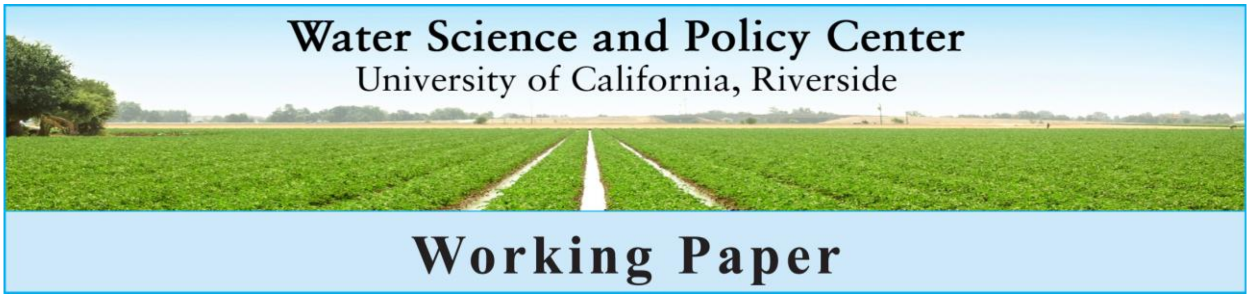

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Propensity for cooperative water management and ecosystem protection under scarcity and drought: Application to the Jucar River Basin, Spain

Mohamed Taher Kahil
Department of Agricultural Economics
CITA–Government of Aragon, Spain

Ariel Dinar
Water Science and Policy Center
Department of Environmental Sciences
University of California, Riverside
ariel.dinar@ucr.edu

José Albiac
Department of Agricultural Economics
CITA–Government of Aragon, Spain

Propensity for cooperative water management and ecosystem protection under scarcity and drought: Application to the Jucar River Basin, Spain

Mohamed Taher Kahil[1], Ariel Dinar, José Albiac

1. Introduction

Pressures on water resources are increasing worldwide, resulting in growing water scarcity and quality problems and giving rise to complex social conflicts and environmental degradation. Global water extractions have increased more than six fold in the last century, which is twice the rate of population growth (UNDP 2006). It is estimated that about 35 percent of the world population suffers from severe water stress and about 65 percent of global river flows and aquatic ecosystems are under moderate to high threats of degradation (Alcamo et al. 2000, Vörösmarty et al. 2010).

Global warming is projected to worsen climate conditions and exacerbate the current situation of water scarcity. Climate change projections in arid and semiarid regions indicate a reduction of water availability with decreased river flows and groundwater recharge, and deterioration of water quality. In addition, drought recurrence has increased by a factor of 10 in some drought-prone regions (IPCC 2007).

Drought is a natural and recurrent climatic event, which is defined as sustained below-average water availability. Drought is induced mostly by the lack of rainfall over an extended period of time. It depends also on other climatic factors such as temperature, on anthropogenic factors such as excessive water extractions from population growth and expansion of economic activities, and on malfunctioning water institutions that could intensify significantly its impacts. Severe drought spells affect all components of the water cycle, resulting in low soil moisture, reduced groundwater levels, drying up of wetlands, and reductions in river flows.

Water scarcity has become widespread in most arid and semiarid regions, including river basins such as the Yellow, Jordan, Murray-Darling, Colorado, and Rio Grande. Water scarcity has been the origin of many cooperative agreements and some serious political disputes. The sustainable management of such agreements becomes a central concern of governments and international institutions (Dinar 2009).[2]

Emerging social demands for environmental protection in the form of minimum ecological flows for water-dependent ecosystems further increase competition for already scarce water in arid and semiarid regions, especially during dry years. Water-dependent ecosystems such as wetlands provide a diverse range of goods and services to society, including habitat for valuable species, flood control, groundwater replenishment, water quality improvement, waste disposal, and recreational opportunities (Woodward and Wui 2001). However, water-dependent

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[1] The work leading to this paper was performed while the first author was a visiting associate researcher at the Water Science and Policy Center, University of California, Riverside.

[2] See Yoffe et al. (2003) for a comprehensive assessment of water-related conflicts and cooperation.

ecosystems are external to markets, and their social values are overlooked in water allocation decisions. For instance, an estimated 50 percent of world wetlands have disappeared over the last century (Finlayson and Davidson 1999). In addition, surface and groundwater bodies that feed wetlands are common pool resources (rivalry and non-excludability) that could be depleted by overdraft leading to the so-called tragedy of the commons (Hardin 1968).

Several examples of severe impacts of scarcity and drought have been observed worldwide. Rapid economic growth together with frequent drought spells in Northern China during recent decades have increased water extractions well above sustainability thresholds, converting the region into an intensely water-stressed area. Acute water scarcity has resulted in declining groundwater levels at a rate of more than 1 meter per year with flows to the sea dwindling by 60 percent, compared to the 1970s.

The Aral Sea located in Central Asia was the world's fourth largest inland water body sustaining an important local economy. Diversion of water to support cotton cultivation and ill-advised water management policies in the Amu and Syr Darya river basins have caused the reduction of water inflows to the Aral Sea by 90 percent, leading to its desiccation and water quality degradation. Consequences are the loss of native fish species and fish catch that has dropped to zero, increase of unusable lands, and human health problems (UNDP 2006).

The Colorado River in the United States runs dry during most parts of the year and no longer reaches the Sea of Cortez because of the excessive water withdrawals for irrigation and the recurrent drought spells. This has caused the loss of more than 50 percent of the Mexican riverine wetlands and shallow water habitat. As a consequence, 68 percent of native fish species have been lost, with 15 rare or endangered fish species becoming extinct in the last five decades (Lemly et al. 2000).

In arid and semiarid regions, groundwater resources are often intensively used especially during periods of shortage in surface water supplies. Global groundwater depletion is quite substantial, reaching 283,000 million cubic meter (Mm^3) per year, which represents 39 percent of the global yearly groundwater extractions (Wada et al. 2010). Groundwater overdraft in the region of the Indus, Ganges, and Brahmaputra, the largest irrigated area in the world, has been estimated at around 50,000 Mm^3 per year (Tiwari et al. 2009). This huge depletion of aquifers has caused serious hardships and health problems to the impoverished population in the region.

Available assessments of the economic impacts of drought and scarcity report considerable damage costs, between 2 and 6 billion US $ per year in the United States (NOAA 2008), and around 3 billion € per year in the European Union (EC 2007a). Drought damage costs in the San Joaquin Valley (California) during 2009 amounted to 340 million US $ (Howitt et al. 2011). Losses in the Murray-Darling River Basin (Australia) during 2009 were 20 percent of the value of irrigated agriculture (Kirby et al. 2012). Drought damage costs for agriculture in Spain during 2005 have been estimated at 2.5 billion € and the environmental impacts at 114 million € (EC 2007b). In the Ebro River Basin of Spain, damage costs of the 2005 drought were 280 million € for agriculture, 18 million € for the urban sector, and 90 million € for the energy sector. Environmental damages were above 20 million € (Hernández-Mora et al. 2013).[3]

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[3] Drought damage costs could be exceptionally high some years, for example the costs of the 2003 summer drought in Central and Western Europe were 13 billion US $ (Munich Re 2004), and the costs of drought that affected the region of Catalonia in Spain during 2007 and 2008 were 1.6 billion € (Martin-Ortega et al. 2012).

Several policy responses have been suggested to cope with water scarcity and to mitigate the negative impacts of climate change-induced drought. These policies include reducing water supply, water transfers, conjunctive use of ground and surface water, recycling and reuse of wastewaters, seawater desalination, improving water use efficiency, adopting water conserving-technologies, changing land use by shifting to high value crops and moving away from water-intensive crops, implementing economic instruments such as water pricing and water trade, and the creation of institutions and the cooperative and participatory management of water resources (Zilberman et al. 1998).

However, the existing literature, while assessing solutions to drought situations, using engineering, economic and institutional approaches, does overlook one important aspect – the strategic behavior of the various stakeholders – that is essential to the stability and acceptability of policy solutions aimed at basin-wide drought mitigation approaches that may affect differently groups, sectors, and sub-regions. Incorporating strategic behavior of various stakeholders vis-à-vis various policy intervention is essential in recommending the policy makers among the policies they design.

This paper develops a game theory framework in order to analyze cooperative water management policies that could address scarcity and drought in the Jucar River Basin in Spain (henceforth JRB). The contribution of this paper is the inclusion of ecosystem benefits in the river sharing problem and in incorporating the strategic behavior of various sectors and sub-regions in the basin. Several cooperative management institutions and stability indexes are used to investigate the propensity for cooperation of the river users under different climate conditions. The paper investigates also the likelihood for ecosystem protection success, and the relationship between scarcity and cooperation.

2. Methodology

This paper develops an empirical river basin model that assesses drought mitigation interventions and involves the main users in the JRB, including irrigation activities, urban uses, and aquatic ecosystems needs. A specific model for each water use has been developed, and these models are linked using a reduced form of the hydrological model of the basin that was developed and calibrated in Kahil et al. (2013). Moreover, a game theory model is developed and applied to the JRB drought management problem.

2.1 Study area

The JRB is located in the regions of Valencia and Castilla La Mancha in Southeastern Spain. It extends over 22,400 km^2 and covers the area drained by the Jucar River and its tributaries, mainly the Magro and the Cabriel Rivers. The climate of the basin is Mediterranean, characterized by recurrent drought spells and normal years with hot and dry summers.

The JRB includes 13 reservoirs, the most important are Alarcon, Molinar, Contreras, and Tous dams. The Alarcon dam located in the upper Jucar with a storage capacity of 1,112 Mm^3 represents the most important element of water management in the basin. There are two important distribution canals, the Acequia Real canal, which conveys water from the Tous dam to the traditional irrigation districts in the lower Jucar, and the Jucar-Turia canal, which transfers water from the Tous dam to irrigation districts situated in the bordering Turia River Basin.

At present, renewable water resources in the JRB are nearly 1,700 Mm^3, of which 930 Mm^3 are surface water and 770 Mm^3 are groundwater resources. Water extractions are 1,680 Mm^3, very close to the renewable resources, making the JRB an almost closed water system (Table 1).

Extractions for irrigated agriculture are about 1,400 Mm^3 per year, which represent 84 percent of total water extractions, to irrigate 190,000 ha. The major irrigation districts are: the Eastern La Mancha aquifer irrigation district (henceforth EM) in the upper Jucar, the traditional irrigation districts of Acequia Real del Jucar (henceforth ARJ), Escalona y Carcagente (henceforth ESC) and Ribera Baja (henceforth RB) in the lower Jucar, and the irrigation district of the Canal Jucar-Turia (henceforth CJT) situated in the bordering Turia River Basin. Urban and industrial extractions are about 270 Mm^3, and they cover the supply to households, industries and services of more than one million inhabitants located mostly in the cities of Valencia, Sagunto and Albacete (Table 2).[4]

The expansion of water extractions in the basin and the severe drought spells in recent decades have triggered considerable negative environmental and economic impacts. The growth of water extractions has been driven especially by irrigation from the EM aquifer. This aquifer is being depleted with escalating water withdrawals for irrigation leading to an accumulated overdraft that is nearly 2,000 Mm^3. The aquifer is linked to the Jucar River stream and it used to feed the Jucar River with about 150 Mm^3/year in the 1980s. Due to the depletion, the aquifer is at present draining the water flow of the upper Jucar rather than feeding it, at an average of 70 Mm^3/year during 2001–2005 (Sanz et al. 2011).

The aquifer depletion combined with other important water extractions in the basin, and the recurrent drought spells have caused the water flows in the Jucar River to diminish. The projected water transfer of 80 Mm^3 from the Jucar to the Vinalopo River Basin by 2015 will further increase pressures on the Jucar River (CHJ 2009). Environmental flows are dwindling in many parts of the basin, resulting in serious damages to water-dependent ecosystems. The environmental flow in the final tract of the Jucar River is below 1 m^3/s, which is very low compared with the other two major rivers in the region, the Ebro and Segura Rivers that flow to the Mediterranean (Ferrer et al. 2006).[5]

There have been negative impacts on downstream water users, such as the ARJ irrigation district, which has seen substantial water availability in the last 40 years reduced from 700 Mm^3 to 200 Mm^3. Consequently, the dwindling return flows from the ARJ have caused serious environmental problems to the Albufera wetland, which is fed by these return flows (Garcia-Mollá et al. 2013).

The Albufera wetland is the main aquatic ecosystem in the JRB. It is a freshwater lagoon with an area covering 2,433 ha, and an average depth of 0.9 m, supporting very rich aquatic ecosystems with unique species of fauna and flora. The wetland plays a role as stopover point for migratory birds. Since 1989, the Albufera was included in the list of wetlands of international importance as a RAMSAR site, and was declared a special protection area for birds.

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[4] These figures are for consumptive uses, and do not include non-consumptive uses such as hydropower, aquaculture and recreation, which are the following: hydropower 3,230 Mm^3 and aquaculture and recreation 72 Mm^3. In the JRB, there are 26 hydropower stations.

[5] The upcoming hydrological plan of the JRB proposes an ecological flow of 1.5 m^3/s in normal flow years and 1 m^3/s in drought years for the final tract of the Jucar River (CHJ 2009).

The Albufera receives water from the return flows of the irrigation districts in the lower Jucar, mainly from the ARJ and the RB irrigation districts. Other flows originate from the Turia River Basin, and from discharge of untreated and treated urban and industrial wastewaters.

Currently, an important problem of the Albufera is the degradation of water quality. This problem is driven by deficiencies in the sewage disposal and treatment systems from adjacent municipalities, and by the reduced flows originating from the Jucar River. The Jucar River flows play an important role in improving the quality of urban and industrial wastewaters reaching the Albufera. Water quality degradation has caused severe damages to the Albufera wetland, such as the loss of biodiversity, the decrease of recreation services, and the decline of fishing activities (Sanchis 2011).

2.2 Empirical river basin model

This paper applies a river basin model for the JRB that was developed in Kahil et al. (2013). The model integrates hydrologic, economic, environmental, and institutional variables within a single framework. The river basin model accounts for decision processes made by irrigation users in the five major irrigation districts (EM, CJT, ARJ, ESC, and RB) and by urban users in the three major cities (Valencia, Albacete, and Sagunto) in the basin. In addition, the model includes the environmental benefits generated by the Albufera wetland. The main focus of the model is on the utilization of river waters without taking into account groundwater dynamics. The model runs on an annual basis.

In order to link the different components of the river basin model and to simulate the spatial impact of drought in the JRB, a reduced form of the hydrological model of the basin is used (CHJ 1998, 2009). The reduced form hydrological model is a node-link network, with flows routed between nodes using simplified hydrologic equations. This model allows controlling the flows of water in each node and estimating the distribution of the available surface water among the users in each climate condition calibrating it to the response by the basin authority to the last drought period (years 2006, 2007, and 2008) and water allocations in normal flow years. This approach to model river basin interactions has been used in several studies such as Booker and Young (1994), Cai et al. (2003), Ward and Pulido (2008), and Dinar and Nigatu (2013).

The reduced form hydrological model is based on the principles of water mass balance and continuity of river flow, which determine the volume of water availability in a river reach or reservoir that can be used for economic activities taking into account environmental restrictions. The most important flows tracked by the model include headwater flows, stream flows at the main stream gauges, reservoir releases and evaporation, water diverted, water applied to crops, water depleted, return flows to river, percolation, aquifer-river interaction, and ecological flows of river reaches. The mathematical formulation of the model is as follows; see also Kahil et al. (2013) for more explanation:

$$WO_d = WI_d \cdot (1 - \gamma_d) - D_d^{IR} - D_d^{URB} \qquad [1]$$

$$WI_{d+1} = WO_d + r_d^{IR} \cdot (D_d^{IR}) + r_d^{URB} \cdot (D_d^{URB}) \qquad [2]$$

$$WO_d \geq E_d^{min} \qquad [3]$$

The mass balance equation [1] determines the volume of water outflow WO_d from a river reach or reservoir d, which is equal to the net (of evaporation loss γ_d) water inflow $WI_d \cdot (1 -$

γ_d) to d minus diversion for irrigation D_d^{IR} and for urban and industrial uses D_d^{URB}. The continuity equation [2] guarantees the continuity of river flow in the basin, where the volume of water inflow to the next river reach or reservoir WI_{d+1} is the sum of outflow from the previous river reach or reservoir WO_d, the return flows from previous irrigation districts $r_d^{IR} \cdot (D_d^{IR})$ and, the return flows from the cities $r_d^{URB} \cdot (D_d^{URB})$. Equation [3] states that the volume of water outflow WO_d from a river reach or reservoir d must be greater than or equal to the minimum ecological flow E_d^{min} established for that river reach or reservoir, which is determined by the basin's regulations.

We incorporate the reduced form hydrological model into a regional economic optimization model. For irrigation activities, a linear optimization model has been developed for each irrigation district. Irrigation districts maximize farmers' private benefits from irrigation activities, subject to technical and resource constraints. A Leontief production function technology is assumed with fixed input and output prices, in which farmers are price takers. The optimization problem takes the following form:

$$Max\ B_k^{IR} = C'_{ijk} \cdot X_{ijk} \qquad [4]$$

subject to

$$A_{ijk} \cdot X_{ijk} \leq R_k \qquad [5]$$

$$X_{ijk} \geq 0 \qquad [6]$$

where B_k^{IR} is farmers' private benefits in irrigation district k. C'_{ijk} is a vector of coefficients of net income per hectare of crop i cultivated under the irrigation technology j. A_{ijk} is a matrix of production coefficients and R_k is a vector of constraint levels including land, water and labor in each irrigation district k. X_{ijk} corresponds to the area of crop i cultivated under irrigation technology j in irrigation district k and it is the decision variable in the irrigation district optimization problem. Crops are classified into three groups: cereals, vegetables, and fruit trees. Irrigation technologies are flood, sprinkler, and drip. The water constraint level is the connecting variable between the economic optimization models of the irrigation districts and the reduced form hydrological model.

For urban water uses, a nonlinear optimization model has been developed for each city. The model maximizes the social (consumer and producer) surplus from water use for each city, subject to several physical and institutional constraints. The optimization problem takes the following form:

$$Max\ B_u^{URB} = \left(a_{du} \cdot Q_{du} - \frac{1}{2} \cdot b_{du} \cdot Q_{du}^2 - a_{su} \cdot Q_{su} - \frac{1}{2} \cdot b_{su} \cdot Q_{su}^2\right) \qquad [7]$$

subject to

$$Q_{du} - Q_{su} \leq 0 \qquad [8]$$

$$Q_{du}\ ;\ Q_{su} \geq 0 \qquad [9]$$

where B_u^{URB} is the social surplus of city u from water use. Q_{du} and Q_{su} are the quantity of water demanded and supplied by/to the city u, respectively. a_{du} and b_{du} are the intercept and the slope of the inverse demand function of city u, respectively. a_{su} and b_{su} are the intercept and the slope of the water supply function for city u, respectively. Equation [8] states that the quantity of water supplied must be greater than or equal to the quantity demanded. The quantity supplied, Q_{su}, is the output from the reduced form hydrological model and it is the connecting variable between urban use optimization models and the reduced form hydrological model. Parameters of the inverse demand functions for Valencia, Albacete, and Sagunto have been estimated from the study by Collazos (2004).

The river basin optimization model accounts also for the environmental benefits of the main aquatic ecosystem in the JRB, the Albufera wetland. The Albufera wetland receives water flows mainly from the return flows of the irrigation districts in the lower Jucar. Other flows originate from urban and industrial wastewater discharges, and from the Turia River Basin. This paper considers only water inflows to the Albufera wetland originated from irrigation return flows of the ARJ and RB irrigation districts. Inflows and benefits of the Albufera wetland are given by the following expressions:

$$E_{Albufera} = \alpha \cdot r_{ARJ}^{IR} \cdot \left(D_{ARJ}^{IR}\right) + \beta \cdot r_{RB}^{IR} \cdot \left(D_{RB}^{IR}\right) \qquad [10]$$

$$B_{Albufera} = \begin{cases} \delta_1 & if\ E_{Albufera} \leq E_1 \\ \delta_2 + \rho_2 \cdot E_{Albufera} & if\ \ E_1 < E_{Albufera} \leq E_2 \\ \delta_3 + \rho_3 \cdot E_{Albufera} & if\ E_{Albufera} > E_2 \end{cases} \qquad [11]$$

where equation [10] determines the quantity of water flowing to the Albufera wetland, $E_{Albufera}$. Parameters α and β represent the shares of return flows that feed the wetland from the ARJ and RB irrigation districts, respectively. The products $r_{ARJ}^{IR} \cdot (D_{ARJ}^{IR})$ and $r_{RB}^{IR} \cdot (D_{RB}^{IR})$ are return flows from the ARJ and RB irrigation districts, respectively. Equation [11] represents economic environmental benefits $B_{Albufera}$ that the Albufera wetland provides to society. The economic environmental benefit function is assumed to be a piecewise linear function of the water inflows, $E_{Albufera}$, to the wetland. This function expresses shifts in the ecosystem status when critical thresholds of environmental conditions (water inflows in this case) E_1 and E_2 are reached. This functional form is adapted from the study by Scheffer et al. (2001), indicating that ecosystems do not always respond smoothly to changes in environmental conditions, but they may switch abruptly to a contrasting alternative state when these conditions approach certain critical levels. $E_{Albufera}$ is the connecting variable between economic environmental benefits model, irrigation district optimization models and the reduced form hydrological model.

Time series of various ecosystem health indicators of the Albufera wetland have been collected such as the quantity of water inflows, the number of water replenishment, *chlorophyll a* concentration, phosphorus concentration and salinity level, to calculate a unique health index of the wetland for each year of the available data following the methodology developed by (Jorgensen et al. 2010). We suppose that environmental benefits of the wetland are a function of its ecosystem health. Then having information about the economic value of the wetland for one year, we extrapolate the economic value for each year of the available data using the health index of such year. Once the economic values are calculated for each year, the thresholds E_1 and E_2 are determined and the relationships between the environmental benefits and water inflows to the wetland are estimated.

The economic value of the Albufera wetland used as a basis for the estimation of the environmental benefit function has been approximated using the study by del Saz and Pérez (1998) that calculates the recreation value of the Albufera wetland in the 1995, and other studies from the literature for non-recreation values of wetlands (Woodward and Wui 2001, Brander et al. 2006). The parameters of the environmental benefit function of the Albufera wetland and the economic value used for its estimation are presented later in Table 3. Figure A1 in the appendix shows the environmental benefit function.

The river basin optimization model presented in this section is used for calculation of benefits accrued to various groups of users (coalitions), under various scenarios of water scarcity and institutional arrangements.

2.3 Cooperative game theory model of the JRB

Assume that a river is shared by L players with $l = 1,\dots, L$. Cooperation among the players consists of sharing water resources with possible transfer payments for foregone use of water. This is the concept of flexible water allocation rule applied by Kilgour and Dinar (2001) for international river basins. Initially, players in the game have predetermined administrative water allocations depending on the climate condition. Then a player that needs more water can obtain it from another player by compensating that player for using less water.[6] Possible arrangements between all players are allowed in the game. We suppose that the existing infrastructure in the basin allows water movements from one player to any other.

Let N be the set of all players in the game, $S \subseteq N$ be the set of all feasible coalitions, and s ($s \in S$) a feasible coalition in the game. The non-cooperative coalitions are $\{l\}$, l=1, . . . , L, and the grand coalition (full cooperation) is $\{N\}$.

Assume that the objective of the players in a feasible coalition s is to maximize their benefits f^s from cooperative water use. Let $\nu(s)$ be the characteristic function of the coalition s, which is the best value that such coalition can obtain. The cooperative game theory problem takes the following form:

$$\nu(s) = Max\ f^s = \sum_{l \in s}(B_l - \omega \cdot ws_l) \qquad [12]$$

subject to

$$\sum_{l \in s}(AA_l + ws_l) \leq WA_s \qquad [13]$$

$$\sum_{l \in s}(\omega \cdot ws_l) = 0 \qquad [14]$$

$$ws_l \lesseqgtr 0 \qquad [15]$$

where B_l is the private benefits from water use of player l in coalition s and $\omega \cdot ws_l$ is the water transfer payment to/from player l from/to the pool, with ω is the payment per cubic meter and ws_l is water shared by player l. The water constraint [13] states that the sum for all players in the coalition s of the administrative water allocation AA_l of player l and water shared by player l must be less than or equal to total water available for that coalition WA_s. Equation [14] states that money transfer for coalition s must be balanced.

A necessary condition for cooperation in the basin is that the benefits from cooperation are greater than the benefits obtained under non-cooperative management. When additional benefits

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[6] A similar cooperative arrangement already implemented in the JRB is the Alarcon agreement of 2001. The agreement establishes that in drought situations the users in the JRB could continue using surface water from the Jucar River and pay an economic compensation to the traditional irrigation districts. These irrigation districts get a special authorization to use groundwater resources instead of using surface water during drought, and the compensation covers the additional costs of the groundwater pumping (CHJ 2001).

are achievable through cooperation, the main challenge is to fairly and efficiently allocate them among the cooperating players. Such a challenge can be addressed through allocating the benefits from cooperation using cooperative game theory concepts. Let Ω_l be the allocated cooperative benefits to player l and let $\Omega = (\Omega_1, \dots, \Omega_L)$ be the vector of allocations. An appropriate allocation under cooperation should satisfy the following constraints:

$$\Omega_l \geq v(\{l\}) \qquad \forall l \in N \tag{16}$$

$$\textstyle\sum_{l \in s} \Omega_l \geq v(s) \qquad \forall s \in S, S \subseteq N \tag{17}$$

$$\textstyle\sum_{l \in N} \Omega_l = v(N) \tag{18}$$

Equation [16] fulfills the condition for individual rationality, which means that the allocated benefits from full cooperation to player *l* must be greater than or equal to its benefits from non-cooperation. Equation [17] fulfills the group rationality condition, which means that the sum of full cooperative benefit allocations to any group of players must be greater than or equal to the total obtainable benefits under any coalition *s* that includes the same players. Equation [18] fulfills the efficiency condition, which means that the total obtainable benefits under the grand coalition must be allocated to the members of that coalition.

An allocation that satisfies these three requirements is in the core of the cooperative game (Shubik 1980). The core is a set of game allocation gains that is not dominated by any other allocation set. The core provides information about the range of acceptable solutions for each player and allows ranking the players' preferences over the possible cooperative solutions. Satisfying the core conditions for a cooperative solution is a necessary condition for its acceptability by the players. Therefore, solutions not included in the core are not acceptable and not stable (Shapley 1971).

Three cooperative game theory solution concepts (cooperative institutions) are used in this study to allocate the gains from cooperation among the players: the Shapley value, the Nash-Harsanyi, and the Nucleolus. These solution concepts have been applied in previous studies for different water management problems such as Loehman (1995), Dinar and Howitt (1997), Wang et al. (2008), and Madani and Dinar (2012).

The Shapley value institution is a uniquely defined solution to an *N*-player cooperative game in the characteristic functional form. The Shapley value allocates Ω_l to each player based on the weighted average of their contributions to all possible coalitions and sequences. In the calculation, an equal probability is assigned for the formation of any coalition of the same size, assuming all possible sequences of formation (Shapley 1953). The Shapley solution takes the following form:

$$\Omega_l = \sum_{\substack{S \subseteq N \\ l \in S}} \frac{(n-|s|)!(|s|-1)!}{n!} \cdot \big(v(s) - v(s - \{l\})\big) \tag{19}$$

where $|s|$ is the number of players participating in coalition *s*, $\forall l \in N$ and *n* is the total number of players in the allocation game.

The Nash–Harsanyi institution solution (Harsanyi 1959) to an *N*-person bargaining game is a modification to the two-player Nash solution (Nash 1953). This cooperative institution provides a unique allocation solution that is in the core of the game (if it is not empty) by maximizing the product of the grand coalition players' obtained benefits from cooperation compared to non-cooperation. The Nash-Harsanyi solution takes the following form:

$$Max \ \prod_{l \in N} (\Omega_l - \nu(\{l\})) \qquad [20]$$

subject to the core conditions (equations [16] to [18]), where Ω_l is the Nash-Harsanyi benefit allocation and $\nu(\{l\})$ is the non-cooperative benefit of player l.

The core of a cooperative game in the characteristic function form may be empty because certain partial coalitions provide greater incentives than the grand coalition. Conversely, conditions may arise where the core does exist but is too large and leaves the allocation problem open for further bargaining. The Nucleolus institution solves this problem by minimizing the worst inequity or dissatisfaction of the most dissatisfied coalition (Schmeidler 1969). The Nucleolus of the benefit allocation game can be determined by finding ε through the following optimization model:

$$Max \ \varepsilon \qquad [21]$$

subject to

$$\varepsilon \leq \sum_{l \in s} \Omega_l - \nu(s) \quad \forall s \in S, S \subseteq N \qquad [22]$$

$$\sum_{l \in N} \Omega_l = \nu(N) \qquad [23]$$

$$\varepsilon \lesseqgtr 0 \qquad [24]$$

where ε is the maximum tax imposed on all coalitions to keep them in the core. Solving equations [21] to [24] provides a fair and efficient allocation of benefits to the players, based on the Nucleolus fairness principle. The Nucleolus allocation is a single solution that is always in the core, if the core is not empty.

To ensure that a cooperative solution works adequately in practice, not only should it be in the core, but also it has to be stable. Being in the core is a necessary condition for acceptability of a cooperative solution by the players, but it does not guarantee stability for a solution, as some players may find it unfair. Solutions that are viewed as unfair by some players are less stable. Some players might threaten to leave the grand coalition and form partial coalitions because of their critical position in the grand coalition. The stability of any solution is important given the existence of considerable transaction costs and fixed investments, and a more stable solution might be preferred even if it is harder to implement. Therefore, some methods are suggested to find the most stable and likely cooperative outcomes.

Loehman et al. (1979) used an ex-post approach to measure power in a cooperative game. The Loehman power index (θ_l) compares the gains to a player with the gains to the coalition. The power index (θ_l) is the following:

$$\theta_l = \frac{\Omega_l - \upsilon(\{l\})}{\sum_{l \in N}(\Omega_l - \upsilon(\{l\}))}, \quad \sum_{l \in N} \theta_l = 1 \qquad [25]$$

where Ω_l is the allocation solution for player l. The power index is used as an indicator of the stability of the allocations for the different cooperative institutions. The higher the power index of a player, the higher that player's propensity is for cooperating and staying in the grand coalition. If the power is distributed more or less equally among the players, then the coalition is more likely to be stable. The coefficient of variation of the power indexes of the different players is defined as the stability index of the grand coalition $\bar{\theta}$. The greater the value of $\bar{\theta}$ the larger the instability of the allocation solution.

2.4 Scenario simulation

The theoretical game theory model and the cooperative benefit allocation institutions are applied to the JRB sharing problem. The main water users in the JRB are classified into four players that have the same characteristics regarding water use and their relation with the environment. Players in the JRB game are: irrigation districts not linked to the environment including the EM, CJT, and ESC irrigation districts (henceforth INE); irrigation districts linked to the environment including the ARJ and RB irrigation districts (henceforth IE); the cities including Valencia, Sagunto and Albacete (henceforth C); and the Albufera wetland (henceforth E). This classification will allow us to capture all important strategic relationship between players in various locations of the basin and their opposed interests, and at the same time to keep the computational burden at a reasonable level.

Two scenarios of water management are presented in this study to analyze the propensity for cooperation among the users in the JRB and the likelihood to protect the Albufera wetland. The two scenarios are simulated under normal flow and drought conditions. Drought is classified into three levels, depending on the severity of the drought event: mild, severe, and very severe, based on historical data about water inflows in the JRB.[7] The two scenarios follow:

Scenario 1 allows the cooperation among players to share water resources with transfer payments. Under this scenario, player E (the Albufera wetland) receives water from return flows generated by player IE. The Albufera wetland is a weak player in the game because it does not compete for water (there is no water sharing or transfer payments from/to Albufera).

Scenario 2 consists of a policy intervention by the basin authority to protect the Albufera wetland and to internalize environmental damages. This scenario introduces a new variable in the model, which is the direct diversion of water to the Albufera wetland. In this case, the wetland is competing for water with other users and does not depend passively on remaining return flows. The mechanism for direct water diversions to the Albufera wetland is that the basin authority pays players that reduce their water use in order to feed the wetland.

Detailed biophysical and economic information has been collected from a large number of primary and secondary data sources and introduced in the models: water inflows to the main reservoirs and river reaches, water diversion for irrigation and cities (CHJ 1998, 2002, 2009 and 2012), crop acreage by irrigation system, crop water requirements, irrigation efficiency in each district (GV 2009, GCLM 2009, INE 1999 and 2009), costs and revenues by crop, water costs and prices by sector (CHJ 2004, Collazos 2004, MARM 2010), and information about the Albufera wetland (Mondria 2010).

The water transfer payment per cubic meter is the shadow price of water estimated in the river basin model, which is used then in the game theory application.[8] Selected hydrologic and

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[7] The characterization of drought events severity is done by dividing equally the range between the mean and the minimum water inflows in the JRB for the period 1989-2011, following the classification of drought severity by the JRB authority.

[8] This water transfer payment per cubic meter is just the same as the water price paid by the basin authority to farmers during the last drought for reducing groundwater extractions in the Eastern La Mancha aquifer.

economic parameters of the JRB model are shown in Table 3. The river basin model and the cooperative game theory application have been run using the GAMS package.

3. Results and discussion

The baseline scenario (the non-cooperative situation) represents the current conditions of water use in the JRB. Each player is maximizing its private benefits from its administrative water allocation, and there is no cooperation among players. The simulation of drought impacts on the JRB in the baseline scenario includes the measures implemented by the basin authority to cope with drought, such as the increase of urban water prices and the conjunctive use of ground and surface water for irrigation and urban demand. The results of the baseline scenario are presented in Tables 4 and 5.

Benefits in the JRB under the baseline scenario for normal flow conditions amount to 548 million €. Water use is 1,149 Mm^3, of which 672 is the total surface water and 477 is the total groundwater resources. Irrigation activities generate 190 million € (35% of total benefits) from using 1,030 Mm^3 (90% of total water). The social surplus of the cities is 283 million € (51% of total benefits) and they use 119 Mm^3 (10% of total water). Environmental benefits provided by the Albufera wetland are 75 million € (14% of total benefits). The Albufera wetland receives 60 Mm^3 from the return flows of the ARJ and RB irrigation districts, which support the good ecological status of the wetland.

Results of the drought scenarios indicate that drought events may reduce the benefits of the JRB between 63 and 137 million € (11 to 25%). Water use patterns show a reduction in extractions of surface water (17 to 52%) and groundwater (4 to 9%). The share of groundwater use expands when drought becomes more severe, from 42 percent in normal years up to 57 percent in very severe drought years.

During droughts, the main adjustment falls on irrigation activities, which reduce surface water extractions (18 to 53%) and groundwater extractions (up to 11%). Irrigation benefit losses range between 19 and 55 million € (10 to 30% of total benefits) under mild and very severe drought conditions, respectively.

The reduction of surface water for irrigation during drought spells is lower in the traditional irrigation districts (14 to 48% in ARJ, ESC and RB) compared with the other districts (42 to 91% in EM and CJT). However, the traditional irrigation districts sustain larger economic losses because they cannot substitute surface water with groundwater. Benefits losses in the traditional irrigation districts (ARJ, ESC and RB) range between 11 and 40 percent, compared with losses between 10 and 23 percent in EM and CJT. The reason is that the EM and CJT irrigation districts are based mostly on groundwater extractions, which reduce their vulnerability to drought. This fact illustrates the stabilization role of groundwater when surface water supplies fluctuate.

The reduction in irrigation water extractions has large negative impacts on the Albufera wetland that is mostly fed by irrigation return flows. Water inflows to the Albufera wetland decrease between 13 and 43 percent. As a consequence, drought damages on the Albufera wetland under very severe drought conditions may exceed 50 percent of benefits in normal years.

The current water resources regulation in the JRB guarantees the availability of urban water to human population. During severe drought spells the urban demand must be first fully covered because of such priority rules. The three simulated drought scenarios show a reduced supply to the main cities in the JRB. However, the full demand of Valencia and Sagunto is always covered with additional water from the bordering Turia River Basin. During extreme drought periods, the provision of water to these cities is shared equally between the Jucar and the Turia Rivers. In the city of Albacete, the supply of water during dry periods is amended by pumping groundwater from the Eastern La Mancha aquifer (CHJ 2009). The simulation results for the urban sector indicate that the provision of surface water from the Jucar River falls between 14 and 45 percent, while groundwater extractions increase up to 8 Mm^3. The benefit losses during droughts in the urban sector are below 14 percent in the worst-case scenario, because water provision is maintained with additional extractions from the Turia River and the Eastern La Mancha aquifer, but at higher costs.

3.1 Cooperative water management

The two scenarios of water management described in section 2.4 are simulated under different climate conditions using three sets of coalitional arrangements: (a) non-cooperation; (b) partial cooperation in which the flexible water allocation rule is allowed among the different combination of players; and (b) full cooperation, in which the flexible water allocation rule is allowed among all the players in the game. Results of the characteristic function of the coalitional arrangements under different climate conditions for the two scenarios are presented in Tables 6 and 7.

The results suggest that full cooperative management of water in the JRB achieves the highest aggregate level of benefits for the two scenarios and all climate conditions. For scenario 1, full cooperation among users improves benefits between 16 and 34 million € (4 to 7%) compared to non-cooperation. When the basin authority introduces a policy to protect the Albufera wetland in scenario 2, full cooperation improves significantly benefits between 195 and 285 million € (36 to 61%) compared to non-cooperation. These improvements in benefits of full cooperation under both scenarios occur because player IE transfers part of its water to players INE and E. Benefits under partial cooperation are always higher than under non-cooperation, but lower than under full cooperation. For instance, partial cooperation ({INE,IE,E}) between the irrigation districts (INE and IE) and the Albufera wetland (E) achieves almost the same benefit as full cooperation.

These results highlight the fact that cooperative water management may reduce drought damage costs in the JRB between 4 and 61 percent. Additionally, results show that there are always incentives for cooperation among the stakeholders in the JRB, and the intervention of a regulator to protect ecosystems increases significantly these incentives. It seems that partial cooperation between players IE, INE, and E is sufficient to maximize the benefits of the JRB and protect the Albufera wetland, and player C could be excluded from the game due to its very minute contribution.

The values of the characteristic functions of the JRB game for the different coalitional arrangements shows superadditivity, which indicates that the additional cooperative benefits can be shared among players. To keep the arrangements stable and assure equity, the reallocation of benefits among players can be performed through transfer payments. These allocations are analyzed in section 3.2.

The relationship between scarcity and cooperation is a key factor for the design of policies to cope with scarcity and mitigate the negative impacts of climate change-induced drought. The existing literature analyzing the relationship between cooperation and scarcity presents two different theories. The first one assumes that the relationship between cooperation and scarcity is a linear increasing relationship. This means that cooperation in a river basin becomes important with increasing water scarcity (Tir and Ackerman 2004). The second theory suggests that the relationship between cooperation and scarcity follows an inverted U-shaped curve. This theory states that for mild scarcity, cooperation is less likely since water is abundant and water needs are satisfied. Then, when scarcity increases, the potential benefits from cooperation also increase. But if scarcity levels continue to increase, then a turning point is reached at which the benefits from cooperation begin to decrease making the agreements between stakeholders quite unlikely. The resource is so scarce that there is very little to benefit from and divide among the users (Dinar 2009).

The results under the first scenario show that gains from cooperation are highest for mild drought (7%), and become smaller for severe drought (5%) and very severe drought (4%). These results are in agreement with the inverted U-shaped curve hypothesis linking cooperation and scarcity. For the second scenario, which includes water diversion to the Albufera wetland, the results show positive linear relationship between cooperation and scarcity. The direct competition of the Albufera wetland for water may explain the increasing incentives for cooperation when scarcity increases. These results are in agreement with the findings by Dinar (2009) who indicates that water scarcity based on environmental degradation tends to encourage joint efforts to halt such degradation and achieve gains in social welfare.

Figures 1 and 2 present the quantity of water flowing to the Albufera wetland under different coalitional arrangements and climate conditions for scenario 1 and 2, respectively. Results indicate clearly that policy intervention to protect the Albufera wetland (scenario 2) is better than non-intervention, securing always a fixed amount of water (138 Mm^3) flowing to the wetland. This amount is well above the minimum requirement of the Albufera wetland and thus ensures a good ecological status. Moreover, cooperation without public intervention fails to provide the wetland with a minimum water threshold that could maintain its good ecological status (scenario 1). Water inflows to the Albufera wetland are far below the minimum requirement for severe or very severe droughts.

A finding is that achieving cooperation without policy intervention to regulate the Albufera wetland degrades the wetland. The reason is that the Albufera wetland is linked to the IE player (ARJ and RB) which displays a lower value of water than the INE player (EM, CJT, and ESC). Under severe and very severe droughts, the IE player gains by transferring water to the INE player and receives payments in exchange. As a consequence, return flows to the wetland decline producing the desiccation and degradation of ecosystems. Both policy intervention and cooperation (scenario 2) are needed for the full protection of the wetland under any climate conditions.

The comparison between the two scenarios indicates that the public intervention of the basin authority to protect the Albufera through direct diversion of water to the wetland with transfer payments (scenario 2) provides high incentives for cooperation, leading to a sustainable use of water resources and a substantial increase of the basin’s benefits. A major policy implication from the analysis is that cooperation may have to be encouraged by outside agents, such as the basin authority, when scarcity is very high, in order to improve water management, protect ecosystems and increase economic benefits.

3.2 Allocations of the cooperative benefits

The results of the different coalitional arrangements suggest that cooperative water management in the JRB yields higher benefits compared to non-cooperation. The challenge here is to allocate the cooperative benefits among the players in a fair and efficient manner. The allocation of benefits is calculated using different cooperative game theory institutions. Then the stability and acceptability of the benefit allocations are tested using the core conditions (equations [16] to [18]), the power index (θ_i), and the stability index ($\bar{\theta}$). Figures 3 and 4 show the allocated benefits to each player, based on the different cooperative allocation institutions.

Results of benefit allocations based on the three cooperative institutions highlight that player E, the Albufera wetland, is the one that benefits the most from cooperation with respect to non-cooperative management, especially in scenario 2. Player C, the cities, is the one that benefits less from cooperation with respect to what it could gain under non-cooperation because of its limited contribution to the cooperative game. Player C may consider defection from the grand coalition.

Among the irrigation districts, both players INE (EM, CJT, and ESC) and IE (ARJ and RB) increase benefits from cooperation. The gain achieved by IE and INE from cooperation are quite large under the second scenario (Figure 4).

The preferred cooperative institution for the players varies depending on the scenario and the climate conditions. Player C always prefers the Nash-Harsanyi institution, while Player E prefers mostly Nash-Harsanyi in scenario 1 and Shapley in scenario 2. The reason for these results lies in the calculation of the Nash-Harsanyi and Shapley institutions. The Nash-Harsanyi institution allocates an equal incremental gain to each player based on its original benefits under non-cooperation, irrespective of its contribution to the coalition. Player C does not contribute to coalitions but gains an equal share of benefits. Player E does not contribute either under scenario 1, but gets an equal share with Nash-Harsanyi. Player E prefers mostly Shapley under scenario 2, because it makes a contribution that is accounted for in the Shapley institution.

These empirical findings about the distribution of benefits from cooperation among the players and the preferred cooperative institutions for each player may be helpful in bargaining aimed at reaching an agreement to share water resources in the JRB under various scarcity scenarios.

The benefit allocations based on the Shapley and Nash-Harsanyi institutions for scenario 1 under different climate conditions satisfy only individual rationality, but not group rationality. These allocations are not in the core of the game, and they are not acceptable by the players. Therefore the Shapley and Nash-Harsanyi institutions are not stable, and players may consider defection from the grand coalition to create partial coalitions. The core conditions are satisfied for benefit allocations based on the Nucleolus institution, and they are acceptable to players in scenario 1.

In scenario 2, the benefit allocations based on the three cooperative institutions satisfy the core conditions, and since these allocations are in the core they are acceptable to all players.

The stability of the cooperative institutions is examined for scenario 2 using the power and stability indexes, which reveal the practical acceptability of institutions to players. Table 8 presents the power indexes and the stability indexes in scenario 2 for each cooperative institution and climate conditions.

The stability indexes show that the most stable cooperative institution is the Nash-Harsanyi for all climate conditions, although for a very severe drought scenario the Nucleolus achieves the same degree of stability as the Nash-Harsanyi. The least stable cooperative institution is the Nucleolus under normal flow, mild, and severe drought, and the Shapley is least stable under very severe drought. Scrutiny of the stability indexes suggests that the stability of the grand coalition increases as drought severity intensifies. This means that the severity of drought is an incentive to act cooperatively.

The power indexes of players under the Shapley institution indicate that player E (the Albufera wetland) has the highest propensity to cooperate and stay in the grand coalition under all climate conditions, while player C (the cities) has the lowest propensity to cooperate and may disrupt the grand coalition unless improving its allocation. Under the Nash-Harsanyi institution, the power is distributed equally among the players, which means that the grand coalition is more likely to be stable. The Nucleolus institution shows that players E, IE, and INE display a high propensity to cooperate.

Conclusions and policy implications

Water scarcity is increasing worldwide, becoming a widespread problem in many arid and semiarid regions, such as Southern Europe and the Mediterranean basin. Climate change is projected to further exacerbate water scarcity problems, by reducing water availability and increasing the frequency and intensity of extreme drought events. The mounting pressures on water resources from economic and population growth is degrading the resources and seriously damaging the water-dependent ecosystems. Under these circumstances, the efficient and fair allocation of water among users is becoming a major challenge for water authorities. New water allocation mechanisms based on the involvement of stakeholders are needed.

The objective of this paper was to empirically test the propensity of stakeholders to cooperate and the options for protecting ecosystems in arid and semiarid basins under water scarcity and drought. The analysis has been performed using an integrated river basin model coupled with game theory concepts. This model has been used for empirical water policy analysis in the Jucar River Basin (Spain), a typical highly stressed river basin in a semiarid region with acute water scarcity problems that are damaging valuable ecosystems.

Results indicate that drought damage costs in the Jucar River Basin range between 63 and 137 million € (11 to 25% of total benefits), and these negative impacts affect all water users in the basin. The impacts are especially strong for irrigated agriculture (10 to 30% of total benefits) and for the environment (more than 50% of total benefits).

The cooperation of stakeholders through the right institutional setting may reduce drought damage costs in the Jucar River Basin between 4 and 7 percent. When environmental damages are internalized through the direct diversion of water to the Albufera wetland the cooperative results are more appealing, reducing drought damage costs by 52 to 61 percent.

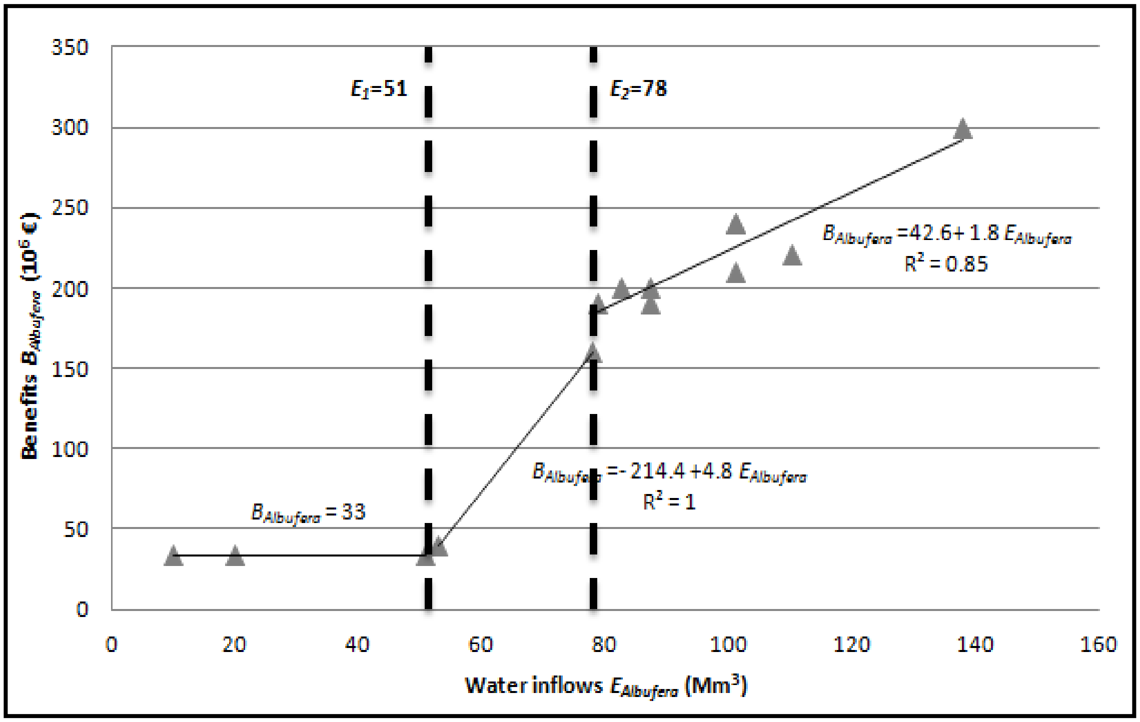
Cooperative water management may be challenging in practice because of the strategic behavior of stakeholders, the high transaction costs of organizing collective action, and the lack of information and knowledge available for the bargaining process. The basin authority can promote cooperative management by creating different incentives for cooperation, such as taxes and subsidies, diversion thresholds, monitoring mechanisms, and technical advice. The role of the basin authority is especially important in protecting ecosystems. Our empirical results indicate that cooperative management improves the economic benefits of water users but it may have little effect on ecosystems protection without other incentives or regulations.

The game theory institutions and stability indexes examined in this study are very useful in analyzing the acceptability and stability of cooperative arrangements. This type of information could be helpful to initiate a bargaining process aimed at reaching an agreement to share water resources in a river basin, and enhance private benefits and social welfare. Our empirical results suggest that cooperation in the Jucar River Basin is a feasible option among the irrigation districts and the Albufera wetland, and that the cities could be excluded from the game. Additionally, internalizing environmental damages could provide more stability to the cooperative arrangements. Also the stability of the cooperative arrangements increases as drought severity intensifies.

The results provide clear evidence that the various cooperative institutions have different outcomes in terms of their acceptability by the players and their stability. This finding has important policy implication because it demonstrates the difficulties in selecting a mix of policy instruments that could address scarcity, and mitigate the negative impacts of climate change-induced drought, and the risk of policy failure.

Appendix

Figure A1. Environmental benefit function of the Albufera wetland.



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Tables

Table 1. Water use by sector and source in the JRB in a normal flow year (Mm^3/year).

Source	Agriculture	Urban	Industrial	Total
Surface water	761	118	24	903
Groundwater	633	104	25	762
Reuse	11	0	1	12
Total	**1,405**	**222**	**50**	**1,677**

Source. CHJ 2009.

Table 2. The main water users in the JRB.

Water users	Water use (Mm^3/year)		
	Surface water	Groundwater	Total
City of Albacete	17	0	17
EM irrigation district	13	386	399
Nuclear central of Cofrentes	14	0	14
City of Valencia	95	0	95
City of Sagunto	8	0	8
CJT irrigation district	70	91	161
ARJ irrigation district	213	0	213
ESC irrigation district	38	0	38
RB irrigation district	254	0	254
Total	**722**	**477**	**1,199**
Other uses	193	285	478
Total JRB	**915**	**762**	**1,677**

Source. CHJ 2009, Expert consultation.

Table 3. Parameters of the JRB model.

Parameters	**Value**	**Unit**
Total irrigated area	157,000	ha
Cereals area	70,650	ha
Vegetables area	21,980	ha
Fruit trees area	64,370	ha
Flood irrigation area	28,260	ha
Sprinkler irrigation area	58,090	ha
Drip irrigation area	70,650	ha
Average irrigation water price	0.05	€/m^3
Average urban water price	0.71	€/m^3
Share of return flows feeding the Albufera:		
ARJ (α)	28	%
RB (β)	23	%
Benefit function of the Albufera from water inflows:		
Intercept (δ_1)	33	10^6 €
First threshold of inflows to the Albufera (E_1)	51	Mm^3
Intercept (δ_2)	-214	10^6 €
Slope (ρ_2)	4.8	€/m^3
Second threshold of inflows to the Albufera (E_2)	78	Mm^3
Intercept (δ_3)	43	10^6 €
Slope (ρ_3)	1.8	€/m^3
Economic value of the Albufera wetland	13,600	€/ha
Water transfer payment (ω)	0.19	€/m^3

Table 4. Benefits under the baseline scenario for different climate conditions (10^6 €).

Users	**Normal flow**	**Mild drought**	**Severe drought**	**Very severe drought**
EM	79.8	71.9	66.4	60.7
CJT	44.9	40.6	37.2	35.7
ARJ	34.1	31.0	27.0	22.9
ESC	7.3	6.8	5.7	4.2
RB	24.2	20.7	16.5	12.1
Irrigation sector	**190.3**	**170.9**	**152.8**	**135.6**
Valencia	216.3	214.0	206.6	186.9
Sagunto	26.1	24.1	22.2	16.8
Albacete	40.2	38.9	38.8	38.6
Urban sector	**282.6**	**277.0**	**267.6**	**242.3**
Albufera wetland	**74.7**	**37.2**	**33.0**	**33.0**
Total JRB	**547.7**	**485.1**	**453.4**	**410.9**

Table 5. Water use under the baseline scenario for different climate conditions (Mm^3).

Users	**Normal flow**			**Mild drought**			**Severe drought**			**Very severe drought**		
	SW	**GW**	**Total**	**SW**	**GW**	**Total**	**SW**	**GW**	**Total**	**SW**	**GW**	**Total**
EM	13	386	399	9	350	359	5	327	332	1	303	304
CJT	64	91	155	36	96	132	16	99	115	6	101	107
ARJ	200	0	200	174	6	180	145	10	155	116	14	130
ESC	33	0	33	28	2	30	22	3	25	15	3	18
RB	243	0	243	206	1	207	164	3	167	119	4	123
Irrigation sector	**553**	**477**	**1,030**	**453**	**455**	**908**	**352**	**442**	**794**	**257**	**425**	**682**
Valencia	94	0	94	81	0	81	67	0	67	53	0	53
Sagunto	8	0	8	7	0	7	6	0	6	4	0	4
Albacete	17	0	17	14	3	17	12	5	17	9	8	17
Urban sector	**119**	**0**	**119**	**102**	**3**	**105**	**85**	**5**	**90**	**66**	**8**	**74**
Albufera wetland	**-**	**-**	**60**	**-**	**-**	**52**	**-**	**-**	**43**	**-**	**-**	**34**
Total JRB	**672**	**477**	**1,149**	**555**	**458**	**1,013**	**437**	**447**	**884**	**323**	**433**	**756**

Note. SW: surface water; GW: groundwater. Total water use in the JRB is the sum of water use in the irrigation and urban sectors, and does not include water return flowing to the Albufera wetland.

Table 6. Results of the characteristic functions under different coalitional arrangements and climate conditions in scenario1 (10^6 €).

Coalitional arrangements	**Players**	**Normal flow**	**Mild drought**	**Severe drought**	**Very severe drought**
Non-cooperation	{INE}	132.0	119.2	109.3	100.5
	{IE}	58.3	51.7	43.5	35.0
	{C}	282.6	277.0	267.6	242.3
	{E}	74.7	37.2	33.0	33.0
	Total	**547.7**	**485.1**	**453.4**	**410.9**
Partial cooperation	{INE,IE}	190.6	181.9	170.3	150.2
	{C}	282.7	277.0	267.6	242.3
	{E}	74.5	33.0	33.0	33.0
	Total	**547.8**	**491.9**	**470.9**	**425.5**
Partial cooperation	{INE,C}	414.8	398.4	379.0	344.1
	{IE}	58.3	51.7	43.5	35.0
	{E}	74.7	37.2	33.0	33.0
	Total	**547.8**	**487.3**	**455.5**	**412.1**
Partial cooperation	{INE,E}	206.8	158.6	144.4	134.8
	{IE}	58.3	51.7	43.5	35.0
	{C}	282.6	277.0	267.6	242.3
	Total	**547.7**	**487.3**	**455.5**	**412.1**
Partial cooperation	{IE,C}	341.1	330.0	314.2	282.2
	{INE}	149.1	119.2	109.3	100.5
	{E}	74.8	40.8	33.0	33.0
	Total	**565.0**	**490.0**	**456.5**	**415.7**
Partial cooperation	{IE,E}	133.5	94.0	76.6	68.1
	{C}	282.6	277.0	267.6	242.3
	{INE}	132.0	119.2	109.3	100.5
	Total	**548.1**	**490.2**	**453.5**	**410.9**
Partial cooperation	{C,E}	357.4	314.2	300.6	275.3
	{INE}	132.0	119.2	109.3	100.5
	{IE}	58.3	51.7	43.5	35.0
	Total	**547.7**	**485.1**	**453.4**	**410.8**
Partial cooperation	{INE,IE,C}	473.3	459.5	441.5	394.3
	{E}	74.5	33.0	33.0	33.0
	Total	**547.8**	**492.5**	**474.5**	**427.3**
Partial cooperation	{INE,IE,E}	299.8	240.8	203.3	183.2
	{C}	282.6	277.0	267.6	242.3
	Total	**582.4**	**517.8**	**470.9**	**425.5**
Partial cooperation	{INE,C,E}	489.5	435.6	412.0	377.1
	{IE}	58.3	51.7	43.5	35.0
	Total	**547.8**	**487.3**	**455.5**	**412.1**
Partial cooperation	{E,C,IE}	416.1	370.9	347.2	315.2
	{INE}	132.0	119.2	109.3	100.5
	Total	**548.1**	**490.1**	**456.5**	**415.7**
Full cooperation	**{INE,IE,C,E}**	**582.4** (6%)	**517.8** (7%)	**474.5** (5%)	**427.3** (4%)

Note: The percentage gain in benefits between full cooperation and non-cooperation is given in parenthesis.

Table 7. Results of the characteristic functions under different coalitional arrangements and climate conditions in scenario 2 (10^6 €).

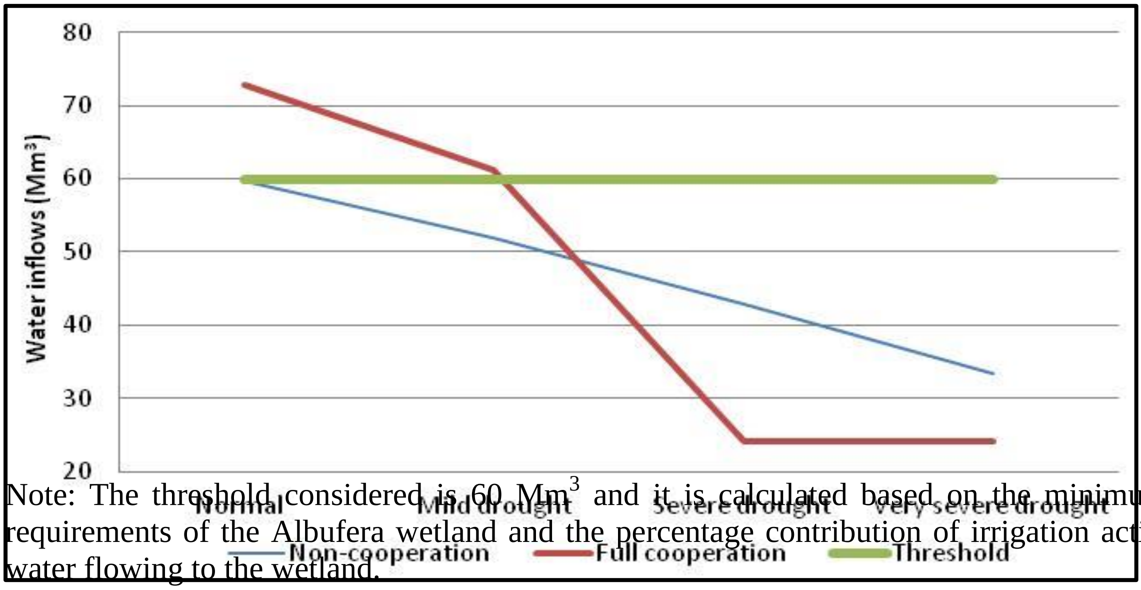
Coalitional arrangements	**Players**	**Normal**	**Mild drought**	**Severe drought**	**Very severe drought**
Non-cooperation	{INE}	132.0	119.2	109.3	100.5
	{IE}	58.3	51.7	43.5	35.0
	{C}	282.6	277.0	267.6	242.3
	{E}	74.7	37.2	33.0	33.0
	Total	**547.7**	**485.1**	**453.4**	**410.9**
Partial cooperation	{INE,IE}	190.6	181.9	170.3	150.2
	{C}	282.7	277.0	267.6	242.3
	{E}	74.5	33.0	33.0	33.0
	Total	**547.8**	**491.9**	**470.9**	**425.5**
Partial cooperation	{INE,C}	414.8	398.4	379.0	344.1
	{IE}	58.3	51.7	43.5	35.0
	{E}	74.7	37.2	33.0	33.0
	Total	**547.8**	**487.3**	**455.5**	**412.1**
Partial cooperation	{INE,E}	389.6	312.3	190.0	134.8
	{IE}	58.3	51.7	43.5	35.0
	{C}	282.6	277.0	267.6	242.3
	Total	**730.5**	**641.0**	**501.1**	**412.1**
Partial cooperation	{IE,C}	341.1	330.0	314.2	282.2
	{INE}	132.0	119.2	109.3	100.5
	{E}	74.8	40.8	33.0	33.0
	Total	**547.9**	**490.0**	**456.5**	**415.7**
Partial cooperation	{IE,E}	166.7	157.5	79.1	68.1
	{C}	282.6	277.0	267.6	242.3
	{INE}	132.0	119.2	109.3	100.5
	Total	**581.3**	**553.7**	**456.0**	**410.9**
Partial cooperation	{C,E}	358.6	314.2	300.6	275.3
	{INE}	132.0	119.2	109.3	100.5
	{IE}	58.3	51.7	43.5	35.0
	Total	**548.9**	**485.1**	**453.4**	**410.8**
Partial cooperation	{INE,IE,C}	473.3	459.5	441.5	394.3
	{E}	74.5	33.0	33.0	33.0
	Total	**547.8**	**492.5**	**474.5**	**427.3**
Partial cooperation	{INE,IE,E}	459.7	449.5	353.1	283.4
	{C}	282.6	277.0	267.6	242.3
	Total	**742.3**	**726.5**	**620.7**	**525.7**
Partial cooperation	{INE,C,E}	672.3	636.9	540.7	386.5
	{IE}	58.3	51.7	43.5	35.0
	Total	**730.6**	**688.6**	**584.2**	**421.5**
Partial cooperation	{E,C,IE}	449.3	439.4	422.6	389.5
	{INE}	132.0	119.2	109.3	100.5
	Total	**581.3**	**558.6**	**531.9**	**490.0**
Full cooperation	**{INE,IE,C,E}**	**742.3** (36%)	**735.0** (52%)	**710.1** (57%)	**659.6** (61%)

Note: The percentage gain in benefits between full cooperation and non-cooperation is given in parenthesis.

Table 8. Power and stability indexes in scenario 2.

Cooperative institution	**Power indexes of players (θ_l)**				**Stability index $\bar{\boldsymbol{\theta}}$**
	INE	IE	C	E	
Normal Flow					
Shapley	0.43	0.05	0.00	0.52	1.05
Nash-Harsanyi	0.25	0.25	0.25	0.25	0.00
Nucleolus	0.00	0.00	0.00	1.00	1.99
Mild drought					
Shapley	0.36	0.13	0.03	0.48	0.83
Nash-Harsanyi	0.25	0.25	0.25	0.25	0.00
Nucleolus	0.69	0.17	0.02	0.13	1.20
Severe drought					
Shapley	0.30	0.20	0.14	0.36	0.39
Nash-Harsanyi	0.25	0.25	0.25	0.25	0.00
Nucleolus	0.48	0.17	0.17	0.17	0.61
Very severe drought					
Shapley	0.22	0.32	0.17	0.30	0.27
Nash-Harsanyi	0.25	0.25	0.25	0.25	0.00
Nucleolus	0.25	0.25	0.25	0.25	0.00

Figures



Note: The threshold considered is 60 Mm^3 and it is calculated based on the minimum water requirements of the Albufera wetland and the percentage contribution of irrigation activities to water flowing to the wetland.

Figure 1. Water inflows to the Albufera wetland under different coalitional arrangements and climate conditions in scenario 1.

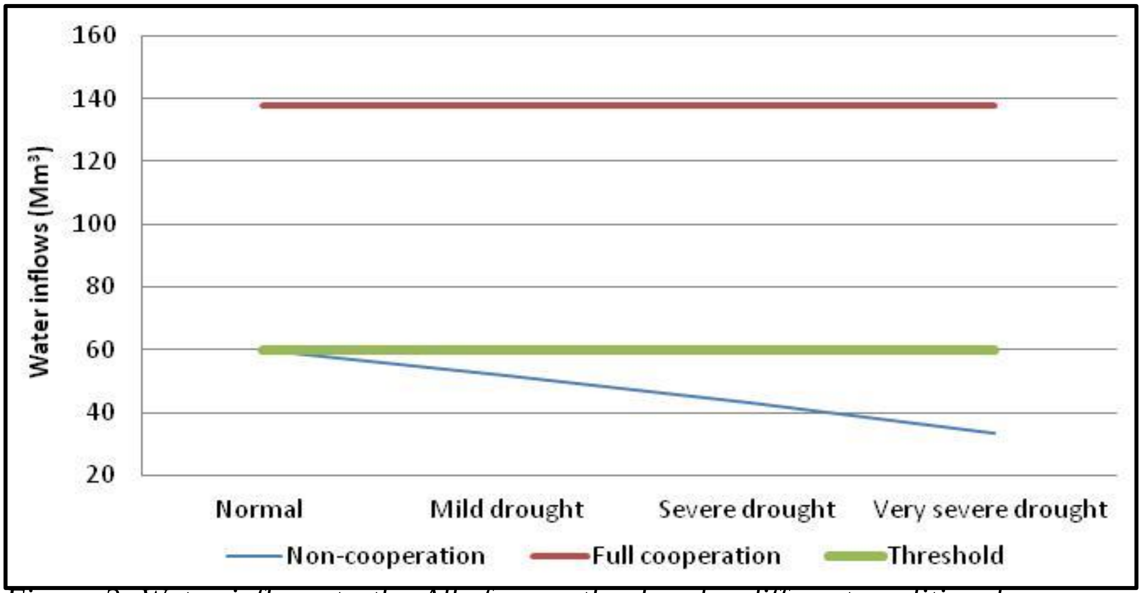
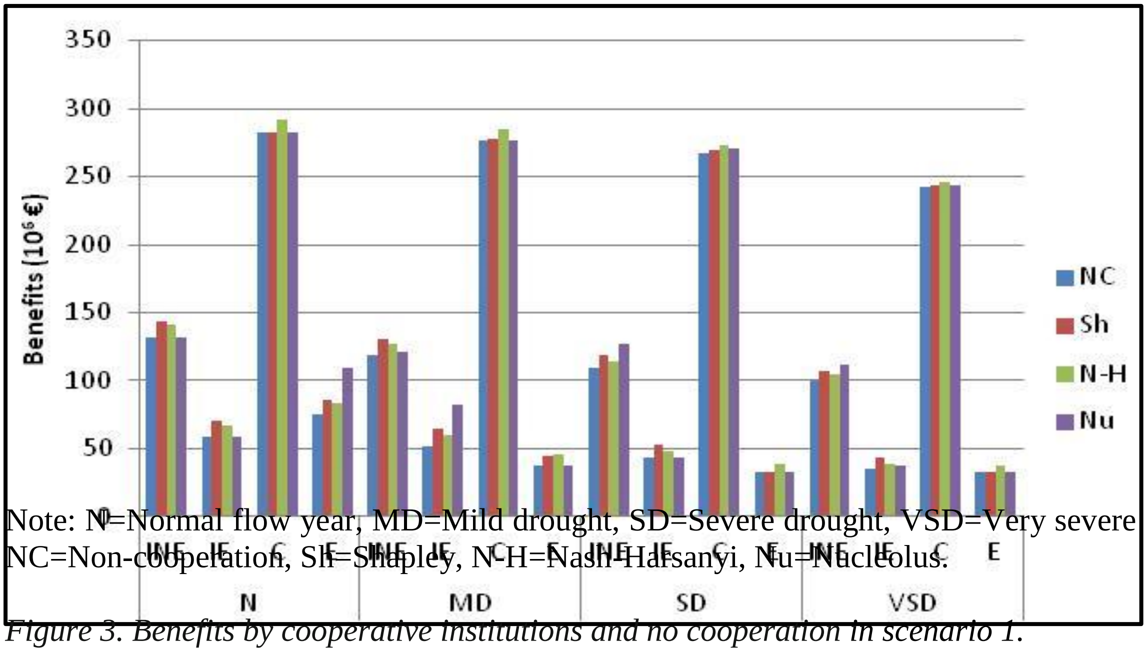


Figure 2. Water inflows to the Albufera wetland under different coalitional arrangements and climate conditions in scenario 2.



Note: N=Normal flow year, MD=Mild drought, SD=Severe drought, VSD=Very severe drought. NC=Non-cooperation, Sh=Shapley, N-H=Nash-Harsanyi, Nu=Nucleolus.

Figure 3. Benefits by cooperative institutions and no cooperation in scenario 1.

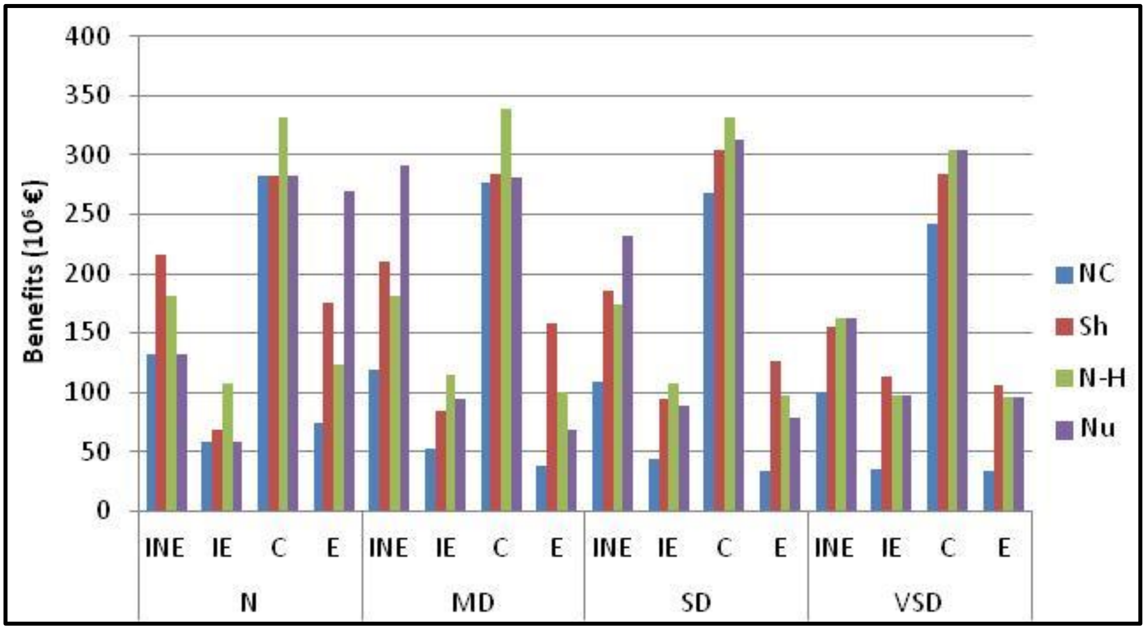


Figure 4. Benefits by cooperative institutions and no cooperation in scenario 2.