molina; 46. Tradicional Vega Baja; 48. Vega Baja, posteriores al 33 y ampliación del 53; 51. Regadíos de acuíferos en la Vega Baja; 53. Riegos de Levante Margen izquierda-Levante; 55. Acuífero de Crevillente; 56. Nuevos regadíos La Pedrera; 57. Acuíferos del Campo de Cartagena; 58. Campo de Cartagena redotado con trasvase; 59. Nuevos regadíos Campo de Cartagena; 60. Regadíos aguas arriba de Puentes; 61. Regadíos de Lorca; 63. Acuífero del Alto Guadalentín; 64. Mixtos del Bajo Guadalentín; 65. Subterráneas zona del Bajo Guadalentín; 66. Nuevos Regadíos Lorca y Valle del Guadalentín; 67. Mazarrón; 68. Águilas; 69. Almería-Segura; 70. Nuevos regadíos Almería-Sur; 72. Nuevos regadíos Riegos de Levante Margen Izquierda-Poniente; 73. Nuevos regadíos Mula y Pliego. The 55 numbers are not consecutive because they indicate the numbering within the Segura River Basin, which also includes AWDUs outside the Murcia region.

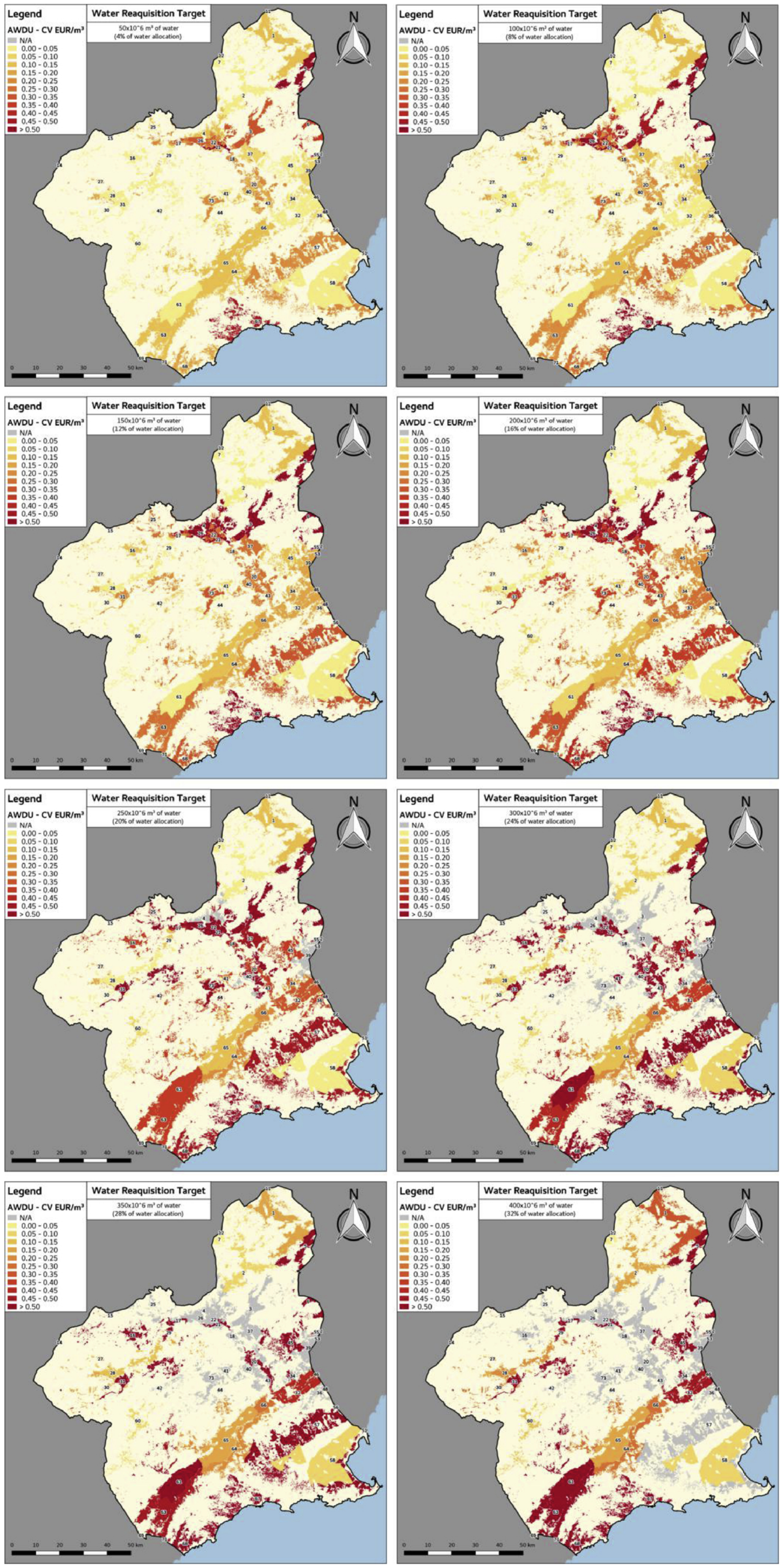

Fig. 3. Compensating variation (€/m^3) in the 55 AWDUs for the 8 reacquisition targets.
Source: Own elaboration.

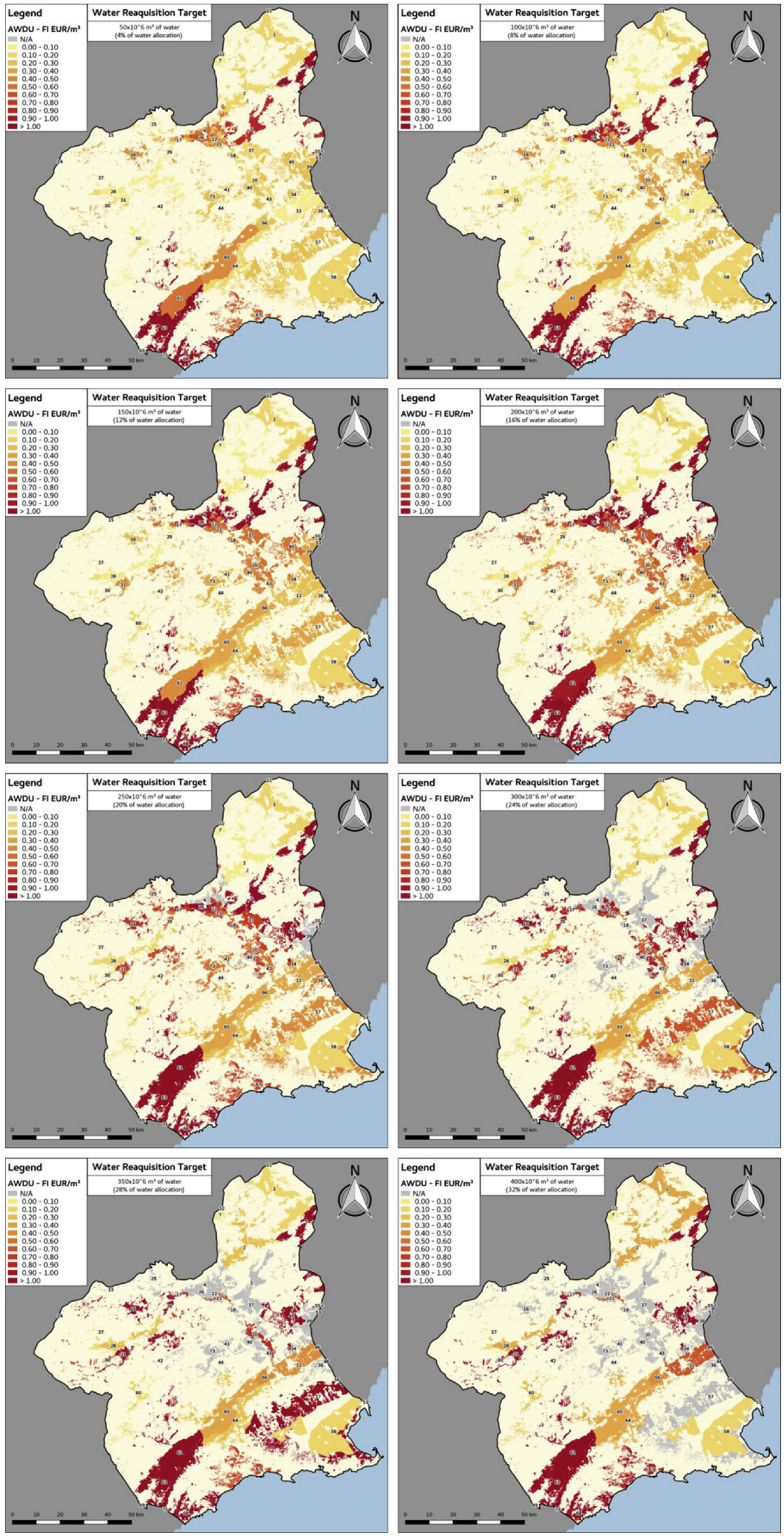

Fig. 4. Foregone income (€/m^3) in the 55 AWDUs for the 8 reacquisition targets.
Source: Own elaboration.

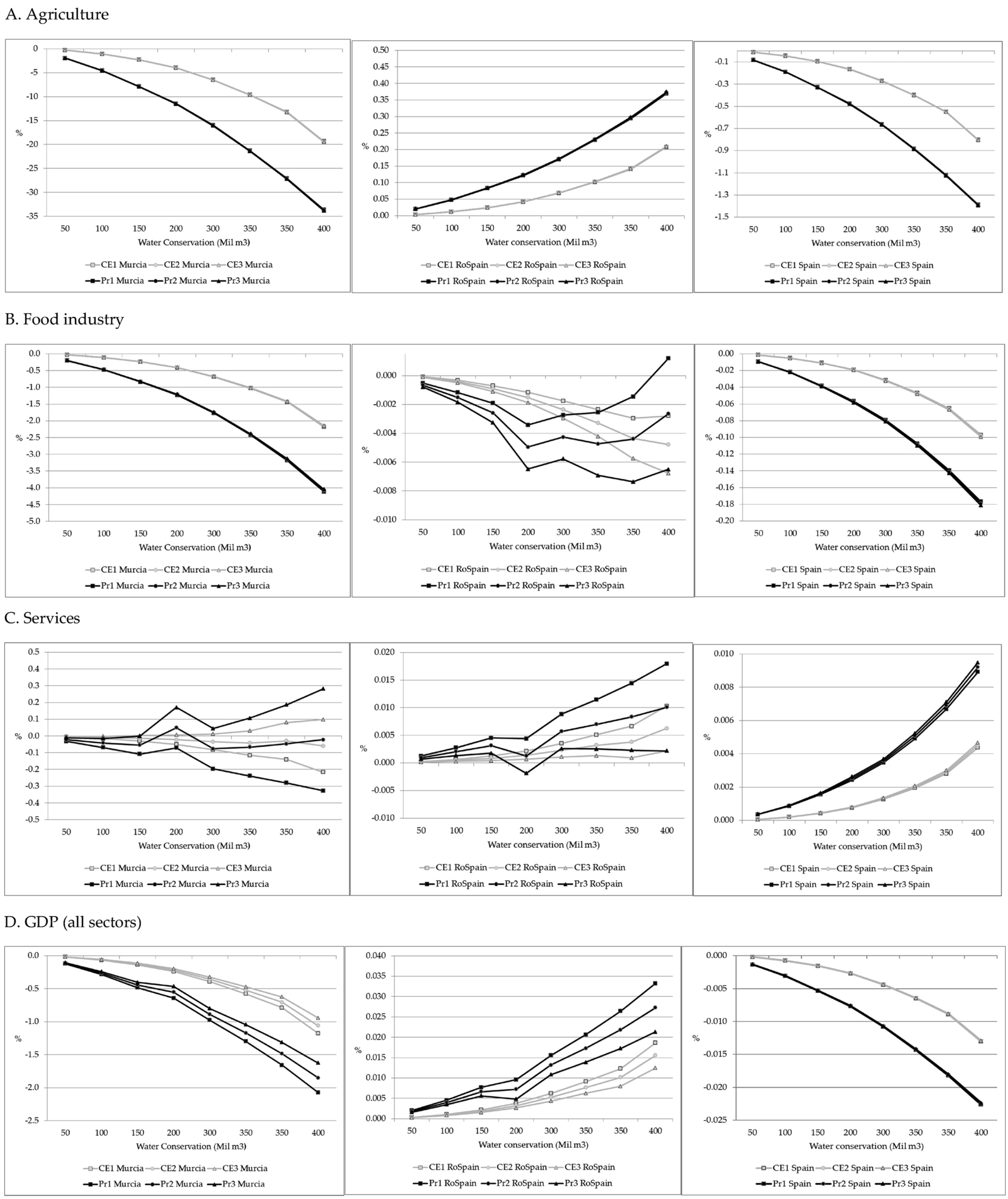

Fig. 5. % Change in real GVA of Murcia (left), Rest of Spain (center) and Spain (right).
Source: Own elaboration.

The worsening water crisis and difficulties to deploy more restrictive caps and charging arrangements led the Segura River Basin to pioneer water purchase tenders in the EU (SRBA, 2014). Two buyback tenders for the temporary reacquisition (1 year) of water rights from rice farms upstream were implemented during the 2007–2008 drought. Tenders had a budget of EUR 700,000 and envisaged a maximum purchase price of EUR 0.18/m^3. In 2007, the first tender consumed EUR 495,000 to purchase 2.93 million m^3 at an average price of EUR 0.17/m^3. Similar results were obtained in the 2008 tender. Both water reacquisitions were fully used to enhance environmental flows (Garrido et al., 2013).

Recent research in AWDUs of the Region of Murcia has estimated the annuity payment of buyback programmes to inform the design of purchase tenders in the area (Martínez-Granados and Calatrava, 2014; Pérez-Blanco and Gutiérrez-Martín, 2017). Yet, a major and persisting concern relates to the economy-wide repercussions of water buyback. The Region of Murcia is highly dependent on agriculture, which represents around 4.4% of regional GDP and 10.4% of regional employment, as compared to 2.3% and 4% at a national level (INE, 2017). Food industry and tourism, closely connected to the agricultural sector, account for 4.5% and 5.6% of the GDP, respectively (INE, 2017) Relevant feedbacks on the output of economic sectors in the region, which are yet to be estimated, can be anticipated from this sectoral GDP distribution.

6. Results

Methods are illustrated with an application to the Murcia Region in SE Spain. The PMAUP is calibrated for the 55 AWDUs in the area following the methodology in Section 2. The parameterization results of the utility function of each AWDU and the corresponding calibration residuals come from Pérez-Blanco and Gutiérrez-Martín (2017) and can be also consulted in the on-line supplementary material. A series of simulations are run in which the water allocation constraint is strengthened in every AWDU. Limiting water availability precludes some portfolio choices and has a negative impact on the utility of agents through a reduced provision of valuable attributes, including profit. Agents readjust their crop portfolio according to their objective function and the new water constraint. For every simulation resolved, the foregone income and compensating variation are estimated.

Results from microeconomic simulations are then elaborated to obtain the productivity shock and the annuity that feed the CGE model. The macroeconomic simulation runs a comparative statics exercise to assess regional and sectorial GVA changes considering eight alternative water reacquisition targets: 50 (4% of water allocation in the baseline), 100 (8%), 150 (12%), 200 (16%), 250 (20%), 300 (24%), 350 (28%) and 400 (32%) million m^3. The economic repercussions of water reacquisitions are assessed following two alternative criteria: i) a cost-effective criterion (CE) in which priority in the reacquisition is given to those AWDUs where water is inexpensive; and ii) a proportional criterion (Pr) in which the same proportion of the initial water allocation is purchased in each AWDU. The motivation for the inclusion of these two criteria lies on the heterogeneity of water. If water was a homogeneous good with the same environmental value across Murcia's AWDUs, the first criterion should apply. However, this is not the case, and purchase tenders focusing on specific AWDUs may be necessary to restore/preserve critical ecosystem services. Finally, a major concern in water reacquisitions regards agency costs: due to information asymmetry, irrigators may perceive a compensation that is not consistent with the shadow price of water, increasing the cost of the buyback program and/or limiting its scope –and henceforth the extent of ecosystem services delivered. Three agency costs scenarios are defined based on the values reported in the literature: $\theta = 1$ (no agency costs, case 1), $\theta = 1.5$ (case 2) and $\theta = 2$ (case 3) (Iftekhar et al., 2013; Martínez-Granados and Calatrava, 2014; Pérez-Blanco and Gutiérrez-Martín, 2017; Zuo et al., 2015).

6.1. Microeconomic assessment

Initially, agents react to the new water allocation constraint substituting irrigated crops in the margin by less water demanding or rainfed crops that yield slightly lower utility levels. When the water reacquisition target becomes more stringent though, agents are constrained to sacrifice increasingly valuable crops and utility losses amplify. This process is visible in Fig. 3, which displays the compensating variation (€/m^3) in the 55 AWDUs for 8 reacquisition targets. As utility decreases, so does income, one of the critical attributes determining utility (Fig. 4).

In some simulations the objective function cannot be resolved within the domain ("N/A" value in the legend). This is largely the consequence of the ligneous crops surface thresholds set in the model[4], and happens with 40% of AWDUs when water allocation is reduced by > 32% (> 400 million m3). A maximum threshold for water reacquisition targets is fixed at this value. Overall, surface water-reliant AWDUs in upstream catchments display less productive crop portfolios and lower purchase prices compared to those located downstream. Focusing water purchase tenders on upstream areas may improve environmental flows along the basin at the least cost (CE criterion). However, complementary purchase tenders may be necessary in other areas to restore the balance locally (e.g. aquifers, tributary rivers).

The results obtained above for every AWDU are aggregated to obtain the inputs for the CGE model. Table 1 displays the foregone income and compensating variation, as a percentage of Murcia's agricultural GVA in the baseline, for alternative reacquisition targets and design (CE and Pr) in the case of no agency costs ($\theta = 1$). Not surprisingly the Pr scheme shows higher compensating variation and income losses than the CE scheme. In absolute value, income losses are greater than the compensating variation in both schemes: as the water allocation constraint is strengthened, an increasing share of land is devoted to less water intensive and rainfed crops, which yield a lower expected income but typically also higher risk and management complexity avoidance –two valuable attributes that mitigate the negative impact income losses have on utility. The opposite may happen, and the compensating variation can be greater than income losses (absolute values) where agency costs are considered.

Table 1
Income losses and Compensating Variation as a percentage of Murcia's agricultural GVA in the baseline year (no agency costs case, $\theta = 1$).

	CE		Pr	
Reacquisition target (million m3)	Foregone income (%)	Compensating Variation (%)	Foregone income (%)	Compensating Variation (%)
50	−0.18	0.07	−1.16	0.52
100	−0.65	0.34	−2.69	1.35
150	−1.36	0.81	−4.69	2.66
200	−2.34	1.41	−6.81	4.12
250	−3.86	2.36	−9.55	6.02
300	−5.71	3.65	−12.78	8.64
350	−7.88	5.51	−16.37	11.70
400	−11.60	7.85	−20.48	15.25

6.2. Macroeconomic assessment

In the PMAUP model agents' choices are taken within a static macroeconomic scenario with exogenous prices –a reasonable assumption for the small AWDUs of Murcia (Gutiérrez-Martín and Gómez, 2011). When the productivity and income shocks stemming from the PMAUP model are aggregated for the entire Murcia's agricultural sector and translated into the CGE model, the macroeconomic scenario is not anymore given but reacts through changes in relative prices, triggering

[4] Uprooting fruit trees would result in disinvestments with negative impacts on future market and non-market (ecosystem services) income -the latter not being accounted for in the model. Alternatively, water requirement for fruit trees could be reduced, resulting in yield losses but preserving the trees, but this necessitates yield functions that are challenging to implement in the PMAUP model -not the least due to the limited hard data available. Consequently, a minimum surface threshold has been set for ligneous crops, which have to remain above 90% of their original surface.

the reaction of other economic sectors, agents and regions. Consistent with the permanent nature of the reacquisitions, the model assumes a flexible CGE setting with a medium- to long-term focus, where labor and capital are perfectly mobile between sectors and CET elasticity for labor and capital mobility within Spain is minus two. This value is consistent with previous CGE studies assuming a flexible economic system at the sub-country level (Carrera et al., 2015; Koks et al., 2015). Accordingly, regional and sectorial GVA changes in this comparative statics exercise should be also understood in a medium- to long-term context.

The regionalized CGE model explores the macroeconomic impacts of Murcia's water buyback programme across sectors and regions of Spain through a series of simulations. Fig. 5 displays simulation results in the agriculture (A), food industry (B), services (C) and aggregate GDP (D) for all water targets (50, 100, 150, 200, 250, 300, 350 and 400 million m^3), CE and Pr reacquisition schemes, and agency cost cases 1, 2 and 3.

The microeconomic results in Table 1 are amplified in the macroeconomic assessment. For example, for the most ambitious reacquisition target in the Pr scheme and no agency costs case, Murcia's agricultural income experiences a -33% contraction as compared to -20.5% in the microeconomic model. Sectors that are strongly linked to agriculture like food industry also experience relevant losses in Murcia (up to -4% GVA). As opposed to the GVA losses experienced by Murcia, agricultural GVA elsewhere in Spain increases by .37% (aggregate agricultural GVA in Spain still decreases by almost 1.5%) and the service sector by almost .02%. This is partly the result of a *substitution effect* led by the reallocation of agricultural supply from Murcia towards other economic sectors and regions of Spain. On the other hand, the contraction of the Spanish aggregate income limits the rise of the GVA in the rest of Spain, resulting in an *income effect* that counterbalances the substitution effect. The trade-off between substitution and income effects is typical of this dynamic macroeconomic scenario where flexible prices determine the adjustment of trading flows.

The underlying reallocation of primary factors is critical to understand these effects. Consumers substitute goods from Murcia with goods produced elsewhere and not affected by the negative productivity shock, thus increasing the firms' demand for capital and labor in the rest of Spain. This leads to a shift of capital and labor force from Murcia to the rest of Spain, where capital and workers can find higher remunerations. As a result, Murcia experiences a substantial GDP loss (up to -2.1%), while GDP increases in the rest of Spain (up to +0.034%). Overall, the policy has a negative impact on Spanish GDP, although limited (up to -0.023%). Not surprisingly, the Pr scheme has a more negative impact than the CE. It is worth noting that higher agency costs do not influence the effects on Spanish aggregate GDP but have implications for its spatial distribution, mitigating losses in Murcia and diminishing gains in other Spanish regions. It should be also noted that relative changes in food industry and services exhibit nonlinear and non-monotonous patterns. This is due to the reallocation of primary factors and the resultant redistribution of trade in the different scenarios. Agency costs mitigate Murcia's losses in the services sector and the overall economy, but have a negligible impact on agriculture and food industry, where results for the three agency costs scenarios are similar.

Fig. 6 assesses policy impacts looking at the Equivalent Variation. Conceptually, the Equivalent Variation is similar to the Compensating Variation, but it is applied at the macroeconomic level to assess welfare impacts. It represents the amount of income that keeps the utility of the agent of the CGE model equal to that of the baseline, and is mainly driven by final consumption. A negative sign denotes a welfare loss as compared to the baseline.

Welfare effects at a regional and national level are also explained by the movements of primary factors and the re-composition of trade in the different scenarios, which depends on the Armington elasticities, whose coefficients differ for every sector. This leads to non-linear adjustment and non-monotonicity. In Murcia, the income transfer from the rest of Spain is insufficient to fully compensate the negative impact of reacquisitions, resulting in a welfare loss in most macroeconomic scenarios. Only for a few reacquisition targets (200, 350 and 400 million m^3) and for the highest level of agency costs (case 3) the income transfer leaves the representative agent with a welfare level comparable or higher to that of the baseline. The rest of Spain finds itself worse off in terms of welfare in several scenarios, despite the GDP increase. On the one hand, the income transfer in Murcia increases imports from the rest of Spain, especially agricultural products, which are cheaper since the production has not been negatively affected by the productivity shock; on the other, this is possible because the rest of Spain finances the consumption of Murcia through the income transfer, thus decreasing its own. Welfare impacts on the rest of Spain are a function of agency costs, with welfare gains where there are no agency costs and welfare losses where agency costs are high. Again, the size of agency costs does not affect aggregate welfare impacts on Spain, and the Pr scheme is more detrimental for welfare than the CE scheme.

7. Discussion

Simulation results show that the economy-wide repercussions of water buyback are relevant and range between -33% and -19.33% agricultural GVA losses in the Murcia Region for the most ambitious reacquisition target (400 million m^3), significantly higher than the GVA losses estimated in the microeconomic model (up to -20.5% for the same scenario). This amplification effect is the result of the reallocation of primary factors from Murcia to the rest of Spain modelled in the CGE context. Despite compensations paid to local irrigators, Murcia's supply contraction in the agricultural and related economic sectors leads to an overall GDP loss in the region between -1% and -2.1%. The remaining Spanish regions partially fill in the supply gap and experience an agricultural GDP increase between 0.21% and 0.37% and an overall GDP increase between 0.012% and 0.034%, which is nonetheless insufficient to compensate GDP losses in Murcia, resulting in a (limited) net GDP loss in the Spanish economy between -0.013% and -0.023% for the most ambitious target. Welfare effects can be unevenly distributed between Murcia and the rest of Spain, with winners and losers depending on the size of the agency costs. Results support the decision to develop investment plans/flanking measures to address the economy-wide impacts of buyback, particularly in affected rural economies and related economic sectors such as food industry.

Previous applied research on the economy-wide impacts of agricultural water buyback programmes is limited and focuses on the Australian case. Dixon et al. (2011, 2012a) analyze the economy-wide impacts of the water buyback programme in the Southern Murray-Darling Basin using a sub-national CGE model for Australia that incorporates water as a primary factor, thus making water trading simulations feasible. Results show that the reacquisition of 1 500 million m^3 (22.8% of initial water allotments) to restore the balance in the Southern Murray-Darling Basin has a marginal impact at the national level (-0.006% of GDP). In the Segura River Basin, restoring the balance would demand the reacquisition of 250 million m^3 (15.9% of initial water allotments). Our results suggest this policy would have an impact on the Spanish GDP comparable to the Australian case (-0.011% in the Pr scheme and -0.004% in the CE scheme), but a significantly higher cost per m^3 of water reacquired: 0.21$ in the CE and 0.51$ in the Pr, as compared to 0.05$ in Australia, in 2015 prices. This is largely explained by the distinct ability of the agricultural sectors in the Southern Murray-Darling Basin and Murcia to absorb the shock: following the reacquisitions, agricultural output falls by -1.3% in Southern Murray-Darling Basin as compared to between -16% (Pr) and -6.5% (CE) in Murcia. In addition, farmers in the Murray-Darling basin increase their consumption and welfare following the buyback, while the opposite situation is registered in most scenarios in Murcia.

Two elements appear crucial to explain the differences between our

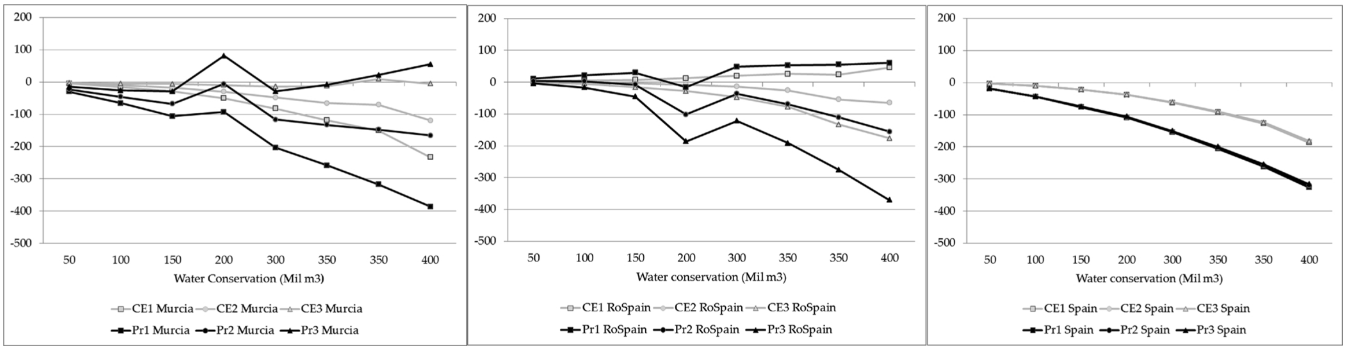

Fig. 6. Equivalent Variation (vertical axis) expressed in 2007 million $ of Murcia (left), Rest of Spain (center) and Spain (right) for the 8 water reacquisition targets (horizontal axis).
Source: Own elaboration.

results and those of Dixon et al. (2012a, 2011): i) the existence of water markets in Australia; and ii) the coupling method used in our approach, which allows for a more detailed representation of the motivations and constraints faced by farmers. In a market environment, buyback constrains supply and increases water prices, and farmers can leverage on this opportunity to increase consumption and welfare. This is not the case in Europe, where water markets do not exist and "prices" are administrative charges that do not respond to the scarcity value of water. The second key element is the coupling. The spatial resolution in the sub-national Australian CGE model does not offer the same level of detail than a locally calibrated microeconomic model such as the PMAUP model for Murcia. The southern half of the large Murray-Darling basin (1 061 469 km^2) is divided into 13 units in Dixon et al. (2012a, 2011) while Murcia, which covers an area equaling 1% of the Murray-Darling Basin's territory (11 313 km^2), is divided in 55 units in our study. The microeconomic analysis makes possible the use of mathematical programming methods to elicit the parameters of agents' objective functions and allows for a more detailed representation of the motivations and constraints faced by irrigators. The Australian CGE model does not consider these constraints, and risks to overestimate irrigators' capacity to shift capital, labor and land from one land use to another. As Wittwer (2012) points out, a finer regional division in CGE models is desirable for three reasons: i) more detailed regional results; ii) environmental issues such as water management often call for smaller regions that can map watershed or other natural boundaries more closely; and iii) more and smaller regions give a greater sense of geographical realism. The coupling between the PMAUP and the regionally-calibrated CGE model is a first step in this direction.

Although macroeconomic models have been previously used to assess the economy-wide impacts of fiscal policy schemes and water markets, to the best of our knowledge this is the first applied study of the economy-wide impacts of buyback policies outside Australia. The most plausible explanation to this gap is the difficulty to accurately simulate the price and value share to water, and water reallocation among users, outside of a market environment. Some macroeconomic models have been developed to inform irrigation water reallocation in the EU context and elsewhere (see e.g. Hertel and Liu, 2016). Even if the focus of these studies is different from ours, they can provide useful insights and policy implications for our work. For instance, insights from other macroeconomic models can be useful to inform policy sequencing in water reacquisitions. Water market scenarios for Europe unequivocally show an increase in GVA through water reallocation to more productive uses (Dudu and Chumi, 2008), suggesting water trading could help mitigate the GVA losses associated to buyback programmes. On the other hand, this very mechanism increases shadow prices (Darwin et al., 1995; Dixon et al., 2012a), and thus the overall cost of buyback for taxpayers. A sensible water policy reform consistent with the cost-effectiveness rationale that governs EU water policy (EC, 2000) may need to consider alternative policy sequencings to the Australian case to enhance acceptability –e.g. commencing reacquisitions before developing full-fledged water markets.

In addition to its economy-wide impacts, water buyback can also involve wider environmental consequences beyond the target basin because of the spatial redistribution of production. For example, Cazcarro et al. (2014) show that a combination of water tariffs and subsidies on food production can save water in the water scarce regions of Southern Spain (Murcia and Andalusia) and enhance food production in the water-abundant regions of the North (Cantabria and Basque Country). In our assessment, water conservation targets in Murcia are achieved at the expense of a significant decrease in the agricultural output, which is replaced by higher agricultural production elsewhere. Although we are not able to precise water use patterns in the remaining Spanish regions, the agricultural production increase is more pronounced in Northern regions such as Asturias, Cantabria and Aragón where water is relatively more abundant –pointing towards a pattern similar to that of Cazcarro et al. (2014). However, as higher value-added (and water intensive) crops are affected by the reacquisition, transferring their production to Northern regions may become increasingly unfeasible due to climatic and agronomic constrains. As a result, water use may increase in other water scarce Southern regions that resemble the physical and socioeconomic conditions of the Region of Murcia, exacerbating water overallocation problems there.

For a discussion on the policy implications of implementing agricultural water buyback schemes, including an analysis on the feasibility of the beneficiary-pays approach adopted by this instrument, we refer the reader to Pérez-Blanco and Gutiérrez-Martín (2017).

8. Conclusions

Coupling the PMAUP and CGE models makes feasible a detailed analysis of the tradeoffs in water conservation, from the sub-regional (AWDU) to the regional, national and supranational scale. Methods are general and replicable in other areas where water markets are non-existent or in an early stage of development and *ex-post* trading data is not readily available. Future research can focus on i) addressing the current limitations of the micro- and macro-economic models and ii) expanding the methodological framework.

The current version of the PMAUP relies on a validated projection method to reveal the efficient frontier, but recent developments in the field could help to minimize the approximation error (see e.g. Gómez-Limón et al., 2016b). Also the calibration residual could be reduced finding alternative and/or complementary attributes in the objective function that are relevant in explaining agents' decisions, although this is ultimately constrained by data availability. The CGE model could be improved introducing temporal dynamics to examine the transition pathway towards the new equilibrium and identify potential trade-offs between short and long run effects which could be relevant for policy implementation. In exploring transition pathways, the sequential coupling and comparative statics used in this paper could be replaced with a recursive coupling where agents in the PMAUP model adapt to the new macroeconomic scenario until convergence is reached. While comparative statics is often used to assess the impact of one-time permanent policies such as buyback, a recursive model would allow a better representation of temporary or recurrent policies (e.g. water charging). From the data perspective, water satellite accounts at a sectorial level (where available) could be used to analyze simultaneously the macroeconomic propagation of the policy and water use changes in economic sectors (other than irrigators in Murcia), e.g. through input-output coefficients. The current methodological framework could be also expanded including a hydrological module that accounts for catchment-specific characteristics and system dynamics (e.g. percolation, runoff) and localizes water flows and water conservation across the basin. This information is instrumental to assess the environmental outputs of the policy, and to estimate its economic benefits through non-market valuation methods.

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