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Irrigation reservoirs as blue clubs: Governance and policy intervention

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ABSTRACT

Reservoirs are increasingly deemed to be important given their potential control of water availability across seasons, from wet to dry seasons, especially given the concerns on the effect of climate change. In this paper, we assess the potential scope for policy intervention on the construction of irrigation reservoirs and its design, focusing on the collective action aspect. We formulate a theoretical model in which farmers pool resources to construct a collective reservoir. We conceptualized the reservoir as a "blue club" that increases the potential water availability in dry season, thus improving water safety for the whole society. We determine the societal potential inefficiency in club size and the policy measures to correct it, focusing on two different club access rules (open vs closed membership). Results show that linear subsidy are ineffective in case of closed membership, and minimum participation rules are required to increase the club size.

1. Introduction

Climate change, environmental concerns and increasing water consumption from manufacturing and urban growth are expected to severely limit the future expansion of irrigation [1], thus potentially putting food security at risk. To increase irrigation water sources, reservoirs are gaining more and more attention. Reservoirs store water during wet seasons, when there is no competition among water uses, so that it is artificially available in the dry season, when irrigation demand is high and natural supply is limited. By smoothing the variability of rainfall, and by increasing the availability of the resources in times of scarcity, reservoirs address some of the key challenges of climate change [2], such as increasing temperature and rainfall variability [3]. Reservoirs can vary in scale - ranging from regional [4] to individual farm [5]; and in ownership - private, public or collectively owned [6].

Water storage is also addressed by specific measures in the framework of the EU Common Agricultural Policy (CAP). More specifically, the 2007–2013 and 2014–2020 Rural Development Plans (RDP) of several regions envision partial financial support (co-financing) for the construction of reservoirs that are collectively managed by, and provide water to, a number of farmers. The rationale for the RDP is the reduction of the pressure on groundwater resources during the irrigation season, when water security is a major societal issue. Paradigmatic examples of this kind of measures are available in Italy and France (e.g. Emilia-Romagna, Haute-Normandie, and Languedoc-Roussillon), where RDP subsidizes the construction of small to medium-sized reservoirs (250 k – 500 k m^3). These subsidies (e.g. in the 2007–2013 RDP of Emilia-Romagna) are often linked to Minimum Participation Rules (MPR), so that eligible projects must provide irrigation water for a minimum number of farmers.

In this prospect, we interpret the RDP policy as a subsidy aimed at incentivizing the emergence of a *blue* club, and the problem can be conceptualized within the framework of the *green* club analysed by van't Veld and Kotchen [7]. A number of farms decide to coordinate themselves to build a club (the reservoir), that delivers positive externalities (higher water security in times of scarcity) to the whole society, and policy mechanisms are put into place to reach the societal optimal size of the club. Two are the likely differences

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between blue and green clubs. First, blue clubs not only produce positive externalities (water security) but potentially even negative ones [8,9], and thus the two must be balanced. Second, it is plausible that the emergence of the blue club results in positive spillovers even on non-member farms, if the alternative source is groundwater.[1] Indeed, groundwater management is a common pool resource plagued by the problem of pumping cost externalities [10], which are in turn alleviated by a reduction in the number of its users.

However, this perspective has not been addressed by the literature. Since their main objective is to smooth the variability of water supply, many economic studies on reservoirs have focused on the effect of uncertainty on the investment decisions [4] and the relationship between water storage and the efficiency of irrigation technology [5,8]. A number of papers focus on reservoir management, explicitly addressing the presence of multiple users. Dudley [11] observes that the distinction between reservoir management and the irrigation managers leads to inefficient outcomes with respect to the water releases. These inefficiencies can be potentially reduced when a system of property rights on the capacity share is developed [12]. Maas et al. [13] focus on how the value of water storage infrastructure also depends on the institutions that allocate the resource across the users. The economic literature on the topic has neglected the collective action aspect of the construction of the reservoir and the role of public policies, even though these two dimensions seem to be relevant in real-world policies, at least in Europe.

The objective of this paper is to assess the potential scope and the design of policy interventions for the construction of irrigation reservoirs, focusing on the way policy interacts with collective actions. We formulate a model in which farmers decide between using groundwater and pooling resources to construct a collective reservoir. An external regulator, conveying societal preferences on the availability of groundwater, can subsidize its construction. The analysis is inspired by RDP measures previously described, which subsidize the construction of collective reservoirs.

We explicitly model the reservoir as a blue club that increases the potential water availability in the dry season, thus improving water safety for society as a whole. More specifically, we theoretically analyse the incentives aimed at affecting the size of the reservoir when farmers have two different water sources (groundwater and the reservoir) and face coordination costs. With respect to the equilibrium concept related to the size of the reservoir, we focus on two different club membership rules (open vs. closed memberships) to address different social, environmental or policy arrangements. While the notion of a closed membership implies the possibility that club members are able to internally define the club size, an open membership can be interpreted as a sort of open list in which users can enrol as long as they find it profitable.

The main novelties of the paper are, first that we modify the model described in Ref. [7] to include the positive spillovers on non-members. Second, we define a policy measure that, under certain conditions, can affect club size in the case of closed access. The results of the theoretical analysis show that including a MPR associated with the subsidies could serve that purpose. MPRs have been investigated in the literature in the context of collective reservoirs, focusing only on their distributional impact [14]. The analysis is also based on the non-cooperative coalition formation games that are often used to model International Environmental Agreements [15,16]. Using such a framework, Ansink and Bouma [17] and Zavalloni et al. [18] analyse the effectiveness of subsidies aimed at increasing the size of a cooperating group; however, they do so in a public good context, with no coordination costs or comparison between open and closed access. Moreover, the collective dimension in the investment and maintenance of irrigation infrastructures has been extensively analysed by the socio-ecological system literature, e.g. Ref. [19], which, however, has seldom investigated the interaction with the policy environment [20,21]. To focus on the collective action issue, however, we neglect the hydrological aspects of the functioning of the reservoir and the potential elements of risk and uncertainty. This also applies to the modelling of groundwater extraction. The sustainability of groundwater management is a complex issue [22–24]. In the following analysis we disregard the time dimension and the dynamics in groundwater management; this is a major simplification that purposefully provides tractable analytical solutions related to the collective aspect of the reservoir investment.

The paper is structured as follows. In Section 2 we theoretically analyse a basic model. First, we assess the *natural* size of the reservoir, i.e. when there is no policy, and in case of open and closed access. Second, we determine the mechanisms that are required to reach an exogenously given level of groundwater availability, when the regulator cannot dictate club size but must rather use subsidies. The basic model relies on three main assumptions: a) an exogenously given desired level of the reservoir size; b) linear costs, leading to a corner solution in which farmers either use the reservoir or groundwater, and c) the delivery of positive spillovers on non-members to address the pumping cost externalities in groundwater management. In Section 3, we address the main limitations of the basic model by relaxing these three assumptions. In Section 3.1 we endogenize the optimal groundwater availability, and thus the reservoir size. In 3.2 we relax the exclusive nature of the source of water by introducing a non-linear water cost function. In section 3.3 we investigate how the management of groundwater, taking into account its common-pool characteristic, affects the size of the reservoir. Section 4 discusses the results and provides conclusions and policy recommendations.

2. Basic model

2.1. Setting

Imagine that there is a population of N homogenous farmers $M = \{1, \ldots, N\}$. A subset of the farmers forms a club, i.e. they build, and are connected to, the reservoir. Denote by S the extensive margin of the club, the n-size hereinafter. We use the subscripts "s" and "f" respectively to indicate whether a farm is part of the club or not.

[1] For the sake of clarity in the exposition, we use the term "spillovers" to indicate the reservoir externalities for the non-member farms, to distinguish them from the reservoir externalities for society as a whole.

The revenue of each farm is a function of water use: $\pi(w)$, where water can come from two sources: groundwater (g) or a reservoir (r): $w = g + r$. As a functional form, we use the classic quadratic function, with a and b being respectively the parameters of the linear and the (negative) quadratic term: $\pi(w) = a \cdot w - \frac{1}{2} \cdot b \cdot w^2$. We assume that the costs related to water management are linear in the water use, with k and c, respectively, being the cost parameters related to the reservoir and groundwater, and with $k < c$. This assumption entails a corner solution where a club member will only use the reservoirs; while this condition eases the interpretation of the results, it is clearly a major simplification that does not cover the range of the potential existing circumstances. We, however, relax this assumption in section 3.2. The available groundwater before the irrigation season is G; assume that there is a societal minimum desired level of groundwater availability g^d (similar to a safety minimum standard). In section 3.1 we endogenize g^d, taking into account both the positive and negative externalities that reservoirs deliver.

The management of the reservoir involves the costly coordination of the users. We model this element by introducing a cost function dependent on S: $T(S)$. This cost is equally shared among club members so that a farmer connected to the reservoir faces $t(S) = T(S)/S$, the average coordination cost. Following the usual specification in the literature [7,25], the cost function $T(S)$ is increasing in the number of club members, and the average cost function is "U" shaped in S, i.e. it is characterised by a minimum (the solution of $t'(S) = 0$) at $\breve{S}$. In other words, as S increases there are first economies and then diseconomies of scale. As a functional form, we can assume that $T(S)$ is a positive cubic function with $T(0) = 0$ and $t(0) > 0$.

Turning to non-members, it is often suggested that common pool characteristics often lead to pumping cost externalities, and ultimately to inefficient outcomes. The consumption of the resource by one user lowers the water table, imposing in turn higher pumping costs on the other users [10,26]. To address this notion, while maintaining the focus on the emergence of the club, we simply assume that the reservoir delivers positive spillovers on non-members. More specifically, we assume that non-members face a fixed cost (for a given farm) A that is proportionally reduced (parameter α) with the reduction in the number of non-members, i.e. $A \cdot \left(1 - \alpha \cdot \frac{S}{N}\right)$. Such a basic modelling strategy lacks the dynamic nature of groundwater management, but still depicts the potential relationship between the use of the reservoir and the use of groundwater. A decrease in the number of groundwater users increases the potential water availability and makes groundwater extraction easier and cheaper. We explore these elements in greater detail in Section 3.3.

Putting together these elements, the utility of a single member of the club is described by:

$$u_s(S, r) = \pi(r) - k \cdot r - t(S) \tag{1}$$

whereas for a non-member, it is given by:

$$u_f(S, g) = \pi(g) - c \cdot g - A \cdot \left(1 - \alpha \cdot \frac{S}{N}\right) \tag{2}$$

2.2. Equilibria

We introduce the model described by equations (1) and (2) into a two-stage game that is solved by backward induction to find the subgame perfect Nash equilibrium in terms of optimal water consumption and club n-size. In the second stage we determine the optimal water consumption for both club members and non-members. In the first stage we apply the two most widely used equilibrium concepts (open and closed memberships) to find the n-size of the reservoir.

The amount of water that is consumed by each club member is the solution of the maximization of (1) with respect to r: $\max_r u_s(S, r)$. The FOC, $\partial u_s(S, r)/\partial r = 0$, yields the usual result that the optimal water extracted from the reservoir r^* is defined by the point where marginal revenues are equal to marginal costs: $\pi'(r) - k = 0$. Similarly, the solution of $\max_g u_s(S, g)$ leads to the optimal water consumption of non-members, g^*, defined by the FOC$\pi'(g) - c = 0$.

In the second step we determine the n-size of the reservoir. By substituting r^* and g^* into respectively (1) and (2) we obtain the utility for both coalition members and non-members as a function of the n-size of the reservoir: $u_s(S,r^*)$ and $u_f(S,g^*)$ (depicted in Fig. 1). In our simple example, the coordination costs fully determine the shape of the utility function for a club member as the number of users vary. $u_f(S,g^*)$ is a linear function of S with slope $(A \cdot \alpha)/N$, so that at maximum there are two points of intersection

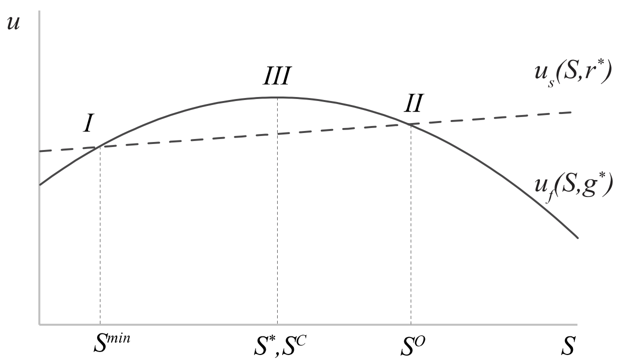

Fig. 1. Graphical analysis of utility for club members and non-members and points of equilibrium.

between $u_s(S,r^*)$ and $u_f(S,g^*)$ – points *I* and *II* in Fig. 1.

For a club to be formed, first, the utility for a club member must be greater than the utility from groundwater use, at least within a certain n-size range: $u_s(S,r^*) \geq u_f(S,g^*)$. Calling the maximum utility for a member $u_s(S^*,r^*)$, given the presence of positive spillovers, a necessary condition for a club to emerge is that $u_s(S^*,r^*) > u_f(0,g^*)$. There are two sufficient conditions. The first is that, when $u_s(0,r^*) < u_f(0,g^*)$, the rate of increase in the utility for a non-member as S increases, must be lower than the slope of the line with intercept $u_f(0,g^*)$ and tangent to $u_s(S,r^*)$. The second is that $u_s(0,r^*) \geq u_f(0,g^*)$.

Once having ascertained this condition, the first point of intersection (point *I* in Fig. 1) between $u_s(S,r^*)$ and $u_f(S,g^*)$ indicates the minimum club size S^{min} below which no club is formed. This is important in case the potential farmers interested in the reservoir construction are lower than S^{min}. Points *II* and *III* represent the equilibrium club size in open and closed membership, respectively. Intuitively, the open membership case is characterised by the equalization of utility for members and non-members, whereas the closed membership maximizes utility for members only. The feasibility of the closed membership n-size imposes a further restriction on the size of the spillovers and on the rate of increase of the non-member's utility. Spillovers must be such that $\alpha{\cdot}A{\cdot}S^C < N{\cdot}[u_s(S^C, r^*) - u_f(0, g^*)]$. The analysis of the two cases follows.

In the open membership case, club members cannot exclude non-members from being part of the cooperating group, and non-members will enter the club as long as the utility from using the reservoir are greater than using groundwater [17]. In this case, the equilibrium size S^O, the number of farmers that will pool resources to build the reservoir, is thus the solution (point *II* in Fig. 1) to:

$$u_s(S, r^*) = u_f(S, g^*) \tag{3a}$$

Substituting equations (1) and (2) into (3a) we obtain[2]:

$$\pi(r^*) - k{\cdot}r^* - t(S) - \pi(g^*) + c{\cdot}g^* + A - \frac{\alpha{\cdot}A}{N}{\cdot}S = 0 \tag{3b}$$

The number of club members in open membership, S^O, is the solution to (3b). Several hints can be obtained by analysing 3b. Implicitly deriving S^O with respect to k yields: $\frac{\partial S^O}{\partial k} = -\frac{r^*}{t'(S^O)+\frac{\alpha\cdot A}{N}}$. Note that $r^*>0$ and $\frac{\alpha\cdot A}{N} > 0$ so $\frac{\partial S^O}{\partial k} < 0$ if $t'(S^O) > 0$ which is certain if $S^O >$ i.e. in the range of S where the average cost function is characterised by diseconomies of scale. This, in turn, implies that an increase in the utility for club members (due for example to a lower k costs) leads to an increase in the open membership equilibrium club size. The solution to (3b) that is lower than $\breve{S}$ defines the minimum size S^{min} below which the club does not emerge. This is the parameter area of economies of scale, where $t'(S) < 0$, and hence given the previously declared assumptions, an increase in the reservoir costs, not surprisingly, implies an increase in the minimum club size. Furthermore, imagine that an impact of climate change is the increase in the marginal revenue function of water, i.e. an increase in the linear term of $\pi(w)$. Such an impact would cause an increase in n-size club equilibrium: $\frac{\partial S^O}{\partial a} = \frac{r^*-g^*}{t'(S^O)+\frac{A\cdot\alpha}{N}}$, since $k < c$ the numerator is positive.

Closed membership implies that club members can effectively exclude non-members from entering the club. This equilibrium concept represents the "within club" point of view that was first conceptualized by Buchanan [27]. In this prospect, the emerging club is the one that maximizes the average utility for club members. If an additional club member was to decrease the utility of the club members, he or she would not be accepted. Thus, in closed access, the n-size of the club (point *III* in Fig. 1) is given by the solution to:

$$\max_S u_s(S, r^*) \tag{4}$$

The FOC of (4) is $\partial u_s(S, r^*)/\partial S = 0$ that yields: $t'(S) = 0$. The number of reservoir users (n-size) is determined by the point that minimizes the average costs for club member$S^C = \breve{S}$ and the q-size of the reservoir: $S^C{\cdot}r^*$.

The total size of the population of farmers (N) can constrain and affect both equilibria. If the population of farmers is in the range of $S^{min} < N \leq S^C$, all of the farmers would join the club, irrespectively of the type of membership. Thus the simple permit for the construction of the reservoir would reduce the pressure on groundwater resources since the equilibrium size of the club is N. If the population of farmers is in the range of $S^C \leq N \leq S^O$, in the case of closed membership, the equilibrium would still be S^C, while in the open membership case the equilibrium size is again N.

2.3. Subsidy design and efficacy

Recall from section 2.1 that we assume that there is a desired level of groundwater availability. The available groundwater, after irrigation use, is given by:

$$g^a = G - (N - S){\cdot}g^* \tag{5}$$

From (5) it is obvious that g^d can either be reached by designing policies that affect g^* (either by using taxes or a quotas on groundwater use $\bar{g} < g^*$) or by subsidizing the club. In this paper we focus on the latter option, namely we design a subsidy for club members in its the simplest form. In this latter option, the desired level of groundwater is translated into the desired number of club members S^d.

By subsidizing club members through a payment P, equation (1) becomes:

[2] If we had heterogeneous players, the equilibrium conditions defined by equation (3) would become a system of equations. However, it might be the case that numerous club compositions could emerge.

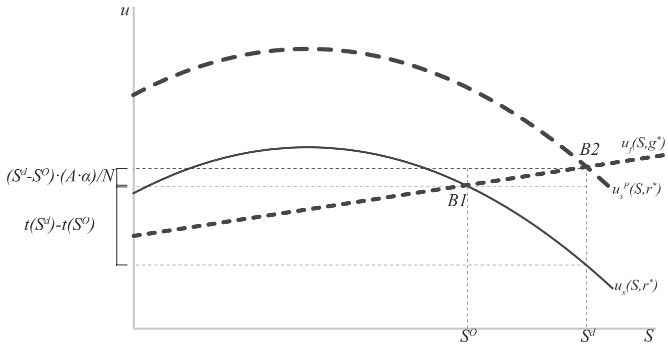

Fig. 2. Graphical depiction of the policy intervention to reach the n-size S^d. The payment shifts the club member utility curve upward (from $u_s(S,r^*)$ to $u_s^P(S,r^*)$) thus moving the point of intersection with the non-member utility curve from *B1* to *B2*. The payment is decomposed, according to equation (8), into the vertical difference between the coordination costs at S^d and at S^O, and the slope of the non-member utility curve times the difference between S^d and atS^O.

$$u_s^P(S, r) = \pi(r) - k\cdot r - t(S) + P \tag{6}$$

The payment does not affect the water consumed, and thus the FOC and the results are the same as the one described in Section 2.2. However, in the case of open membership, given equation (6), the equilibrium condition defined by equation (3a) becomes:

$$\pi(r^*) - k\cdot r^* - t(S) + P - \pi(g^*) + c\cdot g^* + A - \frac{\alpha\cdot A}{N}\cdot S = 0 \tag{7}$$

Calling P^O the payment level in the case of open membership, we derive the subsidy required to reach a level S^d by substituting S^d into (7) and comparing it with equation (3b):

$$P^O = t(S^d) - t(S^O) + (S^d - S^O)\cdot\frac{A\cdot\alpha}{N} \tag{8}$$

The payment needs to cover the higher transaction costs that are faced by club members when they move from the *natural* n-size S^O (prior to the payment) to the *desired* n-size S^d, plus the additional opportunity costs that are due to the spillover effect. Note that the higher the spillovers of the club onto the non-club members (α), the higher the payment level required to reach the desired club size. The same result can be achieved by imposing a per capita tax τ, e.g. the price of the concession to use groundwater, the level of which is also set by equation (8), on the groundwater users. Thus, the relative efficiency of the two instruments (subsidy on the reservoir, tax on groundwater use rights) depends only on the relative size of the desired level of the n-size of the club and the number of the groundwater users. Indeed, the costs of the interventions are $P^O\cdot S^d$ and $\tau\cdot(N\text{-}S^d)$; since $P^O=\tau$, the groundwater tax entails a lower social cost only when S^d is greater than half of the farm population. The logic of the subsidy intervention is depicted in Fig. 2.

Contrary to the open access case, the simple payment does not affect the equilibrium size in a closed membership. The FOC $\partial u_s^P(S, r^*)/\partial S = 0$ are unchanged by the introduction of the policy parameters. Consider instead a policy that subsidizes water consumption from a reservoir. In that case, the closed membership reservoir size is the solution to the maximization of:

$$\max u_s^P(S, r) = \pi(r) - k\cdot r - t(S) + p^C\cdot r \tag{9}$$

Setting the FOC equal to zero, $\partial u_s^P(S, r)/\partial r = 0$, yields $\pi'(r) - k + p^C = 0$, hence, in this case, the intensive margin of the reservoir increases. However, not even this type of policy scheme affects the n-size of the club and hence it is ineffective in reaching the societal desired level of groundwater availability. One possibility to affect the size of the emerging club in the case of closed membership is to

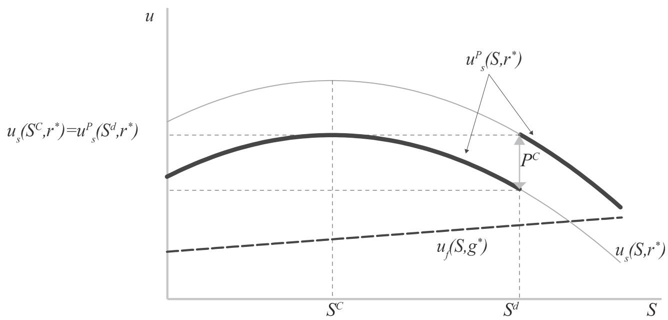

Fig. 3. Graphical depiction of the logic of the subsidy in the closed membership cases. The subsidy increases the utility for club members upward, but the closed membership equilibrium size remains unchanged at the level S^C. Linking a MPR to the subsidy creates a discontinuous utility function where, in case $P^C = t(S^d)\text{-}t(S^C)$, the utility for club members at S^d and at S^C are at the same level.

formulate a policy scheme whereby the subsidy is attached to a minimum participation rule (S^{mpr}) set at S^d. In other words, given S^d, the subsidy level is set so that for a club member, the utility at S^C is equal to the utility at $S^d = S^{mpr}$. The payment is thus the solution to: $u_s(S^C, r^*) = u_s^P(S^d, r^*)$, which entails

$$P^C = t(S^d) - t(S^C) \tag{10}$$

The policy scheme needs to cover the higher costs that an increase in the club above the optimal one entails, as depicted in Fig. 3. Note that spillovers do not affect this payment level but do affect the applicability range of the scheme. Indeed (10) is valid only as long as $u_s(S^C, r^*) > u_f(S^d, g^*)$.

Comparing P^C with P^O shows that the relative level of the payment in the two club membership rules depends on the difference between the coordination costs of the two club size equilibria, and on the spillovers:

$$P^C - P^O = t(S^O) - t(S^C) - (S^d - S^O)\cdot\frac{A\cdot\alpha}{N}$$

Note that in case there are no spillovers ($\alpha = 0$), P^C is undoubtedly greater than P^O, since $t(S^O) > t(S^C)$ by definition.

Moreover, observe that the agricultural sector as a whole would be better off in the closed access case, if considerations of welfare distribution are not involved. Indeed, in the closed access case, the payment ensures that a greater number of players enjoy the highest club payoffs so that the total welfare (W) is $W^C = S^d\cdot u_s(S^C, r^*) + (N - S^d)\cdot u_f(S^d, g^*)$. In the open access case, the entire farmer population welfare is: $W^O = N\cdot u_f(S^d, g^*)$. Being $u_s(S^C, r^*) > u_f(S^d, g^*)$, $W^C > W^O$.

3. Extensions to the basic model

3.1. Optimal reservoir size

3.1.1. Societal point of view

In the previous section we found the equilibrium taking for given the desired level of groundwater availability. Here we endogenize such a level, imagining that the reservoir entails both positive (the increase in the availability of irrigation water) and negative (changes in the landscape and in its hydrological characteristics) externalities. The utility for society generated by the reservoir in that case would be given by:

$$U = v\cdot g^a - E(r\cdot S) + S\cdot u_s(S, r) + (N - S)\cdot u_f(S, g) \tag{11}$$

where g^a is defined by equation (5), v is the positive externality linked to the available groundwater, $E(r\cdot S)$ is the negative externality dependent on the size of the reservoir (with $E' > 0$ and $E'' \geq 0$), and the other two terms are the total welfare of club members and non-members, respectively.

Assuming that only the number of club members can be chosen,[3] taking the first derivative of (11) with respect to S and set it to 0 leads to the optimal club n-size S^d:

$$v\cdot g^* + (N - S)\cdot\frac{\partial u_f(S, g^*)}{\partial S} + u_s(S, r^*) + S\frac{\partial u_s(S, r^*)}{\partial S} = r^*\cdot E'(r^*\cdot S) + u_f(S, g^*) \tag{12}$$

Equation (12) shows that the optimal reservoir size equalizes the sum of the positive externality and the positive spillovers on non-members (first and second term on LHS) and the benefits associated with the club members, with its marginal costs, that are the negative externalities, and the opportunity costs for a farmer to join (the utility for non-users).

Comparing equation (12) with equation (7) leads to the payment that is necessary to reach the optimal reservoir size in the open membership case:

$$P^O = v\cdot g^* + (N - S^d)\frac{A\cdot\alpha}{N} - S^d\cdot t'(S^d) - r^*\cdot E'(r^*\cdot S^d) \tag{13}$$

Note that P^O can actually be negative, and thus it can become a tax on the reservoir size, when its negative effects overcome the positive side.

As we have seen in the previous section, in the closed membership case a simple payment is not sufficient to increase the reservoir size and a two-element mechanism needs to be implemented. More specifically, a MPR is set at the level found by solving equation (12), and a payment is set by equation (10).

3.1.2. Water utility company incentive scheme

Imagine now an external actor, say a water utility company, which is interested in the availability of groundwater and willing to provide a payment to farmers so that they reduce groundwater extraction. Assume that the utility of the company is described by:

[3] In the case that both the intensive and extensive margins were or could be chosen, the optimal reservoir size would be determined by a system of equations comprising equation (12) and. If the negative externalities were linear in the total reservoir size (e.g. $E'(r\cdot S) = e$), then we would have: $\frac{\partial U}{\partial r} = -e + \frac{\partial u_s(S,r)}{\partial r}$, entailing a tax or a quota on the intensive margin of the reservoir. The tax or a quota could still possibly be coupled with a subsidy determined by equation (13). While this seems paradoxical, the actual RDP 2007–2013 measure in Emilia-Romagna did include such a constraint, based on the existing irrigable area, and on the maximum amount of water to be stored for a project to be eligible for financial support.

$$U = v \cdot g^a - S \cdot P(S) \tag{14}$$

In this case, the transfer to the farmers becomes an element in the objective function, and as a result, the type of membership as well. Therefore, the company maximizes (14), where the relationship between the payment and the club size is determined by equation (8) in the open membership case, and equation (10) in the closed membership case. The FOC of the maximization problem, $\frac{\partial U}{\partial S} = 0$, leads to:

$$S \cdot \frac{\partial P(S)}{\partial S} + P(S) = v \cdot g^* \tag{15}$$

Substituting the open membership payment found in equation (8) and (15) becomes, after rearranging:

$$S \cdot \left[t'(S) + 2 \cdot \frac{A \cdot \alpha}{N} \right] + t(S) = v \cdot g^* + t(S^O) + S^O \cdot \frac{A \cdot \alpha}{N} \tag{16}$$

In the closed membership case equation (15) becomes:

$$S \cdot t'(S) + t(S) = v \cdot g^* + t(S^C) \tag{17}$$

In the absence of spillovers, the closed membership case undoubtedly leads to a lower coalition size, since the right-hand side is greater in the open membership case.

3.2. Joint use of groundwater and reservoir

In the basic model described in Section 2, the use of groundwater is an alternative to the use of the reservoir. We now relax this assumption by changing the cost function from linear to quadratic, and for simplicity we remove the spillover effects on the non-members. In this situation, the utility for a club member is given by:

$$u_s(S, r, g_s) = \pi(r + g_s) - \frac{1}{2} \cdot k \cdot r^2 - \frac{1}{2} \cdot c \cdot g_s^2 - t(S) \tag{18}$$

and the utility for a non-member is given by:

$$u_f(S, g_f) = \pi(g_f) - \frac{1}{2} \cdot c \cdot g_f^2 \tag{19}$$

The water consumed by each club member is given by the usual FOCs, respectively $\frac{\partial \pi(r+g_s)}{\partial r} = k \cdot r$ and $\frac{\partial \pi(r+g_s)}{\partial g_s} = c \cdot g_s$. With the quadratic revenue function previously defined, the optimal water individually consumed from the reservoir and the use of groundwater are respectively: $r^* = \frac{a \cdot c}{(c+b) \cdot k + c \cdot b}$ and $g_s^* = \frac{a \cdot k}{(c+b) \cdot k + c \cdot b}$. Note that the use of groundwater (reservoir) increases with the cost of the reservoir (groundwater). Further, it is worth noting that unless $k=0$, a club member will use both the reservoir *and* groundwater.

Similarly, the FOC for non-members leads to the optimal groundwater consumption for a non-member: $g_f^* = \frac{a}{c+b}$. Note that $g_f^* > g_s^*$ so that the emergence of the club would decrease the pressure on groundwater resources.

The open membership n-size equilibrium is given, similarly to (3), by:

$$\pi(r^* + g_s^*) - \frac{1}{2} \cdot k \cdot (r^*)^2 - \frac{1}{2} \cdot c \cdot (g_s^*)^2 - t(S) - f\left(g_f^*\right) + \frac{1}{2} \cdot c \cdot \left(g_f^*\right)^2 = 0 \tag{20}$$

An increase in the cost of groundwater affects the utility of both members and non members, but the impact on the equilibrium size is positive. Implicitly deriving (19) with respect to c yields: $\frac{\partial S^O}{\partial c} = \frac{1}{2} \frac{\left(g_f^*\right)^2 - (g_s^*)^2}{t'(S^O)}$ which is greater than 0 in case $S^O > \breve{S}$.

The closed membership is not affected by the change in the utility function, being still determined by the point that minimizes the average cost function.

We now focus on the role of policy, but, unlike in section 2, we investigate the impact of a subsidy that is linearly related to the water quantity consumed from the reservoir. By introducing the payment, equation (16) becomes:

$$u_s^p(S, r, g_s) = p \cdot r + \pi(r + g_s) - \frac{1}{2} \cdot k \cdot r^2 - \frac{1}{2} \cdot c \cdot g_s^2 - t(S) \tag{21}$$

The FOC leads to: $g_s^*(p) = \frac{a \cdot k - b \cdot p}{(c+b) \cdot k + b \cdot c}$ and $r^*(p) = \frac{(c+b) \cdot p + a \cdot c}{(c+b) \cdot k + b \cdot c}$. It is easy to see that the payment, not surprisingly, increases the intensive margin of the reservoir, and decreases the use of groundwater.

In the open membership case, the subsidy, by positively affecting the utility for club members, increases the n-size equilibrium of the reservoir: $\frac{\partial S^O}{\partial p} = \frac{r^*}{t'(S^O)}$, still in the case $S^O > \breve{S}$. As in the previous section, however, the subsidy does not have any impact on the closed membership case.

Note that the available groundwater after irrigation use is now given by: $g^a = G - (N - S) \cdot g_f^* - S \cdot g_s^*$

The impact of a payment on the availability of groundwater is differentiated across the membership types. In the case of open membership, the derivative of g^a is positive:

$$\frac{\partial g^a}{\partial p} = \frac{\partial S^O}{\partial p}\cdot\left(g_f^* - g_s^*\right) - S^O\cdot\frac{\partial g_s^*}{\partial p}$$

The effect of the payment on the available groundwater is twofold: it simultaneously increases the number of club members and their extraction of groundwater.

On the contrary, in the closed membership case it is simply given by: $\frac{\partial g^a}{\partial p} = -S^C\cdot\frac{\partial g_s^*}{\partial p}$, suggesting that from a policy point of view, in this simple setup, the open membership case seems to be the most effective.

3.3. Groundwater as a common-pool resource and relation to the club formation

Now we further investigate the positive spillovers that the reservoir can deliver to non-members. In the basic model, spillovers are given by a simple increase in the revenues for a non-member. We now investigate how spillovers can positively affect the groundwater users, explicitly conceptualizing the use of groundwater as a common pool resource. To do so, we assume that the parameter c in equation (2) is instead a function of groundwater availability: $c = (\bar{C} - \chi\cdot g^a)$, so that an increase in the available groundwater causes a decrease in the unitary costs. As it is clear by substituting equation (5) and rearranging it, the utility for non-members depends on both the number of club members and on the *total* consumption of groundwater. For simplicity, we further assume that a club member will only use the reservoir. Utility for a non-member is now given by:

$$u_f(S, g_f) = \pi(g_f) - (\bar{C} - \chi\cdot G)\cdot g_f - \chi\cdot g_f\cdot \sum_f g_f \tag{22}$$

If groundwater consumption is not coordinated, each farmer will maximize her own utility, taking for given the water consumption of the other non-members:

$$u_f(S, g_f) = \pi(g_f) - (\bar{C} - \chi\cdot G)\cdot g_f - \chi\cdot g_f^2 - \chi\cdot g_f\cdot \sum_{-f} \bar{g}_f \tag{23}$$

The FOC, $\frac{\partial u_f\left(S, g_f\right)}{\partial g_f} = 0$, reads:

$$\pi'(g_f) - (\bar{C} - \chi\cdot G) - 2\cdot\chi\cdot g_f - \chi\cdot \sum_{-f} \bar{g}_f = 0 \tag{24}$$

Since in equilibrium all of the non-members will consume the same amount of groundwater, equation (23) becomes:

$$\pi'(g_f) = (\bar{C} - \chi\cdot G) + \chi\cdot(N - S + 1)\cdot g_f \tag{25}$$

The Nash-Equilibrium (NE) groundwater consumption, g_f^{NE}, depending on the number of club members, is the solution to (24). With the quadratic water revenue function previously defined: $g_f^{NE} = \frac{a - (\bar{C} - \chi\cdot G)}{b + \chi\cdot(N - S + 1)}$.

The optimal groundwater (OG) consumption from an aggregated point of view is instead found by maximizing the aggregated utility of non-members: $\max_{g_f}[(N - S)\cdot u_f(S, g_f)]$, or:

$$\max_{g_f}(N - S)\cdot\left[\pi(g_f) - (\bar{C} - \chi\cdot G)\cdot g_f - (N - S)\chi\cdot g_f^2\right] \tag{26}$$

The FOC is now:

$$\pi'(g_f) = (\bar{C} - \chi\cdot G) + 2\cdot\chi\cdot(N - S)\cdot g_f \tag{27}$$

or, using the quadratic revenue function previously described, the optimal groundwater is given by: $g_f^{OG} = \frac{a - (\bar{C} - \chi\cdot G)}{b + 2\cdot\chi\cdot(N - S)}$.

The classic result holds: the optimal groundwater is lower than in the NE, the incoordination in groundwater use leads to a non-pareto optimum equilibrium: $g_f^{OG} < g_f^{NE}$ and thus $u_f^{OG}\left(S, g_f^{OG}\right) > u_f^{NE}\left(S, g_f^{NE}\right)$. This also implies that moving from uncoordinated to coordinated groundwater management, holding utility for a reservoir member constant, causes a decrease in the open membership reservoir n-size.

What is the relationship with the reservoir size? First, with respect to individual groundwater consumption, in both the NE and OG management, the n-size of the club positively affects groundwater consumption, since $\frac{\partial g_f^{NE}}{\partial S} > 0$and $\frac{\partial g_f^{OG}}{\partial S} > 0$. With respect to utility of groundwater users, an increase in the reservoir size increases the utility both in the NE and in the cooperative equilibrium, since it positively affects, holding everything else equal, the availability of groundwater. Accordingly, in this case, the reservoir n-size creates positive spillovers on the non-members.

How does a per-capita payment for reservoir users (aimed at increasing the size of the reservoir) affect the total available groundwater in this situation? Rewriting, the available groundwater after irrigation use results in the following:

$$g^a = G - N\cdot g_f^*(S(P)) + S(P)\cdot g_f^*(S(P)) \tag{28}$$

where g* is a function of the equilibrium size, which in turn is a function of the payment. Deriving g^a with respect to P yields:

$$\frac{\partial g^a}{\partial P} = \frac{\partial S(P)}{\partial P} \cdot \left\{ (S(P) - N) \cdot \frac{\partial g_f^*(S(P))}{\partial S} + g^*(S(P)) \right\} \tag{29}$$

which is positive in case: $g_f^*(S(P)) > (N - S(P)) \cdot \frac{\partial g_f^*(S(P))}{\partial S} \frac{\partial U}{\partial r} = 0$.

In this case, a subsidy increases the availability of water only if its effects on the number of people that join the club are greater than the positive effect on the use of groundwater from those that continues to use it.

4. Discussion and conclusions

In this paper we theoretically analyse the role of policy in the emergence of collective irrigation reservoirs. Conceptualizing the reservoir construction as the contribution to a blue club, we focus on the coordination among farmers in such an investment. Based on this framework, we are able to show in which circumstances policy measures are necessary to reach the desired reservoir size, so that the pressure on groundwater resource is reduced. We also identify optimal policy parameters under different, open vs closed, membership types of the club.

The theoretical analysis shows that payment levels and design must be differentiated according to the type of membership in the club. A simple linear subsidy is sufficient to affect the reservoir size in the case of an open membership, even though the potential positive spillovers from the reservoir to the non-user increase the payment level required. However, this type of payment is ineffective in the case of closed memberships. In case of a closed membership, minimum participation rules that explicitly link the subsidy to a desired n-size of the club are required. A real-life example is provided by Emilia-Romagna, where there is a policy scheme that incentivizes the construction of collective reservoirs and that includes such a collective conditionality constraint. The extensions to the basic model show the importance of a hydrological management/policy that explicitly, and not surprisingly, takes into account jointly the reservoir and the alternative water sources. While cooperative, social planner, management decreases the exploitation of groundwater, it might also negatively impact the use of alternative water sources. The net effect remains an empirical question. The model and results can also be interpreted within a social-ecological system framework. The model shows that even admitting a partial cooperative behaviour, large spillovers from the club can prevent the formation of the club to be formed, or to limit its size. However, the model further hints at the potential role that policies can have in positively impacting the contribution to collective infrastructures that are usually considered key elements in socio-ecological systems.

Several limitations apply, each actually hinting at potential topics for further research in this field. A series of weaknesses are related to the conceptual side of the model. First, the separation between coordination costs and extraction costs simplifies the interpretation of the results, but yields the result that individual water consumption does not depend on the n-size of the reservoir. The inclusion of a combined, non-linear, cost function of the type *t(S·r)* would solve this problem. Second, the model does not address the problem of the heterogeneity of farmers. While a detailed analysis is required for the open membership case, the inclusion of heterogeneous players would not affect the equilibrium in the case of closed membership if the coordination costs only depend on the n-size of the club. However, different club compositions could emerge. Similar reasoning could apply to the introduction of a spatially explicit analysis of farm distribution and its effect on the club's emergence. Finally, here we assume that the membership type is exogenously given and the analysis suggests that, if the access type were designable, an open membership would be preferable to a closed one, since the efficacy of the payment is greater in the former than in the latter. Such a conclusion should be further explored along several dimensions. First, distributional considerations between the agricultural sector and the rest of society would impact the choice and the evaluation of the scheme. Second, in practice, the choice between open and closed memberships might be negatively related to the spatial target of the policy schemes, given the spatial dimension of the potential reservoir users. An open list should most likely be restricted *a priori* to specific areas that segment potential users, in turn resulting in very local/specific policy scheme that would then possibly be affected by high administrative costs. On the other hand, a more general, non-spatially restricted, policy scheme could result in lower administrative costs, but ultimately a closed access membership type. This further hints at the cautious evaluation of the theoretical analysis presented here.

Altogether, while the expectation that a collective approach will improve the ability to deal with water management issues is well justified, this paper contributes to show that the complexity of the interplay between collective behaviour and policy requires a careful policy design to achieve such objectives in an effective and efficient manner.

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