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Economic analysis of the long-term effects of groundwater salinity: bringing the farmer's perspectives into policy

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ABSTRACT

This research estimates the economic losses at the farm level caused by groundwater over-exploitation and by seawater intrusion. The problem of coastal groundwater salinity was tackled by considering its hydrological, agronomic and economic aspects. Economic analysis for competitive use vs. regulated management regimes was carried out, considering constant and adaptive watering techniques. We concentrate on the farmers' perspective of water as an input in agriculture, and assess discounted net present value over a period of 30 years. The ultimate goal of this research is to raise the awareness of farmers and policy makers by demonstrating the economic impacts (from the farmer's point of view) of over-exploitation. Our findings for Apulia Region (Southern Italy) indicate that the slowness of the long-term effect of salinity and the ability of farmers to adapt irrigation profiles suggest broadening the perspective of policy intervention. For an effective management of this common resource, policy makers should follow a more comprehensive approach based on economic analysis.

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1. Introduction

Seawater intrusion is a serious problem along the Mediterranean coasts and in other coastal areas around the world, where the water demands of tourism and agriculture are the leading cause of groundwater over-exploitation (COST 2005).

Unlike what has occurred in large catchment projects for surface water, implemented by public agencies under the direct control of central authorities, groundwater resources have been exploited almost everywhere by a large number of small users, thus creating a situation that is difficult to monitor and regulate. In this case, groundwater resources can be considered as a common-pool that is exploited using increasingly simple and low-cost technologies.

When groundwater is exploited by a large number of independent users, none is encouraged to preserve the resource, since it might be equally used by others, and water saving may not be exclusively for individual benefit. Over-exploitation of groundwater resources can generate different types of negative externalities: (i) stock externality, related to reduced

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availability of the resource for other current or future uses, (ii) cost externality, due to the increase in extraction costs, (iii) externality related to quality degradation of the resource (Zeitouni and Dinar 1997), and (iv) an externality associated with damage to groundwater ecosystems (Esteban and Albiac 2011).

Most studies tackling the groundwater problem have applied modelling in order to target the 'Optimal management of groundwater resource' (Cummings 1971; Provencher and Burt 1993; Moreaux and Reynaud 2004; Tsur and Zemel 2004; de Frutos Cachorro et al. 2014). A multidisciplinary approach has been advocated and there has been a long process of theory development. Koundouri (2004a) reviewed two decades of literature on groundwater starting from the controversial Gisser-Sanchez effect (GSE)¹ (Gisser and Sanchez 1980). Basically, disagreements refer to the assumption of Gisser-Sanchez's analysis, such as behavioural model of farmer's pumping decision (Koundouri 2004b), constant well yields and incorrect social discount rates (Birol et al. 2010), or the lack of ecosystem damage issues in their economic analysis (Esteban and Albiac 2011).

Far from giving an exhaustive review, in the context of this research it is worth mentioning groundwater quantity-quality interactions. Groundwater management in the presence of salinity is even more complex for at least two reasons: (i) the groundwater depth on the coast-line hardly changes, unlike the inland aquifer, (ii) the on-farm effects of salinity emerge slowly over a long time period.

In groundwater hydro-economic modelling, an increasing extraction cost is assumed up to a point where it is no longer beneficial to pump. The magnitude of the water-table drop for coastal aquifers is generally smaller than for inland aquifers. For instance, Polemio et al. (2008) analysed the declining trend (1965–2003) of water-table levels in Apulia's karstic aquifers (Southern Italy), and reported a drop of -0.38 m along the coast line. This decrease in the water-table will not affect the farmer's pumping cost. While the water-table level hardly changes (to an extent that affects farmer's pumping cost) the most relevant effect that coastal aquifers undergo involves displacement of the transition zone (Polemio et al. 2008). This leads to the second reason: contrary the assumption of Tsur and Zemel (2004), seawater intrusion does not occur abruptly. Although there are threshold limits for drinking water that impose the abandonment of well use (Moreaux and Reynaud 2004), in the case of irrigation water, quality deterioration generally implies a gradual long-term reduction in yield. Therefore, adaptive farming practices have been proposed that aim to avoid yield losses by increasing the volume of irrigation water (Le Kama and Tomini 2013) or by mulching (Bezborodov et al. 2010).

While paradigms for groundwater management are slowly emerging, and various models are being investigated and tested, it is also clear from actual cases that management of groundwater development and its use (demand management) is generally difficult to implement and enforce, and also expensive. With a few possible exceptions, little has been done to regulate groundwater extraction (Giordano and Villholth 2007).

The scope of the present research does not include a detailed discussion of why management concepts often fail, but key elements of this failure include both (i) timescales, and (ii) inherent scientific limitations on hydrologic dynamic modelling. Regarding timescales, the short-term nature of policy decisions conflicts with the long-term nature of aquifer dynamics. Salinization processes are generally slow in relation to the time-frames used for most management decision-making processes. Time lags exist between costs and benefits, with the bulk of costs (economic, social and political) occurring at the moment of policy

intervention, while the benefits are realized later in time. Furthermore, the slowness of the salinization process may lead to a perception that the benefits of the policy do not justify the costs. With regard to scientific limitations, Sivapalan (2015) has recently highlighted the inherent scientific limitation on the ability to quantify water availability and hydrological dynamics within an aquifer. Moreover, as the hydrological dynamics of an aquifer become increasingly complex, as in the case of coastal aquifers, the information cost rises.

All these elements prevent policy makers from implementing a comprehensive, forward-looking groundwater management policy, while farmers continue to compete for groundwater use.

Within the contest outlined so far, this research presents the results of a modelling exercise aimed at analysing the economic impact at the farm level of groundwater over-exploitation on the coastal aquifer of Apulia Region (Italy). It aimed to represent farmers' behaviour regarding groundwater pumping rates in the case of groundwater threatened by saltwater intrusion. The ultimate goal is to raise farmers' and policy makers' awareness of the economic impacts of over-exploitation. We try to prove that from the farmer's point of view the economic impacts of over-exploitation are not externalities. The economic argument is useful for bringing farmers and policy makers around to the same perspective.

In the aim of adding to the existing literature, the adoption of a new watering technique is considered. The assumption of fixed irrigation watering generally suggests a constant rate of water application over time while, in the long run, the use of increasing volumes may offer effective on-farm responses to worsening quality. To the best knowledge of the authors, this study integrates these issues for the first time.

Section 2 describes the methodology used to simulate the farmer's decisions under the typical technical constraints of irrigated agriculture in semi-arid environments. Section 3 describes empirical application on a farm situated next to the coastal strip, in Foggia Province (Apulia, Southern Italy), providing data and simulated scenarios. Section 4 analyses the main results on the irrigated surface, aquifer salinity level, annual net farm margin and water productivity. The analysis compared the Net Present Value (NPV) under the different water policy scenarios over a period of 30 years. Finally, Sections 5 and 6 contain the discussion and conclusions, respectively.

2. Methodology

Studies and research of groundwater resources in Apulia Region have highlighted the problem of over-exploitation (PTA 2009), defined as occurring when abstraction exceeds the natural groundwater recharge capacity (Directive, 2000/60/EC).² If, for the sake of simplicity, analysis is performed on a steady-state basis, it can be assumed that the sustainability constraint is respected when annual abstraction is equal to the annual recharge rate.

At present, no quantitative value of groundwater over-abstraction is reported in the regional PTA (Water Protection Plan), and no indication is available either on the available water supply or on annual natural recharge (Polemio et al. 2008). The level of salinity is the only data used for monitoring groundwater status, especially in areas near the coast, since salinization is considered as a direct effect of over-abstraction.

This analysis is performed using a simplified mathematical programming model that integrates a hydrologic component, a function of the agronomic response to irrigation water salinity, and a function of the economic return of agricultural activity. Much literature has

focused on the optimal groundwater withdrawal rate by taking a normative stance. In contrast, the model used in the present research adopts the farmer's perspective of profit maximization, while groundwater management policies (i.e. limits on extraction volume) are exogenous.

2.1. Hydrologic component

The hydrologic component attempts to establish a relationship between the annual rate of abstraction and the change in the salinity level over a period of 30 years.

The dynamics of coastal aquifers are complex systems; karstic aquifers like those in Apulia are even more complex, posing limits to groundwater flow modelling on a regional scale for management purposes (Polemio et al. 2008).

This research envisages an empirical approach by extrapolating salinity with a functional correlation to the farmers' pumping decisions. We adopted the model proposed and tested by Vitale (2005) in Apulia Region. Following this equation:

$$ECw_t = \alpha ECw_{(t-1)} - \beta r_{(t-1)} \quad (1)$$

where: ECw_t, ECw_{t-1} : conductivity (electrolytic) value (dS/m) at present and in the previous period; r : rainfall (mm) at time $t-1$; α : experimental parameter of the so-called 'memory effect' (namely, ECw is not steady and depends on the value of conductivity recorded in the previous period); β : experimental parameter to consider the role of rainfall recharge r at time $t-1$ on the reduction of conductivity.

Since we are mainly interested in modelling the increase in salinity due to over-abstraction by farmers, we consider over-abstraction as a kind of 'prolonged drought', with the direct consequence of a reduction in r , and thus increased salinity as described in Equation (1). The relationship between r and the abstraction rate denoted as W is from Civata (2005):

$$r_t = W_t / \chi \quad (2)$$

where χ : potential infiltration coefficient, which depends on the soil's physical characteristics.

Then, Equation (1) can be re-written and the relationship between abstraction and water quality is made explicit:

$$ECw_t = \alpha ECw_{(t-1)} - \beta (W_{(t-1)} / \chi) \quad (3)$$

Adopting the experimental parameters of α and β observed by Vitale (2005), and the value of χ reported in (Civata, 2005), the ECw is estimated by varying the W that ultimately is on-farm abstraction.

2.2. Agronomic component

The second component of groundwater salinization is the effect of irrigation with brackish water on yields. The extensive literature on this subject generally recognizes the inverse relationship between the salinity level of irrigation water and annual yields, following a production function where crop yields, Y , depend on the watering volumes W and a yield reduction coefficient y_δ resulting from the salinity level δ :

$$Y_t = Y(W_t, Y_\delta) \tag{4}$$

In this work, it has been assumed that no change in total soil fertility is observed as a consequence of salt accumulation in irrigation water,³ while watering levels can be kept constant or can vary under the working hypotheses of a steady and evolving response by farmers to increasing salinity (see Section 2.5).

2.3. Economic component

The economic component refers to the farmer’s decision-making process. It is assumed that in order to maximize revenue resulting from the use of resources, the farmer decides in each period to abstract water until the net marginal benefit from the resource becomes zero (Roseta-Palma 2002). With the competitive use of resources, the long-term consequences of groundwater salinization – Equation (1) – are ignored, and the problem of inter-temporal optimization of welfare turns into maximization of profits in each year (memorylessness). Given the salinity level of the groundwater, the farmer optimizes its use in each year, rather than the present net value of future revenues resulting from the use of the resource.

For the purposes of the present research, the farmer’s choices about annual extraction of groundwater were simulated by using a recursive mathematical model. By maximizing the net revenue of the farmer’s activity at year $t-1$, we obtained the abstraction volume W_{t-1} . By replacing the value in Equation (3) we obtained the salinity value ECW at year t . This process was repeated for every year of the time horizon t and allowed clearer delineation of the inter-annual relations between a farmer’s pumping decisions and changes in the groundwater status.

The farmer’s decision-making process can be expressed by:

$$\text{Max } NM_t = \text{Max} \left\{ \sum A_{c,t} \times Y_{c,t,y\delta} \times P_{c,t} - \sum C_{c,z,v} - \sum (w_{c,t} \times p_{w,t}) - \sum \text{fix}_{c,t} \right\}, \forall S \tag{5}$$

where: NM is the net margin at time t ; $A_{c,t}$ (ha/year) is the cultivated area of crop c (irrigated and rain fed); $Y_{c,t,y\delta}$ (kg/ha) is the yield of crop c at year t according to the reduction coefficient y_δ (only for irrigated crops); P (EUR/kg) is the selling price of crop c at year t ; $C_{c,z,v}$ (EUR/ha) are the variable costs for a given technical coefficient (input) z (kg/ha), and input market price v (EUR/kg); $w_{c,t} \times p_{w,t}$ is the cost of irrigation (only for irrigated crops) (EUR/ha) at time t , with $w_{c,t}$ being the annual water consumption (m^3 /ha), and $p_{w,t}$ the average price (EUR/ m^3) of abstraction at year t ; $\text{Fix}_{c,t}$ are total fixed costs (EUR/ha) and include depreciation of machines and buildings, salaries and taxes; S refers to the threshold imposed on groundwater annual abstraction, and varies according to different simulated scenarios.

The objective function (5) is subject to the constraints of revenue maximization, such as: (a) available land resource (ha/year), labour (h/month) and capital (EUR/year); (b) abstraction from groundwater (m^3 /year) and corresponding salinity γ (dS/m) for each year t , in every considered policy scenario; (c) technical and agronomic constraints.

Irrigation technologies are considered as fixed and unchanging following the model currently in use in the case study. Moreover, the model ignores *sunk costs*, namely those already paid by the farmer at time t_0 . Finally, any change in crop allocation is at zero cost, considering that production activities are perfectly substitutable.

2.4. Opportunity cost

From a theoretical economic point of view, externalities caused by over-abstraction represent a cost for society, which actually ‘foregoes’ the use of a portion of the resource that is supposed to be consumed in the future. In the presence of salinization along coasts, over-abstraction causes a change in groundwater quality. Consequently, over-abstraction that exceeds the natural groundwater capacities entails a cost for society in the future. This opportunity cost expresses the economic difference between the benefits derived by current and future use of the resource (Prosperi et al. 2011) and can be compared by calculating the NM of reducing current abstraction in order to maintain acceptable salinity levels for irrigation in the future. The opportunity cost is calculated as the actualized value, at discount rate r , of the lost revenue (ΔNM) to future production cycles caused by the unsustainable use of the resource:

$$\text{Opportunity cost} = \sum_t [\Delta NM_t^s (1+r)^{-t}], \forall S \quad (6)$$

The difference in the economic values of the scenarios corresponding to open-access and regulated access is the opportunity cost to maintain abstraction levels at a level that will prevent worsening of salinity levels.⁴ This difference can also be defined as the measure of economic inefficiency in groundwater resource management.

2.5. Simulated scenarios

In order to simulate the effects of different policy measures aimed at regulating access to water resources, two main factors have been considered:

- (a) *Regulation policies*: sustainable groundwater management requires the setting of abstraction limits in order to control the groundwater salinity level. The present research does not attempt to establish an optimal pumping rate by considering a long-term horizon (Brill and Burness 1994). Regulations here are exogenous to the model and concerned with the policy maker’s perspective of the establishment of limits to abstraction.

In our research, two groundwater management schemes are compared with the unregulated (also called status quo) states. The first scheme is aimed at preserving groundwater status, implying that at least the current conductivity is kept unchanged over the years starting from the present. The second scheme is aimed at recovering groundwater quality. Among the infinite number of scenarios, the simulated policies have been selected by trying to find a compromise between economic losses and environmental gains, in the pursuit of a higher level of consensus among farmers. Although simulated policies might not be optimal, they are in line with the Water Framework Directive (Directive, 2000/60/EC) goals.

- (b) *Irrigation practises*: in order to take into account farmers’ reaction to the effects of water salinity on crop yields, the progressive watering is simulated. Farmers can reduce yield loss by increasing the amount of water per hectare of land, because the more water is applied in excess of crop requirements, the lower the salinity level in the root zone – although more salt may be added as a result of this irrigation (Le Kama and Tomini 2013).

Furthermore, a sensitivity analysis of the pumping cost and discount rate was carried out.

3. Case study

The analysis relates to a representative farm near the Adriatic Sea coast, situated in the municipal district of Zapponeta, Province of Foggia (Apulia Region, Italy). The area is recognized as being within the vast regional area of sea-salt intrusion, where quantitative restriction measures must be applied to protect groundwater (PTA 2009).⁵ In terms of hydrological characteristics, the area's aquifer is representative of Apulia's shoreline.

This municipal district extends over about 40 Km², with a resident population of 3465 inhabitants (2010), and about 62% of active workers are employed in agriculture. The utilized agricultural area (UAA) is 2403 ha, and falls within a high fertility class (data from 6th General Census of Agriculture, Istat (2010)).

The investigated farm is in *Loc. Inacquata*, at a distance of 5 km from the coast of Zapponeta, adjacent to the Carapelle stream. The ground level elevation is approximately 5 m above sea level, and the well is approximately 50 m deep. Available official data on groundwater quality (the only water supply for irrigation) are out of date. According to the data provided by the farmer, the salinity level at the end of the 1990s was approximately 1.6–1.7 dS/m, whereas more recent values (2011) are 2.2–2.3 dS/m, meaning that there is a trend towards progressive deterioration (equal to an average annual increase of 0.04 dS/m), due to the over-exploitation of the resource for irrigation.

The agricultural holding includes a farmstead, a greenhouse (area approximately 1.5 ha), and 20 ha of arable land. In the short term, the farmer does not envisage any need to extend the farm area by renting land. The pumped water is stored in a small reservoir, and the annual average volume is approximately equal to 25,000 m³. A submersible pump is used, and the average pumping cost is approximately 0.14 EUR/m³.

The farm's only irrigated crop is tomato for industrial processing, which is grown in a four-year rotation with wheat to prevent soil fatigue. This scheme is also intended to prevent salt accumulation in the soil. The farmer owns a fleet of machines to perform all cultural operations, except for combine harvesting of wheat and tomato. Labour is mainly provided by the family (one unit employed all year round), and temporary workers are recruited during the peak periods, i.e. transplanting and harvesting. The farmer mainly relies on self-financing for financial sources required for agricultural crops.

It is worth noting that processing tomato is a cash crop, delivered to processing firms; Apulia grows 1/3 of the Italian processing tomato crop. In the area of study, tomato crop is the highest irrigation water demanding crop and the second irrigated crop in terms of land extension (Giannoccaro et al. 2010). Moreover, contrary to other irrigated crops, which exhibits the effects of salinity at earlier stage (e.g. sugar beet, bean, vineyard, artichoke), tomato crop is well-known for being salt-tolerant and, at present, can only be substituted by wheat cultivation (the most common rain-fed crop, in this area).

In order to define the simulation scenarios, we adopted the experimental values suggested by Vitale (2005) for parameters in (1) calculated for Apulia region, and in particular, we used $\alpha = 0.79872$ according to the current level of groundwater conductivity, and $\beta = 0.17393$ (coefficient reduction of conductivity referred to the level of rainfall). In addition, we assumed $\chi = 0.2$ as reported in Tulipano and Sappa (2010) for loam soil. As for the relationship between water salinity and crop yield, we assumed that the reduction in tomato yield resulting from an increasing level of irrigation water salinity corresponds to the data displayed in Table 1:

Table 1. Estimated yields corresponding to different levels of irrigation water salinity.

Water salinity (dS/m)	Yield potential (%)		
	5000 (m ³ /ha)	5500 (m ³ /ha)	6000 (m ³ /ha)
0–1.6	1	1	1
1.7–2.2	0.95	1	1
2.3–2.7	0.90	0.96	1
2.8–3.0	0.80	0.90	1
3.1–3.4	0.75	0.83	1
3.5–4.0	0.6	0.78	0.90
>4.0	0.5	0.68	0.75

Source: Adapted from FAO (1985).

For the purposes of this work, simulated policy scenarios were defined as follows:

- (1) *S1, Status quo*: each year, the farmer extracts water until its net marginal benefit is equal to zero, without any annual discharge rate constraint. Since no constraint is imposed on over-exploitation, and over the years the water resource is subject to quality degradation as given by Equation (3), an increase in EC_w is observed every year.
- (2) *S2, Preserving groundwater status*: this assumes an 8% reduction in annual pumping with respect to the status quo over the whole period, in order to avoid the current deteriorating trend of water quality.
- (3) *S3, Recovering groundwater status*: this assumes a further reduction in abstraction, in order to favour return of groundwater quality to the level before its use for irrigation, which is assumed to be equal to 1.6 dS/m. A 20% reduction in water abstraction for irrigation purposes with respect to status quo is applied until the 15th year, while subsequently and for an infinite horizon, a 7% reduction with respect to the status quo is considered. This approach is also the one that is most consistent with the vision of Water Framework Directive (Directive, 2000/60/EC), whose objective is to improve water quality by 2015; pumping rates of groundwater are to be restricted, in order to reduce EC_w .

Each policy scenarios is assessed under two watering systems, namely fixed and progressive watering: increasing volumes of irrigation water from the current 5000 m³/ha to 5500 m³/ha and 6000 m³/ha, for salinity levels higher than 2.2 and 2.7dS/m respectively, are considered.

The two watering systems will be referred to as *A* and *B*, respectively (Table 2).

Table 2. Simulated scenarios.

Watering system		Regulation policies		
		Status quo	Preserving ground-water status	Recovering ground-water status
Fixed watering		S1_A	S2_A	S3_A
	Progressive watering	S1_B	S2_B	S3_B

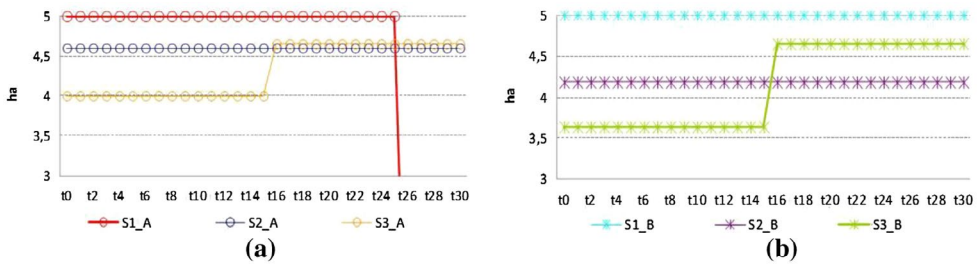


Figure 1. Irrigated surface.

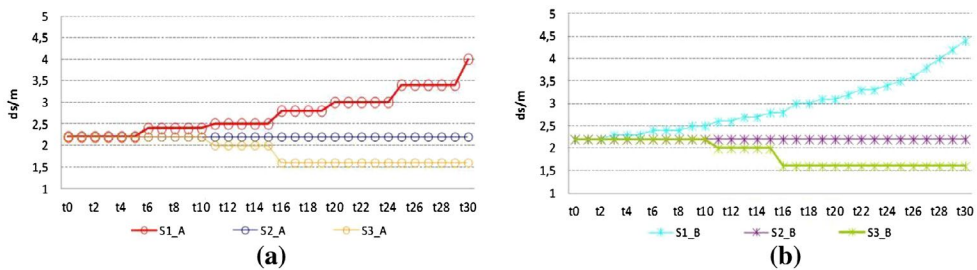


Figure 2. Salinity.

4. Results

The first outcome of the case study analysis is the variation of irrigated surfaces over the years (Figure 1) (Only the change in irrigated land is shown. Any reduction in tomato land is substituted by wheat). In Scenario *S1_A*, the irrigated surface remains unchanged until the 26th year, when it becomes equal to zero because the increased salinity reduces the irrigated tomato yield so much that it is economically unprofitable. In Scenario *S2_A*, the irrigated surface decreases from the 1st year by 8% compared to the current situation, and remains constant for the whole period considered. In Scenario *S3_A*, against a 20% reduction observed in the first 15 years, the irrigated surface in the second half of the considered period increases and stabilizes at 4.6 ha. In Scenarios *S1_B* and *S2_B*, the irrigated surface remains unchanged at 5 and 3.6 ha respectively, while in Scenario *S3_B*, against a 28% reduction observed in the first 15 years, the irrigated surface in the second half of the considered period increases and stabilizes at 4.6 ha. It is worth mentioning that in Scenario *S1_B*, with progressive watering and competitive use of groundwater resources, the irrigated surface remains stable in the long term, at the expense of increasing groundwater use.

The variation in groundwater salinity reported in Figure 2 confirms both the effectiveness of the withdrawal control measures of Scenarios *S2* and *S3*, both with fixed and progressive watering hypotheses. At the same time, competitive use has negative effects on the groundwater salinity level, both in scenario *S1_A*, and in scenario *S1_B*, where the increasing irrigation levels further deteriorate water quality.

The variation in groundwater salinity levels causes a variation in the yield of irrigated crops, with annual yields per hectare decreasing as irrigation water salinity increases.

Given the technology and market price at time t_{σ} we assume the yield reduction threshold to be equal to 25% of current yields.

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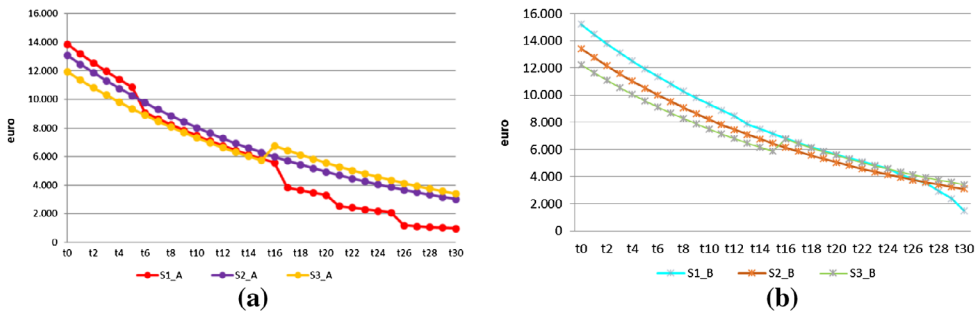


Figure 3. Net margin.

Once the optimal crop allocation is determined, an economic analysis is performed for each of the considered scenarios. The chart in Figure 3 shows the opportunity cost calculated as the annual variation in the net farm margin referred to the different scenarios. Values are discounted at a discount rate of 5%.

At the beginning and for a number of years, the unconstrained use of groundwater under the current regulation policy as simulated in scenario *S1_A* and scenario *S1_B* gives higher revenues compared with the other scenarios. Under the fixed watering system, the economic result of *S1_A* is at least equal to that of *S2_A* and *S3_A* until Year 16. If the farmer adopts progressive watering, the economic losses arrive after 27 years but, from then on a relevant reduction in the annual net farm margin is reported, reproducing the same situation as with the fixed watering hypothesis. Therefore, if farmers' reaction to increasing water salinity is accounted for, the result is a loop in which the problem is postponed.

The NPVs of farm activities in the next 30 years under the different simulated scenarios are shown in Figure 4, in addition to a sensitivity analysis with the variation in the adopted discount rate.

The least cost-effective scenario is scenario *S1_A*, i.e. water resource management under status quo conditions and fixed watering, regardless of the adopted discount rate for the progression and speed with which the groundwater salinity deteriorates increases in the considered period. Scenarios *S2_A* and *S3_A* give better results, meaning that farmers should prefer sustainable water resources management (Figure 4(a)). On the contrary, when progressive watering considered, the competitive use option generates the highest profit (Figure 4(b)). Scenario *S1_B* is the most effective for all the discount rates.

The variation in the shadow price of the resource, assessed through the estimation of its gross marginal productivity (Figure 5), shows that quality degradation over a time frame of 30 years has dramatic effects on the economic value of the resource, which are especially evident for the *status_quo* scenarios, equally with (*S1_B*) and without (*S1_A*) technological progress. On the contrary, the value of marginal water productivity tends to remain constant with regulation policy S2 and to increase with number S3, regardless of the watering systems.

Sensitivity analysis performed with increasing pumping costs (Table 3) demonstrates the following: (i) scenario *S1_B* remains the most profitable option, although the increase in irrigation costs is greater in the competitive use scenarios, which have the highest water consumption; (ii) for higher pumping cost levels, the differences in the economic losses of the alternative policy scenarios are reduced.

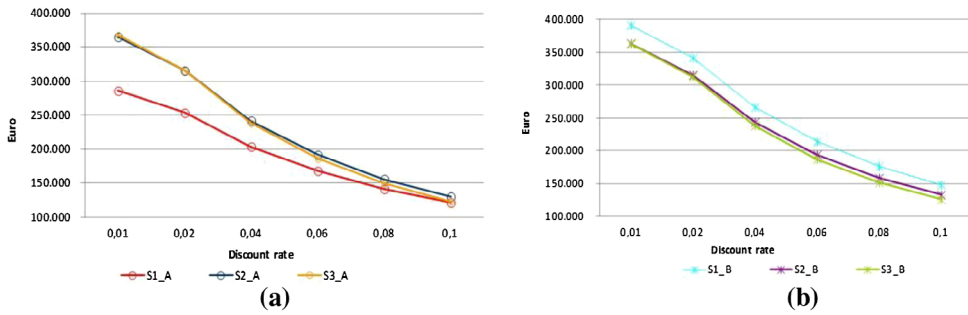


Figure 4. Net present value.

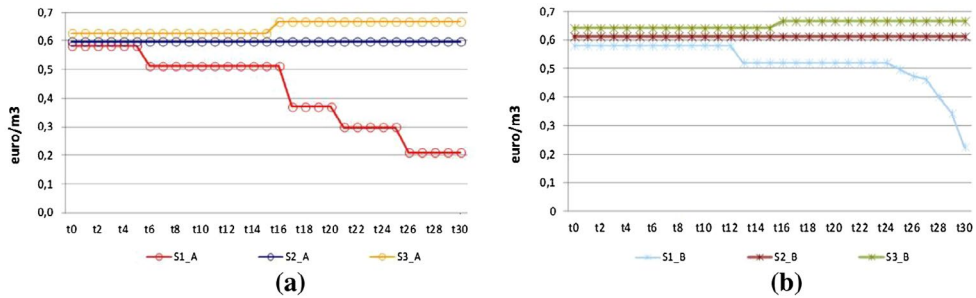


Figure 5. Water productivity.

Table 3. Net present value variation (Current = 0.14 EUR/m³) under different pumping costs.

Discount rate	Current pumping cost			+20% Pumping cost			+40% Pumping cost		
	S1_B	S2_B	S3_B	S1_B	S2_B	S3_B	S1_B	S2_B	S3_B
0.01	100	92.99	92.82	94.66	88.74	88.84	89.31	84.49	84.87
0.02	100	92.41	91.60	94.71	88.18	87.67	89.41	83.96	83.74
0.04	100	91.41	89.41	94.79	87.23	85.57	89.59	83.05	81.72
0.06	100	90.63	87.57	94.87	86.48	83.80	89.74	82.34	80.02
0.08	100	90.02	86.05	94.93	85.90	82.33	89.86	81.79	78.61
0.10	100	89.56	84.82	94.98	85.46	81.15	89.96	81.37	77.48

5. Discussion

Results obtained for the NPV of farming activities with the three groundwater policy scenarios in the case of fixed watering indicate the superiority of the regulated solutions compared with the competitive regime for discount rates lower than 10%. A discount rate of 5% is suggested by the European Commission (EC 2006) in its guidelines on the methodology for carrying out cost-benefit-analysis in the context of WFD and applied in many economic analyses performed in European countries (Galimoto et al. 2013; Arborea et al. 2017). When discount rate sensitivity is taken into account, a significant difference in NPV emerges between regulated and non-regulated water uses, which in turn calls for public intervention. However, results can change substantially under the hypothesis of adapting watering since the economic results (NPV) obtained under a competitive, unrestricted pumping rate, offset those of policy regulations with a sustainable and planned use of the resource. Thus, in the

study's proposed conditions, GSE persists when the adaptation measures to salinity are incorporated in the analysis. Kim et al. (1989) who developed an n-stage optimal control model incorporating the opportunity for adaptation to resource depletion in Texas High Plains, found similar evidence.

The main implication of this finding is that under competitive and unlimited groundwater exploitation, adoption of a technique aimed at reducing yield losses is an unavoidable necessity. Moreover, after a number of years the declining economic return from irrigation will imply the adoption of a technological upgrade. To some extent, competition for resource rents inflicts costly farming adaptation.

In addition, our model assumes perfect information and, most importantly, no transaction costs for farmer's adoption of a progressive watering technique. Results, including operations and economic information, should therefore be considered a best-case. It is unlikely that farmers will adopt this kind of method as soon as salinity increases, and that it will be adopted equally by all farmers. Therefore, the farmer's perspective of the competitive use of this resource leads to economic loss.

The results obtained also stress the problem of declining irrigation water productivity under competitive use of common-pool resources. As expected, a sustainable groundwater use rate makes it possible to keep water productivity constant, while competitive use leads to a substantial reduction. Groundwater depletion along with sea-salt intrusion leads to worsening water quality. The higher the pumping rate, the greater is the water salinity (Figure 3). Over-time-decrease of marginal water productivity is shown. To this regard, Mukherjee and Schwabe (2014) found declining market values of farmland in California in line with increasing groundwater salinity. Practically, the long-term effect of salinity has already been internalized with lower land market prices. In the case of landowners, the value of their asset has been curtailed.

Finally, while we concentrated on the productive value of water as an input in agriculture, we are fully aware that water may have other values or uses, such as the general supply value of water to households and industry, in addition to other *in situ* value items such as supporting local biodiversity, and preventing saltwater intrusion and subsidence, whose consideration tends to enhance the economic benefit of regulated policies (Esteban and Albiac 2011).

6. Final remarks

The research presented in this work has shown that considering a private profit maximising strategy, the competitive use of groundwater is desirable and certainly advantageous to farmers only if the progressive watering technique is adopted. Nevertheless, it could lead to severe consequences for water quality by accelerating the increase in water salinity via a sort of boomerang effect. Moreover, as reported in California, the market value of farmland is also related to groundwater quality (i.e. salinity), with landowners being the most affected. All these economic arguments can raise farmer's awareness of the long-term effects of groundwater over-extraction, making them more likely to accept management policy.

To the policy makers, the slowness of the long-term effects of salinity and the farmer's capacity for adapting irrigation profiles, suggest widening the perspective. Over the last 20 years, the Apulia Regional Government has issued three groundwater acts, each one prohibiting the issue of new licences for groundwater use, while the number of users has steadily increased (both legally and illegally). Moreover, while a rise in the cost of pumping

(i.e. pricing policy) might not be effective, as our findings have shown, effective management of this common resource demands a more comprehensive approach. Groundwater management is a critical issue for agriculture in the currently over-exploited coastal areas of Apulia Region. Despite the positive contribution that could come from economic analysis, the Regional Government's Protection Plan underestimates the importance of economic analyses that might encourage farmers to introduce sustainable management practices to protect the groundwater resource.

While further empirical studies will be necessary before it becomes possible to plan an adequate intervention strategy, it is important to raise farmers' awareness regarding correct management of a resource that is currently, but mistakenly, perceived as fully renewable.

Notes

1. GSE refers to a paradoxical empirical result that the social benefits from managing groundwater extraction are numerically insignificant. Thus, the role and scope of water management are severely limited.
2. The 'available groundwater resource' is defined in article 2, definition 27 as: '... the long term annual average rate of overall recharge of the body of groundwater less the long term annual rate of flow required to achieve the ecological quality objectives for associated surface waters specified under Article 4, to avoid any significant diminution in the ecological status of such waters and to avoid any significant damage to associated terrestrial ecosystems'.
3. Numerical elaborations are based on the data regarding water quality for agriculture by Ayers and Westcot (1985).
4. As we demonstrate with the results, actually the economic losses caused by over-abstraction comes before and might affect the farmer's income living today.
5. Regional Law No.9/21.05.2008 requires farmers to install instruments to record the amount extracted, and to periodically monitor quality for pollutants (e.g. nitrates and organic carbon) and conductivity (electrolytic). In addition, restriction areas and buffer zones have been established. Groundwater licences are no longer issued within restriction areas, and licence holders are subjected to flow limits. However, current compliance with the Regional Law falls far short of the target.

Disclosure statement

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