Collective action and water management in the Moche and Virú valleys of the peruvian coast

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Date received: January 8, 2019.
Date accepted: June 24, 2019.

Abstract

This paper analyzes sustainability-related factors of collective action around irrigation water management in the Moche and Virú valleys, located on the coast of Peru. Using a random effects panel model, this econometric analysis found that the variables which are relevant for the sustainability of collective action are different in each valley. The economic outcome can be measured by the effectiveness of collecting irrigation water rates, a capacity which is transferred from the State to User Boards. The importance of the Chavimochic irrigation project is also highlighted—a project which permanently widened water availability, and which simultaneously combats climate change, as well as the increase in water demand.

Keywords: Peru; collective action; irrigation; prices; water politics

1. INTRODUCTION

The Peruvian coast is the most arid region of the country, yet more than 58% of the total population is located there, mostly based in cities near rivers which have low water flows for much of the year (INEI, 2018). This situation represents a problem in the face of growing demand for food, making the development of complex irrigation systems necessary; simultaneously, irrigation-focused social organizations are present, formed around collective action for the management and distribution of water resources among irrigators.

It should be noted that during the 1980s and 1990s a significant effort was made to study the social organization of irrigation in Peru. These studies analyzed the institutional changes faced by organizations that assumed the task of water management after the enactment of the Agrarian Reform and General Water Law in 1969. Years later, such changes were studied both from a legal perspective and in terms of public policies regarding land and water resources. Additionally, the great importance of the agricultural use of water was addressed, taking into account the water footprint, which covers 89% of total use in the country, leaving only 11% for domestic consumption, industrial, mining, and other uses (ANA, 2015).

There has also been a particular concern to analyze conflicts and procedures that arise within these organizations, in addition to common interests relating to the irrigation system and water distribution infrastructure—which is used as a shared resource. These aspects have also been the subject of study in other countries (Agrawal and Goyal, 2001; Bardhan, 2000; Nagrah *et al*., 2016; Ostrom *et al.*, 2011; Villamayor-Tomas, 2014). In recent years, interest in Peru has been renewed and research regarding social organization around irrigation and its relationship to public policies has been undertaken with the use of case studies (Damonte and Gonzales, 2018; Marshall, 2014; Oré and Geng, 2014; Verzijl and Dominguez, 2015).

The present work addresses the Moche and Virú river valleys, located on the coast of northern Peru, in the La Libertad region (see map in Appendix 1). Export-oriented agricultural production takes place in these areas, with the cultivation of products such as asparagus, artichokes, peppers, avocados, pineapples, mangos and blueberries. Other products which are oriented to the local market are also cultivated in these places, such as hard yellow corn, black eye beans, tomatoes, marigolds, legumes and a variety of fruit and vegetables. Sugarcane is a traditional product of the region, which is industrially processed and marketed both on the national and international markets. In these valleys, as in the others in the country, organizations known as User Boards have been established, which are responsible for irrigation water management.

This paper aims to analyze the various factors that make collective action sustainable in the context of irrigation water management in the Moche and Virú valleys during the period from 2004 to 2011, by using statistical information from the User Boards. Unfortunately, it is limiting to not have a longer data series, but it was not possible at the time to continue with the field visits necessary for the annual reconstruction of the data.

The text is divided into six sections, including this introduction. The second section briefly describes the context of the valleys (the subject of study). In the third section, a synthetic review of the literature on theories of collective action, and its applications to social irrigation management, are presented. The fourth section explains the study's methodology and describes how information was collected. The fifth section presents data and results from the econometric calculations performed. Finally, the conclusions of the study are brought together in the sixth section.

2. CONTEXTUAL CHARACTERISTICS

Changes in land ownership

Since the end of the 1960s, the Moche and Virú valleys have seen a series of changes in terms of land ownership, which have resulted in a new landscape for irrigation organizations. Before the 1970s, there were large privately-owned farms, and small, mostly poor, agricultural producers. With the Agrarian Reform of 1969—carried out by a military government—haciendas were expropriated and became agricultural cooperatives.

Subsequently, in the 1980s, cooperative properties were divided up throughout the country, except for the large sugar cooperatives; this transformed the Moche and Virú valley areas into small-scale production sites, that is, sites with smallholders and an average of approximately six hectares per family.

In the 1990s and 2000s, given changes in public policies that were strongly oriented towards the market and economic liberalization, such property was reconfigured through the process of buying and selling land, along with concessions of deserted land and the establishment of agro-export companies, mainly in the inter-valley territories. At the same time, small properties have survived in the Moche and Virú “old valleys” (Aste, 2018; Bury *et al*., 2013).

The Chavimochic irrigation project

Within this context, the Chavimochic irrigation project was incorporated in 1994, with four valleys contributing to the effort: Chao, Virú, Moche and Chicama. The project consists of water diversion from one of the most important rivers along the coast, the Santa River—whose watershed belongs to the Ancash region (towards the La Libertad region’s valleys and inter-valley desert areas)—via the construction of a mother canal several kilometers long (see map in Annex 2). This allowed for the extension of the agricultural frontier into 46,700 new hectares, and the improvement of irrigation for 28,300 hectares; further, a permanent irrigation system was established in the area (Inga, 2016; Vos and Marshall, 2017). The Chavimochic project’s work, from its beginnings in 1986 until its second stage, had a cost of US $960 million, which was financed by the Public Treasury (Inga, 2016).

The project has allowed for an expanded and improved drinking water supply for families in the city of Trujillo, which has more than 900,000 inhabitants, in addition to urban and rural settlements within its zone of influence. However, it has to face the problem of the ongoing loss of glaciers in the Cordillera Blanca, which has the largest glacier coverage in the country, and which in the last 30 years has lost 34% of its surface due to the effects of climate change. These glaciers are the most important source for the Santa River’s water flow (Aste, 2018; Bury *et al*., 2013).

It was a limitation of the present study, given its scope, not to address conflicts over water usage, especially between agricultural use and domestic use —or the conflicts between regions (Ancash and La Libertad) regarding the use of the Santa River water. It should be noted, however, that the Chavimochic project provided the Trujillo province with an important supply of drinking water, via the Alto Moche treatment plant (PECH, 2016), which produces approximately 24 million m3 of water per year.

However, because irrigation water in the valleys under study was transformed from being seasonal to permanent, a result has been less use of and investment in groundwater wells, as costs have risen. The above circumstances, together with the permanent seepage of water into the subsoil, resulted in the area's aquifer groundwater levels rising until water emerged on the surface, creating in some places—especially in Virú—swamps and salinization of land. This problem resulted in public and private interventions promoting drainage projects and incentives to use groundwater.

3. LITERATURE REVIEW ON COLLECTIVE ACTION AND IRRIGATION WATER MANAGEMENT

Theories of collective action

Collective action refers to the cooperation of individuals to achieve a common goal. There are several theories that allow us to approach an understanding of this state of affairs; these are called theories of collective action. One such theory is explicated by Olson (1965), who, from a microeconomic approach, addresses the theoretical and practical difficulty of getting individuals with common interests to act or cooperate voluntarily in order to promote those interests and obtain the benefits that would result.

Another theory is that of Ostrom (1990, 2009). According to Ostrom, models that predict the failure of collective action (Hardin, 1968; Olson, 1965) have limitations when it comes to explaining the facts, since they are based on extreme assumptions, rather than general theories and multiple methods that would allow for a closer view of the concrete reality and its complexities—especially regarding the management of common resources (Poteete *et al*., 2010). In this sense, if the social context is one consisting of individuals who can defect but who are also capable of adopting cooperative norms, such individuals can be expected to establish contingent and appropriate commitments to follow rules which lead to the better functioning of social organizations (Agrawal, 1996; Ostrom, 1990; Wade, 1988).

A comparative study by Agrawal (2001) examines three of the most influential works on common resources and their implications for collective action, these being the works of Baland and Platteau (1996), Wade (1988) and Ostrom (1990). He does not find unanimity among them regarding a set of relevant variables that explain the sustainability of institutions that shape the use and management of common resources. However, he finds that the approaches coincide in terms of the importance they give to developing institutional agreements which support locally-designed resources management and access regulations, and the need for easy application of these regulations or ways to enforce compliance. Agrawal also finds that—among a large number of variables—group size is an important one in explaining the possibilities of sustainable collective action; another key variable he identifies is having clearly defined group boundaries.

Furthermore, several case studies (Araral, 2009; Cody *et al*., 2015; Fischer and Qaim, 2014; Gardner *et al*., 1990; Putterman, 1983; Wade, 1987, 1988) demonstrate that achieving collective action is more likely when the size of the group, or total number of decision makers, is small. That is, if the group is small enough for people to be able to interact with each regularly, collective action will be more easily sustained. However, there is debate on this issue, as other scholars conclude that the size of the group is not significant, or at least that the degree of sustainability of the collective action is uncertain (Nagrah *et al*., 2016), and give greater importance to other variables such as the heterogeneity of the group (Ruttan, 2008; Villamayor-Tomas, 2014).

Other environmental variables, such as favorable prices or increasing demand for local products, can strengthen common interests, which makes it easier for the group to agree on collective action (Agrawal and Goyal, 2001; Fischer and Qaim, 2014; Ito, 2012). On the other hand, theories of collective action can also explain the emergence of restrictive institutions or rules that limit individual behavior in favor of obtaining collective benefits (Chang and Evans, 2007), as well as the role of trust and positive leadership in the groups that make collective action more likely to be sustained (Nagrah *et al*., 2016).

Collective action and irrigation water management

The sustainable management of irrigation water is a complex and vital issue for farmers. In Peru, User Boards (organized by valley) that belong to a common hydraulic sector are in charge of this management; these are made up of User Commissions (organization of irrigators according to irrigation branch line) based on a hydraulic sub-sector. Within this structure, the organization's larger group is constituted on the basis of smaller user groups, which enables cooperation to develop from the ground up (MINAGRI, 2015; Muñoz, 2009). Several international case studies suggest that this structure lowers the costs of organization, and promotes collective action towards the management of common resources (Nagrah *et al*., 2016; Ostrom, 1990; Wade, 1988).

The User Boards are responsible for planning the distribution of irrigation water at the level of the entire valley to which they pertain, in addition to collecting water rates and representing all of the users in the corresponding irrigation district. The User Commissions are given the power to execute and control the distribution and delivery of water within their jurisdiction, as well how to establish penalties for violators of the organization's norms (MINAGRI, 2015; Muñoz, 2009).

The social irrigation organizations in each of the valleys under study are: the Water User Board of the Moche River Basin (WCBMRB), made up of 4,321 irrigators, and the Water User Board of the Virú River Basin (WCBVRB), with 2,596 irrigators. Each board is made up of User Commissions that are the basis of the irrigation organization. The WCBMRB is made up of 11 User Commissions, where the smallest group is made up of 157 irrigators, and the largest of 780; the WCBVRB is composed of 13 User Commissions, with 33 irrigators in the smallest group and the largest group made up of 586 irrigators.

Additionally, the Pressurized Irrigation Users Board of the Moche, Virú and Chao Irrigation District has been created to facilitate the distribution of the Chavimochic canal's irrigation water. This board is mainly made up of agribusiness companies connected to the export sector, with a total of 55 users. These companies are mainly located in the inter-valley zones, where the land reclaimed from the desert by the Chavimochic project are located. The project diverts water from the Santa River towards the Moche, Virú and Chao "old valleys" and inter-valleys (Bury *et al*., 2013; Vos and Marshall, 2017).

It should be noted that the Peruvian State provides legal support for collective management of irrigation water, as laid out in the General Water Law, Executive Decree 17752 of 1969, and regulated by Supreme Decree 037-89-AG of 1989, which stipulated the type of organization that users should form and gave them the capacity to establish and collect irrigation water rates. This function was ratified by the Water Resources Act of 2009. These legal mechanisms, which are typical of state action, seem to have played a fundamental role in strengthening collective action around water management.

Moreover, taking into account the importance of group size in the development of cooperation, there is evidently a diverse range of group sizes between the Moche and Virú User Commissions. The theory referred to above indicates that if the group is small enough for people to interact with each other several times, then there is more of a possibility that they will cooperate—since actors can negotiate and agree more easily on their common goals and proposed actions (Marshall, 2014; Muñoz, 2009).

In these valleys, changes or variation in local prices, as well as in agricultural production, are factors that should have an effect on farmers' collective action. If both variables move in a positive direction, farmers are incentivized to seek expanded production and demand, and therefore, require irrigation water in greater quantities. The foregoing means that the total amount from the water rate being collected is higher, and therefore, the outcomes of collective action are strengthened by virtue of the groups having more resources available to cover the work of irrigation infrastructure operation and maintenance, as well as to run the user organization.

4. METHODOLOGY

Research question and hypothesis

The question that motivated this research project was: how do group size, changes in prices, value of local production and concentration of land make collective action more sustainable, stronger, or weaker in the Moche and Virú river valleys located on the north coast of Peru?

The hypothesis of the present study can be stated as follows: collective action by irrigator or user groups—as expressed in the economic result or efficiency of irrigation water rate collection, and defining said result as the gap between expected revenue and revenue collected—is more likely to be sustained with smaller group size, positive movement both of prices of goods produced in the valley and growth of local agricultural production value, and with a lower concentration of land that comprises each user commission in the valleys under study.

It is postulated that the gap in the water rate collected by the User Boards depends on the number of members that make up the User Commissions and the conditions of the economic context in which they carry out their productive activity (price changes and agricultural production), in addition to the specifications of irrigated land concentration in the User Commissions.

Collection of data and information

Field visits were made up to three times to obtain data and statistics on the Moche and Virú User Boards, which are boards that have recorded and systematically tracked information about irrigation water rates since 2000. Data were also collected regarding the number of irrigators and the amount of land which was the property of or owned by each user commission.

Data for prices of the primary products of both valleys, and the gross value of agricultural production, were taken from the National Institute of Statistics and Informatics [Spanish acronym INEI] and the Ministry of Agriculture and Irrigation (MINAGRI). The calculations for price changes and the growth of agricultural production gross value are prepared by the author.

It is worth highlighting the way in which irrigation water is delivered to most of the irrigators in both valleys. User Boards deliver the water to the irrigators after they have paid the value of the volume or quantity of water requested. For a user who has not become part of the new system (because of being located on higher ground, or other reasons), the criterion of a fee paid to the User Commission is maintained, so that they do not have to be in default to receive their share of water. The new system is implemented on delivery, meaning that there is no possibility to have water on the property without first paying for it. Each User Commission is responsible for collecting the water rate within the new system, under which each user must make an advance payment for the volume of irrigation water required for their crops. To do this they have constructed infrastructure in the fields and hired personnel for the job. The money collected comes to the User Boards, which are responsible for delivering water to the irrigators and administering the money received, and for the operation and maintenance of the irrigation system.

This system counteracts the possibility of late payment of the service fee, and has been made possible due to the new, modern infrastructure built along with the Chavimochic project that serves to redirect water from the Santa River to the Chao, Virú and Moche valleys. To highlight the importance of this project for the region, it can be noted that the total agricultural water demand in this area is 596 hm3, 87% being covered by the diversion of waters from the Santa River (Aste, 2018). The rest is made up of water from the valley rivers, lagoons and aquifers in the area.

Variables

The following variables were established based on the literature reviewed above, especially the variables that could be utilized by working with the data that was collected, or that would allow the construction of an indicator suitable to test the hypothesis regarding the outcomes of collective action.

Dependent variable

- The gap evident in irrigation water rate collection.

This is defined as the revenue received minus the expected revenue, i.e. the difference between received and expected revenue, which becomes an indicator of sustainability of collective action. Additionally, expected revenue is defined as the minimum amount needed for the annual costs of irrigation infrastructure operation and maintenance, within the scope of each Commission. This will be assumed to be the target revenue amount for an irrigation organization.

The revenue received is defined as the actual amount collected annually by each User Commission. The difference between what is received and what is expected is due to the possibility that the rate—which is negotiated by the users through collective action—is different from what would be required to maintain and operate the irrigation infrastructure managed by each Board of Users.

The annual rate is fixed and may vary for each User Commission; it is officially approved by a local government agency corresponding to the National Water Authority (NWA) called the Local Water Authority (LWA). This irrigation water regulation system found throughout the country depends on the MINAGRI.

In order to determine the expected amount of revenue from the rate, previous studies have not been carried out regarding the real costs of operation and maintenance (O&M) of the infrastructure and irrigation systems along the Peruvian coast (Zegarra, 2014). However, for the purposes of this research, the method of determining the minimum value for the water rate—the amount which would mean sufficient resources to fund O&M of the irrigation infrastructure—was taken from the work of González (2002). González points out that, based on a comparison between countries and projects, an average of US $75 per hectare should be spent annually on O&M. This amount is used for irrigation water distribution systems with more or more regulated infrastructure.

Zegarra and Quezada's work (2010) has determined that the minimum cost for O&M of minor or unregulated irrigation infrastructure along the Peruvian coast is US $34 per hectare. Both calculations will be utilized, using the average annual exchange rate, for the calculation of expected revenue for each

User Commission according to whether it is regulated irrigation (with the Chavimochic project: water from the Moche river or Virú river, and Santa river) or unregulated (without the Chavimochic project: water from Moche river or Virú river).

Independent variables

- The number of irrigators pertaining to a User Commission. This variable accounts for the size of the group which is making decisions regarding the water rate.

It is postulated that there is an inverse relationship between the size of the group (User Commission) and the probability of collective action which is sustainable, as can be seen from the revision of theory that addresses this issue (Araral, 2009; Baland and Platteau, 1996; Cody *et al*., 2015; Fischer and Qaim, 2014; Olson, 1965; Putterman, 1983; Wade, 1988; Walker et al., 1990).

- Inflation rate of agricultural products in the valley.

Given that there are no official statistics on the local or regional inflation rates, a local price index was constructed using consumer prices for the ten main agricultural products grown in the Moche and Virú valleys, and the local inflation rate for the period of study was calculated. For the corresponding regression, a one-year lag will be used for this variable.

It is postulated that if prices rose in the previous year—given that they are consumer prices—the incentive to produce more food will increase during the current year. Therefore, the demand for water increases, making it possible to increase the unit rate, and having the effect of increasing the amount of revenue received.

- Growth rate of the gross value of agricultural production (GVP).

The specific agricultural GVP growth rates for each valley are not recorded in the official statistics, so the one for the La Libertad region was used as a proxy. For the corresponding regression, a one-year lag will be used for this variable. It is postulated that a positive growth rate in the agricultural GVP of the previous year leads to greater demand for irrigation water in the current year, which allows for an increase in the unit rate and, therefore, an increase in revenue received.

Agrawal and Goyal (2001) have studied the way environmental economic variables may strengthen common interests of groups in different countries, as has Ito (2012) in an original work on collective action which uses game theory.

- Degree of land concentration in the User Board.

This is obtained by calculating the Herfindahl-Hirschman Index (HHI) for both User Boards. The HHI is the result of the sum of percentage shares squared for land being irrigated by each User Commission. It is postulated that a greater degree of land concentration gives irrigators more negotiation power in their respective Commissions, which leads to the payment of lower rates for the irrigation water they require, therefore generating less revenue. This argument is based on the work of Ludema and Mayda (2006), who develop the calculation and use of the HHI for international trade, finding a negative relationship between the degree of concentration and the payment of tariffs in a product market.

Model and calculation method

The methodological strategy of this study is based on the characteristics of the hypothesis that we seek to prove empirically. This hypothesis arises from the theory of collective action which assumes that group size is a fundamental factor in sustaining group cooperation. For the Moche and Virú irrigator groups, or User Commissions, cross-sectional data are available for a period of eight years. A data panel is available which can be used to perform the regressions that allow for a comparison with the stated hypothesis. The random effects panel model method was chosen to calculate the variables, allowing the unobservable heterogeneity of the units of analysis to be captured.

The Users Commission was taken as a unit of analysis. The variables to be used for the econometric model are described below, and the equation for the corresponding regression is as follows:

$$Y_{i,t} = \alpha + \beta_1 X_{i,t} + \beta_2 Z_{t-1} + \beta_3 J_{t-1} + \beta_4 I_t + u_{i,t} + \varepsilon_{i,t}$$

Where:

$Y_{i,t}$: Gap (revenue received minus expected revenue) in irrigation water rate collection for each User Commission in the year corresponding to the 2004-2011 period. This is the dependent variable.

$X_{i,t}$: Number of irrigators in each of the User Commissions for each year corresponding to the study period. This is the independent variable.

Z_{t-1}: Growth rate of agricultural production gross value in the La Libertad region, in each of the years of the study period and using a lag of one year. This is another independent variable, a proxy for the economic-productive environment.

J_{t-1}: Inflation rate of the Moche and Virú valleys' primary products. This is the inflation rate created for the years corresponding to the study period, with a lag of one year. It is another independent variable, and another proxy for the economic environment.

I_t: The Herfindahl-Hirschman Index (HHI), which measures the degree of concentration for irrigated land in the Moche and Virú valley user commissions.

α: Intercept.

β_1, β_2, β_3 and β_4: Regression coefficients.

$u_{i,t}$: Error term between groups.

$\varepsilon_{i,t}$: Error term within groups.

5. CALCULATION OF RESULTS

The results calculated by the regressions that were performed are based on indicators obtained from information collected for both the Moche River and the Virú River User Boards, in addition to information found in the INEI and MINAGRI. In the Moche Users Board, given that there are 11 commissions, there are 11 observations per year. In the eight-year period for which there is information and which is included in the analysis, there will be 88 observations. In the Virú Users Board there are 13 commissions, and therefore there will be 13 observations in a year. In the eight-year period for which there is information, there will be 104 observations. Stata 12 was used for the model regressions.

Calculations for the Moche River Basin User Board

The results of the regression for the Moche Board are presented in Table 1.

Table 1. Regression of random effects: determinants of the gap between received and expected revenue Moche Board

	Coefficient	*Standard error*	*Z*	*P >|z|*	*95% Confidence interval*	
Number of irrigations	-0.2981527	0.0605	-4.93	0.000	-0.4167	-0.1795
GVP growth	0.2463901	0.7188	0.34	0.732	-1.1625	1.6552
Local inflation rate	121.0155	23.9724	5.05	0.000	74.0303	168.0007
HHI	-345.9639	1014.488	-0.34	0.733	-2334	1642.397

R-sq: within 0.2545, between 0.7571, overall 0.5773; Observations: 88; Number of groups: 11; Wald chi2(4) = 50.54; Prob > chi2 = 0.000.

Source: prepared by the author based on INEI, MINAGRI, and Moche User Meeting statistics.

The first result is the average variation of Y (gap) when X (number of irrigators) varies throughout the groups in 1 unit. In this case, the ratio is negative and 99% significant. That is, Y widens, forming the most negative gap at 0.29815 units when X increases by 1 unit throughout all of the groups.

Accordingly, it can be noted that the number of irrigators variable is significant in the explanation of the gap between received and expected revenue. This indicates that the addition of an irrigator (user) in a commission could cause the gap to increase by 0.29815 monetary units. This mechanism results in the decrease of revenue received by each Irrigation Commission, and means that the amount collected moves away from the expected or target revenue.

An interpretation of this result would be that with a small number of irrigators it is possible to agree on a higher irrigation water rate than with a large number of irrigators; this is due to the fact that it is more complex and difficult to negotiate the tariff amount within a Commission if a large number of irrigators are involved in the decision, all of whom have to be heard and negotiated with, and who typically seek to reduce the rate proposed by the Board of Users' technical body. In turn, there would also be less revenue, since the amount depends on the rate established for the corresponding year, and thereby the gap would also increase.

The second result, the growth rate of agricultural GVP in the region, is not significant. The third result, the local inflation rate of the valley's primary products, is 99% significant. This result indicates that the average variation of Y (gap) is reduced when the inflation rate varies (rises) by 1 percentage point; in this case the relationship is positive. That is, the gap becomes less negative at 121.0155 units when J (price index) increases by 1 point. Subsequently, for each percentage point that the inflation rate rises, the gap is reduced by 121 monetary units.

This result would indicate that an increase in the prices of products sold by the valley's producers encourages higher production of said products, therefore demanding a larger amount of irrigation water from irrigators or producer-users. Additionally, this allows the unit water rate to be sustained at levels that generate greater revenue.

In the fourth result, the HHI is not significant. The R-squared (R-sq) shows how much Y's variance is explained by the variables included in the model. The R-sq (overall) is included in order to demonstrate the adjustment index at the level of the model as a whole, which is 0.5773.

Likewise, three scenarios are presented for the Moche Board, examining the relationships between the model's dependent variable and its independent or explanatory variables (see table 2).

Table 2. Scenarios: Moche user meeting (2004-2011)
Determinants of the gap between received and expected revenue

	Scenario 1	*Scenario 2*	*Scenario 3*
Number of irrigations	-0.298***	-0.300***	-0.298***
	(-0.0605)	(-0.0572)	(-0.0605)
GVP growth	0.246	0.246	0.247
	(-0.719)	(-0.719)	(-0.827)
Local inflation rate	121.0***	121.0***	
	(-23.97)	(-23.97)	
HHI	-346		-346
	(-1014)		(-1014)
Constant	-82.49**	-85.22**	75.59***
	(-41.72)	(-40.11)	(-27.61)
Obs.	88	88	88
Number of groups	11	11	11

Notes: /Standard errors within parenthesis; //*** p< 0.01, 99% significant; ** p <0.05, 95% significant.
Source: prepared by the author based on INEI, MINAGRI, and Moche User Meeting statistics.

The first scenario is the one analyzed above, in which the variables corresponding to number of irrigators and local inflation rate are 99% significant. In the second scenario, in which the HHI is removed from the regression, the same variables as in the first scenario continue to be significant, also at 99%. The local inflation rate is withdrawn in the third scenario, where only the irrigator number variable emerges as 99% significant in the explanation of the gap.

Calculations for the Virú river basin User Board

The results of the Virú Board regression are presented in table 3.

Table 3. Random effects regression: determinants of the gap between received and expected revenue
Virú Board

	Coefficient	*Standard error*	*Z*	*P >|z|*	*Confidence interval to 95%*	
Number of irrigations	-0.0040542	0.1243	-0.03	0.974	-0.2477	0.2396
GVP growth	1.063751	0.5153	2.06	0.039	0.0537	2.0737
Local inflation rate	77.71953	17.1726	4.53	0.000	44.0617	111.3773
HHI	-3021.347	1336.283	-2.26	0.024	-206.8572	-402.2813

Notes: R-sq: within 0.2178, between 0.4863, overall 0.4196; Observations: 104; Number of groups: 13;
Wald chi2(4) = 34.25; Prob > chi2: 0.000.
Source: prepared by the author based on INEI, MINAGRI, and Moche User Meeting statistics.

The result for the irrigator number variable—in the explanation of the gap between received and expected revenue—is not significant. In this case, the theory of collective action which postulates that the number of members is fundamental for the development of cooperation is not corroborated by empirical evidence.

The result for the growth rate of agricultural GVP in the region is 95% significant in explaining the gap. This means that one point of growth in the region's agricultural production allows the gap to decrease by 1.06375 monetary units. Given that a lag of one year is used, this impacts the decisions that producers make in the following year, when their expectation will be to increase production and, therefore, demand more water—which increases the revenue received by the Board.

The result for the local inflation rate is 99% significant. It indicates that the gap is reduced when the local inflation rate varies (increases) by 1 percentage point. The relationship in this case is positive—that is, the gap is reduced by 77.7195 monetary units when the local inflation rate increases by 1 point. This result is interpreted to mean that an increase in the price of agricultural goods sold by producers encourages greater production of said products, and consequently leads to a higher demand for irrigation water. This allows the unit water rate to be sustained at levels which generate more revenue for the Board.

The result for the HHI is 95% significant in explaining the Virú Board's gap. In terms of the gap, the relationship is negative, a fact which can be interpreted to mean that a higher concentration of irrigated land grants more negotiation power to the irrigation commissions, such that the rate is lower —as postulated in the specifications of the model.

The R-squared (R-sq) that is reported is the R-sq (overall), showing the adjustment index at the level of the entire model, which is 0.4196.

Likewise, for the Virú Board, three scenarios of the relationships between the model's dependent variable and independent or explanatory variables are presented (see table 4).

Table 4. Scenarios: Virú User Meeting (2004-2011):
Determinants of the gap between received and expected revenue

	Scenario 1	*Scenario 2*	*Scenario 3*
Number of irrigators	-0.00405	-0.193*	-0.00405
	(-0.124)	(-0.108)	(-0.124)
GVP growth	1.064**	1.064**	1.068*
	(-0.515)	(-0.515)	(-0.568)
Local inflation rate	77.72***	77.72***	
	(-17.17)	(-17.17)	
HHI	-3,021**		-3,021**
	(-1336)		(-1336)
Constant	-143.5***	-135.7***	-42.01*
	(-32.35)	(-35.1)	(-23.34)
Obs.	104	104	104
Number of groups	13	13	13

Notes: /Standard errors within parenthesis; //*** $p < 0.01$, 99% significant; ** $p < 0.05$, 95% significant; * $p < 0.1$, 90% significant.

Source: prepared by the author based on INEI, MINAGRI, and Moche User Meeting statistics.

The first scenario has already been analyzed, in which the local inflation rate variable is 99% significant, the agricultural GVP growth and HHI variables are 95% significant, and these show a relationship to the dependent variable, as described in the analysis above. In the second scenario, in which the HHI was removed from the regression, the local inflation rate continues to be 99% significant; however, here the number of irrigators and the growth of agricultural GVP are also significant, at 90% and 95% respectively. In the third scenario the local inflation rate was removed, and the HHI is found to be 95% significant, while the growth of agricultural GVP is significant to 90%, and the number of irrigators is not significant in explaining the gap.

6. CONCLUSIONS

The present research was proposed as a methodological contribution to studies of collective action and to common resources and the corresponding literature, in which the temporal dimension was incorporated and a statistical perspective was taken. Thus, through the use of a random effects panel model, this work sought to identify and understand the factors that strengthen, or make sustainable, collective action by the irrigator groups in the Moche and Virú valleys of the Peruvian coast. The results indicate that it is not a single factor, rather several factors exist, which are apparently related to each other, and which contribute to the sustainability of collective action on the part of the irrigation organizations analyzed in the case study—action which is based on the collection of an irrigation water rate.

Likewise, the convergence of two actions taken by the state, the first in 1989 and the second in 1994, have been fundamental in strengthening the irrigation water User Boards in the Moche and Virú valleys and have contributed to the sustainability of collective action on the part of irrigator groups. In 1989, the Peruvian State transferred the capacity to collect a water rate to the User Boards pertaining to the rivers in the country's various valleys; then, in 1994, with the Chavimochic irrigation project beginning its operation, the availability of the water resource was permanently expanded for the Moche, Virú and Chao valleys. In conjunction with the power to collect a water rate, the State also granted User Boards the responsibility of operating and managing the hydraulic infrastructure. This transfer of functions by way of public water policy has been a fundamental element in the strengthening of collective action taken by the Moche and Virú User Boards, which are in charge of irrigation water management. According to the model used, the size of the group that establishes the water rate has a significant effect on the sustainability of collective action in the case of the Moche Board, but not for the Virú Board. However, in both cases, it is the positive movement of agricultural prices that is significant in strengthening collective action by the irrigation groups.

Another state action that has contributed to the sustainability of collective action was the creation of the Chavimochic irrigation project in 1994, which consists of diverting water from the Santa River—one of the most important channels on the Peruvian coast, feeding into the Chao, Virú and Moche valleys as well as into the inter-valley desert areas—through the construction of a mother channel several kilometers long. This has allowed for an expanding agricultural frontier, and the development of a permanent irrigation system in the area.

The above development has influenced agricultural GVP growth, and increased the potential for improved prices and income from agricultural products, which are in demand locally and internationally. It has been observed that both the positive movement of agricultural prices, seen by the Moche and Virú Boards, and the increase in agricultural production value in the Virú Board, are relevant factors for the sustainability of collective action by irrigator groups, making it possible for the rate that is received to be relative to the rate expected by the User Boards.

Additionally, the project allowed for the improvement of public services in rural and urban areas, which are carried out by municipalities or local governments. One of the primary public services that was expanded is the supply of drinking water to the city of Trujillo–with more than 900,000 inhabitants–through the use of water from the project, whose mother channel reaches the valley of Moche.

However, the sustainability of collective action in irrigation water management is threatened by complex problems on an international scale. One of these is climate change, which has the effect of diminishing the Cordillera Blanca glaciers which feed into the Santa River. For the Chavimochic project valleys, this would put the possibility of meeting water demand at risk, since the availability of the diverted water would decrease and conflicts would emerge due to the scarcity of the resource. Another problem, which exacerbates the previous one, is the growing water demand from producers growing export goods with high water demands, such as asparagus, grapes, avocado and blueberries.

The opportunity is at hand to face the challenge of efficient and equitable water management in the region, both for productive and domestic use. The existence of user organizations with experience in the management and distribution of water resources for agricultural production, and projects that improve the populations’ drinking water supply, are advantages provided by public policies that—specifically in the Moche and Virú valleys—seek to prevent water conflicts and contribute to the strengthening of collective action which promotes sustainable water management.

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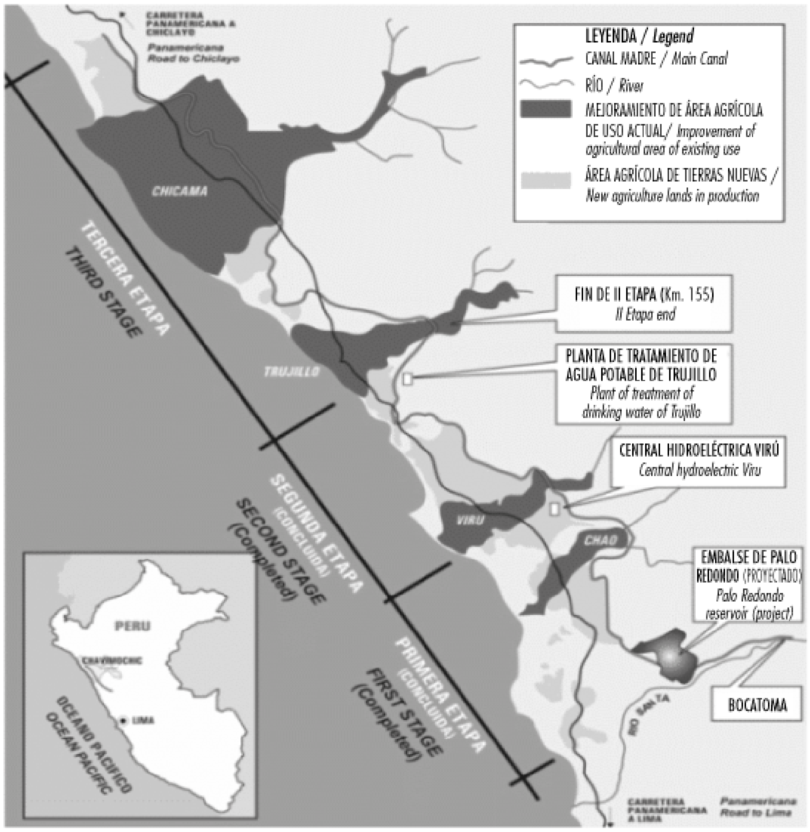
Appendix

Appendix 1. Map of Peru

Source: prepared by the authors

Appendix 2. Chavimochic irrigation project



Source: Ministry of Agriculture (2008). Regional Strategic Plan for the Agricultural Sector 2009-2015. Trujillo: The Regional Management of Agriculture's Agrarian Planning Office of the Regional Government of La Libertad Retrieved on July 12, 2019 from <www.minagri.gob.pe/portal/download/pdf/conocenos/transparencia/planes_estrategicos_regionales/la- libertad.pdf>