Water harvesting reservoirs with internal water reallocation: a case study in Emilia Romagna, Italy
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ABSTRACT
The existence of formal water markets in the European context is limited to the Spanish case, despite its rationale being deeply rooted in the economic literature. In Italy, formal water markets are widely criticized and they are not supported by the national legislation. However, due to some specificity, a form of water reallocation exists in a number of rainwater harvesting reservoirs in the North of Italy. The aims of the analysis are the description of such an institutional arrangement and the economic assessment of the reallocation mechanism, including the distribution of its gains. We formulate a semi-empirical mathematical programming model to study the outcomes of different institutional scenarios. The results suggest that the reallocation increases the gross margins of the area, and that the distribution of the gains are in favour of water buyers. Despite its inefficiencies, the institutional arrangement present in the area adds flexibility to a system that is likely to face major changes in the next decades.

Key words | water harvesting reservoir, water management, water market, water trading

INTRODUCTION
Water markets (WMs) are often proposed by the economic literature as an allocation tool to cope with scarce water conditions, for example, the agricultural sector in Mediterranean countries (Easter et al. 1999). The assumption is that, when water is scarce, WM ensure that the resource follows the most profitable use, thus leading to an efficient allocation (Schoengold & Zilberman 2007).

Although the WM rationale is deeply rooted in economic theory, WM are rarely institutionalized in Europe given the unique character of the resource at stake. In the European context, the most famous examples are the Spanish WM that were established in 1999 and that have been widely investigated from an economic point of view (e.g. Calatrava & Garrido 2005). However, WM are slowly entering the European political agenda; for instance, the EU Commission suggests that WM are a policy tool that could potentially be helpful at the local level and hints at the need for the formulation of implementation guidelines (COM/2012/0673 final).

In Italy, national legislation does not support the trade of water among private users. Water is publicly owned and rights to use water may be transferred to private entities through concessions, but the beneficiaries of concessions cannot further transfer such rights. Moreover, WM/water trading tends to be widely opposed by way of ideologically based arguments and on concerns regarding equity issues. In 2011, a national referendum on the introduction of private capital in the ownership of the drinking water utilities created a great societal participation and emotions that negatively impacted the possibility of having scientific and neutral discussions on water management, especially with regards to the possibility of water trading mechanisms. Water remains a public trust in Italy, but the discussions following the referendum created misconceptions on the topic that underpinned the social and political opposition to the establishment of WM. On the other hand, concerns about climate change, now associated with the drought events that have severely affected the agricultural sector in the past decade, could result in an increase in public interest on a rethinking of water governance, in particular concerning mechanisms that increase allocation flexibility.

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In spite of this general context, some forms of water reallocation mechanisms exist. An example is provided by several rainwater harvesting reservoirs located in the hilly district of the Consorzio Romagna Occidentale (CRBO), an irrigation and reclamation board located in the Emilia-Romagna region of Northern Italy. Water transfers are allowed internally within each reservoir to prevent the emergence of sleeping rights. This is made legally possible by the fact that the resource is made available by way of an artificial infrastructure and reservoirs are partially financed by private agents. However, even internally, several restrictions are in place to control transfers which in turn are not actually priced through a proper market mechanism.

Despite the lack of a real legislative institutional framework in Italy, an *ex ante* analysis can provide insights into the implications of the introduction of WMs in a context where command and control water allocation is the general rule. Up until now, few studies have addressed the potential impact of WMs in Italy. For example, Pujol et al. (2006) investigated the effects of the institutionalization of WM in a small area of a Southern Italian region, with a specific focus on the implications of different typologies of transaction costs. Yet, there is no existing literature that analyses the institutional design present in the area investigated here.

While in general the institutionalization of WM increases welfare through a more efficient allocation of water, both institutional transition and transaction costs reduce the expected benefits of these arrangements (Pujol et al. 2006; Garrick et al. 2015). In addition, while benefits may prevail when considering the group of traders as a whole, relative losers and winners can emerge (Brill et al. 1997), who can oppose institutional changes. To the best knowledge of the authors, no scientific literature addresses the issue of the distribution of the gains related to the potential establishment of WMs in Italy.

Given the dearth of literature addressing the analysis of water trading institutions in Italy and their policy importance, the objectives of the paper are: (1) the descriptive analysis of the institutional design of water reallocation within rainwater harvesting reservoirs; (2) the economic assessment of the water reallocation mechanism, including the distribution of its gains. The descriptive analysis is based on non-structured interviews with relevant stakeholders in the area under analysis, mostly officials of the CRBO and farmers working in the area. The economic assessment is performed by way of a semi-empirical mathematical programming model, which is partly based on secondary data from an area of agricultural macro specialization which is similar to the one under investigation.

**CASE STUDY AREA**

**Rural/hydrological development**

The case study is located in a 70,000 hectare zone in a hilly district in the province of Ravenna (Italy). The area includes the CRBO, an Irrigation Board responsible for the irrigation infrastructures and the hydrological management of the area. Fruit trees characterize the agricultural sector, the main crops of which are highly water demanding (e.g. actinidia) or sensitive to drought (grapes, and to a lesser extent olives). Hence, the entire agricultural sector in the area is strongly dependent on a reliable water supply. Since the end of the 1970s, 16 rainwater-harvesting reservoirs have been built and five more are planned. Farms are connected to the basins by pressurized water pipes. The number of farms connected to each basin varies significantly, ranging from a few units for the oldest basins, to some tens of farms for the newest ones.

Recently, the development of the reservoirs has been financially supported by the regional Rural Development Program (RDP) and in particular by Axis 1, Measure 125, ‘Infrastructure related to the development of agriculture and forestry’. The RDP contribution accounts for up to 70% of the cost. The RDP financial support is provided to projects involving a minimum of 20 farmers. The measures address groups of farmers that pool their resources by contributing to a collective infrastructure. Farmers are obliged to create a ‘Voluntary Irrigation Board’ (VIB), which is a formal institution that acts as the legal representative during the entire permission and funding procedure, and as the reference institution for the subsequent reservoir management. The expected benefits are legion. First, the reservoirs guarantee water availability and compared with individual farm reservoirs they also benefit from economies of scale. Another benefit of the infrastructure is that it technically connects the farms in a system that allows for greater flexibility in yearly water allocation.
Water management

Within each reservoir, both the initial water quota allocation and seasonal management are partially based on a market mechanism.

For each farm, the initial water endowment is determined by individual investment choices. Farmers decide on the investment level for the construction of the reservoir by purchasing investment quotas which are related to the amount of water that each farm is entitled to use. The property of the reservoir itself may have different configurations depending on the type of construction (the law has changed somewhat over time) and the individual choices of each consortium. The prevailing solution is that the reservoir is an indivisible property of the consortium, which means that the rights of the farmers are restricted to the use of water based on the quotas subscribed. The maximum amount of quotas is, however, limited by: (1) the crop plan linked to the quotas and for which water needs are calculated based on average technical coefficients related to water needs by individual crops; and (2) the presence of individual rainwater harvesting infrastructures. Normally, at the full reservoir capacity, each quota gives the right to use 1,000 m³. In particularly dry years, that amount can be reduced proportionally to the total availability. In years of heavier rainfall, the nominal value of the quotas is practically non-binding.

The water pricing is designed to cover all of the costs incurred by the consortium to manage and deliver the resource to the users. The costs are computed ex-post, at the end of the irrigation season, and are shared among the users according to dual-tariffs: (a) the fixed costs are shared according to the quotas owned by the farmers; and (b) the variable costs are shared volumetrically, according to the amount of water actually used by each farm.

A form of seasonal water quota transfer gives flexibility to the seasonal allocation mechanism. The transfer of quotas is based on an indirect transaction arrangement, with the VIB functioning as a sort of water bank, collecting the quotas that users renounce, and the demands for higher consumption. Farmers who renounce using some of the entitled quotas are relieved of the fixed costs related to the unused quotas. The seasonal use of additional water quotas can be obtained at higher costs for the amount that exceeds the regular assignment, the higher cost being equal to the fixed costs of the additional quotas obtained. Variable costs continue to be distributed according to the amount of water used (volumetric).

Even though such a reallocation system is not a ‘water market’, it represents nonetheless a deviation from the normal, centrally planned, management, toward a more flexible, incentive-based approach, which ensures, at the same time, that the water management costs are covered. The design of the institutional arrangement is somehow similar to that proposed by Brill et al. (1997). The authors analyse the problem faced by water agencies, the goals of which are: (1) balancing the budget; (2) efficient water allocation; and (3) some forms of equitable distribution of rents. Among the policy options considered, they analyse the introduction of ‘active’ and ‘passive’ WMUs. In an active water market, the water agency assesses the aggregate demand and supply and assigns water rights based on historical uses. Farmers pay for water according to a tariff based on average costs, and are allowed to trade the rights at the equilibrium price. In a passive water market, the water agency assesses the water tariff according to the equilibrium price (after the assessment of the aggregate demand and supply) thus farmers consume water up to the optimum. The rights are practically determined ex-post, considering the amount of water actually used. In our case, in case of water transfers, the budget balance is ensured by the transfer of the fixed costs related to the quotas. An increase in efficiency, even though it is clearly not fully reached, is generated by preventing the existence of sleeping rights that could emerge in case transfers would be fully forbidden.

ECONOMIC ANALYSIS OF THE YEARLY REALLOCATION MECHANISM

Model simulation and description of scenarios

The structure of the problem is analysed through an optimisation model simulating optimal water allocation under different institutional scenarios. The model is formulated as a maximization problem, the objective function of which is an aggregate profit function and the constraints are differentiated according to the institutional arrangements that apply in different scenarios. In particular, in case water transfers are not permitted, the individual
water quotas constrain the amount of water used by each farm; in the opposite case the water constraint is set at the aggregate level while reallocation among farms is allowed (McCarl & Spreen 1997; Tisdell 2001; Pujol et al. 2006).

Previous works focused significant attention on transaction costs. In this study, after cautious scrutiny of local exchange conditions, we opted not to consider them in the model, as we expect their weight would be negligible (or at least the difference of transaction costs between different institutional solutions would be negligible), given the small number of traders, the technical facilities that supply water to the farms (pressurized water pipes) and the role of the VIB facilitator. This does not exclude that this assumption may be worth empirical testing through further research.

We introduce three scenarios in order to assess the gains and the distribution of the gains in different typologies of reallocation mechanisms: (1) ‘No Trade’ scenario (hereinafter NT), where farms are not allowed to exchange quotas; (2) ‘VIB’ scenario, which represents the actual set-up, in which farms are allowed to internally reallocate quotas at the fixed price set by the VIB; and (3) ‘Free Trade’ scenario (hereinafter FT), in which the quota price is determined endogenously by the model, but trading activities are still limited within the group of farms connected to the reservoir.

Previous literature shows that the relevance of water trading is strictly connected to water availability. In order to take into account this effect, we also carry out a sensitivity analysis on the total amount of water that is available at the reservoir level, which might change due to climatic conditions. It should be noted that each quota nominally corresponds to 1,000 m$^3$ of water, while in the case of low water availability in the reservoir it determines the proportion of water to which each farmer is entitled.

The objective function of the model is the same in all of the three scenarios. The model maximizes the sum of the gross margins for the area

$$\text{max } GM = \sum_{i=1}^{n} (gmi \cdot xi - ci)$$  \hspace{1cm} (1)

where $gmi$ is the gross margin for each farm $i$, $xi$ is the land available for each farm, and $ci$ are the total farm costs. The gross margins per hectare depends on the share of irrigable land, according to a quadratic gross margin function (Viaggi et al. 2010)

$$gmi = \alpha_i \left( \frac{wi}{xi} \right)^2 + \beta_i \left( \frac{wi}{xi} \right) + \delta_i$$ \hspace{1cm} (2)

where $wi$ is the amount of irrigable land (that can be translated into water use) for each farm, and $\alpha_i$, $\beta_i$ and $\delta_i$ are the estimated coefficients of the gross margin function with respect to the share of irrigable land (see the data section for further details).

The maximization problem is subject to a number of institutional and technical constraints that differentiate the water availability per farm and the related cost function.

In the NT scenario, the amount of water used by each farm is constrained by the number of quotas ($q_i$), and by the total water availability of the reservoir

$$wi \leq \omega q_i$$ \hspace{1cm} (3)

with $0 < \omega \leq 1$, where $\omega$ represents a coefficient that translates the actual seasonal storage of the rainwater harvesting reservoir into farm irrigation capacity, given the amount of individual farm quotas. The cost is subdivided in: (i) quota related costs ($f$ – related to the management of the rainwater harvesting reservoirs); and (ii) variable costs dependent on the amount of water that is actually utilized ($v$)

$$ci = f q_i + vw_i$$ \hspace{1cm} (4)

The VIB scenario describes the actual situation, where the reallocation is partially controlled by fixing the water quota price on the quota related costs. Since the price is not allowed to change to clear the market, we compute the amount of quotas that each farm would sell/buy at the fixed price $p$. We then assess the total amount of quotas reallocated, which is determined by the lower number between total quotas supplied and total quota demanded at the fixed price $p$, and $W$ the total amount of water exchanged, we impose

$$\bar{E} = \min \left( \sum_i \bar{S}_i, \sum_i \bar{B}_i \right)$$ \hspace{1cm} (5)

and

$$\sum_i s_i = \sum_i b_i = \bar{E}$$ \hspace{1cm} (6)
By solving the model under these constraints, the water is implicitly reassigned to the most profitable use, even though this does not appear explicitly in the computation of the costs. The water use constraint is given as

\[ w_i = \omega q_i - s_i + b_i \]  

(7)

and the costs per farm are given as

\[ c_i = f q_i + v w_i - p s_i + p b_i \]  

(8)

The FT scenario is differentiated from the VIB scenario by allowing the price of water quotas to be chosen endogenously by the market. The amount of quotas utilized by each farm is still given by Equation (7).

The market is cleared by (Hazell & Norton 1986; McCarl & Spreen 1997; Pujol et al. 2006)

\[ \sum_i s_i = \sum_i b_i \]  

(9)

and the costs are determined by

\[ c_i = f q_i + v w_i - p s_i + p b_i \]  

(10)

where \( p^* \) is the equilibrium price. The equilibrium price is implicitly determined by the water aggregate demand and by the aggregate quantity of water available (McCarl & Spreen 1997; Chiang & Wainwright 2005), and it is introduced in Equation (9) to compute the individual gross margins. More specifically, in GAMS, the software employed for the simulations, the price is determined by the marginal value (shadow value) of the appropriate constraint equation (McCarl et al. 2013), here represented by Equation (8).

**Data description**

Since precise information on the individual farm structures (crop allocation, land and labour availability) are not available, we rely on secondary data from a farming macro-specialization of similar area (Viaggi et al. 2010), and located in the same Irrigation Board. We use the water gross margin function estimated in Viaggi et al. (2010) as a starting point to estimate the coefficients that we use in the quadratic gross margin function employed in the model simulation. The coefficients were the result of the interpolation of the points generated by a mathematical programming model with a medium term time horizon, thus where land allocated to crops is a variable, but the available land is not. Data regarding farmland size were not available; we then estimated it according to statistical figures from the case study area. The secondary data are adjusted to fit the conditions of the case study. Assuming that the original empirically estimated production function correctly reveals the slope of the average marginal productivity of water (share of irrigable land) in the area and that farmers are profit maximisers, the farms’ individual gross margin function has been derived by multiplying the empirically estimated function from the previous study by a coefficient ensuring that each farm is equating the marginal profit with the marginal cost of quotas, for the number of quotas actually used. This coefficient, multiplied by the empirically estimated profit function, leads to the actual profit function used in the model. The general rationale is similar to the one commonly accepted in Positive Mathematical programming studies.

We apply the estimated function to the group of farms connected to rainwater harvesting reservoirs in the area that we chose based on the availability of data regarding the number of farms connected, the initial individual quota endowment, and the quota transfers for the year 2011. The reservoir is located in the hilly area of Ravenna province. Sixty farms are connected, for a total of 510 quotas (\( \geq 510,000 \text{ m}^3 \)). In 2011, there were transfers for \( \geq 40 \) quotas (7% of the total water available) that involved, in total, \( \geq 30 \) farms.

**RESULTS**

Figure 1 depicts the amount of water transferred in the two reallocation scenarios, up to 1,000 m\(^3\) per quota, after which the quotas are practically non-binding, and there is no scope for trade. Water transfers are always greater in the FT than in the VIB scenario for the water availability levels that are considered in the model. In case of a reduction in the total amount of water of 50% or less, the VIB scenario does not create incentives for reallocation, and water flows are depressed to 0, while, as shown in the free trade scenario, there would still be scope for an efficient reallocation of the quotas. Moreover, in the FT scenario, the volume of transferred water in percentage terms declines with the total amount of water available, while in the VIB scenario the relation is more ambiguous.
In Figure 2, the differences in gross margins between the reallocation scenarios (VIB, FT) and the NT can be observed. As expected, both reallocation arrangements are beneficial for the area and the added value of both mechanisms increases with the total amount of water. The FT scenario leads to the highest payoff for any level of water availability. The greatest difference between the FT scenario and the VIB scenario lies at 600 m³ per quota and then decreases, since afterward the endogenous market price gets closer and closer to the fixed price of the VIB. On average, the FT scenario leads to an increase of 3% in the gross margins, whereas the VIB scenario leads to an average increase of 1%, with respect to the NT. In both cases, the increases are rather modest. Prices in the FT scenario clearly decrease with the amount of water available, ranging from 2.7 €/m³ in case of severe droughts to 0.2 €/m³ when water is abundant. The regularity in the evolution is also probably due to the specification of the quadratic gross margin functions.

Finally, we assess how these benefits are shared between suppliers and buyers of the quotas, in order to understand how the two reallocation scenarios affect the distribution of the gains generated by the reallocations themselves. Figure 3 shows how the gains generated by the presence of a reallocation mechanism are shared between suppliers and buyers of quotas. The VIB management creates a reallocation mechanism that is constantly biased in favour of the quota buyers. Moreover, the distribution of the gains is mildly responsive to changes in

![Figure 1](image1.png)  
**Figure 1** | Volumes of reallocated water (% of water available).

![Figure 2](image2.png)  
**Figure 2** | Left: Difference in gross margin between the reallocation scenarios and the NT scenario. Right: Evolution of the water quota price in the FT scenario.

![Figure 3](image3.png)  
**Figure 3** | Distribution of the gains due to the quota reallocation mechanisms.
water availability. The opposite result is generated by the FT scenario, in which the distribution of the gains from the reallocation depends on the total availability of the water, hence giving a relative advantage to those farms that sell their quotas.

DISCUSSION

The results show that the reallocation mechanism in place (VIB) improves the overall welfare of the group of farmers connected to the reservoir, with respect to the NT scenario. Not surprisingly, the FT would further improve the welfare with respect to the VIB by allowing prices to clear demand and supply of the water quota. The VIB is not flexible enough to provide incentives for efficient allocations in case of severe droughts. However, the improvement generated by the reallocation scenarios is rather low (from 3 to 20 €/ha). Both the FT transfers, and the FT percentage increase in the overall welfare of the area are similar to the results obtained by Pujol et al. (2006) in their analysis on the potential effects of the introduction of WM in southern Italy. The volumes of water transferred are also in line with the lower range of the results obtained for Spain by Garrido (2000).

Some characteristics of the model probably lead to the underestimation of the added value of the reallocation scenarios. First, the specification in the model of a medium time horizon does not consider the risks of crop failure and the related investment loss that might occur in case of water shortages. This is likely to be especially relevant for kiwi production, where crop failure means the death of the plants and thus of the loss of the initial investment. Additional limitations in the modelling stem from the fact that, in any case, in the agronomic literature, the effect of water on fruit tree yields is much less studied than that of arable crops. Moreover, the lack of primary data (differences in farm structures, precise information on crop allocations, etc.) prevents capturing completely the heterogeneity inter- and intrafarm (plots, crops), thus reducing the differences in the marginal value of water, and ultimately underestimating the added value of the reallocations.

The analysis of the distribution of the reallocation shows that the different institutions are not neutral with regard to the sharing of the benefits they create. The actual management, in the VIB scenario, improves relatively more the welfare of the water buyers than that of the sellers, with respect to the NT scenario. In contrast, in the FT scenario much of the gains are shared among the suppliers.

These results are not easily comparable with those of Brill et al. (1997) that compare seniority rules with the passive market and that demonstrate that water buyers might lose, and water sellers certainly win, by passing from a seniority rule to the passive market. There are two main differences between our case and the one by Brill et al.: (i) the initial allocation is based on a market mechanism; and (ii) the price here is fixed. However, in both studies the allocation mechanism affects the distribution of the gains, an element that must be considered in case an institutional change is envisioned.

The availability of data severely constrained the analysis. For instance, we had access to information regarding water transfers for only a few years and we do not know the actual structure of the farms. Accordingly, we could not substantially assess the identity of the actual water quota sellers and buyers, another element that is likely to affect any potential institutional change. The limits on the data did not prevent finding results that are consistent with more detailed studies, or to finding a clear pattern in the distribution of the gains. Both encourage further investigation by way of additional primary data.

CONCLUSIONS

In this paper, we described the institutional design that governs the reallocation of water quotas within rainwater harvesting reservoirs in the Ravenna province. Moreover, we provided an economic assessment of the reallocation mechanism in place, which we then compared with a situation where no reallocation is allowed, and with a free trade arrangement. All reallocation mechanisms moderately increase the welfare of the area, and different relative losers and winners emerge from different reallocation management systems, elements that must be considered in case institutional changes are envisioned.

The results from the case study cannot be easily extended to different geographic areas, since the technical and environmental conditions in which the described reallocation mechanism is in place is essentially an ideal situation for water transfers. First, access to the resource is granted symmetrically to all of the farms that are connected (by definition), so there is no chance for any farms to become a monopolistic
supplier of water. Second, farms are connected by pipes and
the water is precisely metered, hence there is no uncertainty
over the amount to which one is entitled, nor regarding the
amount that is used or exchanged. Third, a relatively small
number of farms is connected to each reservoir, and the
farms are geographically close to each other. In this situation,
it is likely that social interactions, and cohesion/coordination
capabilities play a major role that cannot be easily captured by
modelling, and cannot be taken for granted in different con-
ditions. Fourth, private transaction costs are negligible since
transportation costs are absent, and a central management
body facilitates the transfers.

The establishment of WMs in practice needs to outweigh
the institutional transition costs necessary to ensure the
exchange of water (Garrick et al. 2013). In the case study,
the reallocation mechanism is fully coupled with the technical
facility that provides the resource and its governance
structure. Though the facility itself is surely more important
than the institutional arrangement, any institutional/techni-
cal arrangement that adds flexibility to water allocation is
likely to become more and more important as climate
change increases uncertainty in both demand and supply.

The reallocation mechanism that is in place within the
rainwater harvesting reservoir reveals a clear need for
higher flexibility and efficiency to face future challenges;
as such, it hints at the potential for the consideration of
market-based approaches for water allocation in the future
policy toolbox, in a context that is highly dominated by cen-
tralised management. In this respect, despite the challenges
set by legitimate societal concerns, it seems crucial to eco-
nomically assess available institutional design options for
water management, especially those arrangements that add
flexibility to the system, while maintaining control on
water transfers, a characteristic that is likely to become
more and more important in the context of climate change.

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