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Cooperative water-sharing agreements between highlands and drylands: the Tambo-Santiago-Ica river basin in Peru

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ABSTRACT

Inefficient water allocations in river basins limit economic benefits and feed conflicts. We study how institutional change triggered by investments and new technologies can improve water-use efficiency and mitigate conflicts. We develop a bargaining framework to analyse the Peruvian Tambo–Santiago–Ica river basin, which has important economic and social inequalities. We model agents' welfare changes when joint investments are implemented that are instrumental in overcoming conflict. While upstream communities are poor and rely on rainfed agriculture and cattle-raising, downstream agricultural producers are well-off and produce high-value crops. We find that joint investments can increase both regions' payoffs and gains from cooperation can be strengthened by side-payments.

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Introduction

This paper analyses how water users' welfare levels change when infrastructure investments are designed to foster cooperation. Water-sharing remains a challenge in the 21st century despite efforts to resolve conflicts. Growing population and economic development leading to increasing water demand are drivers of water conflicts. Moreover, climate variability threatens water supply (Dinar, 2015; Rahman et al., 2019). Therefore, water infrastructure investments are growing to satisfy water demand. Infrastructure investments have different impacts according to regions' economic, social, ecological and institutional characteristics. They can affect the hydrological system, increase a river basin's vulnerability to climate change and lead to conflicts (Qin et al., 2019; De Stefano et al., 2017). Conflicts are common in transboundary river basins. There are 310 international river basins, according to the updated Transboundary Freshwater Dispute Database, home to 52% of world's population (McCracken & Wolf, 2019). The main regions affected by water conflicts are Sub-Saharan Africa and Southern Asia, where 32% of the world water conflicts are located (Pacific Institute, 2020).

However, the flipside is that conflicts provide an opportunity for cooperation based on benefits and cost-sharing arrangements (Ansink & Houba, 2015; Grünwald et al., 2020; Li et al., 2019; Petersen-Perlman et al., 2017). Effective cooperation requires strong and

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reliable institutions to support the fulfilment of the agreement (Ansink et al., 2017; Houba et al., 2013; Parrachino et al., 2006). Institutions can support economic improvements as well as agents' equitable access to benefits by reducing transaction costs and providing information to minimize uncertainty (Arjoon et al., 2016; Jaeger, 2015).

Unsolved water-sharing problems affect agents' welfare from a perspective of efficiency and equity (Arjoon et al., 2016; Hu et al., 2016; Qin et al., 2019). Many sharing problems include externalities as a source of conflict. Policies addressing only economic efficiency may not curb conflict, while addressing distribution and bargaining power can improve equity (Hu et al., 2016; Mehrparvar et al., 2016; Qin et al., 2020).

Cooperative game theory has provided a framework for facilitating agents' change of behaviour from conflict to cooperation (Dinar et al., 1992; Dinar & Wolf, 1997; Ambec & Ehlers, 2008; Houba et al., 2013; Mianabadi et al., 2014; Ansink & Houba, 2015; Arjoon et al., 2016; Qin et al., 2019). Different solutions, such as bankruptcy rules, Nash Bargaining Solution (NBS) or the Kalai–Smorodinsky solution (KS) have been applied to water-sharing problems. Among those, NBS is most frequently used. It defines a way to uniquely divide the gains from cooperation and can explain water allocation in transboundary river basins with unequal bargaining power due to economic, social or political differences (Houba et al., 2013; Qin et al., 2019). Houba et al. (2013) describe the relationship between institutional strength and welfare applying NBS to the Mekong river basin. They compare the welfare effects of strengthening the governance of the Mekong River Commission, which includes only the lower basin countries, with the joint management of the entire river basin, including China. They conclude that Lower Mekong Basin countries can increase their welfare by strengthening the Mekong River Commission because strong governance increases water use efficiency.

While the NBS is useful and widely applied, it may be less convincing when new opportunities become available. For instance, under NBS, when gains from cooperation appear sequentially, an agent may be worse off after an increase of the potential benefits, that is, after an enlargement of the bargaining set. Therefore, we suggest considering Kalai and Smorodinsky's (1975) solution and compare the benefits derived from improved opportunities under each solution. While our case study is an example where both agents would become better off when new opportunities for welfare arise, still NBS and KS differ. Given the asymmetries in the river basin, we introduce side-payments to facilitate stability and equity of the agreement. Side-payments are a tool for transferring gains from cooperation from one agent to the other.

Efficiency and equity are needed for solving the water-sharing problem. While equity, fairness and distributive justice have their particular definitions, we do not consider them as distinct for the purpose of this paper. Ansink and Houba (2015) argue that equity provides stability to an agreement, while Gauthier (1978) and Weikard (1994) discuss how fairness relates to mutual advantage for the agents involved. Roemer (1986) points out that bargaining theory considers the utilities of the agents after a threat point is defined, while distributive justice is concerned more fundamentally with rights, needs and preferences. Water-sharing agreements need to consider equity, mainly when the context and social and economic differences among the agents are relevant in order to provide stability to the agreement (Arjoon et al., 2016; Atwi & Chóliz, 2011; Dinar & Wolf, 1997; Kalai, 2007).

This paper focuses on the interactions between agents located in highlands (upstream) and drylands (downstream). Water allocation between highlands and drylands has gained importance since increasing demand by multiple water users lead to increasing externalities and conflicts. The construction of dams for hydropower or irrigation systems in the highlands have changed access to water. The highlands are also an important source of recharge for downstream aquifers. For example, in North West China, the water run-off from highland rivers accounts for up to 80% of the total groundwater recharge (FAO et al., 2011). Dryland ecosystems cover 41% of the world's terrestrial surface and 44% of cultivated systems. Increasing water demand in drylands has been facilitated by infrastructure investments such as dams and boreholes to increase water supply (Boelee et al., 2013; Jackson et al., 2001; Safriel & Adeel, 2005). Furthermore, highlands and drylands not only interact as ecosystems but also are vulnerable to climate change and pressures from increasing population and economic development (Bates et al., 2008; Davies et al., 2016; FAO et al., 2011; Magrin & Marengo, 2014).

The objective of the present paper is to analyse how joint infrastructure investments can improve cooperation, water efficiency and welfare. For this purpose, the case study highlights elements such as water and technological constraints in each region and the water institutional changes that facilitate joint investments, strengthening cooperation.

Building on previous theoretical work that uses bargaining models to solve river-sharing problems (Atwi & Chóliz, 2011; Houba et al., 2013), this paper explains the bargaining situation by historical, hydrological, institutional and economic facts which are observed in the case study. We amend the standard model to analyse bargaining over water, tailoring it to include the specific hydrological characteristics of this case study and highlighting the importance of the water institutional framework to reach a cooperative situation. Our case study illustrates how investments increase the welfare of both agents. Our case is the Tambo–Santiago–Ica river basin in Perú with the highlands of Huancavelica department and the drylands of Ica department. In our particular setting the highland–dryland interaction is characterized by rain-fed small-scale agricultural production with cattle-raising upstream and export-oriented high-value agricultural production downstream using irrigation to support higher productivity. This situation defines particular features of the bargaining situation. Coordinated infrastructure investments that benefit both regions fosters cooperation through increased water access year-round for upstream producers and improved aquifer recharge for downstream irrigated agriculture.

Our case study motivates the development of a more general framework. At the same time it serves as a 'proof of concept'. On the theory side, we build new features into a cooperative bargaining game, relevant for regions where technological constraints, water constraints and water conflicts are common. The case highlights the need for an adequate institutional water framework to promote coordinated investments.

The remainder of the paper is structured as follows. The next section presents a literature review. The third section explains the materials and methods used to develop the case study. The fourth section explains the main economic, social and institutional characteristics of the case study area. The fifth section develops a bargaining model which is applied to the case study. The sixth section discusses the results and concludes.

Conflicts, negotiation and bargaining

Water conflicts are likely to continue in the future because of increasing water demand (Kaufman et al., 2014). The water-sharing problem is multidisciplinary, including geographical, hydrological, socio-economic and institutional factors. Here we focus on the latter two and do so from a game-theoretic angle in order to structure the strategic interaction between agents.

The remainder of this section considers three phases of conflict resolution: conflicts, negotiation and bargaining.

Conflicts

Conflicts over water arise when agents seek control over water disregarding the following factors: (1) the degree of scarcity or misallocation of water among users; (2) the interdependence of regions regarding common water resources and particularly an upstream–downstream relationship; (3) the historical context of water ownership between regions; (4) whether a protracted conflict underlies the water dispute; (5) the existence of alternative sources of water or options for a negotiated agreement; and (6) the relative power of the parties (Dinar et al., 2013; Petersen-Perlman et al., 2017; Wolf, 1998). Water is a resource with particular features such as: (1) public and private goods characteristics; (2) being a flow; (3) being variable in space and time; and (4) its importance for production and consumption (Ansink & Houba, 2015).

Recent contributions introduce agents' location to analyse water conflicts and negative externalities (Ambec & Sprumont, 2002; Ambec & Ehlers, 2008; Just & Netanyahu, 1998; Ansink & Houba, 2015). Therefore, identifying the conflict requires understanding the geographical and historical relationships between upstream and downstream in a river basin (De Stefano et al., 2017). Unilateral decisions without considering previous interactions may generate negative externalities and inequity conditions in the river basin, but are often adopted to impose threats and seek advantage in later negotiations (Dinar et al., 2013; Dinar & Wolf, 1997; Mehrparvar et al., 2016; De Stefano et al., 2017; Wolf, 1998).

Negotiation

Conflicts and cooperation have different time patterns. Conflicts may emerge at any time while establishing cooperation requires a negotiation process. The negotiation process is driven by internal and external factors. The internal factors refer to agents' preferences that reflect agents' interests, alternatives to negotiate an agreement and approaches to manage the conflict. The external factors comprise economic, political, geographical and environmental interdependences. In a negotiation process third parties' participation can facilitate conflict resolution (Kimbrough et al., 2020) or get in its way (Ansink & Weikard, 2009).

A negotiation process entails transaction costs related to time and resources allocated to gathering information, monitoring and enforcement (Ansink & Houba, 2015; De Bruyne & Fischhendler, 2013). However, the process engages the agents to develop an understanding of their interdependencies and of each other's preferences through interactions. Negotiations prepare the ground for cooperation which, in turn, can generate further benefits. We approach the distribution of these benefits as a cooperative bargaining game.

Bargaining

Reaping the gains from cooperation may not be easy as the distribution of the gains can become a new source of conflict. Ansink et al. (2017) find that strong free rider incentives may block cooperation leaving potential gains unexploited when there are more than three agents. However, coordinated investments can incentivize cooperation, facilitating efficient and equitable solutions for water allocation problems (Dinar, 2001). Nash (1950) frames the bargaining problem as an opportunity for collaboration between agents for mutual benefit. Bargaining models analyse the water-sharing problem using different solutions. For instance, Ansink and Weikard (2012) introduce sequential sharing rules for water allocation when agents are ordered from upstream to downstream and have resource endowments and claims to water. They point out that agents' positions and endowments are critical for the solution. In a similar framework Mianabadi et al. (2014) suggest a rule to distribute water deficits. Mehrparvar et al. (2016) consider benefits reallocation among water users to enhance cooperation and apply different solution concepts.

The NBS has been widely applied to analyse water-sharing problems. It suggests sharing benefits such that the product of the individual gains is maximized. Despite its widespread use, it may not seem to be convincing in some circumstances where gains from cooperation become available sequentially. NBS violates a monotonicity property that requires that no agent becomes worse off when the bargaining set, that is, the set of feasible options, increases. NBS leads to different outcomes when we compare the immediate distribution of a prize X with the sequential distribution of X_1 and X_2 with $X_1 + X_2 = X$, that is, when the prize becomes available in two steps. Intuitively, we require a bargaining solution that is consistent in the sense that it would not depend on whether or not the prize is paid in instalments. To meet such requirement, Kalai and Smorodinsky (1975) suggest an alternative to NBS that satisfies the monotonicity condition as long as the agents' aspiration levels (i.e. what an agent can maximally expect to get) remain constant. The Kalai–Smorodinski solution (KS) suggests sharing the benefits of cooperation proportional to aspiration levels. The monotonicity property can be interpreted as a minimum equity condition.

Atwi and Chóliz (2011) consider a two-player game for the Jordan river basin and estimate that cooperation increases welfare by 20% compared with the status quo. They apply the NBS and KS solution and include the option of side-payments, that is, monetary transfers between the agents, which further improves efficiency but also affects the distribution of the cooperative gains.

Infrastructure development enhances benefits, facilitates sharing and may contribute to equitable solutions. For instance, Li et al. (2019) study how to share water benefits associated to future water infrastructure (reservoirs, dams), among five stakeholders (China, Laos, Vietnam, Thailand and Cambodia) in the Lancang–Mekong basin. The authors conclude that future damming plans will enhance cooperation in the river basin and additional benefits would be particularly high in the dry season. Cooperation requires compensation for China and Laos to operate their reservoirs to benefit downstream agents, reallocating the incremental benefits from cooperation in the river basin. Moreover, infrastructure investments such as dams or irrigation systems designed to increase economic benefits can enhance cooperation, mainly through issue linkage. Dinar (2001) analyses a problem of optimal size of a joint facility combined with benefit and cost sharing using NBS. In summary, infrastructure investments can be instrumental for enhancing cooperation.

The literature on water-sharing highlights the importance of equity in the water allocation solution (Ansink & Houba, 2015; Arjoon et al., 2016; Atwi & Chóliz, 2011), however there are concerns about how it is conceptualized. It is agreed that an equitable or fair allocation does not refer to equal allocation. Equitable water allocation is more related to the right to access shared water considering needs. To assess equity, stakeholder participation seems crucial for addressing local river basin conditions (Arjoon et al., 2016; Qin et al., 2020). From a conceptual perspective, however, distributional properties of the benefits derived from water use offer relevant assessment criteria (Ansink & Weikard, 2015). Equitable water-sharing is relevant in order to assure stability of the water allocation agreed among water users.

In summary, bargaining games have provided solutions to water-sharing problems, offering a perspective on how to overcome conflicts and foster cooperation. In this context, we analyse how joint investments create opportunities for cooperation to the benefit of the agents in a river basin.

Materials and method

The objective of the paper is to analyse how joint investments can improve cooperation, water-efficiency and welfare in the Tambo–Santiago–Ica river basin located in Perú. For this purpose, a case study was used to highlight institutional changes in the river basin that have facilitated cooperation as well as water and technological constraints. Secondary data and technical reports were used to document our case. The main sources of information were reports by the Ministry of Agricultural Development and Irrigation, the National Water Authority (ANA) and the National Institute of Statistics and Informatics (INEI) (see Table A1 in Appendix A in the supplemental data).

The Tambo–Santiago–Ica river basin illustrates a water conflict where many stakeholders are involved (Ministerio del Ambiente (MINAM), 2020) displaying extreme socioeconomic asymmetries. Therefore, for a deeper understanding of the problem, we complement the secondary information with expert interviews. The interviewees were representatives of both public and private sector. Interviewees selection was based on a set of criteria. At least one of the following criteria was required to be met: (1) involved in the negotiation process; scientific or practical experience on (2) water management, (3) asparagus production, (4) alpaca-raising and pasture productivity, and (5) ecosystem development in the river basin. The list of interviewees is reported in Table A2 in Appendix A in the supplemental data.

To analyse how infrastructure can enhance cooperation and welfare, NBS and KS solution are applied. It is assumed that each region produces only one product, which is alpaca fibre by communities upstream and asparagus by producers downstream. We calibrate production functions depending on water use for alpaca and asparagus producers. For this purpose, data related to prices, production volume, yields, production cost are gathered from secondary sources and complemented by interviewees information (for details, see Tables A3 and A4 in Appendix A in the supplemental data).

The Tambo–Santiago–Ica river basin

River basin characteristics

The Tambo–Santiago–Ica river basin is located in southern Perú and covers 7300 km^2. Its geographical altitude ranges between 300 and 4625 masl (MINAM, 2020). Two provinces share the water: Huaytara province in Huancavelica department and Ica province in Ica department (Figure 1).

This bi-regional river basin comprises highlands and drylands. In the highlands, the hydrological system is characterized by lagoons, Andean wetlands and rivers which

Figure 1. Tambo–Santiago–Ica river basin map, Perú and South America.
Source: Adapted from Ministerio del Ambiente (MINAM) (2020, p. 18).

provide surface water for upstream and downstream. The Andean wetlands are an important ecosystem as they contribute to hydrologic regulation services and serve as habitat for different types of vegetation besides being a source of water (The International Union for Conservation of Nature (IUCN) & World Wide Fund for Nature (WWF), 2006). Farmland is limited in the highlands. In Huancavelica department, 56% of total land available is not suitable for productive use because of steep slopes or deficient soil quality. Further, 24% of the land is suitable for pastures; the remaining is for forestry (16%) and agriculture (4%). Upstream producers face technology and water constraints. Technology constraints are due to a lack of infrastructure to store water and of adequate irrigation systems. As a result, water constraints affect agricultural production and cattle raising during the dry season (Ministerio de Desarrollo Agrario y Riego (MIDAGRI) & Gobierno Regional de Huancavelica (GORE Huancavelica), 2008).

Downstream, drylands are dominated by desert and some small valleys (Gobierno Regional de Ica (GORE Ica), 2018). The desert has changed to intensive agricultural production over the last two decades. Agricultural producers increased the cultivated area (mainly asparagus). In Ica department, between 2000 and 2018 the asparagus area grew by 3.3% annually from 8269 ha in 2000 to 14,821 ha in 2018, while yield grew by 2.3% annually (Ministerio de Desarrollo Agrario y Riego (MIDAGRI), 2010, 2018). Nowadays, there is a portfolio of agri-exports such as grapes, avocados and mandarins, among others. There are three water sources for agriculture in the drylands: Ica River, groundwater and the Choclococha system which is a public infrastructure to transfer water from Huancavelica to Ica during the dry season.

There are significant social and economic differences between the regions. Social differences are related to population size, poverty and access to social services. Downstream generates 94% of the total gross domestic product (GDP) in the river basin and concentrates 92% of the population (Seminario & Palomino, 2022). Upstream, in Huaytara, the population decreased by 0.9% annually between 1993 and 2019; a reduction from 23,319 to 18,529 inhabitants. In contrast, in Ica province, the population increased 2.2% annually in the same period, from 244,741 to 433,860 inhabitants (Instituto Nacional de Estadística e Informática (INEI), 2019). Regarding poverty, in Huancavelica, 70% of the population is poor, while in Ica the rate is 10% (INEI, 2017). Freshwater and energy access are also limited. In Huaytara only 22% of households have access to freshwater by indoor pipes, while in Ica it is 69% (see Table A5 in Appendix A in the supplemental data).

Economic differences are related to the size of the agricultural production units, technology and market participation. Huaytara comprises 29 communities, out of 640 in the department. Communities have historical communal land rights and preserve cultural values. Communities depend on rainfall to rear alpacas and sheep and grow some crops for self-consumption (i.e. potatoes and beans). Alpaca fibre is the main source of income and it is sold without classification to the textile industry. Alpacas are raised in a traditional system, feeding mainly on natural pastures with low productivity (GORE Huancavelica & MINAM, 2018). Lack of water hampers the development of cultivated pastures, which, in turn, limits alpacas' weight as well as fibre length and volume (Fernandez et al., 2016) (see Table A2 in Appendix A in the supplemental data). Perú is the dominant alpaca fibre producer in the world and Huancavelica represents 2.3% of the national alpaca fibre production. Additionally, well-managed pastures also contribute to improve water

Table 1. Irrigated area in Ica province by water source.

Water source	1994	2012
Only river	38%	14%
Only groundwater (borewells)	27%	58%
River and groundwater	9%	11%
Only lagoons ('*pozas*')	5%	8%
Other combinations	21%	5%
Others	–	4%

Sources: Instituto Nacional de Estadística e Informática (INEI) (1994, 2012). Information is according to latest available agricultural census.

catchment, infiltration and water recharge, sedimentation control, climatic and hydrologic regulation. However, pastures are sensitive to droughts and irregular rainfall. Currently, the lack of infrastructure investments in small reservoirs and water harvesting systems limit pasture development (GORE Huancavelica & MINAM, 2018).

Ica province comprises 35% of the department's farmland. There are two types of agricultural producers: (1) small–medium producers and (2) large-scale producers mainly agri-exporters. The small–medium producers use surface water. They use *pozas*, small ponds, to store water during the rainy season for use in the dry season; traditional gravity irrigation systems are used for agricultural production. However, some medium asparagus producers also have borewells to extract groundwater. The agri-exporters cover 88% of the province's farmland. They use mainly groundwater for crops (asparagus, grapes, avocado) with hi-tech irrigation systems. Groundwater has sustained agricultural area growth. From the total irrigated area, groundwater irrigated area increased from 27% in 1994 and to 58% in 2012 (Table 1) (INEI, 1994, 2012). Irrigation efficiency varies according to farm size, water source and technology. For instance, water efficiency of drip systems is 90% while it is 60% for gravity systems using surface water (Correa-Cano et al., 2022).

Water deficit is a critical issue in Ica. The Ica River has two seasons: rainy and dry. The rainy season lasts from January to March where 90% of the total annual precipitation falls. The heavy rains are in February and March (GORE Ica, 2018). The dry season spans from April to December and accounts for the remaining 10% of rainfall (Instituto Nacional de Recursos Naturales (INRENA), 2003).

Growing asparagus production, as well as other agri-export crops (e.g. grapes) have increased groundwater extraction, threatening Ica's aquifer sustainability and agricultural production. Since 1970, technical reports have pointed to the aquifer's overexploitation. To reduce aquifer overexploitation, a ban on new boreholes was introduced to improve groundwater management. Still, due to lack of monitoring, the number of borewells increased. There is an overexploitation of the aquifer, with an extraction of 232 million cubic metres (mcm) annually while the annual natural recharge is 179 mcm. ANA estimates that the aquifer descends 0.6 m every year. For that reason, the ban on new borewells still remains. The aquifer recharge depends on the water availability coming from rivers Tambo and Santiago in Huancavelica, that feed the Ica River and comprise 57% of the recharge. The other recharge sources are water conduction loss in the irrigation systems (11%) and return flows from irrigation (32%). The larger part of the aquifer recharge (70%) happens from December to April (Autoridad Nacional del Agua (ANA) & Ministerio de Agricultura y Riego (MINAGRI), 2017) (see Figure 2 for an overview of the water system).

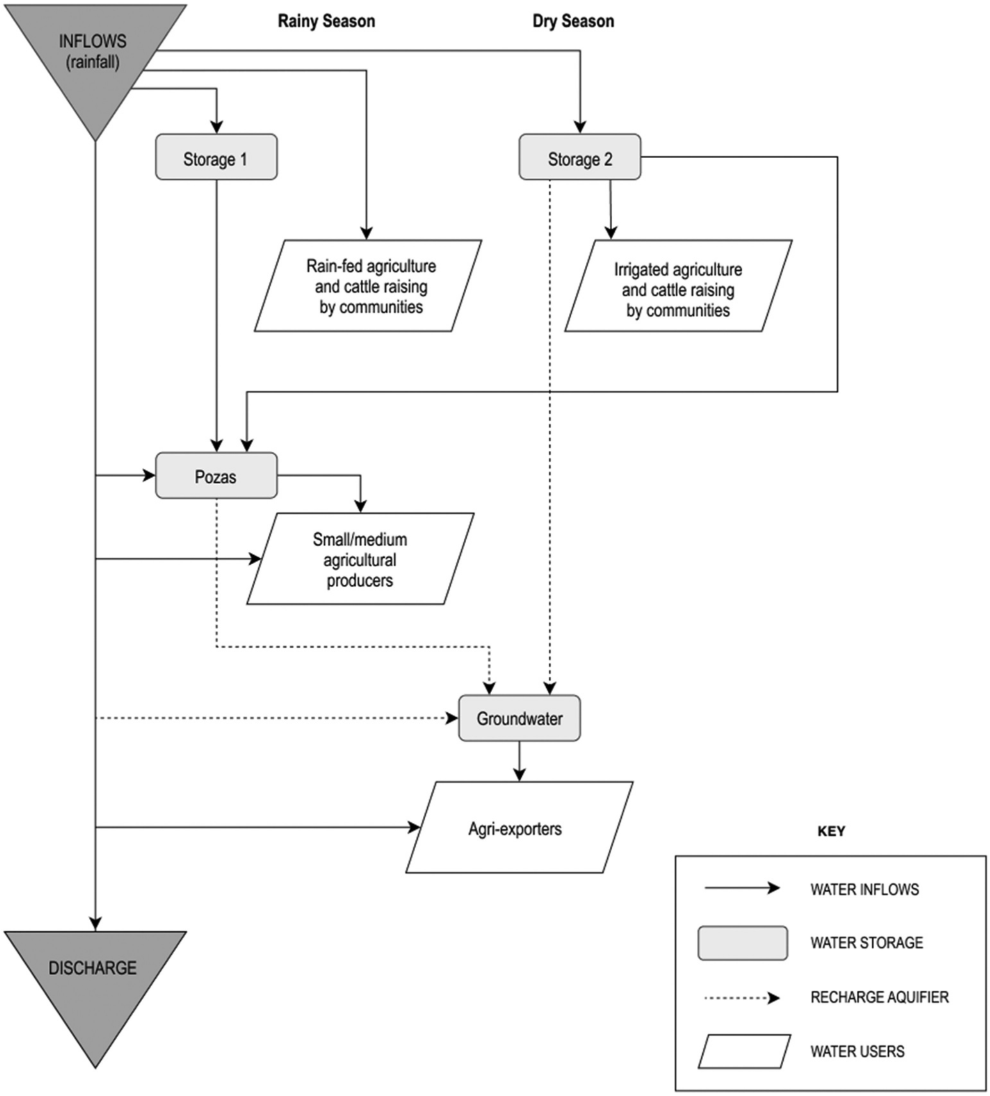

Figure 2. Water flows and water users in the Tambo–Santiago–Ica river basin: relationship between water sources and water users during the rainy and dry seasons.

The water conflict and negotiations

There is a history of tension and conflict between upstream and downstream driven by previous national government interventions and public investment design. Ica's large agricultural producers, economically and politically powerful, were influencing the national government. This economic power is visible since 1945 when the National Government approved the Ley No. 10253 (1945) to transfer water from Huancavelica to Ica. At that time, until the agrarian reform in 1969, the main crop in the Ica valley was cotton to supply the national textile industry and for exports. Cotton production was mainly concentrated in large-scale production units where latest technology was used.

The public investment did not consider the economic, social and environmental consequences in the river basin, in particular the adverse effects on communities in Huaytara. Public investment refers to the irrigation infrastructure built by the national government (i.e. reservoirs and canals) to provide water only to downstream. The social and economic consequences for communities were (1) income reduction due to lack of water which reduced pastures and alpacas' feed; (2) increased poverty; (3) increased conflict between community representatives and national and regional authorities; and (4) division of the Carhuancho Community into two parts, with the families from the lower area being forced to migrate. The environmental consequences were the disappearance of the Parionacocha Lagoon which changed the hydrological system degrading water infiltration and aquifer recharge conditions. Environmental degradation became visible over the long term, specifically the destruction of Andean wetlands and natural pastures, soil degradation and biodiversity loss due to habitat alteration (Centro de Estudios Peruano de Estudios Sociales (CEPES), 2009).

Overall, the public infrastructure investment generated negative externalities to the upstream communities. Communities faced irreversible losses in their means of living (water, land, Andean cattle and alpacas) and income, leading to conflict (Boelens, 2014; Damonte, 2019; Damonte et al., 2018; Urteaga, 2014).

Furthermore, building the infrastructure in the highlands was decided without local and regional stakeholders' participation. In particular, upstream communities were not included in the dialogue nor could they benefit from water transfers. Different studies have argued that the basis of the conflict was uneven bargaining power between the two regions (Damonte, 2019; Oré & Geng, 2014). The history of tension and conflict between Ica and Huancavelica is described in Box 1.

Different factors contributed to the enduring conflict, mainly (1) the lack of an institutional water framework to support benefits sharing between different producers in the river basin; (2) lack of an integrated water management perspective in the river basin; and (3) information asymmetries responsible for a lack of trust between the parties (CEPES, 2009; Zeisser & Gilvono, 2016) (Box 1).

Political and institutional water framework

The political and institutional water framework has changed in the course of the water conflict. Water governance changed when ANA was created in 2008 and a new Water Resources Law was approved in 2009 (Ley No. 29338, 2009). The new law establishes not only the integrated water management but also recognizes the communities' water rights. The previous water law (Decreto Ley No. 17752, 1969) had established that water is a state patrimony, that is, the state defines water access through permits or licences. Still, because of lack of enforcement, informal water use was common.

According to experts, favourable factors to overcome conflict and exclusion of the communities from dialogue and negotiations were (1) the change in the political and institutional water framework; (2) that regional governors decided to solve the conflict; (3) stakeholder participation including regional and local authorities, communities' authorities and non-governmental organizations (NGOs) a new stakeholder providing technical support to communities; and (4) international cooperation providing resources to enhance technical capacities (for the list of interviewed experts, see Table A2 in Appendix A in the supplemental data).

Box 1: Ica–Huancavelica: A history of conflict and opportunities for cooperation

Phase 1: Lack of trust

Ica has been an important agricultural production area. In 1945, a public infrastructure was built to transfer water from Huancavelica to Ica. The communities affected did not receive any compensation for the negative impacts, despite their property rights to land and water being recognized since 1713.

In 1990, the National Institute for Development (INADE) created the Special Project Tambo–Ccaracocha (PETACC) to rehabilitate the hydraulic infrastructure and to identify new alternatives to transfer water from Huancavelica to Ica. PETACC mainly focused on water transfers to Ica without taking into account the communities' goals, water recharge projects, pastures and Andean wetlands restoration.

In 2003, PETACC's administration changed from national government (INADE) to Ica's regional government without considering that the Choclococha Lagoon and 90% of the irrigation infrastructure is located in Huancavelica. The communities and PETACC's representatives faced violent conflict.

In 2006, the national government declared a water reserve of 52 mcm, only for Ica. For that purpose, the Ingahuasi canal (73 km) would be constructed to collect water from springs and streams to channel them to Choclococha system. The canal would affect hundreds of Andean wetlands. There was neither an environmental impact assessment (EIA) nor communities' participation. The bi-regional conflict worsened.

In 2007, communities sued the national and regional governments in the Latin American Water Tribunal. The court resolution established: (1) to stop the Ingahuasi canal Project; (2) to prepare the EIA and (3) to establish a compensation system.

In 2014, after attempts to begin a dialogue between the two regions, negotiations ended unsuccessfully and conflict returned with violent events when the communities denied access to PETACC representatives for infrastructure maintenance. Finally, the Ingahuasi canal project was cancelled.

Phase 2: Bi-regional efforts for a joint water management

In 2015, a Dialogue Board was established with the participation of the different stakeholders. The Dialogue and Sustainability National Office, which is part of the Prime Minister's Office, participated in the Dialogue Board.

In 2016, new regional governors were elected and dialogue began based on stakeholder participation and regional alignment of agendas. The agreements showed regional authorities' willingness to keep a power balance. The agreements were the following: (1) joint water management; (2) population, including from Santiago and Tambo, will have access to water that comes from Choclococha; (3) further establishment of the Water Council of the Tambo–Santiago–Ica river basin; and (4) constitution of the Biregional Special Ecosystems Committee Choclococha.

Phase 3: Cooperation is feasible

In 2016, a Dialogue Board started negotiations based on five principles: equity, justice, mutual respect, trust and environmental conservation. The common goals are: (1) to increase water availability; (2) to share benefits from infrastructure investments. In 2017, a bi-regional institution, called the Regional Mancomunity Huancavelica–Ica (MANRHI) was established. A memorandum of understanding was signed to promote agriculture development in Ica and Huancavelica based on the construction of two dams and construction of irrigation systems. (3) A permanent payment from Ica to Huancavelica which will be used for ecosystems conservation and water infrastructure maintenance.

Sources: Centro de Estudios Peruano de Estudios Sociales (CEPES) (2009); Zeisser and Gilvono (2016); Guerrero and Verziljl (2015); Gobierno Regional de Huancavelica (GORE Huancavelica) and Ministerio del Ambiente (MINAM) (2018); and Perú Mancomunidad Regional Huancavelica Ica (MANRHI) (2018).

These factors provided the conditions to create a bi-regional institution with the following objectives: (1) to build, maintain and rehabilitate hydraulic infrastructure to improve agricultural production; (2) to develop projects for energy generation and ecosystem services conservation to improve integrated water management; and (3) to promote a diversified and competitive interregional production (Perú Mancomunidad Regional Huancavelica Ica (MANRHI), 2018). Aligned with the objectives the regions agree on infrastructure investments projected to make 100 mcm per year available for use in the Tambo–Santiago–Ica river basin and increase welfare based on efficiency and equity (Box 1).

Analytical framework

In order to quantitatively assess the gains from cooperation, we develop a bargaining model. Our model is based on Atwi and Chóliz (2011), Houba et al. (2013) and Degefu et al. (2017) but extended to include investments. Different from Houba et al. (2013), who focus on the welfare effects in 2030 from strengthening the Mekong River Commisssion versus the joint management at the river basin; our paper highlights the role of joint investments to increase profits at a subnational river basin, when the water institutional framework is changed. Joint investments are instrumental in incentivizing cooperation. Our model approach explicitly accounts for the role of investments changing the standard bargaining models used to analyse river sharing. Our model is tailored to include the specific hydrological characteristics of a case study area and the water institutional framework. A limitation of our assessment of the gains from cooperation is that we take into account gains from specific economic activities (alpaca-raising and asparagus production). However, there are other benefits from the joint investments such as aquifer recharge and water cost reduction downstream, as well as additional revenue from crops during the dry season and freshwater availability for the household upstream. Lack of information limits the assessment. In this section, we first explain the main features of the problem and then we calculate the net gains from cooperation and their distribution. The model does not take into account climate change effects on water variability but can be extended to do so.

The basic setting

The agents in the game are two regions, upstream and downstream, who have the possibility to cooperate in order to improve water-use efficiency. The results show that cooperation triggered by investments can improve water-use efficiency and create benefits for both regions.

In our bargaining game upstream producers raise cattle (alpacas) and downstream producers cultivate crops (i.e. asparagus) and, for simplicity, water is the only input for both activities. Each activity employs different water-use technologies. Upstream producers use conventional technologies and their economic activities depend on rainfall, while downstream producers use the latest irrigation technologies (i.e. drip irrigation) for agri-export crops. These technological differences are an opportunity for cooperation; however, technological improvements have underlying factors such as financial resources and production practices which are constraining factors upstream.

Before any investment has occurred, each region produces based on its water endowment. Upstream is water-constrained in the dry season lacking the capacity to store water in the rainy season, while downstream is water-constrained by the natural geography. In our case, previous public investments have generated a contentious situation where water is reallocated to downstream at the expense of upstream through a reservoir (storage 1) and a canal (grey infrastructure) (Figure 2). This coercive reallocation through initial investments is described in Box 1. Previous investments have affected important upstream water sources limiting economic activities indicated by a move from point M to point d in Figure 3. Point d is located on the truncated benefit possibility frontier PF_1 representing downstream's gains when receiving more water (moving from d towards point A), while upstream is constrained by lacking options to transfer water from the rainy to the dry season (the vertical part of PF_1).

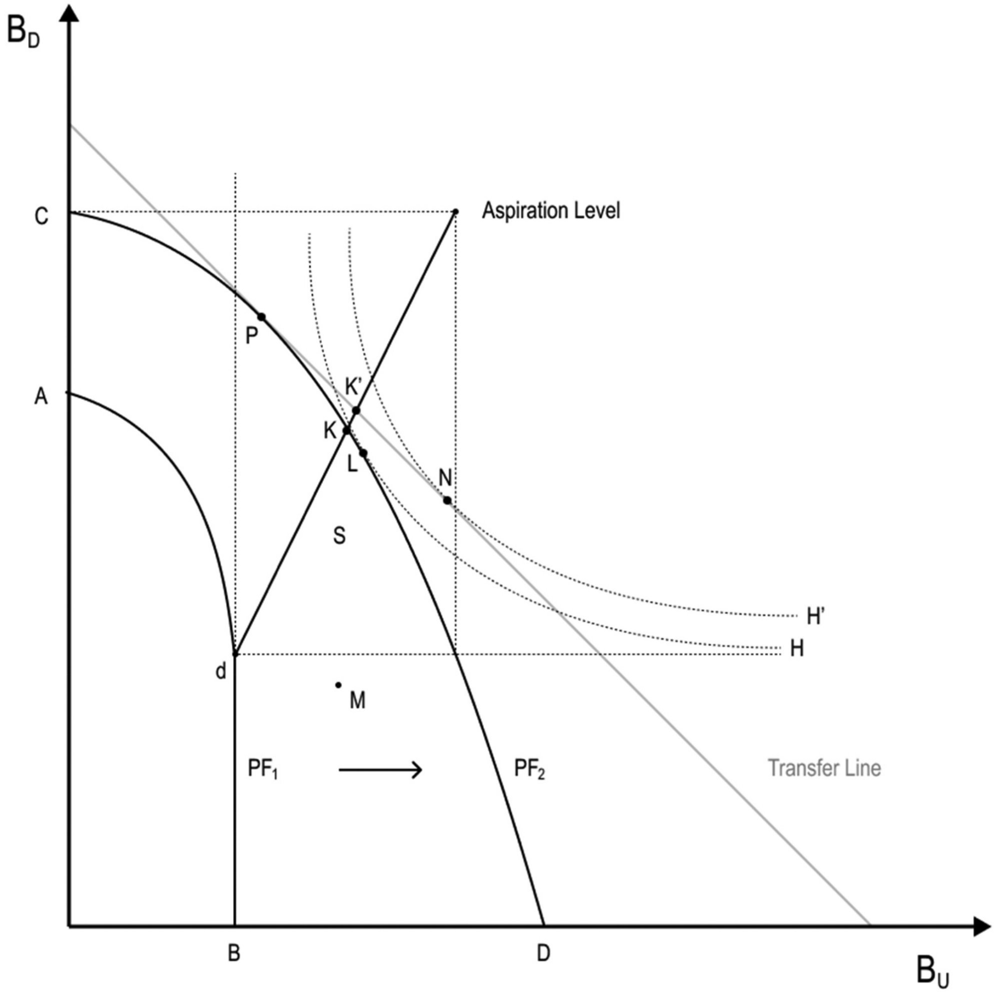

Figure 3. Infrastructure investments and side-payments.
Note: The initial allocation leads to benefits depicted by point M. Initial investments have shifted water to downstream, increasing their benefits at the expense of upstream, illustrated by point d. New joint investments create a bargaining situation with Nash bargaining solution (NBS) at point L where the highest feasible social welfare level H is reached; see the dotted hyperbola. Side-payments (water trade) can further improve benefits and the NBS becomes N, located on the social welfare level represented by the H´ curve. Point P indicates the efficient water allocation without side-payments. Points K and K´ are the Kalai–Smorodinsky (KS) solutions for the respective bargaining sets. New joint infrastructure investments create a bargaining situation. Two solutions are applied to assess welfare changes: NBS and KS. The former focuses on sharing the net gains such that the highest level of social welfare is achieved. The latter uses the ratio of the aspiration levels to the agents. Side-payments allow to enlarge the bargaining set and improve welfare.

New opportunities for joint investments allow to exploit technological options facilitated by cooperative planning of infrastructure such as the construction of a big reservoir, canals (grey infrastructure) and *cochas* (green infrastructure), both located upstream, to distribute water between both regions, where upstream is the first user. Joint investments are feasible due to changes in the institutional framework, as described in Box 1. Joint investments expand opportunities for production and benefits for both agents as reflected in an outward shift of the frontier from PF_1 to PF_2. Joint investments create a bargaining situation with disagreement point d and a bargaining set S limited by PF_2 (Figure 3).

In practice, joint investments allow upstream to store water and use it in the dry season. Upstream communities can improve pastures which in turn improve alpaca fibre quantity and quality. Furthermore, upstream communities can receive a compensation for the maintenance of the green water infrastructure serving aquifer recharge for downstream producers who can increase irrigated farmland and production. The literature called this compensation as payment for ecosystem services (PES). The PES is an instrument to transfer benefits among agents for environmental conservation, compensating for the opportunity cost of doing or giving up an activity and can help for conflict resolution (Perevochtchikova et al., 2021; Wang & Nuppenau, 2021)

Such investments were not feasible before the creation of the bi-regional institution, as explained in Box 1. The financial resources for the joint investments can have different sources such as national government (Ministry of Economic and Finance, Ministry of Agriculture), regional governments of Ica and Huancavelica, and the multilateral banks, among others.

Side-payments can further improve welfare. Given that downstream's marginal value of water is higher than upstream's, water transfers to downstream combined with a side-payment further improve overall production and benefits in the river basin. Water transfers implement point P reflecting the optimal water allocation. With side-payments the bargaining set is enlarged and becomes the triangle up and to the right of point d limited by the downward sloping 45° line in Figure 3. Points L and N show the NBS without and with side-payments, respectively. NBS with side-payments increases the social welfare level from H to H´. The side-payments can be interpreted as the result of water trade.

Comparing the NBS with and without side-payments, it is notable that increasing the bargaining set through water trade can be to the disadvantage of one party. In Figure 3, N gives less benefits to downstream than point L. For the KS solution both agents always benefit from introducing side-payments, provided aspiration levels remain constant. For our model calibration, presented in the next subsection, we find that side-payments (through water trade) increase benefits for both players under both solutions, NBS and KS.

The Tambo–Santiago–Ica River Basin in Perú

In this section we introduce the numerical calibration of our bargaining model. The game is applied to the river basin Tambo–Santiago–Ica in Perú, where each region's benefits $(B_i, i = U, D)$ depend on water use.

Huaytara, located upstream, rears alpacas for fibre production. Ica, located downstream, grows asparagus as the main crop. Joint investments build infrastructure upstream to store water in the rainy season to make it available during the dry season. Therefore, managed pastures are available in the dry season improving alpacas' feed which, in turn, increase alpacas' fibre volume and quality. However, there are limits to

Table 2. Summary of solutions: Nash bargaining solution (NBS) and Kalai–Smorodinsky (KS).

Variables	NBS (point L)	NBS with side-payments (point N)	KS (point K)	KS with side-payments (point K´)
Water use (mcm)				
Upstream	14.6	1.74	12.5	1.71
Downstream	85.4	98.26	87.5	98.29
Payoff (net gains)				
Upstream				
Million soles	1.93	2.14	1.87	2.10
Million US$	0.572	0.635	0.555	0.623
Downstream				
Million soles	105	120.86	107.6	120.9
Million US$	31.16	35.86	31.93	35.88
River basin				
Million soles	106.96	123	109.47	123
Million US$	31.73	36.50	32.48	36.5

Exchange rate: US$1 = 3.37 soles
Source: Calibration details are provided in the supplemental data.

improving pastures. Yields are lower at higher altitudes because of soil and climate conditions and steep slopes in the highlands.

On the other hand, downstream can take new farmland into production when water constraints are relaxed. As a result, both regions bargain over water that increases benefits from increasing production.

The calibration of the bargaining game focuses on opportunities from joint investments, the construction of a reservoir to distribute water to regions. We do not include the green infrastructure mentioned in the second section for lack of information on production impacts. Joint investments establish an irrigation system upstream that contributes to improve pastures and alpacas' fibre production. The downstream region improves aquifer recharge and increases farmland.

After joint investments are undertaken, benefits increase in both regions which is reflected under NBS and KS solutions. Applying NBS, an efficient solution is reached at point L (Figure 3), resulting in net gains amounting 1.93 million soles for upstream and 105 million soles for downstream (Table 2). Applying KS, the payoffs are 1.87 million soles for upstream and 107.6 million soles for downstream.

Increasing water availability, upstream increases water productivity (intensive margin) because of the introduction of an irrigation system that allows to manage water all year round. It also increases the extensive margin by increasing managed pastures area. Downstream also increase the intensive margin, improving productivity and extensive margin, thru incorporating new farmland.

The supplemental data include the technical details to calculate the disagreement point, the NBS and KS solution.

Although the NBS and KS solutions show benefits improvements compared with the status quo, side-payments can further enhance welfare. Downstream compensates upstream for water transfers to secure water access and avoid conflicts. Side-payments improve efficiency and bargaining facilitates equity.

Discussion and conclusions

We analyse how joint investment is instrumental to increase mutual benefits of agents. The results show that the NBS and the KS solution, annual gains are higher than in the non-cooperative situation. Upstream payoff increases because production is feasible in the dry season, after joint investments. Therefore, alpaca fibre quantity increases as well as quality. Downstream payoff increases due to farmland expansion for asparagus production. Thus, joint investments alleviate the water and technological constraints for each agent, enlarging the bargaining set. Side-payments will further increase the gains from cooperation. With side-payments NBS and KS give the same payoff in the overall river basin but distribute the gains differently (Table 2).

The case illustrates how the previous infrastructure affected negatively upstream welfare, as it is explained in the third section. As a consequence, upstream was worse off and a conflict was created. Different from other studies, our study points out the role of investments facilitating welfare gains for both agents. The case shows how changes in the water institutional framework allow joint investments in the river basin. Joint investments store more water during the rainy season for mutual benefits of both regions. Moreover, for the first time, upstream communities can access water during the dry season, improving water distribution in the river basin and welfare. The interregional investments were not feasible before the creation of the bi-regional institution for joint water management. PES is an instrument to foster welfare in the river basin while requires to consider institutional, ecological, social and economic factors on its design (Brouwer et al., 2011; Dextre et al., 2022).

The analysis of both solutions (NBS and KS) has particular features when one or both agents have a satiation point, meaning that cannot absorb the total additional water due to, for example, land constraints. This is represented by a truncated bargaining set (see Figure 3 and the supplemental data). In our case, upstream receives the maximum payoff at less than the available water, implying that some water is uncontested. We assume that side-payments will not exceed a level that gives upstream the payoff level associated with maximum productive water use (Table 2).

The case also suggests that water markets can increase agents' payoffs. For instance, assuming upstream has the market power to sell water at a price 2.13 soles/m^3 and has all rights to uncontested water. Then the payoffs are 79.8 million soles and 133.1 million soles for upstream and downstream, respectively. On the other hand, if the agents first bargain and implement the NBS water distribution, without side-payments, upstream gets 14.6 mcm and downstream 85.4 mcm (Table 2). Trading water, they could earn 31.1 million and 181.9 million soles, respectively. Thus, water markets increase agents' payoffs.

The bargaining situation is feasible due to changes in the water institutional framework that allows a regional water management. Two solutions are applied to assess the bargaining situation. Both solutions show that the distribution of gains, strengthen cooperation. The water-sharing problem underlies the trade off between efficiency and equity. Equity stands for a fair allocation where each agent has the right to a reasonable part in the use of the water shared (Atwi & Chóliz, 2011). The literature points out that both solutions approximates equity. The KS solution uses the ratio of the aspiration levels of the agents and NBS focuses on sharing the net gains such that the highest level of social welfare is achieved (Bertsimas et al., 2012). According to the literature (Arjoon et al., 2016; Qin et al., 2020), both solutions, to some extent, include the equity or fairness objective.

The case study shows the relationship between agents with asymmetries, that can change from conflict to cooperation, through investments to improve water efficient allocation, increase profits and welfare. Five lessons can be learned: First, an adequate water institutional framework is necessary to support joint investments and agreement compliance. A water institutional framework that promotes stakeholders' participation, water-use efficiency and compensation mechanisms provides conditions to foster cooperation in a river basin. The lack of an adequate regulatory framework limits the use of instruments, such as side-payments, that help to improve equity. Second, to solve a water-sharing problem requires to choose a solution that better captures the economic and social conditions of the river basin. The case study shows how both solutions (NBS and KS) generate gains from cooperation. Third, water satiation gives a particular interpretation of the KS solution because the agent will not have claims to uncontested water. Fourth, water markets development is feasible given increasing water needs in the river basin. Competitive water markets contribute to efficient water allocation. Fifth, following previous studies, the equity objective in a water-sharing problem is relevant to support a stable agreement (Ansink & Houba, 2015; Arjoon et al., 2016). However, there is a trade-off between efficiency and equity that needs to be assessed (Bertsimas et al., 2012; Qin et al., 2020). In fact, the complexity of a water-sharing problem and the characteristics of the agents involved in the bargaining requires active agent participation to agree on a rule to distribute the benefits and ensure equity in the water-sharing solution.

The current analysis is static, however, further analysis can be dynamic, considering changes in the disagreement point. It means, considering the latest solution as a disagreement situation when a new investment is implemented. Future research can also be oriented to include climate change effects (i.e. rainfall reduction, increasing droughts). Uncertainty of water availability raise the question to what extent joint investments would help to improve water access also in the long run. Moveover, the model could consider short-term dynamics between the wet and dry season explicitly as Houba et al. (2013). However, as we are interested in the analysis of long-term agreements this seems less appropriate for our purpose. Another research topic is the role of green infrastructure development such as artificial ponds/lagoons (*cochas*) as a complementary investment that would increase water availability and improve downstream aquifer recharge and further shift the bargaining frontier.

Disclosure statement

No potential conflict of interest was reported by the authors.

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