Governing the (Privatized) Commons: Evidence from the introduction of Water Boards

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Abstract

This paper studies the role of legally empowered users' organizations when river waters are allocated through private property in a context of weak state enforcement. Our analysis is based on a novel dataset that integrates administrative records, geographic information, and satellite imagery. We show that the establishment of such organizations limits the creation of conflicting new property rights, and results in the redistribution of water towards users more exposed to over-extraction by others, primarily due to improved enforcement of extant property rights. This redistribution increases agricultural yield, mostly among large downstream farmers. A misallocation test suggests that these organizations reduce misallocation caused by the natural advantage of upstream users to over-extract. Our results provide micro-evidence of the consequences of effective governance for both allocative efficiency and equity.

1 Introduction

Control over natural resources is often presented as a tradeoff between well-defined individual property rights –where enforcement relies on a fence or wall, and a means of legal

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recourse if rights are violated– and community management, in which decisions and allocations about resources are made collectively. In practice, there is a wide array of possible governance arrangements, which may incorporate elements of both community management as well as enforceable rights in order to regulate resource use (Ostrom, 1990). The decision to allocate rights, for example, may be enacted by community deliberation, and a community may organize together to ensure property rights are enforced, while at the same time giving exclusive access to some users to a given resource (e.g. Rossignol, Lowes, and Montero, 2023).

Different institutional arrangements will naturally have distinct implications for the efficiency and equity of resource allocation. Economists have studied extensively the efficiency benefits of private property rights, but there is limited evidence on the types of entities that can effectively enforce these rights. We commonly assume that the state should act as enforcer (North, 1990), but in many settings the government is unable or unwilling to perform this role (e.g. Baland and Platteau, 1998; Sanchez de la Sierra, 2020).

In this paper, we study the effects of a "hybrid" arrangement, combining community-governed enforcement and private property rights in Chile. Specifically, we examine the economic impacts of establishing legally empowered boards, called Water Boards (*Juntas de Vigilancia*). These organizations are established, elected and funded by the water users themselves, with the mandate to provide enforcement of water rights –formal private property rights over river waters. Water rights enjoy constitutional protection against expropriation, are inheritable and fully tradable, and their ownership is separated from the land, implying that most of the friction sources studied in other natural resources markets are absent (e.g. Chari, Liu, Wang, and Wang, 2021; Manysheva, 2022). To protect users against expropriation, the regulation of water issues and courts have restrained government action, but these limits also have made it difficult to prevent upstream users from using large amounts of water even during times of scarcity, thus leaving downstream users without access to their water allotments.

Water Boards have the power to enforce water allocation and to adjudicate conflicts among users, and thus may have the potential to step in to protect users' access rights in the absence of government oversight. The basins governed by such boards are otherwise legally identical to neighboring areas, providing a setting that is well-suited to studying the economic implications of enforcement of property rights and governance over economic resources. We show how property rights enforcement via Water Boards increases river streamflows, slows the process of appropriation of rivers, increases downstream water consumption and agricultural yield, and increases usage of summer crops; thus covering the full causal chain of economic impacts of Water Boards. The resultant redistribution, in turn, eliminates differences in the shadow value of water within a basin, implying the reduction of misallocation of water.

In our first set of results, we use a difference-in-differences design to show how enforcement changes the distribution of water across a basin. Water Boards are established independently and autonomously over time, allowing us to exploit their staggered adoption. Water Board adoption increases river streamflows in the dry season –when incentives to over-extract are strongest– by more than 20%. These results suggest that the lack of enforcement in the absence of Water Boards allows over-extraction from upstream users.

We also study the legal allocation of rivers. The rivers under study were overallocated, as a result of the lack of information and control by the government (Barría, Sandoval, Guzman, Chadwick, Alvarez-Garreton, Díaz-Vasconcellos, Ocampo-Melgar, and Fuster, 2021). We provide evidence that these boards slow down the appropriation of the river, by stopping the issuance of new water rights that interfere with pre-existing ones. This reduction can be attributed to better monitoring of the water source. We decompose the increase in streamflows into the direct effect of water boards –which arguably reflects the effect of introducing property rights enforcement– and their indirect effect through water rights (i.e. the increase in streamflows caused by the lower rate of appropriation). This indirect effect reflects the impact of better monitoring of the allocation of the river. We show that just 11% of the streamflow increase can be attributed to better information and monitoring, and so 89% of the increase in streamflows is the direct effect of Water Boards (i.e. enforcement).

Second, we develop a novel database, containing remote sensing-based estimates of water consumption and agricultural yield for more than $75,000$ farms with access to canals across our sample area. This dataset allows us to measure effective water consumption at the farm-plot level in different locations within a basin. We use these data to show that downstream farms under the authority of a Water Board consume 5% more water than downstream farms without boards, while upstream farms under the authority of a Water Board consume 9% less water than farms outside boards' jurisdictions.

The establishment of a Water Board is endogenous: conflict over water is more likely to happen in agricultural areas where water is scarcer. This may imply a downward bias on the estimation of the benefits of Water Boards. At the same time, the incentives are different for agents in different locations. Downstream users may be particularly active in the establishment of an authority in charge of distributing water, to ensure access to water. By contrast, upstream users may prefer to remain outside of their authority, as a board will restrict their water consumption.

To address these issues, we construct instruments for the establishment of water boards in downstream and upstream locations, based on the costs of establishing a water board: the process of creating a board will be initiated in a court located in the most upstream provincial capital city in the basin, in a context where most basins cover several provinces.

Our IV estimates suggest that our cross-sectional results understate the economic consequences of redistribution: Water Boards increase water consumption per unit of area by 49% among farms located in the last third of each basin, while they reduce consumption among upstream farms by 17%. We observe qualitatively similar effects in agricultural yield: an increase of 24% among downstream irrigated farmers, and a decrease of 4% among upstream ones.

By identifying individual land plots, we are able to analyze the former impacts by farm size, to check whether small or large farms benefit more from Water Boards' introduction. We find stronger increases in water consumption among larger farms downstream, while upstream reductions are more substantial among smaller farms. In addition, in our difference-in-differences analysis, we show that most of the streamflow increases happen among basins with higher land concentration. Voting power and representation in water boards mimic the structure of water ownership within the jurisdiction, which may be a driver for these distributional effects; in the main IV analysis we discuss alternative mechanisms. Overall, our results suggest that the creation of these water boards is driven by intra-elite conflict: large downstream farmers –i.e. those with enough resources– are the largest beneficiaries of restraining over-extraction by large upstream users.

Finally, we measure the allocative consequences of Water Boards. A market equilibrium should equalize the marginal value of the resource within a market, and deviations from this benchmark would imply a Pareto inefficient allocation or unexploited arbitrage opportunities. We design a misallocation test, that compares the shadow value of water at different locations in a basin; this is a measure of economic losses even after accounting for adaptation, entry and exit decisions, and private arrangements made by the agents. We then test for differences in the productivity of irrigation water within a basin, based on the revenue response to rainfall shocks within locations within a year. Our results imply that the average marginal productivity of water is constant within basins governed by water boards, while in areas without boards the marginal productivity of water is higher downstream, suggesting over-extraction by upstream users, relative to a socially optimal allocation.

The last set of results indicate that individual adaptation and markets cannot fully offset the lack of effective governance in ensuring efficient resource use. Our context satisfies the most widely discussed condition for the application of Coase Theorem –namely, clearly defined property rights–, but does not satisfy a less discussed one: property rights enforcement (Coase, 1960; Medema, 2020; Deryugina, Moore, and Tol, 2021). The lack of enforcement is a consequence of a deliberate regulatory design that was intended to rely on decentralized transactions rather than government intervention (Bauer, 2004; Tamayo and Carmona, 2019). It therefore reflects an inherent tension in market design: giving more power to users relative to a governing authority may reduce some market frictions, but the presence of externalities without an authority to manage them could ultimately lead to inefficiencies.

To summarize, this paper provides new insights into how markets allocate resources under private property, and how the success of natural resources privatization relies heavily on the governance institutions used to manage property rights. The same decision-making power and infrastructure that allows the government to enforce contracts could be used to expropriate, explicitly or implicitly (e.g. Espín-Sánchez and Truffa, 2020). Protections against expropriation in the Chilean context effectively left the state powerless to enforce private property rights in water matters. The institution of Water Boards partially filled this institutional void. We thus provide evidence of the tension in market design between effective governance and protections against expropriation.

We also offer new evidence on the distributive effects of institutions. Our results suggest that the introduction of governance works most effectively in unequal basins, but also that even though most downstream farms benefit from this institution, the benefits are stronger among larger farms, while the costs of redistribution are born disproportionately by smaller upstream farms. While it is not possible to construct an appropriate counterfactual of a similar institution with a distinct governance structure (e.g., one in which the votes do not reflect directly the ownership over the resource, as in these boards), it illustrates how policies that increase efficiency may also exacerbate inequalities.

Related Literature. Our paper contributes to a range of literatures, including management of common pool resources, frictions in developing markets, the economic impacts of agricultural infrastructure and the economics of climate change. We first contribute to the body of work in environmental economics on the management of common resources. Water is considered a common pool resource, given the difficulties in enforcing exclusion, and the rivalry on its consumption (Ostrom and Gardner, 1993), implying the emergence of a "Tragedy of the Commons", where free-riding behavior leads to the over-exploitation of the resource (Hardin, 1968). Traditional approaches to managing common pool resources allocate the decision rights over the resource to either the state or private agents through privatization, but implicitly assign the tasks of monitoring and enforcing the decisions to the state. The literature on the different institutional arrangements over water is extensive; Meinzen-Dick (2007) and Ostrom (2010) provide good reviews and discussions on this topic.

In a classic work, Ostrom (1990) identifies local communities as a third possible managing agent and discusses conditions under which communities can succeed in environments where neither state management nor privatization can, by introducing locally managed monitoring and enforcement and decision-making. Among these conditions, she identifies monitoring capability, availability of sanctions among community members and closed access to outsiders. Most of the related literature has focused on testing these conditions in case studies or lab-in-the-field experiments in small-scale settings (e.g. Cardenas and Carpenter, 2008; Cárdenas and Ostrom, 2004; Henrich, McElreath, Barr, Ensminger, Barrett, Bolyanatz, Cardenas, Michael, Edwins, Henrich, Lesorogol, Marlowe, Tracer, and Ziker, 2006). In the environment we are studying –distribution of water within basins encompassing several local communities–, these conditions do not apply[1]. Our results, therefore, extend Ostrom's by showing how local communities can address free-riding problems in wider environments by relying on tools usually reserved for the state, like the authority to resolve legal disputes or establish legal punishments.

Another strand of the literature focuses on contexts with private property rights over water, opening questions about how water markets work. The prior work closest to our own includes Rafey (2023a), who estimates the gains from trading water rights in the context of Australia, where the government exerts stronger monitoring, control and enforcement of property rights over water across the full country. Studies that compare markets versus others allocation mechanisms include Ryan and Sudarshan (2022), who estimate the efficiency losses from rationing groundwater relative to a counterfactual Pigouvian allocation, and Donna and Espín-Sánchez (2023), who study how liquidity constraints may imply that markets are less efficient than a quota system on allocating water in Spain. This work studies the efficiency gains associated with different institutional arrangements. Our work complements them by exploring how governance and enforcement are preexisting conditions for the proper operation of markets.

A related line of research explores the economic consequences of water infrastructure. Duflo and Pande (2007) estimates the productivity and distributional impacts of dams using an instrumental variable approach, showing that even though the net impacts are positive but modest, they have substantial distributional consequences, with downstream areas getting substantial benefits at the expense of upstream areas. Asher, Campion, Gollin, and Novosad (2022) and Blakeslee, Dar, Fishman, Malik, Pelegrina, and Singh (2021), using different identification strategies based on the local geography, estimate the structural

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[1] First, agents cannot observe the actions of people outside their community; second, they cannot exclude others from locating into the basin by purchasing either land or water rights, and finally, people located downstream do not have informal tools to punish upstream people actions, so is not possible the emergence of informal agreements driven by repeated interactions, along the lines of the "Folk's Theorem".

transformation consequences of canals; both papers show that canals increase agricultural productivity but do not affect the productivity of other sectors, which they attribute to labor displacement. Our contribution is to show how the productivity and distributional consequences of infrastructure –in particular, canals– are shaped by the interaction between institutions and geography.

We contribute to a growing empirical literature on agriculture and adaptation to climate shocks, that increasingly relies on design-based strategies to understand the causal effects of climate shocks and different adaptations. Early contributions include Schlenker, Hanemann, and Fisher (2005), Lobell, Roberts, Schlenker, Braun, Little, Rejesus, and Hammer (2014) and Burke and Emerick (2016), who use different methods to characterize the extent to which adaptation can mitigate the agricultural costs of climate shocks. More recent contributions include Hagerty (2021), who studies short and long-term adaptations to changes in water availability by farmers through crop and operation decisions. Our contribution is to provide a new misallocation test on a key resource, and also to show how institutions may shape how farmers adapt, and the effectiveness of such adaptations.

We also contribute to the literature on the economic consequences of natural resources privatization and misallocation. While this literature is extensive, to our knowledge, this is the first paper to causally estimate the economic impact of enforcement of private property rights, and also over water specifically. Most of the related work identifies misallocation caused by legal limits to the exercise of property rights, which translates into market frictions. We provide evidence of the opposite: how limits to government action -in place to avoid their interference over markets- can also be a source of misallocation (Bauer, 2004).

Related work includes De Janvry, Emerick, Gonzalez-Navarro, and Sadoulet (2015), which finds that land titling enables land reallocation towards more efficient farmers and labor reallocation through migration, and Chari, Liu, Wang, and Wang (2021) that shows how a property rights reform that allows farmers to lease out their land increases productivity and output by reallocating land towards more efficient producers. Our work shows that a necessary condition for the realization of such efficiency gains is the proper enforcement of property rights under trade. A related strand of the literature is the one studying the economic consequences of input misallocation. Recent examples of this literature include

Manysheva (2022) who quantifies the efficiency gains from reducing frictions in the land market in the presence of credit constraints, and Gollin and Udry (2020), who improve on previous misallocation estimates by addressing measurement error.

This paper is organized as follows: in Section 2 we present the Chilean system of property rights over water, the institution of Water Boards and how both operate and in Section 3 we present the different datasets we use on our analysis. In Section 4 we present our river segment-level analysis, and show the results of our difference-in-differences exercise. In Section 5 we present our farm-level dataset with satellite estimates of water consumption, agricultural production and instrument, and our IV results. Finally, in Section 6 we present our misallocation test and our results.

2 Context

We study the introduction of Water Boards, a local governance institution that manage rivers in periods of water scarcity and solve legal conflicts among users. Thanks to their local nature, Water Boards know and interact with water users –in contrast to most centralized bureaucracies in charge of water management. In this section, we provide background information on the study area, the system of property rights over water, and the characteristics of Water Boards.

Geography. The area under study covers latitudes -30 to -38 and the full longitudinal range of Chile in this area (approximately -68 to -72.5) as shown in the central panel of figure 2. This area covers 87% of Chile's population and 85% of the agricultural GDP. The geography is marked by both the Andes –which defines the eastern border of the country– and Coastal Mountain Ranges that extend in a North-South axis. Most agricultural activity takes place in the Central Valley that separates both ranges, and most rivers run from the Andes (East) to the Coast (West)(Fernández and Gironás, 2021). This rugged geography makes very costly the construction of infrastructure connecting basins.

The climate in this area is Mediterranean with rainfall increasing in a North-South gradient; and a dry season that goes from November to March. Rivers in this area are mostly fed by both rainfall and snow-melting (Varas and Varas, 2021; CNR, 2018a). This implies that rivers reach their maximum stream levels in the boreal winter and spring, and decline reaching minimum levels in summer and early fall (between February and April). Importantly, longer days make summer a key period for agricultural production, implying that irrigation is most important in the driest months.

Background on the Chilean System of Private Property Rights. Since 1981, Chile has been the only country in the world where perpetual private property rights over water (water rights in what follows) have constitutional protection against expropriation, which has resulted in limited administrative action by governments (Bauer, 2004; World Bank, 2011a, 2021). These rights are fully transferable, separated from land, and they are legally considered real estate; so a legal transaction of water rights is equivalent to a purchase of land (CNR, 2018a)[2]. These rights are defined in terms of a stream of water (measured in liters per second) to be extracted from a specific location and source and following a monthly schedule; all these attributes are defined during the creation of each water right. Figure 19 in Appendix A presents an example of a water right.

These rights can be claimed for free through public requests to the Directorate of Water (DGA, a national public institution similar to the US Bureau of Reclamation), the technical government institution in charge of assessing water resources and applying the law on water matters. These rights can be created until the DGA declares the river exhausted. The process comprehends the following steps (the process is summarized in figure 1):

Step 1: The person or firm interested in claiming the water starts a claim at the DGA.

Step 2: The DGA sends a field officer, who will check the physical and legal availability of water in the source.

Step 3: The agent interested in the water right has to publish the claim. There is a 30 business days period open for complaints, and for other potential users to express

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[2] The titles also include the property over the infrastructure that allows the distribution of water, but there are legal figures that allow to mandate one user to share the infrastructure with other users that own water rights (CNR, 2018a).

interest in the newly established right (if it is not possible to create rights for the two users).

  - Any complaints will be reviewed by a judge; if the judge rules them as valid, the new water right is not created.
  - If any other user is interested in the water right, there is an auction.

Step 4: The title is created, legalized and registered in a local property registrar.

After a source is declared exhausted, any user needing water rights in the area must purchase them from other users. They can be freely traded among both individuals and firms, without any interference by the government, and legally they are considered real estate (Biblioteca del Congreso Nacional, 1981).

The law that regulates water matters is the Water Code of 1981[3]. Enforcement in principle relies on the actions of the DGA, which is supposed to address water stealing and over-extraction. However, this institution has been overruled and their actions limited systematically by courts (Bauer, 2004). A second enforcement layer is that the infrastructure in place should be built consistent with the water rights owned: the diameter of the pipe -checked by DGA agents at the moment of the reclamation- connecting the farm to the canal or well limits the total extraction capacity (CNR, 2018a). This coarse measure limits over-extraction in normal times by limiting the maximum water intake, but it does not during droughts: while the law establishes that users should limit their water extraction proportionally to the reduction in total streamflow (Biblioteca del Congreso Nacional, 1981), the infrastructure does not adapt accordingly.

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[3] Before 1981, there were two legal bodies regulating water (Peña, 2021):

- Water Code of 1951: here was created the process of creation of water rights as it exists now, but only for agricultural users; they legally consisted on concessions by the state to the users, they were tied to a specific land parcel and they could not be traded. The administration of canals was left to Canal Associations, and the administration of rivers under droughts was under the authority of Water Boards wherever there was one in place, or to the state otherwise.
- Water code of 1967: this water code was enacted to harmonize the legal administration of water to the successive Land Reforms implemented between 1962 and 1973. In essence, this code reallocated the management of all water bodies to the state, and all water titles in place were replaced by new titles that allocated water proportionally to the plot size. This code was never fully implemented, but it created an administrative disorder and future confusion regarding what titles were valid after the 1981 code was enacted.

Background on Water Boards. Droughts reduce the total stream flow, and the law establishes that these reductions should be prorated proportionally among all users: a reduction of 50% of the total river streamflow should imply a 50% reduction in the maximum extractions by all users. Until recently, public agencies have not been able to intervene effectively in the allocation of water under scarcity, due to restrictions on administrative government action and lack of resources, leaving a void in the enforcement of drought-induced reductions (Bauer, 2004).

In response to droughts, early in the XX century agricultural users created Water Boards as a representative of the water users (Peña, 2021). After the passing of the the Water Code of 1981, Water Boards have the legal authority to:

- determine and enforce water allocations across legal users under extraordinary circumstances, such as drought,
- adjudicate disputes among users within their jurisdiction,
- keep track of Water Rights claims, and
- provide common goods such as legal assistance and common infrastructure, and define its own funding sources.

They report only to their constituents –who elect them with votes weighted by their Water Rights streamflow property– during their 2 or 3-year tenure. They are subject to regulation by the DGA, but courts have curtailed DGA's intervention. Therefore, Water Boards are effectively the highest administrative authority in water-related issues in the basins under their jurisdiction, except for emergency situations

The creation of Water Boards is triggered by either an agreement by at least half of the water rights owners within the area under consideration, or a lawsuit by at least one water user. This process is under the jurisdiction of an ordinary judge housed in the most upstream province capital city within the basin in question[4]. During this process, each community agrees on the final jurisdiction and statutes, which are subject to restrictions

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[4] Articles 269^{th} and 270^{th} of the Water Code of 1981(Biblioteca del Congreso Nacional, 1981).

by the Water Code. The location and establishment date of these boards are presented in figure 2.

Administrative and legal jurisdiction. Water Boards' jurisdictions covers surface water bodies within their boundaries[5]. We present in figure 3 flowcharts of how water boards relate to the administrative (figure 3a) and legal institutions (figure 3b) in Chile on water matters. Administrative decisions, such as cutting allotments in the context of drought, will be decided by the Water Board, for water rights within their jurisdiction[6]. If any user wants to dispute this decision, they can appeal to the DGA; however, in practice, DGA's capacity is limited and its decisions have been overruled by courts in several lawsuits (Bauer, 2004; World Bank, 2011b).

In the case of legal actions, any people and firms owning water rights should ask for a ruling from the Water Board that has jurisdiction over the source[7]. Part of the duties of a Water Board is to appoint a "Judge of Waters", who most of the time is part of the board or an employee of the board. This judge has full authority to solve legal disputes and to enforce their ruling, with the authority of the Water Board. In the absence of a Water Board, instead, the only option users face is to initiate legal action on ordinary courts (civil or penal courts, depending on the nature of the conflict). Water Boards substitute ordinary courts on water matters, with additional field expertise.

Appeals to Water Board rulings -or lawsuits against the boards themselves- must be made to the Appeals Courts -which almost in all cases have jurisdiction over Regions, the first level administrative unit in Chile-, and eventually can be escalated to the Supreme Court. Bauer (2004) discusses how higher courts lacked water-specific knowledge and have ignored in their rulings substantive water issues, focusing exclusively on the legal issues at

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[5] In 2005, their jurisdiction expanded, to include groundwater (CNR, 2018a; Fernández and Gironás, 2021).

[6] For water rights registered in canals, Water Boards take decisions regarding allotments for the full canal, and the corresponding Canal Association will solve the matter within the canal. Users willing to dispute their Canal Association decisions may direct their complaints to the Water Board.

[7] If the users under conflict own water rights linked to a canal, their first step is to address their Canal Association, which manages water issues within a given canal. If the agents are unsatisfied with their ruling, they can appeal to their Water Board, or ordinary courts, if there is no Water Board with jurisdiction in the area. Water Boards also have jurisdiction over all conflicts that may arise among canals themselves, as long as they are within the Boards' jurisdiction.

hand and emphasizing the “letter of the law”.

3 Data

We gathered a richness of information that reflects the *de jure* and *de facto* allocation of water across space and time, together with detailed agricultural information to measure outcomes and climatic controls. Our analysis has three stages: first, a basin level analysis, then a farm level analysis, and finally our Misallocation Test, implemented using farm level data.

3.1 Basin level analysis

Water Organizations. The information on the jurisdictions and establishment date of Water Boards was provided by the DGA. This institution also provided the maps of the jurisdictions of each board, and also information on the location and jurisdiction of Canal Associations.

Basins, Streamflows and Climate. The DGA publishes the maps of the network of rivers, together with the boundaries of all basins and aquifers identified in the country. Also, the DGA maintains a network of 803 monitoring stations in rivers and canals across the country since 1913. Our main sample is composed of 516 of these stations that have been created before 1980 and operated for at least 10 years after this. The Center for Climate and Resilience Research (CR^2) has identified the drainage areas of each monitoring station.

In parallel, CR^2 has also created daily climatic estimates for the entire Chilean territory at a $70km \times 70km$ resolution, by calibrating satellite measures with local input from climatic monitoring stations (Alvarez-Garreton, Mendoza, Boisier, Addor, Galleguillos, Zambrano-Bigiarini, Lara, Puelma, Cortes, Garreaud, McPhee, and Ayala, 2018). These estimates include precipitation, potential evapotranspiration and minimum and maximum temperatures. We aggregate these climatic estimates at the drainage basin or the county level, according to the analysis on which the data is being used.

Water Rights. The DGA has been collecting information on water rights since 2010 across the different local agencies and registrars where the titles have been created. With this input, the DGA publishes a Water Rights Cadaster, that includes detailed information about each water right, including the monthly schedule of extractions, the source (including if the source is a surface water body or groundwater), the name of the original owner of the right and the geographic coordinates of the water intake. From the name of the original owner, we infer if they are people or firms (and in the latter case, their economic sector when it is reflected by the name).

3.2 Farm Level Analysis

Land plot limits. SII (the Chilean Tax Authority) maintains for tax purposes a Land Cadaster, with detailed information on each plot of land in the country. CIREN geocoded the Land Cadaster for 2013. Our sample corresponds to land plots located less than 1km from a canal.

Satellite information on Evapotranspiration and Greenness. EEFlux is a platform that provides Evapotranspiration estimates using the METRIC method (Allen, Morton, Kamble, Kilic, Huntington, Thau, Gorelick, Erickson, Moore, Trezza, and others, 2015) using as input images from Landsat 7, 8, 9 and Sentinel 1 and 2. This method recovers Evapotranspiration from an Energy Balance condition that equates the measured sun radiation on the surface to the calculated surface reflectance, estimated soil heat absorption and Evapotranspiration (which is recovered as a residual)(Allen, Morton, Kamble, Kilic, Huntington, Thau, Gorelick, Erickson, Moore, Trezza, and others, 2015). We use images captured since the year 2000 using as input Landsat-7 images, with a resolution of $30m \times 30m$, a resolution fine enough to allow us to perform farm-level analysis. We also use NDVI and EVI estimates based on Landsat 7 images from the USGS, and so they also have a resolution of $30m \times 30m$.

3.3 Farm level, Misallocation Test

2007 Agricultural Census. The misallocation test uses data from the 2007 Agricultural Census, collected by the National Statistic Bureau (INE, the official statistical office of Chile). This Census includes operation-level information on land use and extension, crop choice, capital and employment decisions, managerial characteristics and legal organization. Importantly, includes information on production for more than 20 crops, and self-reported information on the use of irrigation and the sources and legal status of irrigation water, together with affiliation to agricultural organizations (specifically to Canal Associations).

4 Basin level analysis

To study the effect of governance, we explore the full causal chain that links board establishment and agricultural outcomes. The first stage is to show that boards cause changes in both the *de jure* allocation of water (i.e. that they modify the rate of creation of water rights) and the *de facto* allocation of water (i.e. streamflows, which reflect where water is being extracted). In the second stage, we show how this affects the actual water consumption by farms, and in our final stage, we show the economic consequences of the reallocation of water caused by the establishment of the boards.

4.1 Identification Strategy

In our first stage of the analysis, we exploit the staggered adoption of Water Boards across basins to estimate the causal impact of property rights enforcement and governance on the allocation of water. Table 15 in Appendix A presents the year of establishment of Water Boards, and the number of river segments under their jurisdiction -defined by the locations of streamflow monitoring stations in the river network. Given the data available and the institutional design in place, we focus our analysis on the boards established after 1982[8].

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[8] We consider 4 years before and 4 years after the establishment of the board for our analysis, and so we need to exclude those boards established in 1982. The results are not affected by reducing the number of pre-periods to 3 to include the boards established in 1982.

Sample. The establishment of Water Boards is triggered by either an agreement among water users or a lawsuit by one user that perceives their interest to be affected by the lack of governance in the basin. In both cases, there is conflict latent over the resource, driven by both water supply and demand factors. The process is long and irreversible, though, implying that the more likely driver of their adoption is long-term conflict[9].

The first challenge in building the counterfactual water availability and reclamation for treated areas is to identify a proper set of control river segments. Two key features of rivers that may determine conflict around them are total streamflow and hydrologic regime . While the first is linked directly to water scarcity, the second attribute is linked to the temporal availability of water over the agricultural cycle. Rivers with a nivo-glacial regime (i.e. the streamflow is high in the seasons when snow and glaciers are melting) will have relatively more water available in the Summer. This season is when water is more needed for irrigation, especially for high-value crops and fruits that need year-round water input.

In figure 4a, we present the monthly pre-1985 streamflow and precipitation medians for all river segments without boards before 1980, separating between those that eventually were under a Water Board (treated segments onwards) and those that are not (control segments). Relative to control river segments, treated segments have lower streamflow and total precipitation, with hydrological regimes less dependent on rainfall and more on snow-melting, which is reflected by having streamflow peaks during the Austral Spring (October and November) instead of the Winter.

To ensure a comparable control group, we identify non-treated units that satisfy three sets of conditions:

> **Condition 1:** Common Support: we identify a Common Support condition based on two observable measures in the baseline: average streamflows and total water rights in 1980[10]. For each measure, we identify the support of the distribution for the treated and exclude control segments whose values fall out of it. Since both quantities are

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[9] There is no systematic documentation of the time length of the full constitution process, but one testimony about the establishment of a water board through a lawsuit in 2015 describes a process of at least two years, with the lawsuit resolution taking the first year and the second year devoted to the execution of the resolution; the organization of the board actually started during this year (CNR, 2018b).

[10] Water rights claimed by 1980 were claimed under previous Water Code versions, and they were eligible for regularization under the new rules introduced under the 1981 Water Code. They reflect the intensity of extraction of each river before the 1981 Water Code reform.

non-negative and the minimum values for the treated and control groups are similar and close to zero, this implies excluding segments with streamflows and water rights higher than the maximum observed for the treated group.

Condition 2: Only non-yet-treated units: to address non-observable trends, we only consider river segments where water boards were eventually established.

Condition 3: No externalities: we exclude all river segments subject to that were located downstream of any previously established boards, or water boards established before the 1981 Water Code.

Figure 4b presents streamflows over the year and precipitation for the final sample; treated and control units have comparable streamflows across the whole year, and overall a similar hydrological regime.

To gain power, we take advantage of the staggered adoption of the boards by including segments within the jurisdiction of water boards established in future periods as control segments for board establishment events with a time difference of at least 5 years. Table 1 presents the number of river segments in the full sample (excluding those subject to externalities and those with boards before 1981) and those in the Study Sample (i.e. those who satisfy Conditions 1, 2 and 3 above).

Our identification strategy relies on the assumption that the timing of adoption is as good as random, conditional on the set of fixed effects and covariates; such that there are no unobservable trends affecting treated and control units differently around the event. In our case, we argue that all the basins in our sample are facing increasing long-term counterfactual water demand, and so the differences in adoption timing are driven by long-term water availability and possibly short-term observable water availability shocks, but not by short-term unobservable shocks. Economically, this is reasonable: it is a permanent institution, implying permanent monetary costs (in the form of organization fees) and expected loss of control under foreseeable circumstances, such as future droughts. As anecdotal evidence suggests that establishing a Water Board is a slow process even in the case of agreement among users (Andres Arriagada Puentes, Claudia Quiroz Sánchez, Natacha Valenzuela López, Blanca Rivera Flores, José Contreras Urízar, and Ovidio Melo

Jara, 2018), it does not seem appropriate as a tool to deal with temporary shocks, such as a current drought. In particular, droughts in Chile are frequent but not long-lasting (Fernández and Gironás, 2021): while 45 years during XX century can be classified as dry, the longest critical meteorological drought event between 1940 and 1988 lasted only 22 months (Fernández, Bonifacio, Gebhardt, A, and Vial JA, 1990).

To support this argument, we present different characteristics of the different areas adopting water boards by year of adoption in figures 5, 21 and 22. Figure 5 presents three different measures of water availability before 1985: precipitations (5a), river streamflow 5b and glacier surface in the basin 5c. We separate the figures for areas where the board was established before 1981 -when the Water Code of 1981 was passed- and after; the distinction is relevant, as it was the Water Code of 1981 that opened the reclamation of rivers and established the water markets we are studying.

Figure 5a shows that even though the average precipitation was higher in areas that established boards before 1981 -areas where agriculture developed earlier-, we can see that for those boards established after[11], there is a trend: higher precipitation in areas where boards were established later. This is consistent with boards facing dryer long-term conditions adopted boards earlier. In figure 5b we see that the average streamflows increase with the year of establishment, too. Finally, we consider the share of the basin that is covered by glaciers at the head of the rivers, in the Andes. This is a measure of the natural availability of water during the Summer: glaciers smooth the relationship of precipitations and streamflows, by accumulating snow during the winters, and slowing down the melting process, allowing solid water to melt and flow downstream during the Spring and Summer. Figure 5c shows that except for the years 1982 and 1983, it seems that the presence of glaciers increases as the year of establishment increases. This is consistent with boards being adopted earlier in places with less natural water availability during Summer when water is most needed for irrigation.

Figure 21 presents similar figures for the average minimum and maximum temperatures, latitude and longitude of monitoring stations. For basins that adopted boards after

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[11] Except for those boards established in 1982, which establishment process was probably started before the passing of the Water Code of 1981.

the passing of the Water Code of 1981, minimum and maximum temperatures seem to increase with the year of establishment of boards. Latitude and longitude do not display any distinctive pattern. Finally, in figure 22 we present some measures of long-term agricultural activity: agricultural land surface between 1980 and 2010, and water rights established before 1985. While agricultural activity is endogenous to water governance -as we show later in this paper-, most of the increases in water demand and changes in agriculture are a result of intensification and technological change in a fixed agricultural area (Meza, Gil, and Melo, 2021). Basins that adopt boards earlier actually have a lower agricultural land share -at odds with the idea that early adopters might be facing stronger demand driven by extensive agriculture-; and there is no clear pattern regarding the early (i.e. before 1985) creation of water rights.

Difference-in-Difference Design for Water Rights creation. We implement Cengiz, Dube, Lindner, and Zipperer (2019) Stacked DID design to estimate the following baseline equation:

$$\text{Water Rights}_{gst} = \beta \text{Board}_{gst} + \gamma X_{gst} + \mu_t + \eta_g + \varepsilon_{gst} \tag{1}$$

where WR_{gst} denote the total water rights issued in river segment g in basin s and year t and Board_{gt} is an indicator function that equals 1 if segment g is within a Water Board jurisdiction. X_{gst} is a vector of covariates that include rainfall, potential evapotranspiration and temperatures, η_g correspond to segment fixed effects and μ_{st} are year fixed effects[12]. We use detailed georeferenced Water Rights records from the National Water Rights Cadaster, combined with climatic estimates by Alvarez-Garreton, Mendoza, Boisier, Addor, Galleguillos, Zambrano-Bigiarini, Lara, Puelma, Cortes, Garreaud, McPhee, and Ayala (2018) and the geological basin borders identified by CR2.

To address potential pre-trends, we also estimate a dynamic effects specification:

$$\text{Water Rights}_{gst} = \sum_{i=-4}^{4} \beta_i \text{Board}_{gst} \times 1\left[t - t^* = i\right] + \gamma X_{gst} + \mu_t + \eta_g + \varepsilon_{gst} \tag{2}$$

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[12] Following Cengiz, Dube, Lindner, and Zipperer (2019), the time fixed effects are actually separated by treatment adoption event. This applies to all DID estimates throughout the paper.

where t^* denotes the year where the event of board establishment takes place. This means that $i = -4, -3, -2, -1, 0, 1, 2, 3, 4$ represent years relative to the event of board establishment. In our specifications, we consider relative year -1 as the baseline period, and include only observations within 4 years of the establishment.

The identification assumption in both cases corresponds to parallel counterfactual trends: water rights created in treated basins would have grown the same as control basins' water rights grew around the establishment of a board. We use Poisson Regression in our preferred estimates of equations 1 and 2 as it allows to deal with heavy right-tails while properly dealing with zeroes(Chen and Roth, 2023); our data on water rights satisfies both characteristics.

Difference-in-Difference Design for Streamflow. Streamflow effects estimations present the additional challenge of seasonality: rivers and precipitation display seasonal patterns that introduce noise in the estimation, and could potentially bias the estimation of board effects when focusing on the dry season. To address this, we estimate:

$$\text{Stream}_{gmt} = \delta \text{Board}_{gt} + \sum_{k=m}^{m-L} \alpha_2^k \text{Rain}_{gskt} + \alpha_3 \text{PET}_{gmt} + \alpha_4 \text{Water Rights}_{gmt} + \mu_t + \eta_{gm} + \varepsilon_{gmt} \tag{3}$$

where Stream_{gmt} is the streamflow in segment g in month m and year t and Board_{gt} is equal to 1 if segment g is under the jurisdiction of a Water Board in year t. Upstream_{g-1mt} is the streamflow at the head of the segment, Rain_{gsmt}, PET_{gmt} and WR_{gmt} denote monthly rainfall and potential evapotranspiration, and Water Rights issued in the segment. μ_t and η_{gm} are year and segment-month fixed effects, accounting for seasonality at the segment level. We include L lags of precipitation (including the current period precipitation) to account for streamflow fed by snow-melting instead of rainfall runoff.

We also estimate dynamic effects according to the following equation:

$$\begin{aligned}\text{Stream}_{gmt} &= \sum_{i=-4}^{4} \delta_i \text{Board}_{gst} \times 1\left[t - t^* = i\right] \\ &+ \alpha_1 \text{Upstream}_{g-1mt} + \sum_{k=m}^{m-L} \alpha_2^k \text{Rain}_{gskt} + \alpha_3 \text{PET}_{gmt} + \alpha_4 \text{Water Rights}_{gmt} + \mu_t + \eta_{gm} + \varepsilon_{gmt}\end{aligned} \tag{4}$$

This specification will allow us to identify pre-trends.

Equations 3 and 4 are derived from a water balance equation, where the inflows equalize outflows in a basin. The equation does not exactly hold, given the use of proxy variables and measurement error. The most important concern regards the potential endogeneity of water rights: this is literally among our outcome variables, given the mechanisms discussed above –i.e. Water Boards can provide better monitoring, and so to stop the creation of new water rights that may interfere with preexisting ones. Our results are not sensitive on their inclusion.

4.2 Results

In this section, we present estimates of the impact of Water Boards on the creation of water rights and streamflows. Using OLS and Poisson regressions, in subsection 4.2 we show that the establishment of boards decreases the rate of water rights creation by 40% in the 4 years after its establishment. We find limited evidence of displacement of the demand for new water rights from surface to groundwater sources, which are outside the Water Boards' jurisdiction. Using a similar strategy, in subsection 4.2 we find that streamflows increase by between 5% to 8%, and more than 20% during the dry season. Additional results show these effects are concentrated in upstream locations.

Water Boards impact on water rights creation. In this section, we present the impacts of Water Boards' establishment on water rights creation. While water boards are not entitled to prevent the creation of water rights, they can affect their growth indirectly by identifying potential conflicts between new applications for water rights creation with already existing rights. We expect Water Boards to do this faster than the government because they keep detailed updated records of water rights in their jurisdiction[13]

We present our results on the estimation of equation 1 using Poisson Regression in table 2. Column 1 shows the results for the total streamflow allocated through new water rights within 4 years after the establishment of a water board, while column 2 shows the result for total surface water rights per km^2 of the surface of the basin: the coefficient implies a reduction of 36% in the reclamation of the river. We present the results using OLS over water rights creation in levels and using the Inverse Hyperbolic Sine in table B17; the qualitative results are the same.

We test for the displacement of the demand towards less regulated sources of water in columns 3 and 4, where we present the results for total groundwater rights (column 3) and for groundwater rights per km^2 (column 4). Aquifers were outside the Water Boards' jurisdiction until 2005. There is an increase in groundwater rights of a similar magnitude to the reduction in surface water rights found in column 2. The coefficients are similar, but they imply an increase of around 55%.

Figure 6 presents estimates of dynamic effects (i.e. equation 2) over total water rights created in the segment, for surface sources and for groundwater sources. There is no evidence of pre-trends for surface rights, and for groundwater rights, anticipation seems limited to the last year before the establishment of the board. Also, the figure shows the reduction in surface water rights and an increase of similar magnitude for groundwater rights but with more noisy estimates.

In Appendix A we include as robustness checks dynamic effect estimates using OLS, by total water rights (figure 20) and water rights created by km^2 of surface in the basin (figure 23); the results are similar. Tables 17 and 18 present the full set of estimates of dynamic effects over surface and groundwater water rights, both totals and per unit of surface, using OLS and Poisson regression. Overall, we conclude that water boards reduce the creation of water rights on surface water -where they have jurisdiction-, while there is some non-robust

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[13] Bauer (2004) points out how the lack of centralized records allowed the reclamation of duplicated water rights by some users: by claiming the same title through more than one channel, they were allowed to duplicate their ownership and to sell them. There is evidence of over-reclamation of rivers, that can be linked to this lack of records (Barría, Sandoval, Guzman, Chadwick, Alvarez-Garreton, Díaz-Vasconcellos, Ocampo-Melgar, and Fuster, 2021).

evidence of displacement.

Water Boards impact on streamflows. In this subsection, we present the impacts of the establishment of water boards on river streamflows. This is the most important outcome in this section, given that this reflects the effects of water boards on the *de facto* allocation of water. We expect that enforcement will cause increases in the streamflow, as this would reflect previous extraction by agents located upstream of a monitoring station, that once is stopped by the water board, allows more water (i.e. water that otherwise would have been consumed upstream of the station) to flow.

We do not expect this effect to be uniform across the agricultural production cycle, though. Irrigation does not have the same intensity across months, as in wet months it is possible to rely only on precipitation (and so irrigation may even be damaging), and so the incentives to over-extract will be strongest in the dry season. At the same time, the mandate of Water Boards to guarantee access to water to their lawful users may not require any actions under normal circumstances, and would only require their intervention in the dryest seasons and years.

Table 3 presents the results of estimating equation 3 for 4 years after the establishment of the board, for the full year. Panel A presents the results for the Common Support sample: a board establishment event increases the average streamflow between 4% to 10%, but the increase is not significant.

The former results ignore the fact that most irrigation takes place in the dry season. Table 4, therefore, estimates the same models but only for the months of January and February, when water is more scarce and there is more irrigation, and so, incentives to over-extract are stronger. The estimated effect is stable across specifications: water boards increase the streamflow between 0.96 and 1.46 m^3/s, which represents an increase between 23% to and 34% of the average seasonal streamflow.

To understand better the results in tables 3 and 4, we estimate equation 3 but interacting the Board establishment dummy with dummies per month. These coefficients will reflect the impact of Water Boards on streamflow for each month. We present the results of this exercise in figure 7.

For both samples, we find increases in the streamflow for the dry season, while in the months with the highest streamflow due to snow-melting (October and November) we observe zero effects or even nonsignificant reductions in streamflow. The increase in the Summer streamflows is almost 45% for January and 30% for February for the Event Study sample, while the increments in the middle of the year (July - August) are just around 13%, and during the Spring (October - November) the effects are nonsignificant and between 0 and -10%. Figure 24 in Appendix A presents the results using Poisson regression.

Dynamic effects. In this subsection, we present estimates of dynamic effects using equation 4 using OLS. The intra-segment-inter-year variance in streamflows is high for Central Chile, due to short-term cycles with droughts of varying intensity every 2 to 7 years -mostly associated with the ENSO (El Niño-Southern Oscillation cycle)(Fernández and Gironás, 2021). Given this challenge, we estimate dynamic effects binning relative years to gain power. The results are presented in figures 8a for the full year and 8b for the dry season. We fixed as the baseline period the bin containing the two years prior to the board establishment event.

In both figures, there is no evidence of pre-trends in years prior to the establishment of the board, and the specifications that control only for the set of fixed effects and contemporaneous climatic variables display persistent effects across all years post-board establishment. While for the full year (figure 8a) there is weak evidence of increases in the first 2 bins(years 0 to 3), for the dry season (figure 8b) the evidence is clear, with all specifications giving statistically and economically significant increases in streamflows. In the third bin (years 4 and 5 after board establishment), instead, the results are mixed, so effects continue to be significant in the model that do not control for lags of precipitation or water rights.Tables 19 in Appendix A present the full set of estimates of dynamic effects over streamflows during the full year and in the dry season. Overall, we conclude that the boards have a short-term positive effect on streamflows.

Redistribution within the basin. Increases in streamflow reflect more water flowing downstream from a given point where we measure water. If there are no lawful users downstream of a location, then there is no incentive nor (non-environmental) reason to keep water flowing after that point. Therefore, we expect to find a stronger effect upstream, as river segments located downstream will have relatively fewer lawful users located below them.

Figures 9a, 9b and 9c illustrate why we expect higher streamflow increases in upstream locations: in normal times (figure 9a), the infrastructure itself restricts users from over-extracting water. In a drought, the total streamflow available for distribution is reduced, and so the law established proportional reductions for all users. Figure 9b presents this case when no board is in charge of enforcing water rights: as the infrastructure is not binding anymore, the users upstream are able to over-extract, leaving not enough water for downstream users. Figure 9c shows how this situation changes in the presence of water boards: enforcement by the water boards implies increased streamflows between upstream and downstream locations. The increase in streamflow will be captured by the monitoring stations located between the users that would over-extract in the absence of a board, and those who receive water thanks to the board.

Table 5 presents estimates of heterogeneous effects, by interacting the treatment variable with dummy variables for river segments closer to the coast (below the median of the distribution of distances to the coast, in degrees) or farther away from the coast. Columns 1 and 2 consider the full year, while columns 2 and 4 only include the dry season.

The results show that the coefficients are higher for upstream locations in the full year, and for the dry season when we control for precipitation lags. Also, the coefficients are strongly significant for the dry season only for upstream locations, while for downstream locations are significant only at the 10% when controlling for precipitation lags. Finally, the table reaffirms the previous results that the effect is economically and statistically significant only for the dry season.

Land Concentration and Water Boards. Water boards allocate power according to property: each water rights owner have a vote that is proportional to their streamflow ownership. This is a departure from conventional democratic rules that may imply improved economic outcomes (e.g Alesina and Rodrik, 1994), but also could reinforce elite capture dynamics (Bardhan and Mookherjee, 2000; Banerjee, Mookherjee, Munshi, and Ray, 2001).

In table 6 we compare the impacts of the establishment of Water Boards in basins with higher versus lower land concentration. Using 2013 data on farm size, we measure land concentration for all the river segments under analysis[14].

Our results suggest that most of the observed impacts of Water Boards are driven by areas with higher land concentration. Columns 1 and 2 show that the reduction in the creation of water rights is similar for areas with low and high land concentration (although the effect is not significant in areas with higher land concentration due to higher standard errors). Columns 3 and 4, instead, show that all the increase in groundwater rights (i.e. the displacement of the demand) happens in basins with higher land concentration. Finally, columns 5 and 6 show that the streamflow increase in the irrigation season is significant and higher for areas with higher land concentration, while for lower land concentration this does not happen.

One interpretation for the former results is that the presence of local elites -associated with higher land concentration- enhances the performance of water boards: local elites may be able to discipline more effectively the team managing the river[15]. It is possible, too, that these aggregate results hide heterogeneous distributional impacts, and so these improvements in property rights enforcement are beneficial only for local elites We will revisit this question in section 5.2.

Monitoring and Enforcement. So far, we have argued that water boards affect the allocation of water through two main mechanisms:

> **Monitoring:** water boards, by keeping track of the creation of water rights, are in a better position than both the state and the water users to identify interference by new water rights, and so introduce more complaints to stop the creation of rights.

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[14] In principle we could directly measure water rights ownership concentration. In practice, this was not possible due to the low quality of the geolocation of water rights in the period under study.

[15] In a simple agency model with liquidity constraints (available upon request), the presence of agents with enough resources to start litigation against a "shirking" Water Board is a necessary condition for an equilibrium where water boards effectively enforce property rights, as the board is disciplined by the threat of a lawsuit by water rights users affected by over-extraction. The Water Board does not exert effort (and so, property rights are not enforced in equilibrium) if lawsuits are unaffordable for all users that do not have water access as a consequence of over-extraction in an equilibrium without enforcement.

Enforcement: water boards reallocate water according to the legal mandate to enforce the existing water rights.

Our results in sections 4.2 and 4.2 suggest that both mechanisms are working, opening the question of their relative roles in shaping the allocation of water in the space.

In order to disentangle the relative roles of both mechanisms, we apply a statistical mediation argument (Baron and Kenny, 1986; Valeri and VanderWeele, 2013) to estimate the direct causal effect of water boards on streamflows, and their indirect effect, mediated by their effect on water rights. Statistical mediation exercises rely on several assumptions, but the Difference-in-difference design already assumes part of them[16].

To formalize the argument, let's consider a simplified version of equation 2 i.e. our models for water rights:

$$\mathrm{WR}_{gst} = \beta_1 \mathrm{Board}_{gst} + \beta_2 X_{gst} + \mu_t + \eta_g + \varepsilon_{gst} \tag{5}$$

With this definition, we can define the counterfactual expected water rights under water boards and without water boards as respectively:

$$\begin{aligned} \mathrm{WR}(\mathrm{Board}=1) &= \mathbb{E}\left[\mathrm{WR}_{gst} | \mathrm{Board}=1\right] = & \beta_1 + \beta_2 X_{gst} + \mu_t + \eta_g \\ \mathrm{WR}(\mathrm{Board}=0) &= \mathbb{E}\left[\mathrm{WR}_{gst} | \mathrm{Board}=0\right] = & \beta_2 X_{gst} + \mu_t + \eta_g \end{aligned}$$

Now, we can extend our model for streamflows, allowing water boards to affect also the relationship between water rights and streamflows:

$$\begin{aligned} \mathrm{Stream}_{gmt} = & \alpha_1 \mathrm{Board}_{gt} + \alpha_2 \mathrm{WR}_{gmt} + \alpha_3 \mathrm{Board}_{gt} \times \mathrm{WR}_{gmt} \\ & + \alpha_4 \mathrm{X}_{gsmt} + \mu_t + \eta_{gm} + \varepsilon_{gmt} \end{aligned} \tag{6}$$

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[16] Statistical mediation exercises in a causal environment rely on four assumptions: (1) no unmeasured treatment-outcome confounding, (2) no unmeasured mediator-outcome confounding; (3) no unmeasured treatment-mediator confounding, and (4) no mediator-outcome confounder affected by treatment (Valeri and VanderWeele, 2013). While assumptions (1) and (3) were already assumed on running the Difference-in-difference analysis, assumptions (2) and (4) are non-standard, and imply in this setting a causal interpretation to the relationship between streamflows and water rights claimed, conditional on the set of fixed effects and controls. Providing evidence of such a causal relationship is currently under development, but the results so far do not contradict this assumption: the coefficient of water rights on streamflow is negative and in the same order of magnitude, as expected.

Then, from estimates of equations 5 and 6, we can recover the effect of water boards on streamflows, mediated by water rights. Following Baron and Kenny (1986) and Valeri and VanderWeele (2013), we define

1. Natural Direct Effect of Water Boards on Streamflows:

$$\begin{aligned}&\mathbb{E}\left[\text{Stream}|\text{Board}=1,\text{WR}(\text{Board}=0)\right]-\mathbb{E}\left[\text{Stream}|\text{Board}=0,\text{WR}(\text{Board}=0)\right]\\&\quad=\alpha_1+\alpha_3\mathbb{E}\left[\text{WR}|\text{Board}=0\right]\end{aligned}$$

2. Natural Indirect Effect of Water Boards on Streamflows, mediated by Water Rights

$$\begin{aligned}&\mathbb{E}\left[\text{Stream}|\text{Board}=1,\text{WR}(\text{Board}=1)\right]-\mathbb{E}\left[\text{Stream}|\text{Board}=1,\text{WR}(\text{Board}=0)\right]\\&\quad=(\alpha_2+\alpha_3)\times\left(\mathbb{E}\left[\text{WR}|\text{Board}=1\right]-\mathbb{E}\left[\text{WR}|\text{Board}=0\right]\right)=(\alpha_2+\alpha_3)\times\beta_1\end{aligned}$$

The Natural Indirect Effect will be our estimate of the effect of Monitoring over streamflows. If water boards affect streamflows only through these two channels, then the Natural Direct Effect reflects the role of Enforcement.

In table 7 we present the results of the mediation exercise. The Natural Indirect Effect of water boards mediated by water rights is an increase of just $0.097m^3/s$; the Natural Direct effect is $0.842m^3/s$. Taken together, these results imply that just 10.3% of the total effect of water boards on streamflows is mediated by water rights. This suggests a limited role of Monitoring in increasing streamflows, compared to the effects of Enforcement.

5 Farm level Analysis

In this section, we present estimates of the impact of Water Boards on the effective water access of farms in the long run. We show here that our previous results -a short-term increase in streamflows to downstream locations during Summers- translate effectively into increased water access for parcels located downstream, by using a novel Instrumental Variable for the costs of establishing boards.

Our analysis relies on a novel database, containing more than $75,000$ parcels located less than 1km away from a canal in the whole area of study (i.e. regions IV to IX, in Central

Chile). We estimate parcel-level water consumption using EEFlux, a new LANDSAT-based product that provides estimates of Evapotranspiration at a 30m resolution every 16 days since 1999 (Allen, Tasumi, and Trezza, 2007; Allen, Morton, Kamble, Kilic, Huntington, Thau, Gorelick, Erickson, Moore, Trezza, and others, 2015). In addition, we also estimate agricultural yield using Enhanced Vegetation Index (EVI) estimates from LANDSAT 7[17](Burke and Lobell, 2017; Blakeslee, Dar, Fishman, Malik, Pelegrina, and Singh, 2021). To illustrate the detailed nature of this data, figures 10a and 10b present our estimates of water consumption and agricultural yield (proxied by actual evapotranspiration and EVI, respectively) for all farms in the Aconcagua Basin. In figure 10a we observe a decline in water consumption when comparing upstream (right) to downstream (left) locations. Similarly, figure 10b present a similar decline in yield. However, there is substantial intra-location variation, especially in upstream locations.

Our conceptual framework implies the existence of heterogeneous effects of Board Establishment according to the location where water users are located. Lawful water users located downstream under the jurisdiction of a Water Board should see increases in water access relative to a counterfactual situation without a Water Board, primarily driven by the introduction of property rights enforcement. This corresponds to redistribution from upstream users able to over-extract, to downstream users. The effects over lawful upstream users are less clear: we expect to observe a decrease in water consumption, associated to the same redistribution discussed above, but there might be efficiency gains from other public goods provided by Water Boards, such as legal security and assistance, better records, or improved infrastructure.

We will first document cross-sectional differences across locations, to then run a regression analysis exploiting the richness of data available to us. To address endogeneity concerns, we will finally implement an Instrumental Variable approach based on the legal costs of establishing a Water Board.

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[17] LANDSAT 7 is a satellite program launched in 1999 by the US government. This program provides pictures of all across the globe every 16 days, with a resolution of 30 meters. These images are managed by USGS. More detailed information is available at `https://www.usgs.gov/landsat-missions/product-information`

Cross-sectional variation in Water Access. Figure 11a corresponds to a Kernel regression of average Evapotranspiration per unit of surface[18] and the distance to the coast, as a measure of exposure to over-extraction by users located upstream. We can see a decline in the average evapotranspiration as we get closer to the river mouth, reflecting over-extraction by upstream users; however, while basins with Water Boards have a lower average Evapotranspiration, there is no discernible difference in trends between basins with and without Water Boards.

Figure 11b presents a measure of total water consumption per parcel, incorporating the heterogeneity in farm operations. The figure now illustrates the main mechanism described in this paper: in the absence of Water Boards, upstream farms extract more water than farms within the jurisdiction of Water Boards, while this relationship reverses downstream, with farms without Water Boards extracting less water than their counterparts subject to a Water Board authority.

This difference in the spatial distribution of Water Consumption translates into differences in hydric stress for crops. Following Allen, Morton, Kamble, Kilic, Huntington, Thau, Gorelick, Erickson, Moore, Trezza, and others (2015), we construct a Water Availability Index by dividing the actual Evapotranspiration by estimates of vegetal biomass using NDVI[19]; this is a measure of how much water is actually receiving the vegetation within an area. We create this index at the farm level, and figure 11c presents a kernel regression between Water Availability and distance to the coast. Water Availability is constant in areas under the authority of a Water Board, but for areas without any Water Board, there is decreasing Water Availability as we advance towards the coast.

In table 8 we present summary statistics of the farms under analysis. There are no salient differences between treated and control farms, except for the fact that farms under

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[18] The unit used corresponds to mm of water evaporated per pixel, with pixels measuring $30m^2$. Evapotranspiration includes both evaporation of water from the soil and transpiration from the vegetation; as we are including in our sample farms located close to canals in agricultural regions, transpiration will originate mostly from cultivated vegetation. Evaporation, in turn, may happen as long as there is soil moisture available for evaporation; this moisture may come from natural sources -such as rainfall- or artificial ones -such as irrigation. Therefore, Evapotranspiration could be considered an upper bound for water consumption, unless we can measure accurately natural sources of soil moisture; in this paper, we address that by controlling for rainfall during the year and during the summer.

[19] Allen, Morton, Kamble, Kilic, Huntington, Thau, Gorelick, Erickson, Moore, Trezza, and others (2015) present this index as a Hydric Stress Index, with lower values reflecting more hydric stress; we renamed it for the sake of interpretability.

water boards seem to face dryer climates, and to have better market access (i.e. being closer to the ports of Valparaiso and San Antonio, and to Santiago, the largest internal consumption market). This is consistent with the idea that Water Boards are adopted in areas where competition for water is stronger, due to scarcity or higher demand. Farms within Water Board jurisdictions seem to be larger. In table A24 we present similar Summary Statistics by location in the basin.

OLS regressions. We further explore these patterns by running OLS regressions of water consumption (i.e. Evapotranspiration) during Summer and agricultural yield[20] per area versus an indicator of being under the jurisdiction of a Water Board, interacted with dummies by quantile of basin location, which we measure as the distance to the river mouth through the river network. We include as controls indicators by quantiles of farm surface, precipitation during the full year and the summer, and we also include different cells of fixed effects: at the basin, at 1-degree$\times$1-degree grid cell, and sub-basin level.

We present the results of the former exercise in figures 12a for water consumption (i.e total estimated evapotranspiration within the farm divided by the farm area, and the logarithm of the total estimated evapotranspiration, respectively). These results are also presented in table A21. Farms with water boards located upstream consume less water per unit of area, but not significantly less total water consumption, than farms located outside Water Board jurisdictions but in similar locations. Farms located downstream, instead, consume more water per unit of area, and moreover, more total water.

This redistribution of water has economic consequences: figure 12b presents results for agricultural yield (average EVI per pixel within the farm, and the logarithm of the sum of EVI within the farm respectively. These results are also presented in table A22. Farms within Water Boards located upstream have lower yield per area than farms in similar locations but outside Water Board jurisdictions but total yield is not significantly different. Meanwhile, farms located downstream within Water Boards jurisdictions have more yield per area and total yield than those farms in similar locations but outside.

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[20] proxied by the maximum EVI index reached during the potential Harvest season, between October and February

The increase in water access in downstream locations benefits farmers in those locations, while the reduction in upstream locations does not seem to affect the total water consumption and agricultural output of upstream farms.

5.1 Instrumental Variable analysis

The former analysis suffers from endogeneity, as locations may adopt water boards based on non-observable characteristics that may affect also how water is distributed in the space. Figure 2 illustrates a first example of this: there is a non-linear relationship between Water Boards establishment and water availability. Locations where water is too scarce do not attract enough agricultural activity, and so the demand for water is too low to trigger any conflict; while locations where water is too abundant may attract agricultural activity, but conflict may not escalate under abundance. Similar phenomena may arise from different heterogeneities, such as agricultural suitability, land quality or climate. To address these concerns, we will construct an instrument based on the costs of establishing a new water board in a basin. In this section, we will discuss the legal foundations of this instrument, and later the results of its implementation.

We exploit a unique feature of the process of establishment of water boards: the Water Code explicitly states that board establishment may be triggered by an agreement of users or a lawsuit, which shall be presented in front of a judge in the province capital city where the water source is located if a water source is contained within just one province, or in the most upstream province capital city in case the water source crosses province boundaries (Biblioteca del Congreso Nacional, 1981).

In principle, a new Water Board will have jurisdiction over the full extent of the basin (i.e. the area that drains to the mouth of said river) over which it is being established. However, the legal process will define endogenously the borders of the potential new Water Board, for example, by users arguing about the starting and ending points of said river[21]. To address this, we consider the costs of establishing a water board in the full geological basins (i.e. the area that drains to a river mouth in the sea coast), which in all cases run

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[21] Consider the example of a basin with one main river and a secondary feeding river; if users in the secondary river want to establish a water board, users in the main river may argue that they are part of a different river.

from the Pacific Ocean in the West to the Andes Mountains in the East. As almost all basins will cross province borders, we can identify the most upstream Province Capital City by finding the most eastward province capital city within each basin.

Instrument by location. Before defining our instrument, is worth remarking an asymmetry that pervades the problem of establishing governance under our setting: only upstream users are able to over-extract, and so only downstream users can be worse-off due to the lack of enforcement[22]. While downstream users may demand the establishment of a water board, upstream users will not. More important is the fact that the institution is demanded explicitly to impose enforcement over those able to over-extract (i.e. the upstream users). Therefore, while downstream users will demand the establishment of a water board, upstream users will be forced to join it: the institution is imposed upon them.

The former argument implies that lowering the cost of establishing water boards faced directly by users, in principle, should only affect the likelihood of adoption by downstream users, as upstream users will not demand it. Instead, the adoption of water boards by upstream users should be determined by the costs faced by downstream users. Our instrument for downstream locations consists of the driving distance of the optimal route between a location and said city. Our instrument for upstream locations, instead, will be the average driving distance to the most upstream capital city for the farms located in downstream locations in the same basin.

With these instruments for different locations, controlling for geographical characteristics -including basin location-, we can identify the causal effects of the establishment of a Water Board over the compliers (Angrist and Pischke, 2009), who in this case would be 1) farms located in areas where a Water Board is established because downstream agents have a lower cost of establishing it, due to the upstream capital city being located closer, and 2) farms located in areas that do not adopt a Water Board because the upstream capital city is located too far away.

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[22] The former argument is a simplification, as the same situation may arise within canals at different locations in the basin: farmers located closer to the river may -in absence of proper enforcement- over-extract, leaving farmers located far from the river with less water. However, it is possible that appropriate enforcement at the river level may imply enough water availability on each canal, such that the within-canal enforcement problems become negligible.

In figure 15 we illustrate the data and our instrument in a white-to-red gradient. In the case of this instrument, we can see how downstream areas that are closer to the most upstream province capital city (in lighter red colors) are eventually under the jurisdiction of a water board, while downstream farms too far from this city are not under the jurisdiction of any board.

We estimate different IV models for three different quantiles of the distribution of distance to the river mouth of each basin. We ran separate regressions given that we expect the presence of heterogeneous effects, but more importantly, to mitigate potential SUTVA violations[23] .

For downstream locations, the equation is

$$\begin{aligned} \text{Water Consumption}_{igcb} =& \alpha \text{Board}_i + \gamma X_i^d + \mu_g + \varepsilon_{icb} \\ \text{Board}_i =& \beta \text{Distance Upstream Capital}_{ib} + \delta X_i^d + \eta_b + u_{icb} \end{aligned} \tag{7}$$

where i denotes farms, c counties, g cells in a 1-degree×1-degree grid and b basins. X_i^d is a vector of farm-level controls including our market access measures (driving distance to Santiago and the main ports); dummies for soil quality quartiles; second-degree polynomials for farm area, annual and summer precipitation; and temperature, measured as extreme heat days", or the number of days with maximum temperatures above 29 degrees Celsius (Hsiang, 2016). We also control for exposure to over-consumption, by controlling for the distance over the river to the most upstream farm[24].η_g is a latitude-longitude cell fixed effect. Our instrument is $DistanceUpstreamCapital$, the driving distance to the most upstream capital city in the basin. In order to emphasize longer distances relative to shorter distances

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[23] In principle, we assume –as it is our main premise across the paper– that there are downstream externalities in water consumption under scarcity: extraction by upstream users affects water availability of downstream users. We do separate analysis by quantile of distance to the coast –i.e. by location within the basin– under the additional assumption that these externalities depend on aggregate extraction by users located upstream, and not by other agents located closely.

A second concern regarding SUTVA violations is that the actions of one individual adopting Water Boards due to the reduction in transportation costs may impose a treatment externality: all the users in their area will adopt a board. To address this interpretation of our first stage, in Appendix we provide estimates of the main equations but using as an instrument the predicted probability of having a water board at the level of river segment, where we use as predictors polynomials of our driving distance measure to the most upstream capital city, interacted with basin fixed effects.

[24] The results are the same if we measure exposure by the number of farms located upstream, or the total area among farms located upstream.

-which may be sensitive to local features of the road network-, we use as our instrument $\max\{50, DistanceUpstreamCapital\}$ given that corresponds roughly to a 45-minute drive. The results are not sensitive to higher thresholds; imposing lower threshold imply higher second-stage point estimates, with higher standard errors and weaker first stages.

For midsection and upstream locations, instead, our main equation is

$$\begin{aligned} \text{Water Consumption}_{igcb} =& \alpha \text{Board}_i + \gamma X_i^d + \mu_g + \varepsilon_{icb} \\ \text{Board}_i =& \beta \text{Mean}(\text{Distance Upstream Capital}|\text{downstream})_b + \delta X_i^d + \eta_b + u_{icb} \end{aligned} \tag{8}$$

where $Mean(DistanceUpstreamCapital|downstream)$ is the average instrument for downstream locations; all other terms are the same as for downstream locations. We also control for the average exposure of downstream farms.

We address spatial correlation using clustered standard errors by county. To assess the strength of our first stages, we include the first stage robust F-statistic (Kleibergen and Paap, 2006), and following Andrews, Stock, and Sun (2019) we also provide the Effective F-statistic of Olea and Pflueger (2013)[25].

IV results. Table 9 presents the Instrumental Variable estimates of equations 7 for downstream farms, and 8 for midsection and upstream farms for our measure of water consumption (Evapotranspiration per pixel). Columns 1, 2 and 3 present OLS estimates as benchmarks. Columns 4, 5 and 6 present our main IV estimates by section of the river (Downstream, Mid-section and Upstream, respectively). Column 4 implies that Water Boards increase water consumption by downstream farms on $2.14mm$ per pixel, which represents an increase of almost 60%. Column 5 implies a similar but statistically insignificant increase for mid-section farms, and with a very weak first stage. Column 6 shows a 17% reduction in water consumption for upstream farms. Overall, we observe that once we instrument the presence of a Water Board, we can see an economically significant redistribution from farms located upstream to farms located downstream, but implying even higher

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[25] Both indexes are equal on exactly identified IV models.

economic gains downstream[26].

In table 10 we present similar results for our measure of agricultural yield per area (EVI per pixel). The results are similar, but suggest that there presence of decreasing returns to scale on water consumption: there is an increase of 18% in yield for farms located downstream, but a reduction of just 4% among upstream farms[27]. Midsection farms see an non-significant increase similar to downstream farms, but the F-test suggest the presence of a weak instruments problem.

These results imply a substantial increase in water consumption for downstream farms, which translates into increased yields. Our results also suggest that upstream locations see smaller reductions in water access, that do not translate into reductions in yield. There are several potential reasons for observing net increases in water consumption and yield (i.e. the benefits for downstream farmers being greater than for upstream farmers), being the most plausible complementarities between reliable water provision and individual and colective investments (e.g. Karlan, Osei, Osei-Akoto, and Udry, 2014). We will discuss this channel in the Mechanisms subsection.

5.2 Distributive effects of water boards

In the previous section, we explored the extent of redistribution implemented by Water Boards in a geographical dimension: redistribution from upstream users to downstream users. We will call this vertical redistribution. We can consider also horizontal redistribution, i.e. redistribution across users at the same location. We will focus now on one important dimension of horizontal redistribution: between smaller and larger farms. While understanding the impacts on inequality of property rights institutions in the context of a developing economy is important in itself (e.g. Besley and Burgess, 2000), it is particularly relevant in this context, given that the "the jure" power structure reflects directly the ownership distribution. It is possible, however, that the internal political economy of these organizations implies non-obvious distributional consequences (e.g. Banerjee, Mookherjee,

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[26] Notably, we cannot reject that the OLS and IV estimates for upstream locations are different, which is consistent with the idea that the establishment of a water board is imposed to upstream farmers by decisions taken by users in downstream locations, and so, it can plausibly be exogenous.

[27] In results not reported, the effect over the NDVI index -a measure of agricultural activity- over Summer Months shows an increase of 44%.

Munshi, and Ray, 2001). Our farm data allows us to identify these potential redistribution dynamics by measuring directly water consumption across users.

To understand better the incentives faced by small and large farmers to create Water Boards, in figure 16 we plot the average farm size by location in the basin, separately for farms located close and far from the river (i.e. below and above 3.5 kilometers of distance to the river that feeds the canal). The position within the canal matters, as those located farther in the canal will be among the first ones to lose water access if water supply is insufficient. The first observation is that for farms closer to the river, farm sizes are similar for areas with and without water boards, and the largest farms are found in upstream locations. However, when looking at areas farther from the river, we see divergence across locations with and without boards at both extremes of the basin: for areas with water boards, the distribution follows a U-shape pattern, while for areas without boards, it follows an inverted U. Farm size is larger among farms within water boards than outside, too.

Smaller farms in downstream locations may lack the resources needed to create or mantain a water board, and upstream farms of smaller scale may lack the capacity to over-extract at a scale that makes worthwhile for downstream users to demand the creation of a Water Board. At the same time, large downstream farms far from the river can receive the largest benefits from reliable water access. This pattern suggests that Water Boards emerge as a result of intra-elite conflict: between the largest upstream users -who can over-extract- and the largest users downstream -who can invest in the creation of the organization. Given the structure of votes within a Water Board -proportional to the ownership of water rights- we may expect control by the elite, but with representation across locations[28].

In table 31 we use our Instrumental Variable approach separately by farm size: columns 1, 2 and 3 present the IV estimates for farms below the Median of the farm area distribution, while columns 4, 5 and 6 present the same results but for farms above the percentile 90[29]. To address concerns regarding the scale of each operation, we consider the average

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[28] This may explain our finding that Boards increase streamflows more in more unequal basins: if the increased inequality is explained by higher inequality in downstream locations, the downstream elite is able to press for stronger redistribution towards downstream locations.

[29] We considered assymetric rules to define smaller ("below percentile 50") and larger farms ("above percentile 80") because the distribution is very asymmetric with a heavy right tail -implying that farms below the median are more similar among themselves than farms above the median-, and also because we will probably have higher measurement error -on the independent variable, which implies more noisy

consumption of water per unit of area as our outcome measure.

We find that both smaller and larger downstream farms increase their water consumption, but the increase is substantially higher for larger farms: while for small farms the increase in water consumption per pixel is 56%, for larger farms this increase is almost 85%. On the other side, we see that although smaller and larger upstream farms reduce their water consumption, the reduction is stronger for smaller farms: while smaller farms reduce their water consumption per pixel by 22%, larger farms decrease it only by 8%.

In table 12 we repeat the exercise for yield per area as our outcome, with similar conclusions. While downstream small farms do not have a statistically significant (although the increase in yield is 28%), large farms increase by 58%. Meanwhile, in upstream areas, small farms reduce their yield by almost 8%, large farms do not see a reduction at all. In summary, the largest benefits are captured by downstream large farms, while the largest costs of the redistribution in place are beared by upstream smaller farms.

6 Misallocation Test

In this section, we provide evidence of water misallocation in areas without water boards, which is absent in areas with water boards. We propose a test of misallocation based on the idea that if irrigation water can be reallocated within a basin through a frictionless market, the marginal productivity of water (MPW) should be equalized within the basin.

The full argument is as follows[30]: first, consider the problem of a farmer choosing the amount of water rights to acquire at the beginning of the season, knowing that they define the maximum amount of irrigation the farmer could use during the irrigation season. Rainfall is a perfect substitute for irrigation water, up to a rate of substitution, but it falls according to a known random distribution (Rafey, 2023a). The First Order Condition of this problem is that the farmer acquires water rights such that the expected marginal productivity of water is equal to the expected shadow value of water in the irrigation season. Second, the effect of an unexpected rainfall shock during the irrigation season is equal to the marginal productivity of water (up to the rate of technical substitution between rainfall and

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estimates- for smaller farms, given that the pixel size is the same for all farms.

[30] The details of the theoretical model are included in Appendix A

irrigation water), as a consequence of the Envelope Theorem combined with the presence of fixed inputs (Hsiang, 2016; Deryugina and Hsiang, 2017). Finally, a benevolent Social Planner maximizing the total value of the production by society will equate the shadow values of water across users.

We can test the null hypothesis of equal average marginal productivity of water across locations by identifying unexpected rainfall shocks by position within the basin, for treated and control areas, and then to measure their impact over profits; the semielasticity of profits to these rainfall shocks will equate the marginal value of water (Deryugina and Hsiang, 2017). Our Agricultural Census data do not measure the effective water input for each parcel; but as rainfall is a perfect substitute for irrigation water, up to an absorption rate (equal to the marginal rate of technical substitution between rainfall and irrigation water) (Rafey, 2023b), we exploit the timing of rainfall to get within county variation in water input received during the irrigation season -which we call "useful rainfall"- at the parcel level across the production cycle. This will allow us to test for differences in the average shadow value of water among farms with canal-based irrigation and with water rights, in different locations in the same basin.

County fixed effects will capture common shocks to all farms and average expectations, and individual farm controls will capture long term and short term determinants of output. One threat to our identification strategy is the presence of imbalances: farmers may try to match the pattern of rainfalls to optimize their water (Kala, 2019); if our controls do not capture their information, then it is possible to have biased estimates. In table 14 we present a Balance Table for useful rainfall, after including all our controls: other than a decrease in rainfall as we move from the coast to upstream locations, there is no significant differential rainfall pattern between counties with and without water boards.

We implement our misallocation test using the 2007 Chilean Agricultural Census, which contains a rich set of technology and input choices (including irrigation technology, planted surface, hired and total workers, machinery use and property of water rights), which we combined with soil quality estimates and daily climate data at the county level, including precipitation and temperature by calendar day. The sample for the estimation includes farms with irrigation from canals, owning or renting water rights and with a cultivated area below 50 hectares[31].

We estimate

$$
\begin{aligned}
\log\left(\frac{Y}{\text{Hectares}}\right)^{2007}_{irc} &= \beta_1 \text{Board}_c + \beta_2 \text{Useful Rain}_{rc} + \beta_3 \text{Distance to Sea}_c \\
&+ \beta_4 \text{Board}_c \times \text{Useful Rain}_{rc} + \beta_5 \text{Board}_c \times \text{Distance to Sea}_c \\
&+ \beta_6 \text{Useful Rain}_{rc} \times \text{Distance to Sea}_c \\
&+ \beta_7 \text{Board}_c \times \text{Useful Rain}_{rc} \times \text{Distance to Sea}_c \\
&+ \beta_X \mathbb{X}_i^{2007} + \mu_c + \mu_r + \varepsilon_{irc}
\end{aligned}
$$

where $\log(Y/\text{Hectares})$ is the logarithm of the value of output per hectare obtained by farm i on planting crop r in county c, Useful rainfall$_{r,c}$ is the rainfall received during the irrigation season of crop r in county c, Distance to Coast$_c$ is the distance to the coast of the centroid of county c (in longitude degrees). $\mathbb{X}_i^{2007}$ is the set of controls, which includes the logarithm of the total labor hired during the 2007 agricultural year, a vector of capital and technology choices and the irrigated surface. Finally, μ_c is a county fixed effect, and μ_r is a crop fixed effect.

On estimating equation 9, we are exploiting within county-across-crop, within crop-climatic zone across counties variation in the timing of rainfall, which is arguably exogenous on most determinants of agricultural production[32]. More importantly, the former equation allows us to estimate directly the functions needed for our Misallocation Test:

- Average Shadow Value of Water as a function for the distance to the coast, in the absence of water boards:

$$
\frac{\partial \mathbb{E}\left\{ \pi_i | \, I_0, \text{Distance to Sea, No Board} \right\}}{\partial w_i} = \beta_2 + \beta_6 \times \text{Distance to Sea} \tag{9}
$$

- Average Shadow Value of Water as a function for the distance to the coast, under

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[31] We eliminate farms above 50 hectares to eliminate outliers; the results do not change qualitatively including operations above this threshold, but the standard errors are higher.

[32] Table 20 in Appendix A presents a balance table for Useful Rainfall across specifications; there are no significant differences in Useful Rainfall, and more importantly, there are no differences between treated and control areas across positions within basins.

water boards:

$$\frac{\partial \mathbb{E}\left\{\pi_i \middle| I_0, \text{Distance to Sea, Board}\right\}}{\partial w_i} = (\beta_2 + \beta_4) + (\beta_6 + \beta_7) \times \text{Distance to Sea} \quad (10)$$

We test for Misallocation over the water flow direction dimension: we test if the shadow value of water is equal at the top of the basin (head of the river) and where the river drains to the sea (mouth of the river). Our null hypothesis is that there is no misallocation: the average marginal productivity of water is equal across locations in the river. In principle, we could reject the null due to higher shadow values of water upstream or downstream, but our previous results suggest that shadow values are higher downstream.

Results. In table 13 we present the results of estimating equation 9, considering an array of location-fixed effects. Our preferred specification is in column 4, which we also present graphically in figure 17. For counties outside any water board jurisdiction located on the coast, for farms with water rights, affiliation to a canal association and irrigation, an extra cubic meter of water per hectare per month would increase yield by more than $50pp$, while for farms located approximately $200km$ upstream, the increase is a nonsignificant reduction of $10pp$. The estimated average MPW is presented as the red function in figure 17 and clearly displays a higher average shadow value of water in locations downstream versus upstream.

This result is consistent with misallocation: farms located downstream are water-restricted, while farms located upstream are not; a marginal displacement of water through the river from upstream locations to downstream locations would increase the total value of production, but the lack of enforcement prevents the creation and enforcement of contracts that would imply such reallocation of water. In fact, at the bottom of table 13 we present the p-values of the test of equality of MPW across locations; for all specifications, we reject the null hypothesis of no misallocation[33].

In contrast, for counties located within the jurisdiction of water boards, the average

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[33] This test was performed considering the standard errors clustered by county; the results do not change by considering the SE clustered by county and irrigation season crop type.

shadow value of water is similar: for counties located next to the coast, there is a non-significant reduction in value per hectare of around 10pp per extra cubic meter of water per hectare per month), which is approximately the same for farms located 200km upstream. The average shadow value of water as a function of the distance to the coast is presented as the blue function in figure 17, is flat compared to the function for places with boards, and never significantly different from zero. These results do now allow us to reject that the shadow value of water differs within basins governed by Water Boards, as it is reflected in the last row of table 13. The results are similar controlling for basin, 0.5-degree cells and county fixed effects.

Placebo exercise: rainfed parcels. To address concerns regarding potential confounders that may cause the former cross-sectional results, we present a placebo exercise, where we estimate equation 9 including the same set of controls, but for rainfed parcels. These parcels display different technology choices but are located in the same counties as the former sample, so they are exposed to similar geographies and climates. While there may exist spatial sorting within these counties, with parcels deciding to focus on rainfed strategies instead of irrigation; given the Chilean geography, the within-county differences may not be comparable (and be smaller than) across-county differences. For these parcels, there is no control over the water input, and so our estimates will correspond to the Marginal Productivity of Water[34]. More importantly, we do not expect any effect of water boards on these parcels, as the boards cannot affect their water input (i.e. rainfall).

Table 14 presents the results of this exercise. Our preferred specification is in column 4, where we again exploit within-county variation in useful rainfall across crops. The results suggest that the yield per hectare increases by around 20pp per extra cubic meter of water per hectare per month at the coast. The increase in yield for farms 160 from the coast is 25pp, which is not statistically different from the effect on the coast. This may be due to the fact that precipitation is higher in areas closer to the coast (see table 20), implying a higher marginal productivity of water in areas farther away. Importantly, all interaction terms

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[34] Manysheva (2022) and Rafey (2023b) use this strategy to estimate the production functions of rainfed farms

with the water board dummy are not significant and economically small. The last rows of table 14 show that after including 0.5-degree cells or county fixed effects, we cannot reject that the MPW is equal for all locations, either with or without water boards, as expected.

Figure 18 presents the estimated functions of Average MPW for areas with and without water boards. The most important conclusion from the figure is that both functions are parallel, and despite the existence of some (statistically non-significant) differences in levels, both functions are contained in the confidence intervals of the other. This placebo exercise suggests that the estimated effects of rainfall on irrigated parcels (our main exercise) recover a causal relationship between water and yield across different geographies, and so our Misallocation Test identifies the underlying misallocation existing in the absence of water rights enforcement. More importantly, our test fails to find such misallocation in places with water boards exerting property rights enforcement.

7 Conclusions

In this paper, we estimate the economic impacts of community-governed property rights enforcement on the allocation of water. To this end, we study Water Boards, legally empowered boards, elected and funded by the users themselves, in charge of enforcing formal private property rights over river waters. We first show that property rights enforcement allows to limit the *de jure* allocation of the good –i.e. slowing down the creation of titles created over water– by centralizing records and responsibility over the resource. Second, we show how the introduction of enforcement affects the *de facto* allocation of water by displacing water from upstream users to downstream users. We also show that the institutions in place are able to accommodate increased demand for water when the resource is relatively abundant, but constrain the actions of the users when the resource is scarce so the incentives for over-extraction are strongest.

We also provide estimates of the long-term consequences of this reallocation of water at the farm level, showing substantial increases in water consumption and yield among downstream farms, and reductions in water consumption among upstream farms, with less strong reductions in yield, consistent with decreasing returns to scale in water consumption.

In our analysis, we provide evidence of the existence of misallocation of irrigation water in areas that do not have a Water Board, suggesting over-extraction by upstream users –i.e. those who have the opportunity to over-extract, given their relative position in the basin. We cannot find similar evidence of misallocation in areas governed by Water Boards. The fact that water rights are perpetual, fully transferable, separated from the land, and legally equivalent to any real estate, and that the market for trading water rights does not have any special regulations in all areas –either governed by water boards or not–, suggest that the enforcement of property rights is essential for the operation of markets, and so to realize the efficiency gains from trade, it is necessary the existence of authorities with the power to take and implement decisions to adapt to special circumstances -such as droughts- and to enforce those decisions. These attributions, in turn, may allow said authority to expropriate under some legal and political circumstances.

This tension between the threat of expropriation and property rights enforcement arises from the lack of perfect information and self-enforcement: we need agents that enforce in order to allocate physical resources, who are able to take decisions based on information that is not necessarily publicly available. This leads us to a second-best world where market designers need to choose between giving more space to one threat or another. While most of the literature has focused on the economic consequences of insecure property rights due to the threat of expropriation, we are to the best of our knowledge the first ones providing causal evidence of the economic costs of insecure property rights due to a deliberate institutional design that, in order to minimize the threat of expropriation, weakened the state capacity and so the enforcement of property rights.

Another contribution is to provide evidence of misallocation due to the lack of governance –even after allowing individual adaptation and transactions in a context with well-defined property rights. This misallocation translates into violations of the Law of One Price. This might help to understand violations of this law in other water markets, where governance is not unified, and as a consequence, markets are not integrated (Edwards and Libecap, 2015).

Our next steps will focus first on quantifying the economic losses from lack of enforcement, building up on our previous results. A second avenue for future work is to understand how markets respond to the introduction of governance. Finally, we are exploring how Water Boards mediate adaptation to the increasing uncertainty over water availability driven by Climate Change.

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8 Tables and Figures

8.1 Tables

Table 1: Number of river segments and Board establishment year

	(1) Full sample			(2) Event Study sample		
	N segments	%	cum %	N segments	%	cum %
1983	2	1.26	1.26	2	3.23	3.23
1985	8	5.03	6.29	8	12.90	16.13
1992	2	1.26	7.55	2	3.23	19.35
1993	5	3.14	10.69	5	8.06	27.42
1995	16	10.06	20.75	14	22.58	50.00
1998	16	10.06	30.82	12	19.35	69.35
2018	27	16.98	47.80	19	30.65	100.00
No Board	83	52.20	100.00			
Total	159	100.00		62	100.00	
Observations	159			62		

Table 2: Effect of Water Boards on creation of new water rights within their jurisdictions (Poisson)

	Surface WR		Groundwater WR	
	(1) Water Rights (m3/s)	(2) Surface WR/Area	(3) Groundwater Rights (m3/s)	(4) Groundwater WR/Area
Board established	-0.450 (0.122)***	-0.461 (0.0696)***	0.449 (0.0329)***	0.452 (0.143)***
Climatic controls	Yes	Yes	Yes	Yes
Segment FE	Yes	Yes	Yes	Yes
Year x Event FE	Yes	Yes	Yes	Yes
Observations	1,248	1,248	1,248	1,248
Outcome mean	0.192	0.015	0.067	0.003
Outcome SD	0.709	0.066	0.176	0.008

Notes: this table present estimates of equation 1 using Poisson regression. Implemented using Stacked DID design by Cengiz, Dube, Lindner, and Zipperer (2019) design, considering *segment* × *event* and *year* × *event* fixed effects, climatic controls for January and February and also including 8 lags of precipitation and precipitation squared. Standard errors clustered at the river-segment level.

Table 3: Effect of Water Boards on streamflows

	Streamflow					
	(1)	(2)	(3)	(4)	(5)	(6)
Board established	0.838	0.413	1.051	0.656	0.750	0.539
	(0.543)	(0.464)	(0.580)*	(0.478)	(0.581)	(0.483)
Water Rights (m3/s)					-1.070	-0.439
					(0.359)***	(0.307)
Climatic controls	Yes	Yes	Yes	Yes	Yes	Yes
Precipitation lags	No	Yes	No	Yes	No	Yes
Segment FE	Yes	Yes	No	No	No	No
Segment x Month FE	No	No	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes	Yes	Yes
Observations	13,856	12,841	13,792	12,759	13,792	12,759
R-squared	0.507	0.585	0.702	0.776	0.702	0.776
Outcome mean	10.086	10.210	10.105	10.237	10.105	10.237
Outcome SD	20.366	20.475	20.402	20.527	20.402	20.527

Notes: This table present impact estimates of water boards on streamflows. Stacked DID design by Cengiz, Dube, Lindner, and Zipperer (2019). Controlling for contemporaneous temperature, precipitation and evapotranspiration, and 8 lags of precipitation and precipitation squared. Standard Errors clustered at the River Segment level.

Table 4: Effect of Water Boards on streamflows during the Dry Season (January and February)

	Streamflow in Dry Season (Jan-Feb)							
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Board established	1.457	1.014	1.443	0.961	1.046	1.013	1.019	0.959
	(0.586)**	(0.312)***	(0.573)**	(0.307)***	(0.439)**	(0.338)***	(0.424)**	(0.329)***
Water Rights (m3/s)					-1.398	-0.00359	-1.439	-0.0103
					(0.972)	(0.287)	(1.015)	(0.297)
Climatic controls	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Precipitation lags	No	Yes	No	Yes	No	Yes	No	Yes
Segment FE	Yes	Yes	No	No	Yes	Yes	No	No
Segment x Month FE	No	No	Yes	Yes	No	No	Yes	Yes
Year FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Observations	2,285	2,037	2,277	2,025	2,285	2,037	2,277	2,025
R-squared	0.450	0.681	0.478	0.699	0.454	0.681	0.481	0.699
Outcome mean	4.150	4.021	4.160	4.019	4.150	4.021	4.160	4.019
Outcome SD	8.345	8.222	8.358	8.222	8.345	8.222	8.358	8.222

Notes: This table present impact estimates of water boards on streamflows during the Dry Season (January and February). Stacked DID design by Cengiz, Dube, Lindner, and Zipperer (2019). Controlling for contemporaneous temperature, precipitation and evapotranspiration, and 8 lags of precipitation and precipitation squared. Standard Errors clustered at the River Segment level.

Table 5: Heterogeneous effects, by distance to the coast.

	Streamflow			
	Full Year		Dry Season	
	(1)	(2)	(3)	(4)
Board × segment close to coast	0.680	0.607	1.049	0.858
	(0.642)	(0.543)	(0.638)	(0.476)*
Board × segment far from coast	0.890	0.404	1.040	1.297
	(0.669)	(0.560)	(0.527)*	(0.431)***
Water Rights (m3/s)	-1.069	-0.440	-1.398	-0.00176
	(0.360)***	(0.306)	(0.975)	(0.286)
Climatic controls	Yes	Yes	Yes	Yes
Precipitation lags	No	Yes	No	Yes
Segment FE	No	No	Yes	Yes
Segment x Month FE	Yes	Yes	No	No
Year x Experiment FE	Yes	Yes	Yes	Yes
Observations	13,792	12,759	2,285	2,037
R-squared	0.702	0.776	0.454	0.681
Outcome mean	10.105	10.237	4.150	4.021
Outcome SD	20.402	20.527	8.345	8.222

Notes: This table present heterogenous effects estimates of water boards on streamflows, according to the relative distance to the coast. We interact the Board Establishment dummy variable with dummy variables indicating if a river segment is below or above the median of the longitude distance to the coast (0.3 longitude degrees). Stacked DID design by Cengiz, Dube, Lindner, and Zipperer (2019). Standard Errors clustered at the River Segment level.

Table 6: Water Board effects and Land Concentration

	Surface water rights		Groundwater rights		Streamflow	
	(1)	(2)	(3)	(4)	(5)	(6)
Board Est. × high land concentration	-0.210	-0.152	0.119	0.105	1.828	1.081
	(0.135)	(0.0983)	(0.0549)**	(0.0520)**	(0.660)***	(0.375)***
Board Est. × low land concentration	-0.195	-0.162	-0.00999	-0.00925	0.500	0.849
	(0.0954)**	(0.0845)*	(0.0198)	(0.0150)	(0.638)	(0.677)
Climatic controls	Yes	Yes	Yes	Yes	Yes	Yes
Precipitation lags	No	Yes	No	Yes	No	Yes
Segment FE	Yes	Yes	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes	Yes	Yes
Observations	1,917	1,704	1,917	1,704	2,285	2,037
R-squared	0.827	0.868	0.731	0.773	0.451	0.681
Outcome mean						
Outcome SD						

Notes: This table present heterogenous effects estimates of water boards on streamflows, according to the land concentration within the basin. We interact the Board Establishment dummy variable with dummy variables indicating if a river segment is below or above the median of the Gini Coefficient of land concentration. Stacked DID design by Cengiz, Dube, Lindner, and Zipperer (2019). Standard Errors clustered at the River Segment level.

Table 7: Monitoring vs Enforcement

	Mediation exercise: indirect effect of water boards	
	(1) Water Rights (m3/s)	(2) River level (m3/s)
Board established	-0.199	1.349
	(0.112)*	(0.412)***
Water Rights (m3/s)		-0.239
		(0.292)
Board × Water Rights (m3/s)		-0.625
		(0.649)
Climatic controls	Yes	Yes
Precipitation lags	Yes	Yes
Segment FE	Yes	No
Segment x Month FE	No	Yes
Year FE	Yes	Yes
Observations	1,818	2,222
R-squared	0.829	0.721
Natural Direct Effect		1.044
Natural Indirect Effect		0.172

Notes: This table presents the results of a Mediation exercise. We implement Valeri and VanderWeele (2013) results on Statistical Mediation to estimate the indirect effect of water boards on water rights mediated by water rights (i.e. the increase in streamflows attributable to the effect of water boards on reducing the creation of water rights).

Table 8: Summary Statistics: parcel level dataset

	No Board					
	Mean	SD	p10	p90	Min	Max
Water Consumption per area	3.77	1.2	2.1	5.2	0.1	7.4
Total (Estimated) Water Consumption	289.18	673.3	11.7	765.6	0.2	23368.2
EVI (max over Summer)	0.45	0.1	0.3	0.6	0.1	0.9
Area (m2)	64399.23	142356.7	4176.2	162067.0	47.6	5350225.5
Latitude	-35.07	1.4	-36.8	-33.2	-37.8	-29.8
Longitude	-71.44	0.5	-72.1	-70.7	-73.0	-70.5
Precipitation (year, plot)	1763.99	782.0	843.0	2828.8	0.0	4267.5
Precipitation (Summer)	50.52	19.6	26.1	80.6	3.9	99.7
Mkt. Acc. (Santiago)	258.16	166.3	48.9	498.8	9.4	616.5
Mkt. Acc. (Valparaiso)	335.06	183.7	107.7	592.2	15.8	709.9
Mkt. Acc. (San Antonio)	273.88	156.9	100.5	506.4	20.4	624.1
Distance to Coast (location in basin)	120.38	40.7	62.9	171.2	1.5	219.8
Dist Upstream Capital	67.75	16.7	50.0	88.2	50.0	179.6
Observations	54877					

	Water Board					
	Mean	SD	p10	p90	Min	Max
Water Consumption per area	3.78	1.2	2.1	5.3	0.1	7.2
Total (Estimated) Water Consumption	298.70	648.0	12.6	745.6	0.2	22422.0
EVI (max over Summer)	0.46	0.1	0.3	0.6	0.0	0.9
Area (m2)	67970.24	140647.0	4132.4	159690.5	188.9	3593806.8
Latitude	-34.22	1.5	-36.6	-32.7	-37.0	-29.9
Longitude	-71.13	0.4	-71.8	-70.7	-72.3	-70.5
Precipitation (year, plot)	1311.22	534.4	782.9	2081.1	0.0	3380.8
Precipitation (Summer)	42.01	12.9	28.8	59.5	2.6	83.9
Mkt. Acc. (Santiago)	202.18	144.9	78.3	475.5	20.7	589.8
Mkt. Acc. (Valparaiso)	267.78	144.3	119.4	546.1	35.5	609.3
Mkt. Acc. (San Antonio)	224.17	134.9	100.5	481.6	43.2	595.3
Distance to Coast (location in basin)	126.08	39.7	63.4	174.6	0.9	212.6
Dist Upstream Capital	74.92	14.6	50.0	88.2	50.0	107.0
Observations	23580					

Table 9: Total Water Consumption: Instrumental Variables estimation at the parcel level.

	OLS, ETa (mm) per surface			IV, ETa (mm) per surface		
	(1) Downstream	(2) Mid section	(3) Upstream	(4) Downstream	(5) Mid section	(6) Upstream
Board	0.151	-0.00647	-0.349	2.144	1.847	-0.605
	(0.110)	(0.0610)	(0.0785)***	(0.873)**	(1.516)	(0.149)***
Area (polynomial)	Yes	Yes	Yes	Yes	Yes	Yes
Precipitation (pol.)	Yes	Yes	Yes	Yes	Yes	Yes
Prec. Summer (pol.)	Yes	Yes	Yes	Yes	Yes	Yes
Soil quality	Yes	Yes	Yes	Yes	Yes	Yes
Market Access	Yes	Yes	Yes	Yes	Yes	Yes
(lat lon) bin FE	Yes	Yes	Yes	Yes	Yes	Yes
Observations	26,780	26,138	25,539	26,780	26,138	25,539
R-squared	0.457	0.473	0.581	0.207	0.130	0.574
Mean Dependent Var.	3.545	4.085	3.665	3.545	4.085	3.665
First Stage F-stat				16.856	2.473	59.690
p-value Under Id LM test				0.001	0.131	0.002
Effective F-stat				16.856	2.473	59.690

Notes: This table present estimates of equation 7 and 8 for parcels located within a 1km buffer around canals in the area of study. Distance to the coast measured through the river network. Controlling for 20-quantile dummies of parcel area, county precipitation during the year and county precipitation during the summer, and 1x1 degree fixed effects. Standard errors clustered by county.

Table 10: Agricultural Production: Instrumental Variables estimation at the parcel level.

	OLS, EVI (yield measure)			IV, EVI (yield measure)		
	(1) Downstream	(2) Mid section	(3) Upstream	(4) Downstream	(5) Mid section	(6) Upstream
Board	0.0180	0.000358	0.000808	0.180	0.191	-0.0223
	(0.00935)*	(0.00634)	(0.00630)	(0.0799)**	(0.145)	(0.0190)
Area (polynomial)	Yes	Yes	Yes	Yes	Yes	Yes
Precipitation (pol.)	Yes	Yes	Yes	Yes	Yes	Yes
Prec. Summer (pol.)	Yes	Yes	Yes	Yes	Yes	Yes
Soil quality	Yes	Yes	Yes	Yes	Yes	Yes
Market Access	Yes	Yes	Yes	Yes	Yes	Yes
(lat lon) bin FE	Yes	Yes	Yes	Yes	Yes	Yes
Observations	26,792	26,138	25,539	26,792	26,138	25,539
R-squared	0.238	0.277	0.399	0.019	-0.065	0.394
Mean Dependent Var.	0.501	0.524	0.506	0.501	0.524	0.506
First Stage F-stat				16.840	2.473	59.690
p-value Under Id LM test				0.001	0.131	0.002
Effective F-stat				16.840	2.473	59.690

Notes: This table present estimates of equation 7 and 8 for parcels located within a 1km buffer around canals in the area of study. Distance to the coast measured through the river network. Controlling for 20-quantile dummies of parcel area, county precipitation during the year and county precipitation during the summer, and 1x1 degree cell fixed effects.Standard errors clustered by county.

Table 11: Inequality and Average Water Consumption: Instrumental Variables estimation at the parcel level.

	Smaller Farms, ETa (mm) per surface			Larger Farms, ETa (mm) per surface		
	(1) Downstream	(2) Mid section	(3) Upstream	(4) Downstream	(5) Mid section	(6) Upstream
Board	1.862	3.488	-0.770	3.492	1.081	-0.279
	(0.969)*	(3.556)	(0.191)***	(1.499)**	(0.863)	(0.149)*
Area (polynomial)	Yes	Yes	Yes	Yes	Yes	Yes
Precipitation (pol.)	Yes	Yes	Yes	Yes	Yes	Yes
Prec. Summer (pol.)	Yes	Yes	Yes	Yes	Yes	Yes
Soil quality	Yes	Yes	Yes	Yes	Yes	Yes
Market Access	Yes	Yes	Yes	Yes	Yes	Yes
(lat lon) bin FE	Yes	Yes	Yes	Yes	Yes	Yes
Observations	14,561	12,021	11,386	6,270	7,427	7,447
R-squared	0.254	-0.758	0.561	-0.307	0.396	0.626
Mean Dependent Var.	3.279	3.963	3.585	4.031	4.295	3.833
First Stage F-test	11.286	1.286	55.615	8.796	3.767	61.042
p-value Under Id LM test	0.004	0.255	0.003	0.009	0.091	0.001
Effective F-stat	11.286	1.286	55.615	8.796	3.767	61.042

Notes: This table present estimates of equations 7 and 8 for parcels located within a 1km buffer around canals in the area of study. Distance to the coast measured through the river network. Controlling for 20-quantile dummies of parcel area, county precipitation during the year and county precipitation during the summer, and Basin fixed effects. Robust standard errors in superior panel; county clustered standard errores in inferior panel.

Table 12: Inequality and Agricultural Production: Instrumental Variables estimation at the parcel level.

	Smaller Farms, EVI (yield measure)			Larger Farms, EVI (yield measure)		
	(1) Downstream	(2) Mid section	(3) Upstream	(4) Downstream	(5) Mid section	(6) Upstream
Board	0.138 (0.0883)	0.301 (0.310)	-0.0420 (0.0169)**	0.311 (0.138)**	0.132 (0.0907)	0.00628 (0.0236)
Area (polynomial)	Yes	Yes	Yes	Yes	Yes	Yes
Precipitation (pol.)	Yes	Yes	Yes	Yes	Yes	Yes
Prec. Summer (pol.)	Yes	Yes	Yes	Yes	Yes	Yes
Soil quality	Yes	Yes	Yes	Yes	Yes	Yes
Market Access	Yes	Yes	Yes	Yes	Yes	Yes
(lat lon) bin FE	Yes	Yes	Yes	Yes	Yes	Yes
Observations	14,571	12,021	11,386	6,270	7,427	7,447
R-squared	0.137	-0.496	0.446	-0.581	0.090	0.382
Mean Dependent Var.	0.486	0.518	0.503	0.530	0.530	0.506
First Stage F-test	11.286	1.286	55.615	8.796	3.767	61.042
p-value Under Id LM test	0.004	0.255	0.003	0.009	0.091	0.001
Effective F-stat	11.286	1.286	55.615	8.796	3.767	61.042

Notes: This table present estimates of equations 7 and 8 for parcels located within a 1km buffer around canals in the area of study. Distance to the coast measured through the river network. Controlling for 20-quantile dummies of parcel area, county precipitation during the year and county precipitation during the summer, and Basin fixed effects. Robust standard errors in superior panel; county clustered standard errores in inferior panel.

Table 13: Shadow Value of Water: Impact of rainfall on Production Value during the irrigation season for irrigated parcels, by longitude and treatment status

	Main Equation: effect on irrigated farms			
	(1)	(2)	(3)	(4)
	log(value production/Ha.)			
Useful pp. (m3 per Ha per month)	0.467	0.297	0.404	0.429
	(0.203)**	(0.205)	(0.220)*	(0.242)*
	[0.203]**	[0.207]	[0.219]*	[0.241]*
Useful pp. (m3 per Ha per month) × Distance to coast (100km)	-0.303	-0.254	-0.303	-0.279
	(0.136)**	(0.133)*	(0.141)**	(0.154)*
	[0.134]**	[0.133]*	[0.137]**	[0.150]*
Water Board × Useful pp. (m3 per Ha per month)	-0.278	-0.348	-0.559	-0.472
	(0.254)	(0.246)	(0.241)**	(0.266)*
	[0.252]	[0.243]	[0.241]**	[0.258]*
Water Board × Useful pp. (m3 per Ha per month) × Distance to coast (100km)	0.121	0.202	0.352	0.289
	(0.178)	(0.173)	(0.163)**	(0.174)
	[0.175]	[0.168]	[0.160]**	[0.166]*
Parcel Controls	Yes	Yes	Yes	Yes
County Controls	Yes	Yes	Yes	No
Basin FE	No	Yes	No	No
0.5 degree cell FE	No	No	Yes	No
Crop FE	Yes	Yes	Yes	Yes
County FE	No	No	No	Yes
Observations	14,716	14,716	14,714	14,712
R-squared	0.537	0.571	0.583	0.639
Misallocation Test: No Board	0.03	0.06	0.03	0.07
Misallocation Test: with Board	0.05	0.59	0.56	0.91

Notes: This table present estimates of equation 9 for irrigated parcels, with water rights, registered in canal associations. Distance to the coast measured through the river network. Controlling for capital and technology choices, logarithm of labor input and irrigated surface, and County and Crop fixed effects. Standard errors clustered at the county level (round parenthesis) and at the county× irrigation season level (squared parentheses).

Table 14: Placebo exercise: Impact of rainfall on Production Value during the irrigation season by longitude and treatment status for rainfed parcels.

	Placebo: effect on rainfed farms			
	(1)	(2)	(3)	(4)
	log(value production/Ha.)			
Useful pp. (m3 per Ha per month)	-0.0695 (0.0637) [0.0575]	0.0493 (0.0708) [0.0622]	-0.00424 (0.0647) [0.0642]	0.0786 (0.0455)* [0.0483]
Distance to coast (100km)	-0.171 (0.107) [0.0976]*	-0.174 (0.114) [0.106]	0.150 (0.0892)* [0.0843]*	
Useful pp. (m3 per Ha per month) × Distance to coast (100km)	0.103 (0.0583)* [0.0535]*	0.149 (0.0497)*** [0.0464]***	0.0283 (0.0300) [0.0332]	0.00576 (0.0278) [0.0270]
Water Board	-0.841 (0.436)* [0.443]*	-0.997 (0.507)* [0.477]**	0.128 (0.526) [0.502]	
Water Board × Useful pp. (m3 per Ha per month)	0.123 (0.147) [0.167]	0.153 (0.117) [0.138]	-0.0836 (0.0925) [0.154]	0.00985 (0.0664) [0.0677]
Water Board × Distance to coast (100km)	0.887 (0.316)*** [0.318]***	1.059 (0.365)*** [0.340]***	-0.0490 (0.384) [0.379]	
Water Board × Useful pp. (m3 per Ha per month) × Distance to coast (100km)	-0.130 (0.114) [0.123]	-0.182 (0.0911)** [0.102]*	0.0662 (0.0723) [0.121]	-0.0141 (0.0500) [0.0497]
Parcel Controls	Yes	Yes	Yes	Yes
County Controls	Yes	Yes	Yes	No
Basin FE	No	Yes	No	No
0.5 degree cell FE	No	No	Yes	No
Crop FE	Yes	Yes	Yes	Yes
County FE	No	No	No	Yes
Observations	56,717	56,716	56,716	56,715
R-squared	0.564	0.575	0.606	0.626
Misallocation Test: No Board	0.08	0.00	0.35	0.84
Misallocation Test: with Board	0.79	0.69	0.15	0.83

Notes: This table present estimates of equation 9 for non-irrigated parcels, as a placebo exercise. Distance to the coast measured through the river network. Controlling for capital and technology choices, logarithm of labor input and irrigated surface, and County and Crop fixed effects. Standard errors clustered at the county level (round parenthesis) and at the county× irrigation season level (squared parentheses).

0.2 Figures

Figure 1: Water Right creation process.

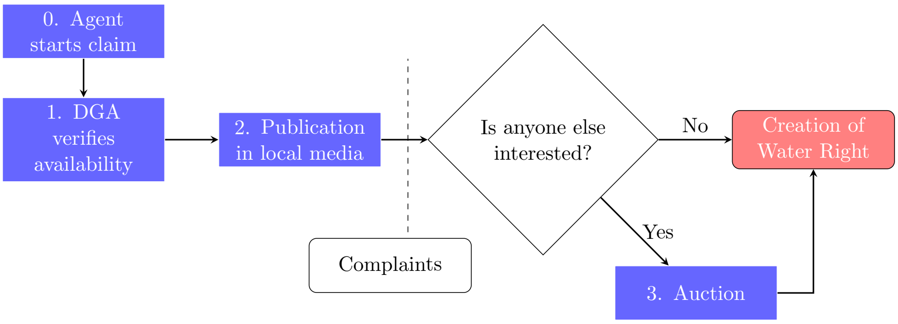
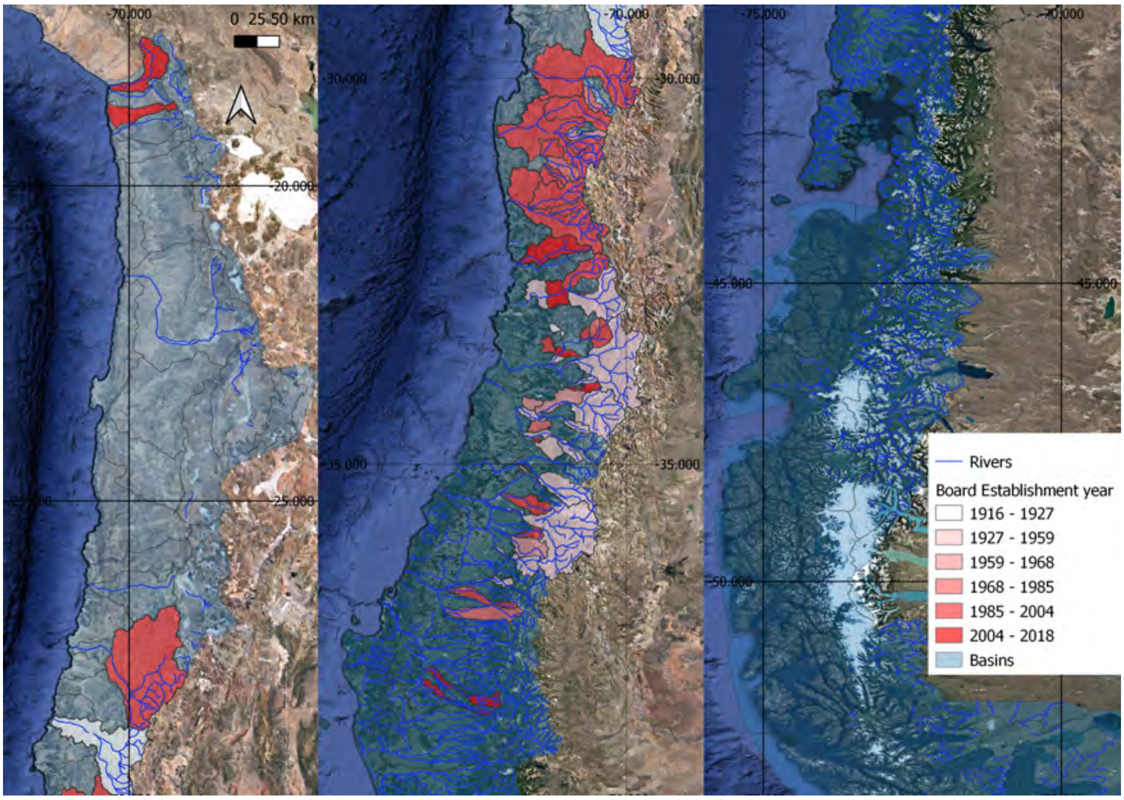


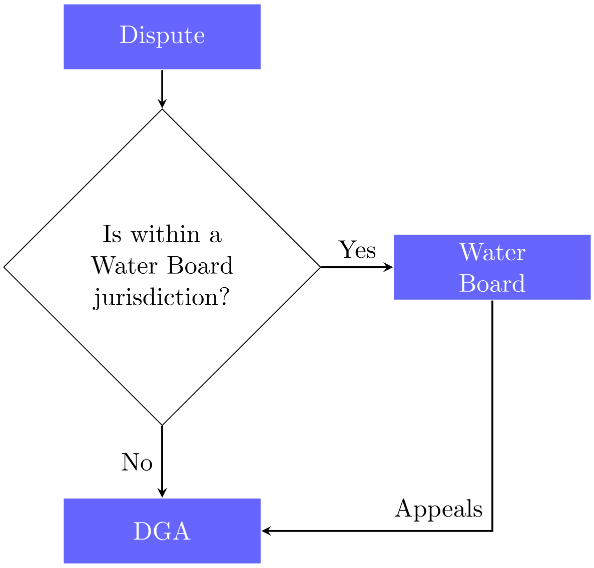
Figure 2: Area of study and Water Boards jurisdictions



Notes: Left, center and right panels corresponds to the northern, central and southern areas of Chile. The colored areas represent each of the existing Water Boards jurisdictions, with their color reflecting the establishment year.

Figure 3: Administrative and legal hierarchy of institutions over water rights issues.

(a) Administrative



(b) Legal

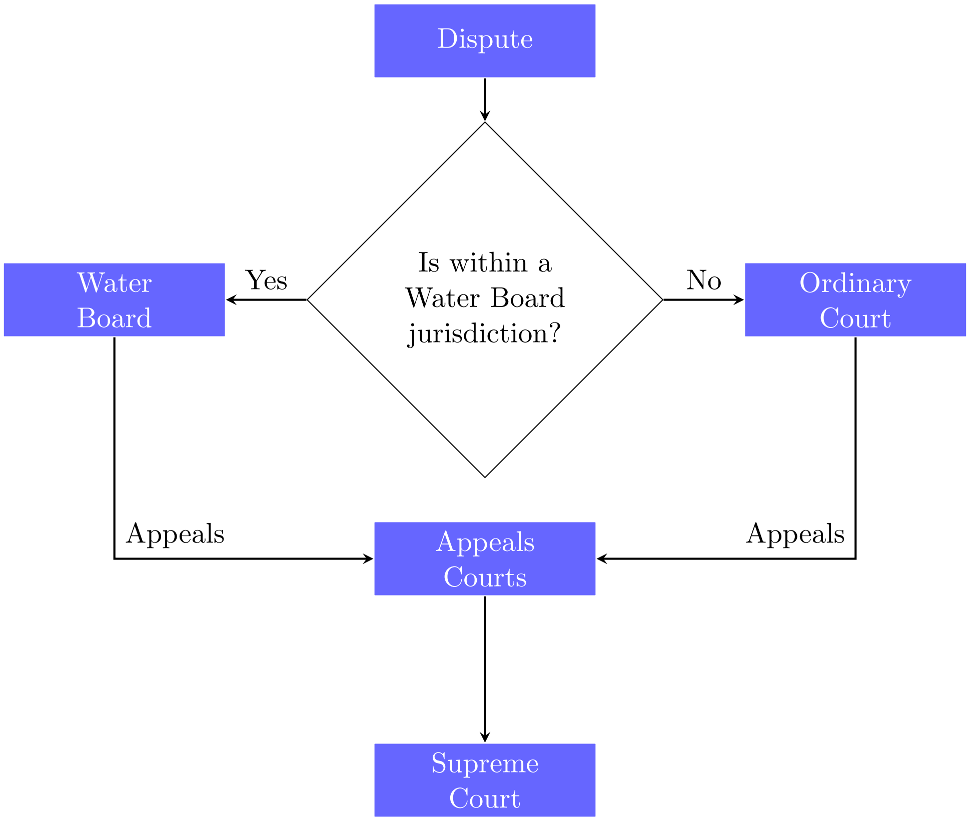
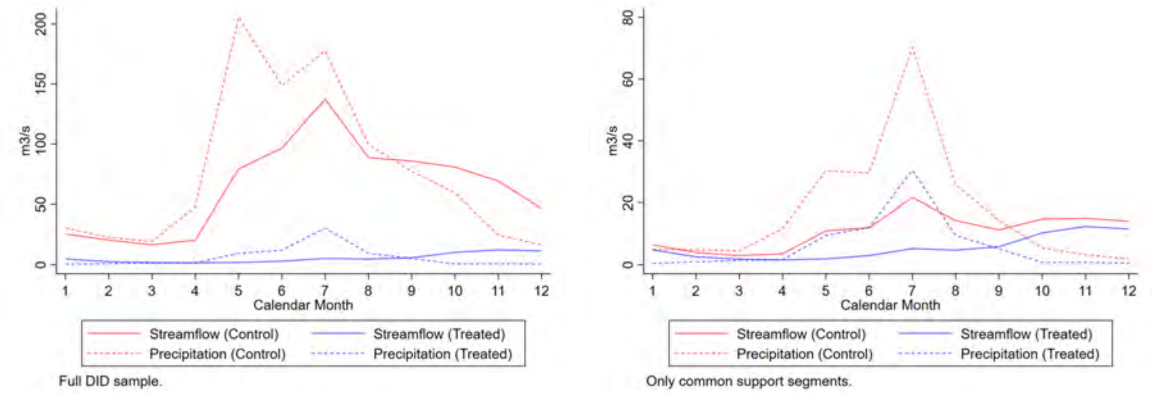


Figure 4: Hydrological regime before 1985, by treatment assignment



Full DID sample.

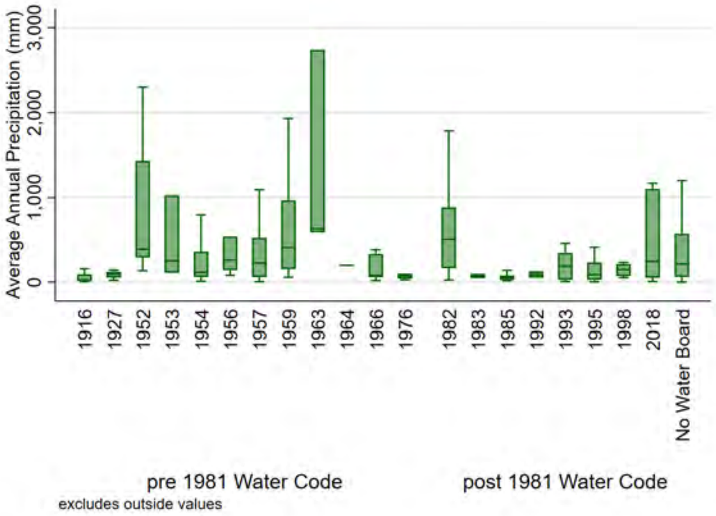
Only common support segments.

(a) Hydrological regime before 1985, by treatment assignment. Full sample.

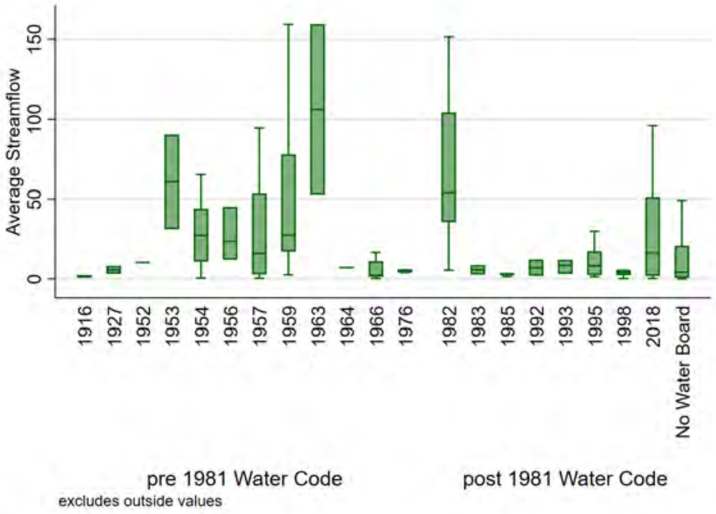
(b) Hydrological regime before 1985, by treatment assignment. Study sample: only segments within the common support in average streamflow and pre-existing water rights in 1980, that eventually have Water Boards.

Figure 5: Climatic and geographic characteristics, by year of establishment

(a) Average Precipitation



(b) Streamflow



(c) Glacier surface

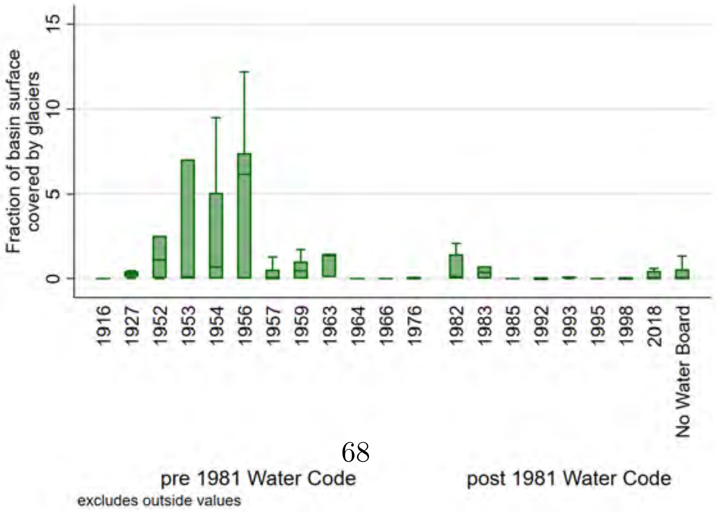
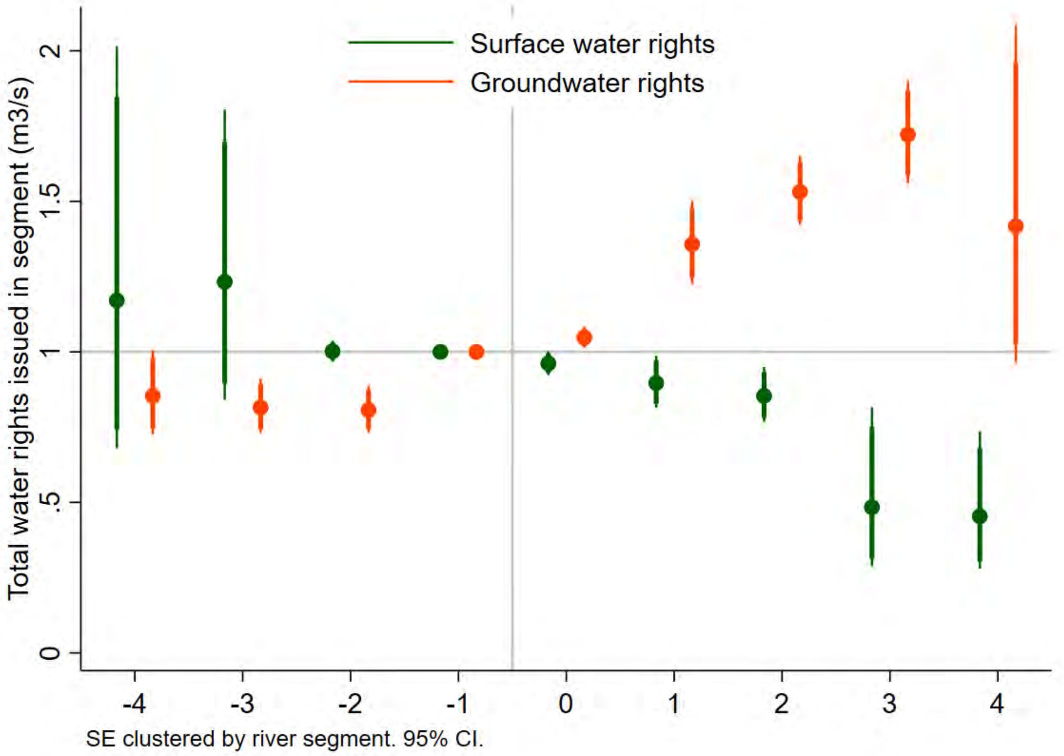
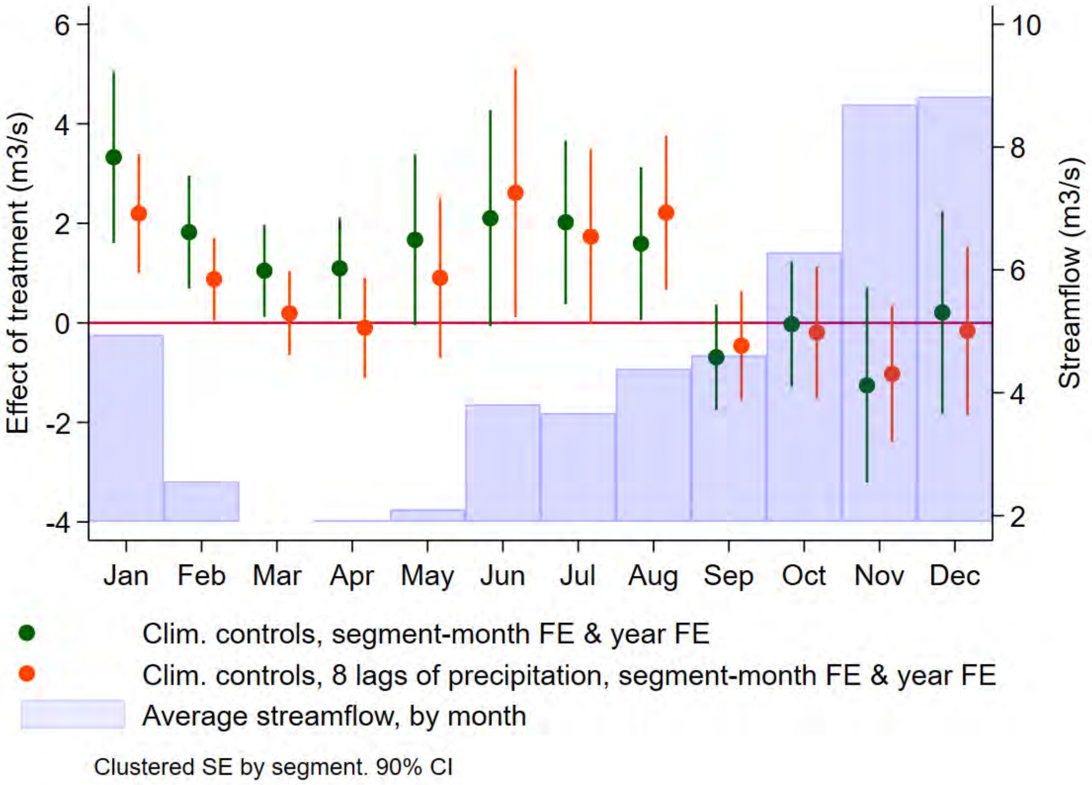


Figure 6: Effect of boards establishments on Water Rights issued in their jurisdictions, by source of the water (Poisson).



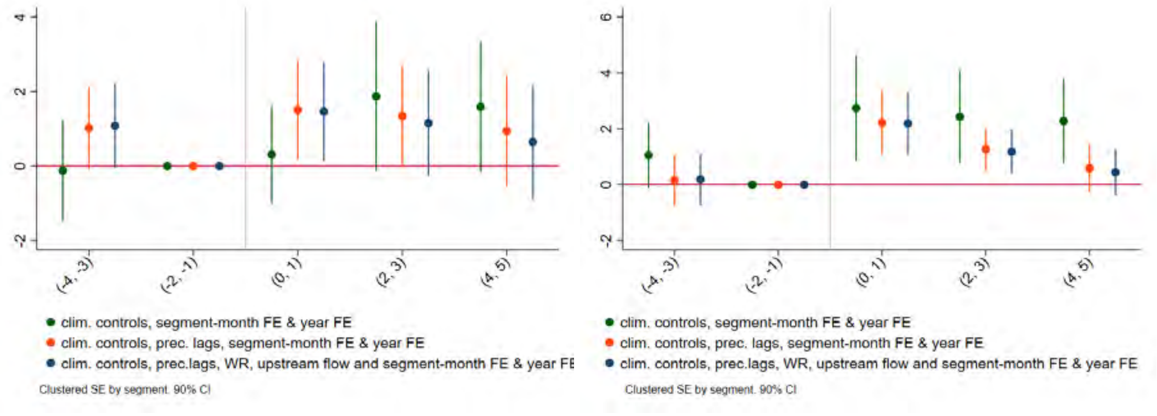
Notes: this figure present estimates of dynamic effects of water boards on water rights issued (measured in m^3/s) separately by source: in green, the effect of water boards on surface water rights; in orange, the effect of water boards on groundwater rights. Using OLS, implemented using Stacked DID design by Cengiz, Dube, Lindner, and Zipperer (2019) design, considering *segment* × *event* and *year* × *event* fixed effects, climatic controls for January and February and also including 8 lags of precipitation and precipitation squared. Standard errors clustered at the river-segment level.

Figure 7: Effect of board establishments on streamflow within their jurisdiction, by month.



Notes: This table present heterogenous effects estimates of water boards on streamflows, by month. We interact the Board Establishment dummy variable with dummy variables indicating each month. Stacked DID design by Cengiz, Dube, Lindner, and Zipperer (2019). Controlling for contemporaneous temperature, precipitation and evapotranspiration, and 8 lags of precipitation and precipitation squared. Standard Errors clustered at the River Segment level.

Figure 8: Effect of board establishments on streamflow within their jurisdiction, by relative time (binned years) to the board establishment event.

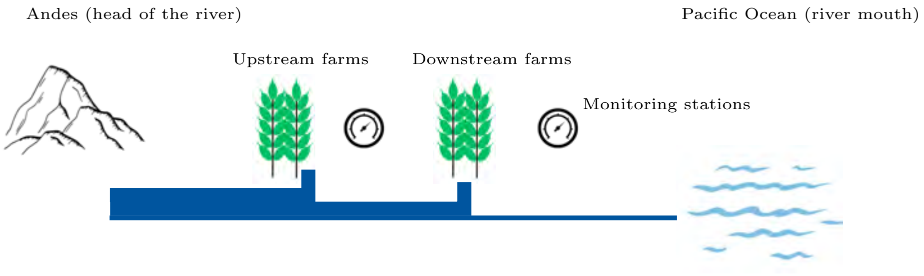


(a) Full year.

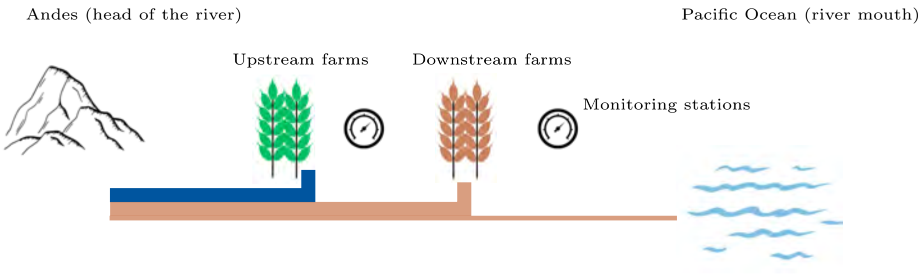
(b) Dry season.

Notes: This table present dynamic effect estimates of water boards on streamflows, according to relative time to board establishment. We created 2-year bins, and consider the two years prior to the board establishment as the baseline period. Controlling for contemporaneous temperature, precipitation and evapotranspiration, and 8 lags of precipitation and precipitation squared, and water rights. Standard Errors clustered at the River Segment level.

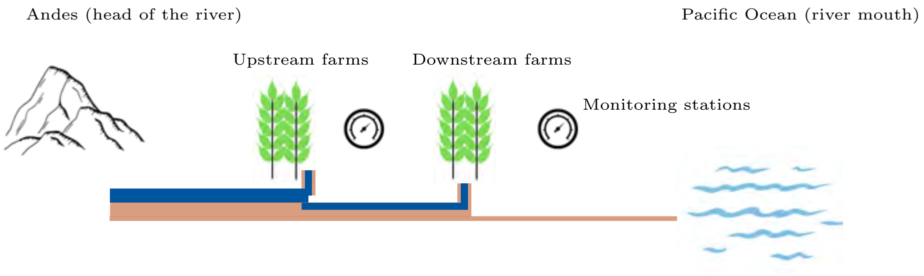
Figure 9: Illustration: how streamflows measurement allows to recover impacts of enforcement by water boards on streamflow.



(a) No drought



(b) Drought, and no enforcement of water rights



(c) Drought, and Water Boards enforce water rights

Figure 10: Example: water consumption and agricultural yield estimates for farms in Aconcagua Basin

(a) Water consumption

(b) Agricultural yield

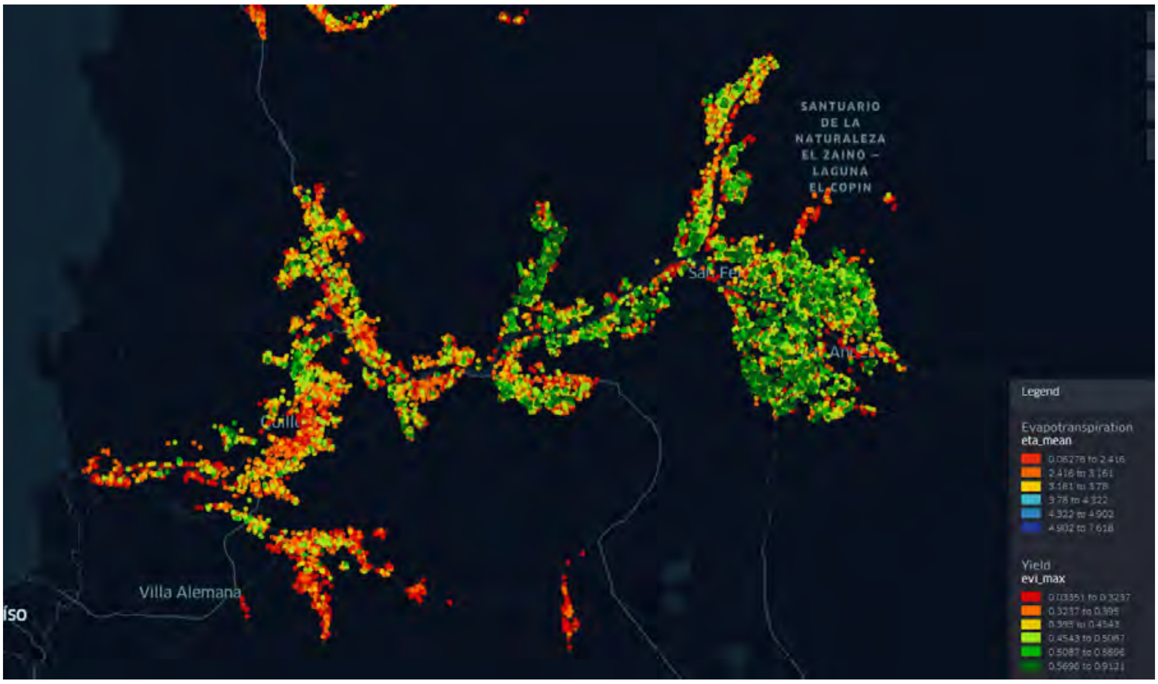
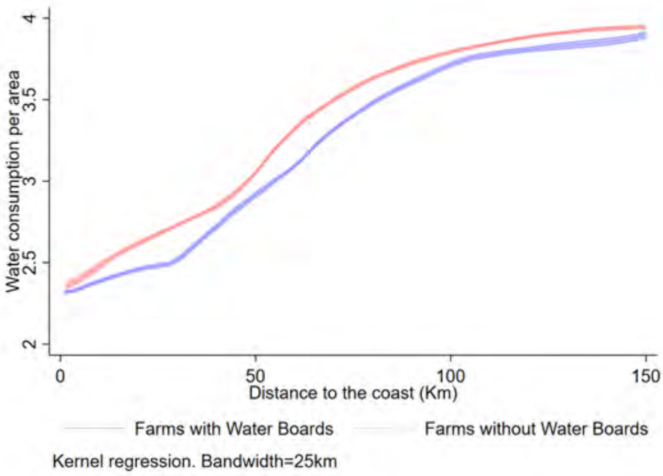
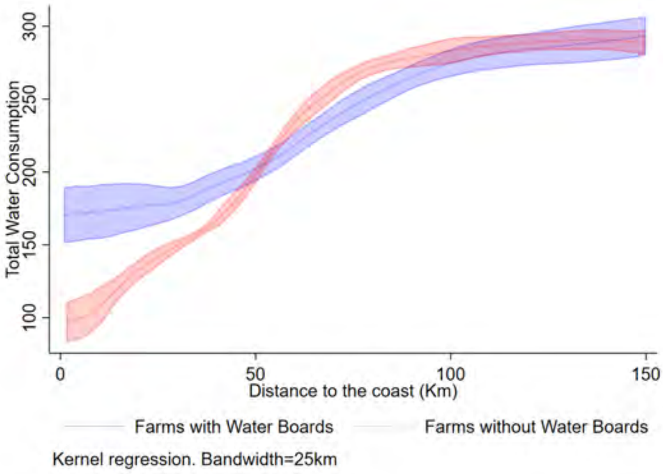


Figure 11: Kernel Regressions between Water Consumption measures and Basin Location (measured as Distance to the Coast), by Treatment Assignment

(a) Average (per m^2) Evapotranspiration during Summer vs farm location within basin



(b) Total Evapotranspiration during Summer vs farm location within basin



(c) Water Availability Index vs farm location within basin

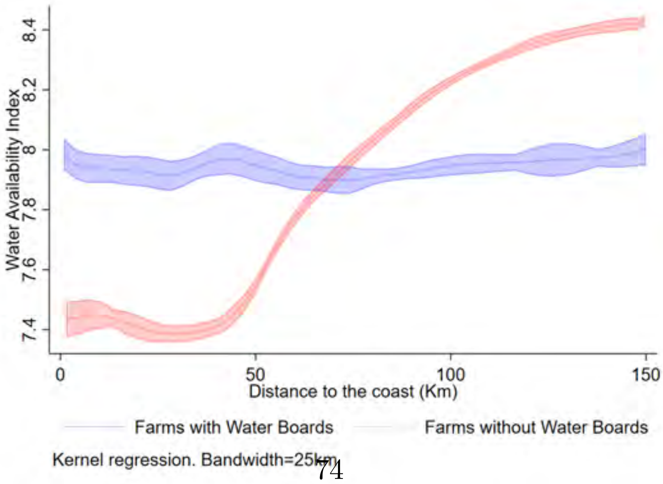
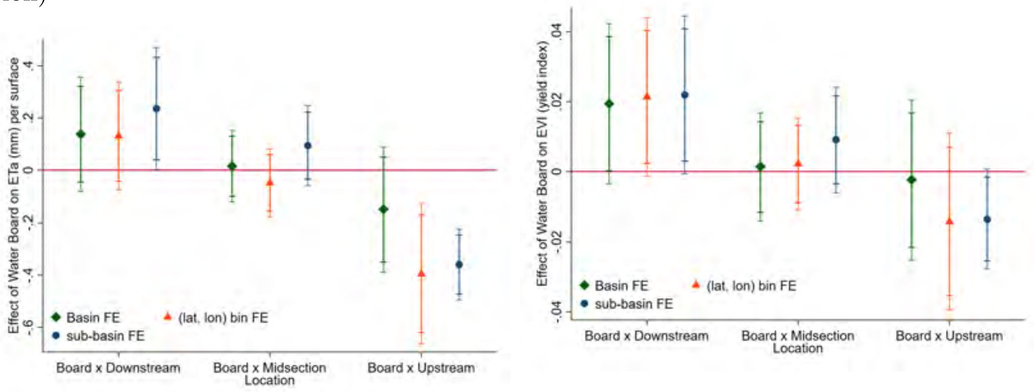


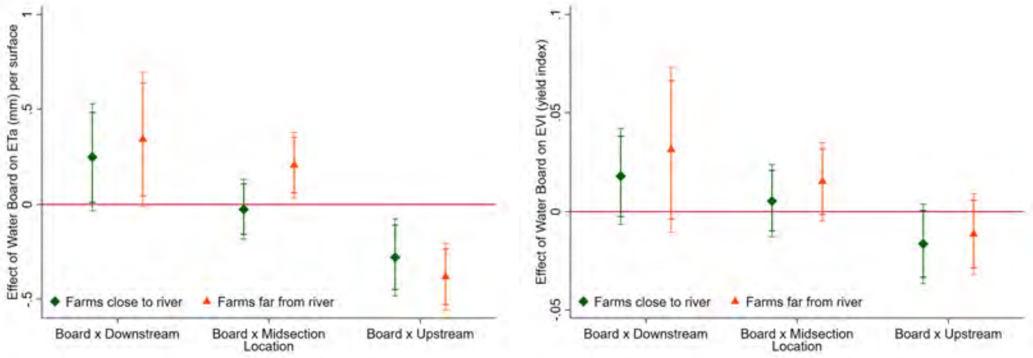
Figure 12: OLS regressions: water consumption and yield by treatment status and basin location.



(a) Water Consumption (Evapotranspiration)

(b) Yield (EVI)

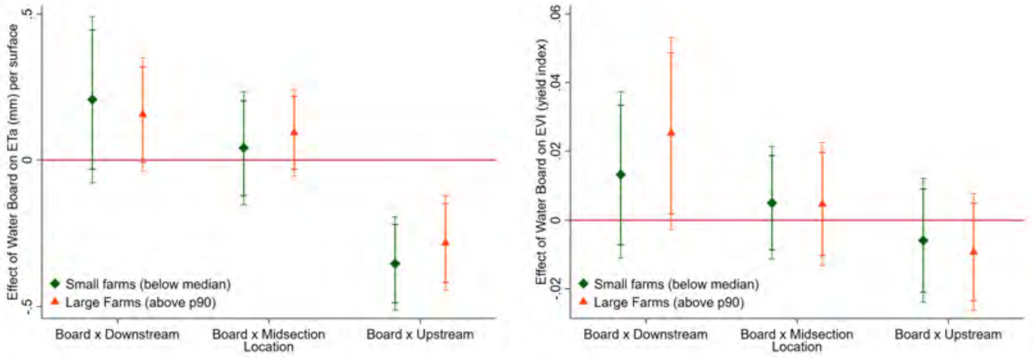
Figure 13: Heterogeneous effects: by location within canal .



(a) Water Consumption

(b) Agricultural yield

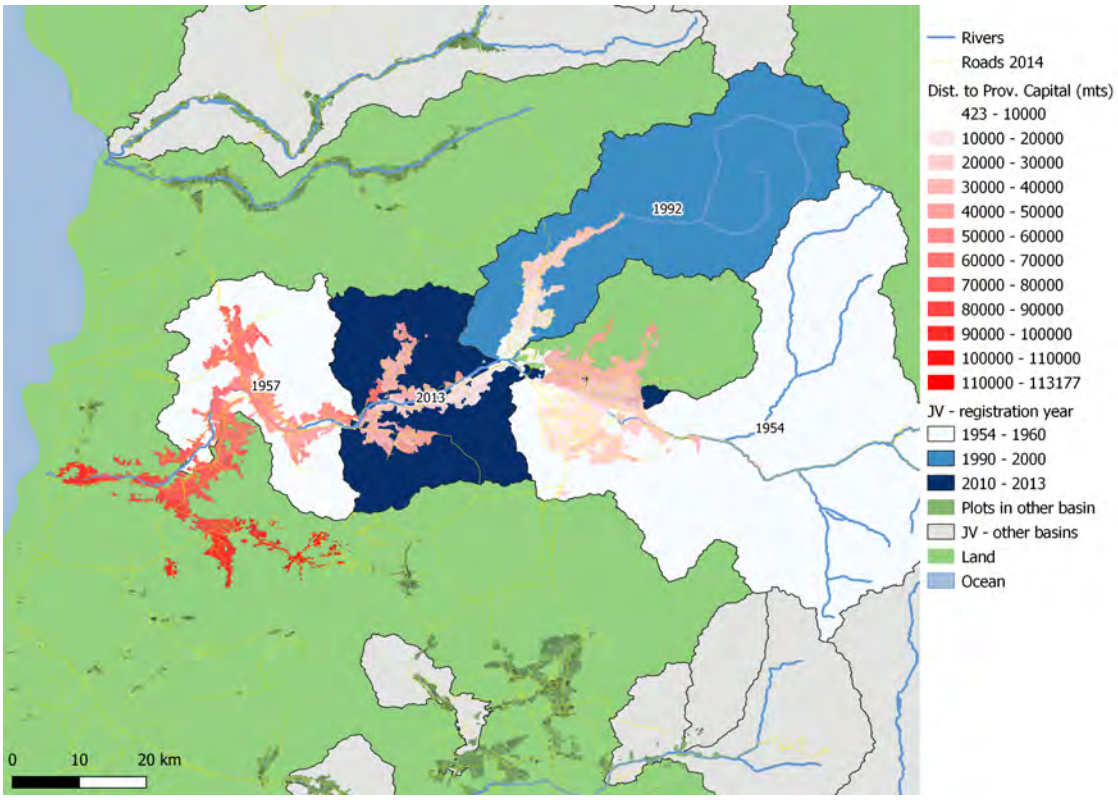
Figure 14: Heterogeneous effects: by farm size.



(a) Water Consumption

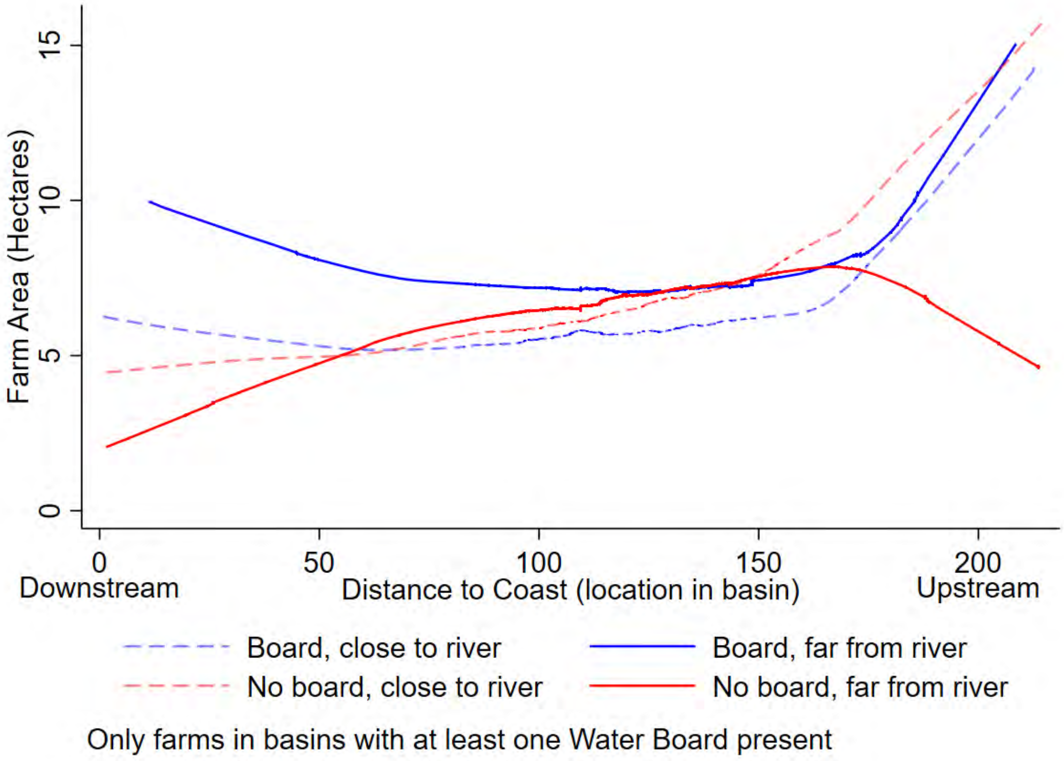
(b) Agricultural yield

Figure 15: Illustration: farm level data and instrument



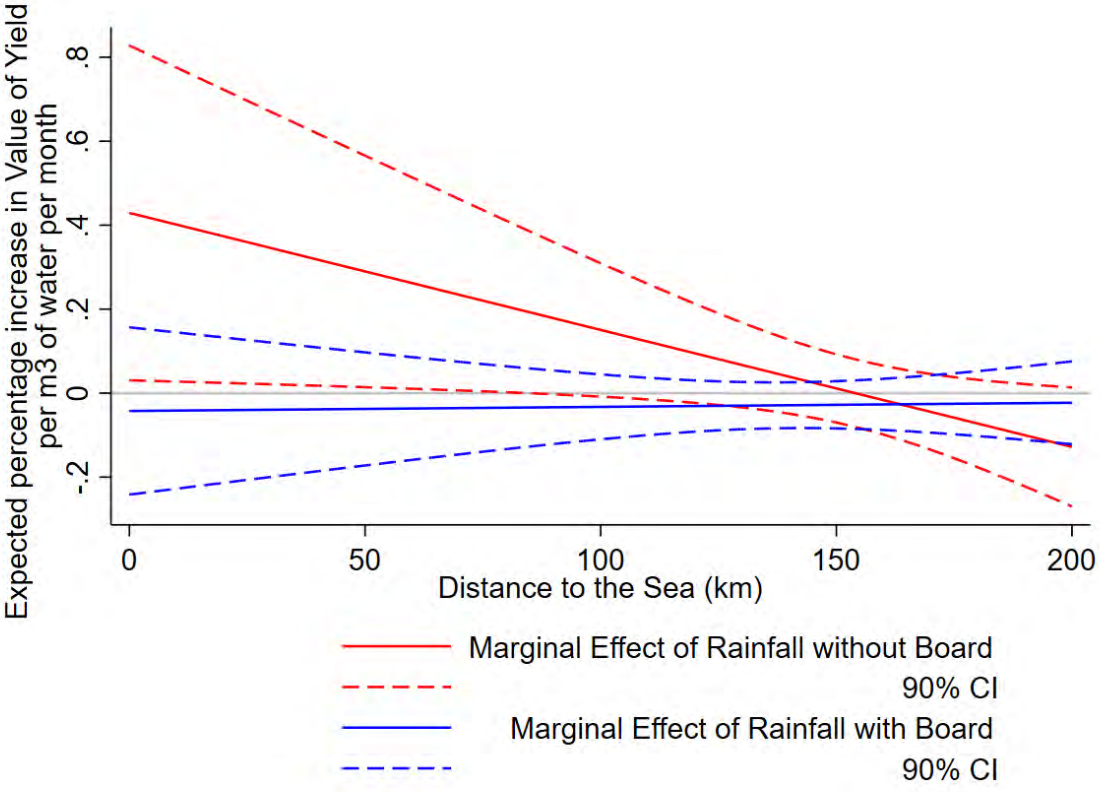
Notes: The map presents the Aconcagua Basin, illustrating the jurisdiction and ear of Establishment of its four Water Boards, our sample of irrigated farms and the river and road network. The color of each farm illustrates

Figure 16: Farm size distribution across locations



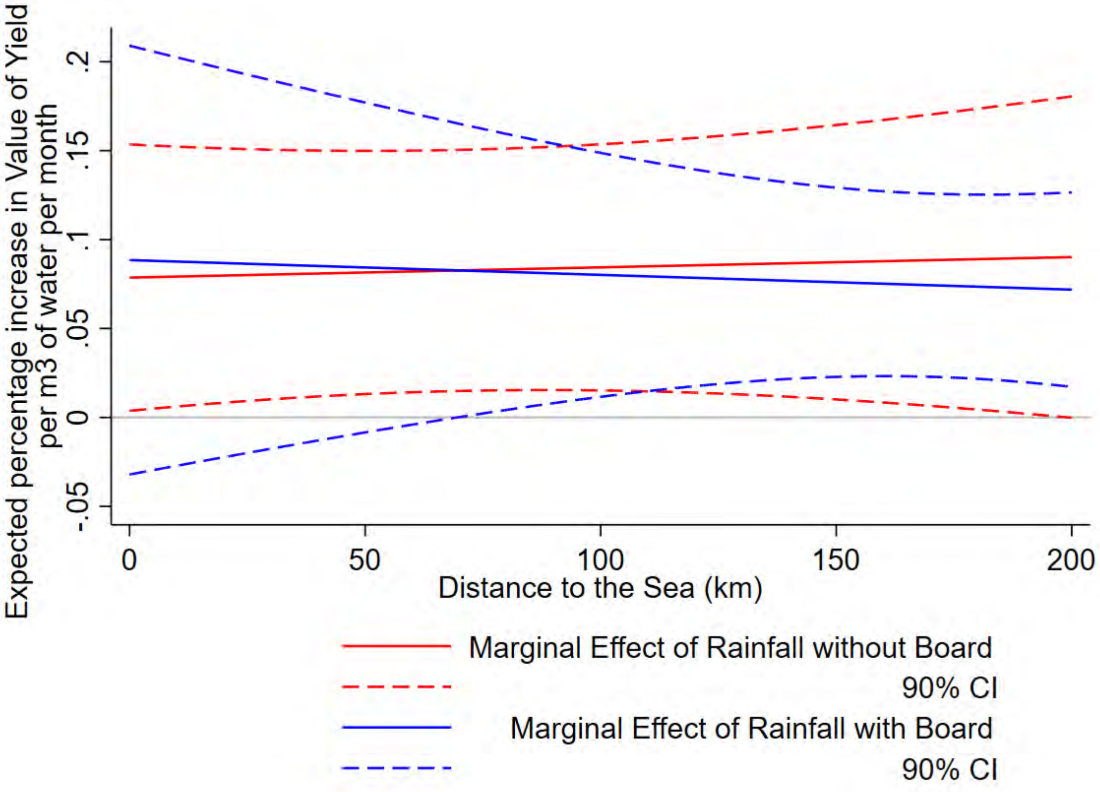
Notes:

Figure 17: Main results: effect on log(Production) of rainfall during the irrigation season by longitude and treatment status for irrigated parcels registered in canal associations.



Notes: Graphical representation of results in Table 13.

Figure 18: Placebo exercise: effect on log(Production) of rainfall during the irrigation season by longitude and treatment status for rainfed parcels.



Notes: Graphical representation of results in Table 14 .

A Model of Agricultural Production and Irrigation under Water Rights

This section discusses a model of agricultural production and irrigation under water rights, that provides the framework to interpret the results in presented in Section 6 as a misallocation test. The first part presents a model of agricultural production, that allows us to define the shadow value of water as the marginal productivity of irrigation water. The second part discusses briefly the problem of a Social Planner and shows that a Social Planner willing to maximize the value of production would equalize the shadow value of water across users. In this environment, an application of the First Welfare Theorem allows us to conclude that the solution of the Social Planner would be implemented as the Market Equilibrium under a well-functioning market.

The key insights from this section are that the partial derivative of the output with respect to rainfall is equal to the shadow value of water, times the marginal rate of technical substitution between rainfall and water from irrigation, and a definition of short-term misallocation.

Environment

Consider the problem of allocating water across N agricultural users within a basin. Agricultural production follows a cycle over the year, with 3 seasons: a Planting season $s = 0$, a Growing season ($s = 1$) and Harvest time ($s = 2$). Water supply has different impacts depending on this stage; in what follows, we assume that irrigation is only useful in $s = 1$.

At stage $s = 0$ each farmer $i \in N$ chooses crop c, capital K_i and land S_i, which are fixed over the full production cycle. At each stage, the farmer chooses the flexible inputs, namely labor L_i and effective irrigation w_i. Effective irrigation is capped by the amount of water rights allocated to the farmer $\bar{w}_i$. Rainfall r is a perfect substitute for irrigation water, up to a technical rate of substitution constant θ. Rainfall is a random variable with a distribution known by all agents. We assume that input and output prices are known in advance, and all markets are competitive.

There is a Social Planner who allocates Water Rights to each user; each user will extract after rainfall uncertainty is realized. The timeline of decisions is therefore:

time= 0 : Social planner allocates water rights. Farmers choose crops, capital and land.

time= 1 : Farmers hire labor and apply irrigation water subject to their Water Rights caps

time= 2 : Profits are realized

Finally, each production function F_c is continuous, strictly concave and monotone[35].

Farmers' problem

We solve by backward induction: the problem of user i at stage $s = 1$ is to choose the optimal irrigation and labor quantities to maximize profits:

$$\begin{aligned} \max_{L_i, w_i} \quad & p_c F_i^c(S_i, K_i, L_i, w_i + \theta r_i) - \lambda_i^s (w_i - \bar{w_i}) - c_L L_i \\ FOC(w_i) \quad : \quad & p_c F_{i\ w}^{c\prime} = \lambda_i^w \\ FOC(L_i) \quad : \quad & p_c F_{i\ L}^{c\prime} = c_L \end{aligned}$$

Under the assumptions above, each farmer will just use the total amount of water rights allocated to them. The shadow value of water will be equal to the marginal productivity of irrigation water.

In stage $s = 0$ the problem of the farmer is to choose the optimal Capital, Land, and

---

[35] While the first two properties are assumed to keep the analysis simple (i.e. to guarantee that the demands for all factors are functions and not correspondences) and it is possible to replace them without loss of generality, the last assumption may be more controversial, as it rules out scenarios where excessive rainfall adversely affects production. While such a scenario is certainly realistic, in the area under study -with mostly dry Mediterranean weather with a well-marked rainfall season in the winter- is rare, and it did not take place in the period under analysis (2006-2007 Austral agricultural year).
Consider the case where irrigation increases production until a total water input threshold, after which water damages production: any rainfall that falls below this threshold will just affect the solution to the farmer's problem by reducing irrigation, in which case the irrigation restriction is not binding. In this scenario, the shadow value of water is zero, and so the problem and the shadow value preserve their meaning.

crop: The fixed inputs are chosen based on

$$\begin{aligned}
\max_{K_i,S_i} \quad & \mathbb{E}_r \left\{pF_i^c \left(S_i, K_i, L_i \left(K_i, S_i, \bar{w}_i\right), w_i \left(K_i, S_i, \bar{w}_i\right) + \theta r_i\right) - c_S S_i - c_K K_i | I_0\right\} \\
FOC(S_i) \quad : \quad & \mathbb{E}_r \left\{p_c F_{i\ S}^{c\prime} | I_0\right\} = c_S \\
FOC(K_i) \quad : \quad & \mathbb{E}_r \left\{p_c F_{i\ K}^{c\prime} | I_0\right\} = c_K
\end{aligned}$$

where the Envelope Theorem rules out any indirect effects on any flexible inputs. Given the choices for each input, we can define the expected profits for farmer i conditional on choosing crop c:

$$\begin{aligned}
\pi_i^c(\bar{w}_i) \equiv & \mathbb{E}_r \left\{p_c F_i^c \left(S_i\left(\bar{w}_i\right), K_i\left(\bar{w}_i\right), L_i\left(\bar{w}_i\right), w_i\left(\bar{w}_i\right) + \theta r_i\right)\right. \\
& \left. - c_S S_i\left(\bar{w}_i\right) - c_K K_i\left(\bar{w}_i\right) - c_L L_i\left(\bar{w}_i\right) - \lambda_i^w \left(w_i\left(\bar{w}_i\right) - \bar{w}_i\right) | I_0\right\}
\end{aligned} \tag{11}$$

The farmers, therefore, will choose the crop with maximum expected profits. The farmer's expected profits are therefore

$$\bar{\pi}_i(\bar{w}_i) \equiv \max \left\{k : \pi_i^k(\bar{w}_i)\right\} \tag{12}$$

Social Planners' Problem

Let's define the Social Welfare Function as the sum of the expected production of all farmers within the basin:

$$\Omega\left(\bar{\mathbf{w}}\right) \equiv \sum_i \bar{\pi}_i(\bar{w}_i)$$

The problem of the social planner is to allocate water rights across users to maximize the total production value, subject to the total availability of water:

$$\max_{\{\bar{w}_i\}|_{i=1}^N} \sum_i \bar{\pi}_i(\bar{w}_i) - \lambda^W \left(\sum_i \bar{w}_i - \bar{W}\right) \tag{13}$$

Note that the social planner's objective function is just the sum of value functions of all farmers; therefore, as a consequence of the Maximum Theorem, the social planner's objective function is continuous on each water right $\bar{w}_i$. The first order condition with respect to $\bar{w}_i$

is

$$\frac{\partial \Omega}{\partial \bar{w}_i} = 0 \iff \frac{\partial \bar{\pi}_i}{\partial \bar{w}_i} = \lambda^W \tag{14}$$

Therefore, the optimal allocation satisfies $\frac{\partial \bar{\pi}_i}{\partial \bar{w}_i} = \frac{\partial \bar{\pi}_j}{\partial \bar{w}_j}$. Note that:

$$\frac{\partial \bar{\pi}_i}{\partial \bar{w}_i} = \frac{\partial \mathbb{E}_r \left\{ p_k F_i^K | I_0 \right\}}{\partial \bar{w}_i} = \mathbb{E} \left\{ \lambda_i^w | I_0 \right\}$$

where the second equality is a consequence of the Envelope Theorem[36][37]. In the socially optimal allocation, therefore, the expected shadow value of water is equal across farmers; any deviation from that implies the opportunity to increase expected welfare by redistributing water rights from users with a high shadow value of water to users with a low shadow value.

The effect of a rainfall shock

Consider the effect on the welfare of an unexpected rainfall shock over farm j. As the water rights allocation is fixed, then:

$$\frac{\partial \Omega}{\partial r_j} = \mathbb{E}_r \left[\frac{\partial p_k F^{k'}_{j\,w}}{\partial w_i} \right] \times \theta = \theta \mathbb{E}_r \left[\lambda_j \right] = \theta \mathbb{E}_r \left[\lambda^W \right]$$

where the second equality comes from the problem of farmer j and the third comes from the planner FOC. So the total effect of an unexpected rainfall shock on production is equal to the shadow value of water of the affected farmer, times the marginal rate of technical substitution between irrigation water and rainfall. Note that Rafey (2023b) estimate θ to be equal to 1.048 for annual irrigated crops[38], which is approximately equal to 1.

We can conclude from the former discussion that

1. the optimal allocation of water rights equalizes the expected marginal productivity of irrigation water across users, and

---

[36] The application is direct in this case; a more general discussion can be found in Hsiang (2016); Deryugina and Hsiang (2017)

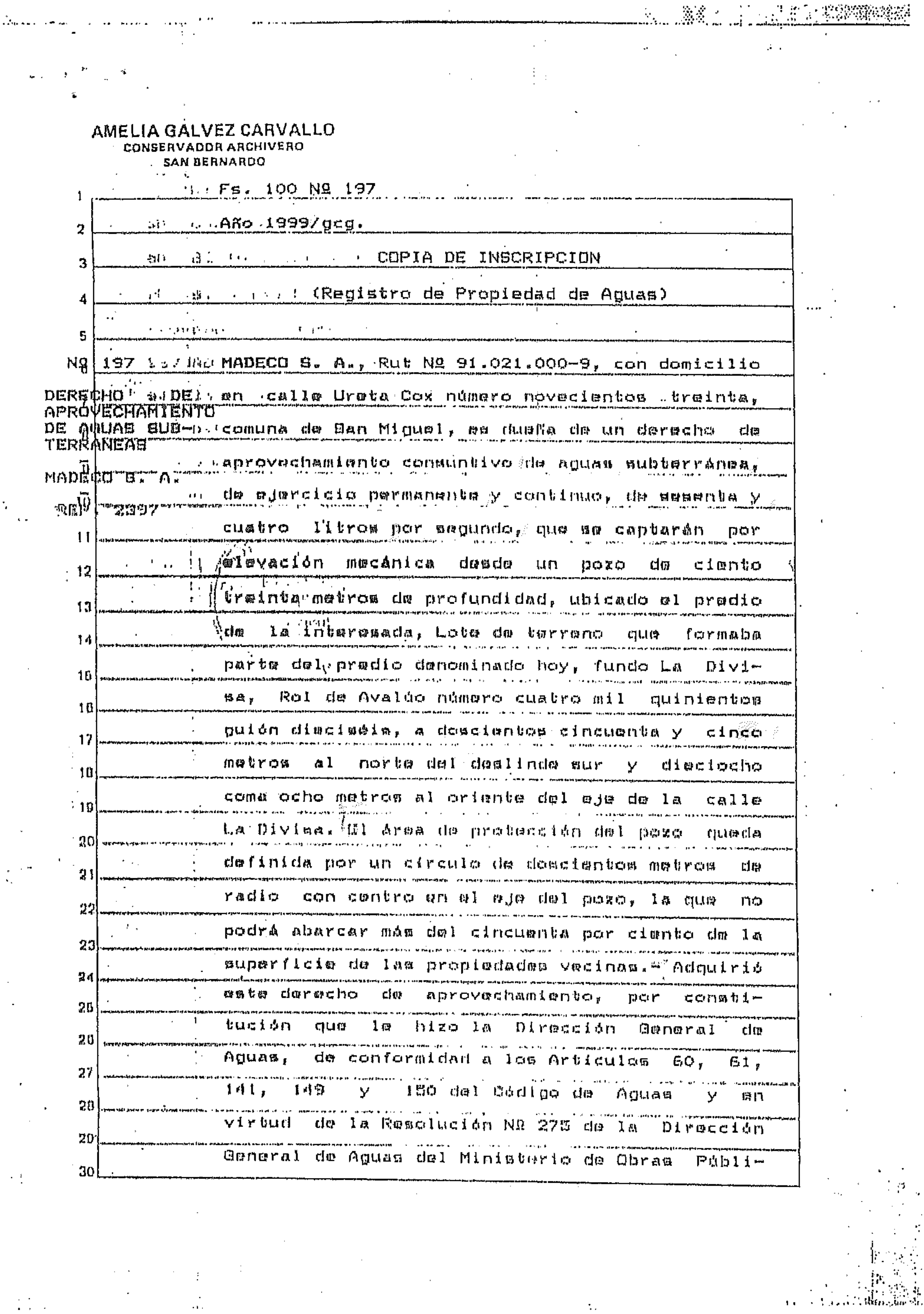
[37] The K index here denotes the crop chosen by the farmer; this choice is not affected by an unexpected rainfall shock.

[38] The estimates of θ for other crop choices are 1.081 for perennial crops, for annual non-irrigated crops is 0.591 and for dairy is 0.148.

2. The effect of an unexpected rainfall shock is equal to the marginal productivity of irrigation water.

A Appendix

Figure 19: Example: water right title.



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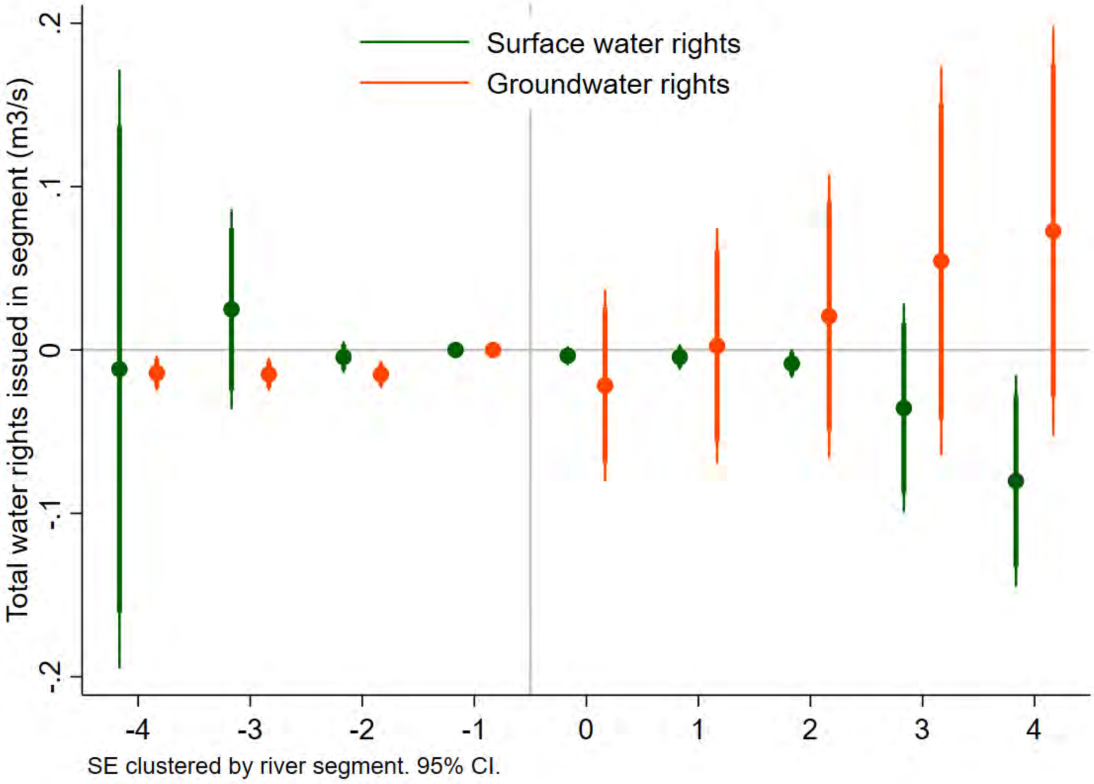
MADECO S. A.
REP 2397

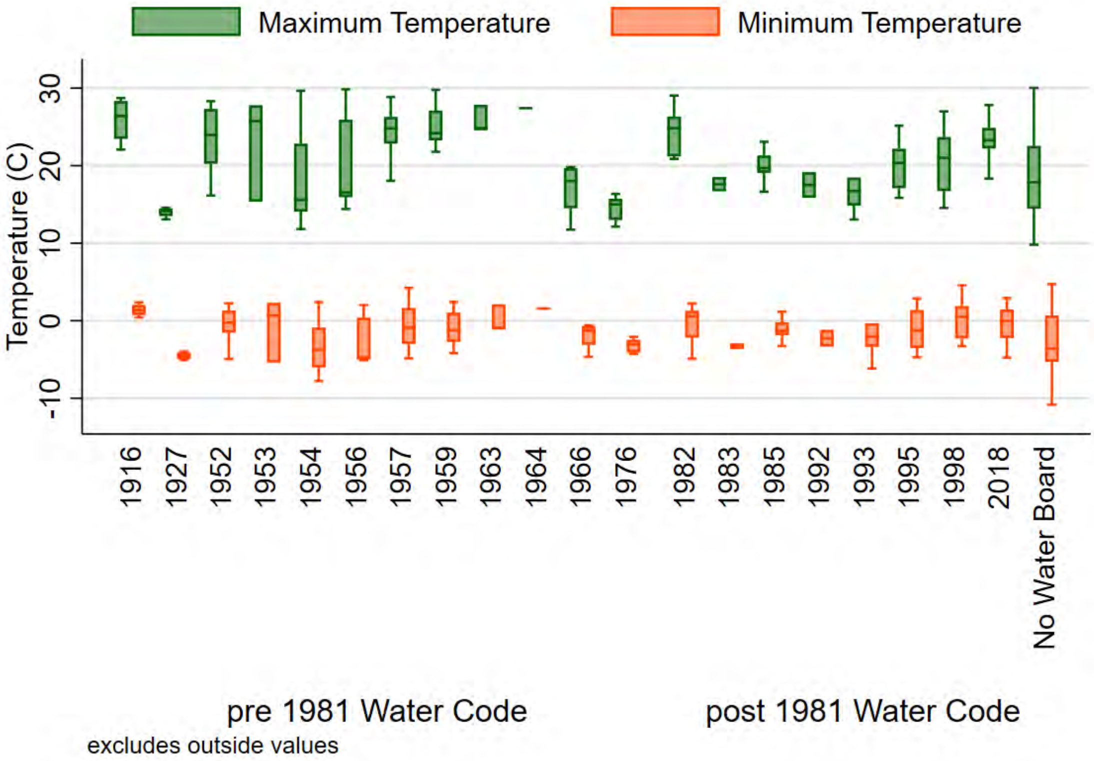
MADECO S. A., Rut Nº 91.021.000-9, con domicilio en calle Ureta Cox número novecientos treinta, comuna de San Miguel, es dueña de un derecho de aprovechamiento consuntivo de aguas subterránea, de ejercicio permanente y continuo, de sesenta y cuatro litros por segundo, que se captarán por elevación mecánica desde un pozo de ciento treinta metros de profundidad, ubicado el predio de la interesada, Lote de terreno que formaba parte del predio denominado hoy, fundo La Divisa, Rol de Avalúo número cuatro mil quinientos guión dieciséis, a doscientos cincuenta y cinco metros al norte del deslinde sur y dieciocho coma ocho metros al oriente del eje de la calle La Divisa. El Area de protección del pozo queda definida por un círculo de doscientos metros de radio con centro en el eje del pozo, la que no podrá abarcar más del cincuenta por ciento de la superficie de las propiedades vecinas.-" Adquirió este derecho de aprovechamiento, por constitución que le hizo la Dirección General de Aguas, de conformidad a los Artículos 60, 61, 141, 149 y 150 del Código de Aguas y en virtud de la Resolución Nº 275 de la Dirección General de Aguas del Ministerio de Obras Públi-

Figure 20: Effect of boards establishments on Water Rights issued in their jurisdictions, by source of the water (OLS).



Notes: this figure present estimates of dynamic effects of water boards on water rights issued (measured in m^3/s) separately by source: in green, the effect of water boards on surface water rights; in orange, the effect of water boards on groundwater rights. Using OLS, implemented using Stacked DID design by Cengiz, Dube, Lindner, and Zipperer (2019) design, considering $segment \times event$ and $year \times event$ fixed effects, climatic controls for January and February and also including 8 lags of precipitation and precipitation squared. Standard errors clustered at the river-segment level.

Figure 21: Climatic and geographic characteristics, by year of establishment (cont.)



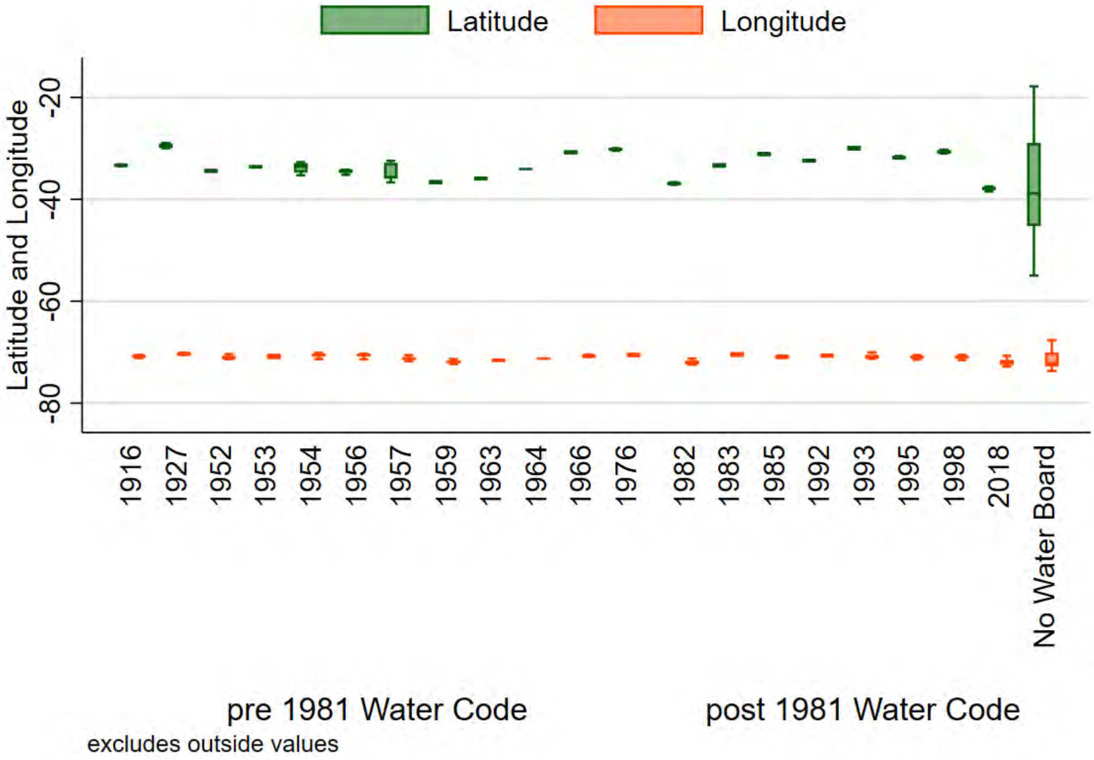


Figure 22: Climatic and geographic characteristics, by year of establishment

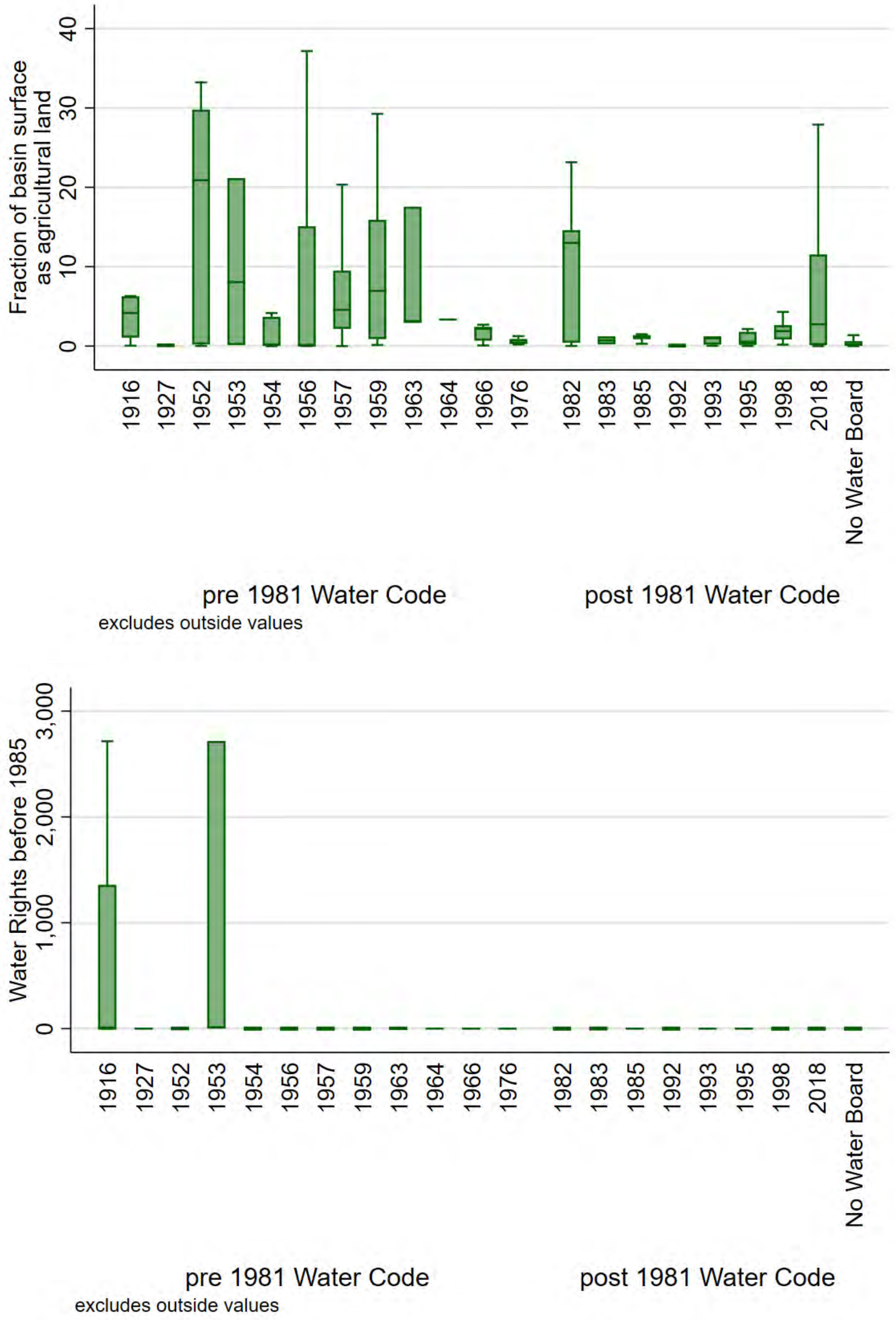
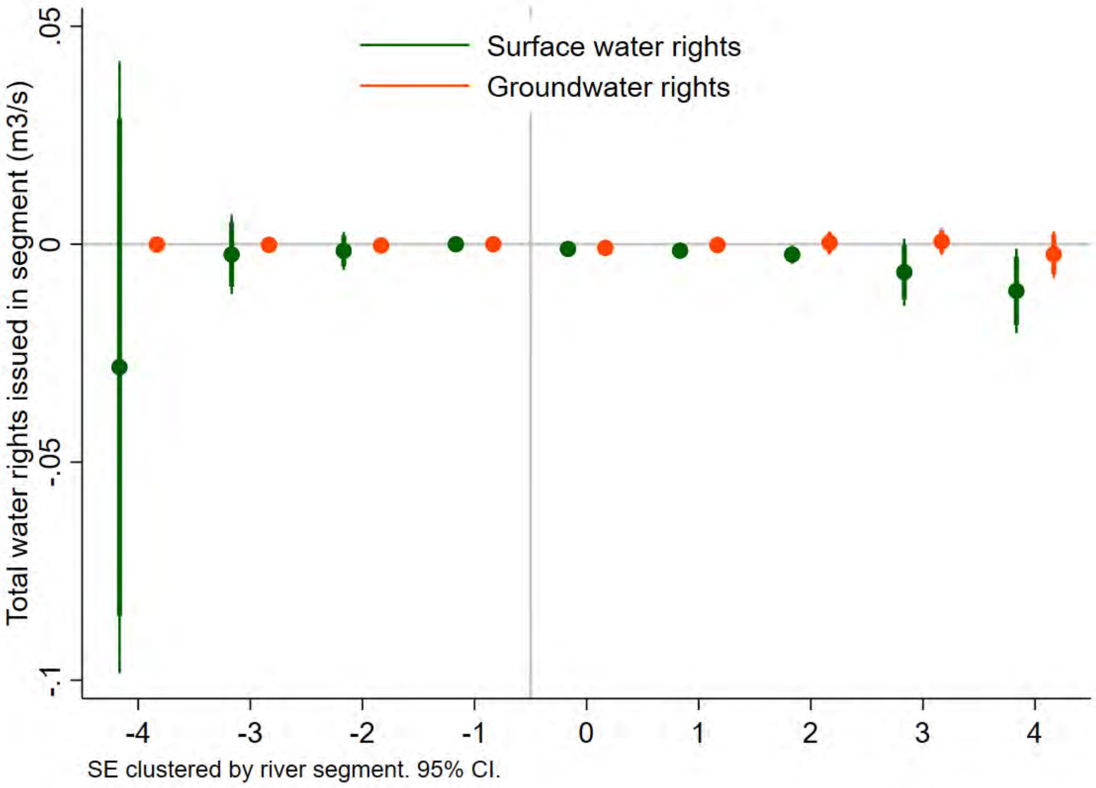


Figure 23: Effect of boards establishments on Water Rights issued per km^2 in their jurisdictions, by source of the water.



Notes: this figure present estimates of dynamic effects of water boards on water rights issued (measured in m^3/s,) per km^2 of surface of the basin, separately by source: in green, the effect of water boards on surface water rights; in orange, the effect of water boards on groundwater rights. Using OLS, implemented using Stacked DID design by Cengiz, Dube, Lindner, and Zipperer (2019) design, considering $segment \times event$ and $year \times event$ fixed effects, climatic controls for January and February and also including 8 lags of precipitation and precipitation squared. Standard errors clustered at the river-segment level.

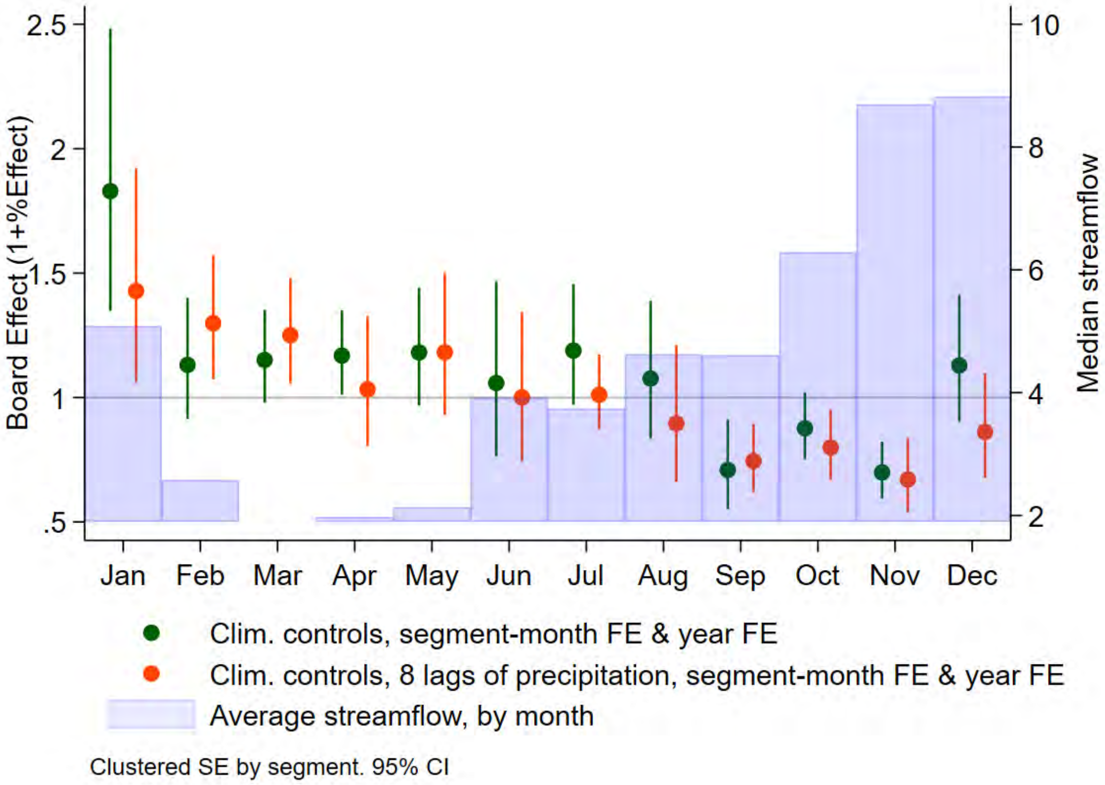
Table 15: Years of Board Establishment, by river segment

	(1)		
	Board establishment year		
	N segments	percent	Cumulative perc.
1916	4	0.78	0.78
1927	4	0.78	1.55
1952	6	1.16	2.71
1953	3	0.58	3.29
1954	43	8.33	11.63
1956	7	1.36	12.98
1957	38	7.36	20.35
1959	12	2.33	22.67
1963	3	0.58	23.26
1964	1	0.19	23.45
1966	7	1.36	24.81
1976	7	1.36	26.16
1982	11	2.13	28.29
1983	2	0.39	28.68
1985	8	1.55	30.23
1992	2	0.39	30.62
1993	5	0.97	31.59
1995	16	3.10	34.69
1998	16	3.10	37.79
2018	27	5.23	43.02
No Board	294	56.98	100.00
Total	516	100.00	
Observations	516		

Notes: This table shows the total number of monitoring stations available, and the establishment date of a water board (in case the river segment associated to a monitoring station is within a water board jurisdiction).

Stations in red are excluded from the study, as the creation of their water boards took place under a different institutional regime.

Figure 24: Effects by month, estimated using Poisson Regression.



Water Rights created

Panel A: OLS

	Surface WR (m3/s)		Groundwater WR (m3/s)	
	(1)	(2)	(3)	(4)
-4	-0.0118 [-0.241, 0.117] 0.923	-0.00571 [-0.252, 0.116] 0.947	-0.0142 [-0.0250, -0.00276] 0.0450 **	-0.0125 [-0.0271, 0.00212] 0.203 *
-3	0.0249 [-0.0202, 0.0731] 0.442	0.00803 [-0.0271, 0.0617] 0.692	-0.0149 [-0.0256, -0.00416] 0.0190 **	-0.0127 [-0.0288, 0.00179] 0.109
-2	-0.00436 [-0.0172, 0.00350] 0.432	-0.00358 [-0.0264, 0.0157] 0.635	-0.0150 [-0.0246, -0.00488] 0.0480 ***	-0.0147 [-0.0284, -0.00528] 0.00100 **
0	-0.00352 [-0.0110, 0.00113] 0.183	-0.0254 [-0.0581, 0.0246] 0.473	-0.0217 [-0.0722, 0.0263] 0.588	-0.0123 [-0.0591, 0.0306] 0.728
1	-0.00438 [-0.0126, 0.00345] 0.311	0.00480 [-0.0231, 0.0272] 0.706	0.00248 [-0.0805, 0.0716] 0.936	0.00153 [-0.0640, 0.0719] 0.968
2	-0.00835 [-0.0163, 0.000501] 0.112 *	-0.0229 [-0.0295, -0.0134] 0 ***	0.0207 [-0.0670, 0.112] 0.613	0.0245 [-0.0589, 0.113] 0.605
3	-0.0356 [-0.106, 0.0174] 0.278	-0.0252 [-0.100, 0.0224] 0.539	0.0544 [-0.0850, 0.200] 0.431	0.0562 [-0.0603, 0.200] 0.356
4	-0.0803 [-0.133, -0.0378] 0.0300 **	-0.0786 [-0.171, 0.00387] 0.134	0.0729 [-0.0761, 0.226] 0.273	0.0680 [-0.0629, 0.215] 0.321
Climatic controls	No	Yes	No	Yes
Segment FE	Yes	Yes	Yes	Yes
Year x experiment FE	Yes	Yes	Yes	Yes
Observations	1,404	1,404	1,404	1,404
R-squared	0.893	0.896	0.751	0.753
Outcome mean	0.180	0.180	0.062	0.062
Outcome SD	0.686	0.686	0.170	0.170

Panel B: Poisson

	Surface WR (m3/s)		Groundwater WR (m3/s)	
	(1)	(2)	(3)	(4)
main				
-4	0.158 , 0.548	0.184 , 0.499	-0.158 , 0.0721 *	-0.101 , 0.248
-3	0.209 , 0.154	0.147 , 0.400	-0.204 , 0.0511 ***	-0.164 , 0.236 ***
-2	0.00204 , 0.853	0.0691 , 0.366	-0.215 , 0.0350 ***	-0.154 , 0.133 ***
0	-0.0391 , 0.227 *	-0.0103 , 0.890	0.0467 , 0.0501 ***	0.0959 , 0.474
1	-0.109 , 0.0310 **	-0.0774 , 0.338	0.306 , 0.0210 ***	0.341 , 0.0651 ***
2	-0.158 , 0.00801 ***	-0.110 , 0.418	0.426 , 0.0420 ***	0.412 , 0.0891 ***
3	-0.725 , 0.0811 ***	-0.676 , 0.0731 ***	0.543 , 0.0490 ***	0.480 , 0.105 ***
4	-0.790 , 0.0270 ***	-0.823 , 0.0340 ***	0.350 , 0.395 *	0.435 , 0.0631 ***
Climatic controls	No	Yes	No	Yes
Segment FE	Yes	Yes	Yes	Yes
Year x experiment FE	Yes	Yes	Yes	Yes
Observations	1,404	1,404	1,404	1,404
R-squared				
Outcome mean	0.180	0.180	0.062	0.062
Outcome SD	0.686	0.686	0.170	0.170

Table 17: Dynamic effects of Water Boards on water rights. Baseline period correspond to the last two years before the boards establishment.

Water Rights per squared Kilometer

Panel A: OLS

	Surface WR per Area		Groundwater WR per Area	
	(1)	(2)	(3)	(4)
-4	-0.0282 [-0.126, 0.0110] 0.952	-0.0284 [-0.126, 0.0111] 0.929	-0.0000869 [-0.000757, 0.000806] 0.768	0.0000348 [-0.000538, 0.00107] 0.926
-3	-0.00237 [-0.0140, 0.00336] 0.983	-0.00252 [-0.0143, 0.00484] 0.861	-0.000141 [-0.000518, 0.000412] 0.493	-0.0000798 [-0.000517, 0.000549] 0.691
-2	-0.00153 [-0.00706, 0.00100] 0.837	-0.00162 [-0.00798, 0.00157] 0.553	-0.000289 [-0.000462, -0.0000499] 0.0410 **	-0.000166 [-0.000412, 0.000130] 0.338
0	-0.00108 [-0.00313, 0.0000582] 0.133	-0.000222 [-0.00185, 0.00208] 0.872	-0.000842 [-0.00221, 0.000616] 0.408	-0.000866 [-0.00271, 0.000690] 0.467
1	-0.00147 [-0.00384, 0.000301] 0.227	-0.00207 [-0.00537, 0.000137] 0.101 *	-0.000172 [-0.00222, 0.00157] 0.803	-0.000114 [-0.00213, 0.00179] 0.897
2	-0.00237 [-0.00541, -0.000689] 0.0470 **	-0.00137 [-0.00364, 0.00157] 0.322	0.000325 [-0.00322, 0.00299] 0.846	0.000279 [-0.00261, 0.00273] 0.829
3	-0.00641 [-0.0146, 0.000119] 0.0951	-0.00662 [-0.0147, -0.000537] 0.0671 *	0.000637 [-0.00307, 0.00367] 0.662	0.000656 [-0.00333, 0.00360] 0.673
4	-0.0107 [-0.0200, -0.00504] 0 **	-0.0126 [-0.0219, -0.00618] 0.00200 **	-0.00231 [-0.00892, 0.00310] 0.464	-0.00191 [-0.00747, 0.00285] 0.498
Climatic controls	No	Yes	No	Yes
Segment FE	Yes	Yes	Yes	Yes
Year x experiment FE	Yes	Yes	Yes	Yes
Observations	1,404	1,404	1,404	1,404
R-squared	0.882	0.882	0.666	0.667
Outcome mean	0.014	0.014	0.003	0.003
Outcome SD	0.062	0.062	0.008	0.008

Panel B: Poisson

	Surface WR per Area		Groundwater WR per Area	
	(1)	(2)	(3)	(4)
main				
-4	0.158 , 0.515	0.184 , 0.519	-0.158 , 0.0761 *	-0.101 , 0.230
-3	0.209 , 0.162	0.147 , 0.429	-0.204 , 0.0420 ***	-0.164 , 0.232 ***
-2	0.00204 , 0.858	0.0691 , 0.405	-0.215 , 0.0400 ***	-0.154 , 0.140 ***
0	-0.0391 , 0.192 *	-0.0103 , 0.881	0.0467 , 0.0440 ***	0.0959 , 0.501
1	-0.109 , 0.0581 **	-0.0774 , 0.333	0.306 , 0.0100 ***	0.341 , 0.0591 ***
2	-0.158 , 0.00901 ***	-0.110 , 0.425	0.426 , 0.0400 ***	0.412 , 0.0861 ***
3	-0.725 , 0.0931 ***	-0.676 , 0.0641 ***	0.543 , 0.0591 ***	0.480 , 0.0931 ***
4	-0.790 , 0.0270 ***	-0.823 , 0.0200 ***	0.350 , 0.402 *	0.435 , 0.0671 ***
Climatic controls	No	Yes	No	Yes
Segment FE	Yes	Yes	Yes	Yes
Year x experiment FE	Yes	Yes	Yes	Yes
Observations	1,404	1,404	1,404	1,404
R-squared				
Outcome mean	0.180	0.180	0.062	0.062
Outcome SD	0.686	0.686	0.170	0.170

Table 18: Dynamic effects of Water Boards on water rights per unit of area. Baseline period correspond to the last two years before the boards establishment.

	Streamflows					
	Full year			Dry season		
	(1)	(2)	(3)	(4)	(5)	(6)
(-4, -3)	-0.117	1.016	1.081	1.055	0.156	0.190
	(0.814)	(0.667)	(0.675)	(0.703)	(0.552)	(0.565)
(-2, -1)						
(0, 1)	0.309	1.512	1.460	2.742	2.222	2.194
	(0.786)	(0.802)*	(0.795)*	(1.137)**	(0.687)***	(0.678)***
(2, 3)	1.873	1.350	1.157	2.430	1.279	1.184
	(1.201)	(0.814)	(0.843)	(0.993)**	(0.454)***	(0.467)**
(4, 5)	1.587	0.945	0.644	2.280	0.583	0.443
	(1.047)	(0.891)	(0.914)	(0.922)**	(0.515)	(0.496)
Water Rights (m3/s)			-0.637			-0.299
			(0.290)**			(0.308)
Climatic controls	Yes	Yes	Yes	Yes	Yes	Yes
Precipitation lags	No	Yes	Yes	No	Yes	Yes
Segment FE	No	No	No	Yes	Yes	Yes
Segment x Month FE	Yes	Yes	Yes	No	No	No
Year FE	Yes	Yes	Yes	Yes	Yes	Yes
Observations	14,926	13,922	13,922	2,476	2,234	2,234
R-squared	0.680	0.763	0.763	0.448	0.705	0.706
Outcome mean	10.249	10.361	10.361	4.508	4.419	4.419
Outcome SD	20.575	20.684	20.684	9.220	9.206	9.206

Table 19: Dynamic effects of Water Boards on streamflows. Baseline period correspond to the last two years before the boards establishment.

Rainfall during the crop irrigation season

	Full Sample				Irrigated fields sample			
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Distance to coast (100km)	0.107	0.0121	0.0171	-0.0321	-0.0323	-0.313	-0.240	-0.372
	(0.0321)***	(0.0350)	(0.0208)	(0.0247)	(0.0910)	(0.138)**	(0.0630)***	(0.0943)***
Water Board	0.127	0.0398	0.0138	-0.0250	0.0833	-0.146	-0.142	-0.233
	(0.0822)	(0.0544)	(0.0512)	(0.0456)	(0.164)	(0.236)	(0.105)	(0.155)
Water Board× Distance to coast (100km)	-0.106	-0.0376	-0.0174	0.0358	-0.0689	0.0713	0.0775	0.141
	(0.0485)**	(0.0359)	(0.0318)	(0.0301)	(0.105)	(0.146)	(0.0694)	(0.101)
Constant	0.0783	0.192	0.188	0.233	0.315	0.713	0.616	0.791
	(0.0523)	(0.0449)***	(0.0320)***	(0.0344)***	(0.158)**	(0.224)***	(0.101)***	(0.147)***
Agro-climate zone FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Basin FE	Yes	No	Yes	No	Yes	No	Yes	No
0.5 degree cell FE	No	Yes	No	Yes	No	Yes	No	Yes
Crop FE	No	No	Yes	Yes	No	No	Yes	Yes
Observations	220,162	220,162	216,334	216,334	15,908	15,905	15,149	15,147
R-squared	0.238	0.296	0.879	0.900	0.302	0.356	0.922	0.945
Outcome mean	0.204	0.204	0.205	0.205	0.276	0.277	0.278	0.278
Outcome SD	0.314	0.314	0.316	0.316	0.301	0.301	0.304	0.304

Table 20: Balance table: outcome variable is precipitation fell during the irrigation season of the crop planted in the parcel

Table 21: Boards and redistribution of water across locations

	Average ETa			log(total ETa)		
	(1)	(2)	(3)	(4)	(5)	(6)
Board x Downstream	0.138	0.131	0.236	0.186	0.202	0.197
	(0.111)	(0.105)	(0.119)**	(0.0999)*	(0.0961)**	(0.0823)**
Board x Midsection	0.0151	-0.0488	0.0940	0.0437	0.0592	0.109
	(0.0697)	(0.0658)	(0.0778)	(0.0938)	(0.0952)	(0.0992)
Board x Upstream	-0.150	-0.396	-0.359	0.0793	0.00508	0.000482
	(0.121)	(0.136)***	(0.0687)***	(0.0713)	(0.0729)	(0.0730)
Downstream	0	0	0	0	0	0
	(.)	(.)	(.)	(.)	(.)	(.)
Midsection	0.272	0.318	0.0897	0.246	0.262	0.164
	(0.0862)***	(0.0957)***	(0.0916)	(0.0844)***	(0.0878)***	(0.0906)*
Upstream	0.0209	0.277	-0.0258	0.257	0.352	0.237
	(0.127)	(0.120)**	(0.0880)	(0.0937)***	(0.0917)***	(0.0902)***
Area (polynomial)	Yes	Yes	Yes	Yes	Yes	Yes
Precipitation (pol.)	Yes	Yes	Yes	Yes	Yes	Yes
Prec. Summer (pol.)	Yes	Yes	Yes	Yes	Yes	Yes
Soil quality	Yes	Yes	Yes	Yes	Yes	Yes
Market Access	Yes	Yes	Yes	Yes	Yes	Yes
Basin FE	Yes	No	No	Yes	No	No
(lat, lon) grid FE	No	Yes	No	No	Yes	No
Sub-basin FE	No	No	Yes	No	No	Yes
Observations	78,457	78,457	78,456	78,457	78,457	78,456
R-squared	0.456	0.462	0.528	0.564	0.564	0.571
Mean Dependent Var.	3.771	3.771	3.771	4.417	4.417	4.417

Table 22: Boards and redistribution of Agricultural Production

	Yield (peak EVI)			log(total yield)		
	(1)	(2)	(3)	(4)	(5)	(6)
Board x Downstream	0.0179	0.0199	0.0182	0.190	0.206	0.178
	(0.0113)	(0.0110)*	(0.00887)**	(0.0899)**	(0.0925)**	(0.0695)**
Board x Midsection	-0.000572	-0.0000164	0.00689	0.0435	0.0726	0.0959
	(0.00907)	(0.00716)	(0.00815)	(0.0902)	(0.0928)	(0.0918)
Board x Upstream	0.00219	-0.00372	-0.00811	0.143	0.144	0.111
	(0.00783)	(0.00767)	(0.00635)	(0.0687)**	(0.0674)**	(0.0700)
Downstream	0	0	0	0	0	0
	(.)	(.)	(.)	(.)	(.)	(.)
Midsection	0.00956	0.0125	-0.00369	0.170	0.183	0.123
	(0.00776)	(0.00864)	(0.00760)	(0.0783)**	(0.0818)**	(0.0815)
Upstream	-0.00513	0.000119	-0.0178	0.217	0.252	0.194
	(0.0125)	(0.0118)	(0.0101)*	(0.0858)**	(0.0840)***	(0.0839)**
Area (polynomial)	Yes	Yes	Yes	Yes	Yes	Yes
Precipitation (pol.)	Yes	Yes	Yes	Yes	Yes	Yes
Prec. Summer (pol.)	Yes	Yes	Yes	Yes	Yes	Yes
Soil quality	Yes	Yes	Yes	Yes	Yes	Yes
Market Access	Yes	Yes	Yes	Yes	Yes	Yes
Basin FE	Yes	No	No	Yes	No	No
(lat, lon) grid FE	No	Yes	No	No	Yes	No
Sub-basin FE	No	No	Yes	No	No	Yes
Observations	78,469	78,469	78,468	78,469	78,469	78,468
R-squared	0.279	0.288	0.323	0.559	0.560	0.566
Mean Dependent Var.	0.510	0.510	0.510	0.253	0.253	0.253

Table 23: Heterogeneous effects: location within canal

	Farms close to river				Farms far from river			
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
	ETa (mm) per surface		log(total water consumption)		ETa (mm) per surface		log(total water consumption)	
Board × Downstream	0.107	0.267	0.180	0.300	0.265	0.398	0.359	0.282
	(0.145)	(0.154)*	(0.0882)**	(0.0893)***	(0.153)*	(0.200)**	(0.121)***	(0.132)**
Board × Midsection	-0.126	-0.0260	-0.160	-0.117	-0.0229	0.200	0.206	0.248
	(0.0958)	(0.0791)	(0.0752)**	(0.0748)	(0.101)	(0.0881)**	(0.157)	(0.153)
Board × Upstream	-0.302	-0.302	-0.0509	-0.100	-0.467	-0.395	0.0526	0.0557
	(0.109)***	(0.110)***	(0.0888)	(0.0872)	(0.172)***	(0.0846)***	(0.0827)	(0.0910)
Midsection	0.405	0.194	0.495	0.412	0.325	0.0524	0.181	0.0940
	(0.0981)***	(0.102)*	(0.0906)***	(0.0740)***	(0.137)**	(0.120)	(0.105)*	(0.113)
Upstream	0.266	0.0339	0.434	0.358	0.344	-0.0310	0.302	0.175
	(0.128)**	(0.120)	(0.101)***	(0.105)***	(0.167)**	(0.124)	(0.105)***	(0.107)
Area (polynomial)	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Precipitation (pol.)	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Prec. Summer (pol.)	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Soil quality	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Market Access	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
(lat, lon) cell FE	Yes	No	Yes	No	Yes	No	Yes	No
Sub-basin FE	No	Yes	No	Yes	No	Yes	No	Yes
Observations	24,432	24,430	24,432	24,430	54,025	54,024	54,025	54,024
R-squared	0.468	0.505	0.568	0.580	0.463	0.552	0.567	0.572
Mean Dependent Var.	3.652	3.652	4.222	4.221	3.825	3.825	4.505	4.505

	Farms close to river				Farms far from river			
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
	EVI per area		log(total EVI)		EVI per area		log(total EVI)	
Board × Downstream	0.0107	0.0183	0.174	0.271	0.0424	0.0408	0.378	0.272
	(0.0121)	(0.0129)	(0.0833)**	(0.0753)***	(0.0189)**	(0.0248)	(0.115)***	(0.123)**
Board × Midsection	0.00144	0.00566	-0.124	-0.0905	0.00269	0.0145	0.219	0.222
	(0.00839)	(0.00910)	(0.0710)*	(0.0754)	(0.0112)	(0.0105)	(0.156)	(0.151)
Board × Upstream	-0.0176	-0.0193	-0.00526	-0.0560	-0.0147	-0.0140	0.192	0.167
	(0.0114)	(0.0108)*	(0.0847)	(0.0783)	(0.0159)	(0.00942)	(0.0722)***	(0.0860)*
Midsection	0.0123	-0.00259	0.386	0.332	0.0160	-0.00656	0.116	0.0628
	(0.0106)	(0.0105)	(0.0864)***	(0.0727)***	(0.0121)	(0.0104)	(0.0986)	(0.104)
Upstream	0.000384	-0.0153	0.330	0.286	0.00842	-0.0266	0.212	0.120
	(0.0132)	(0.0124)	(0.0952)***	(0.0959)***	(0.0159)	(0.0119)**	(0.0967)**	(0.0995)
Area (polynomial)	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Precipitation (pol.)	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Prec. Summer (pol.)	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Soil quality	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Market Access	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
(lat, lon) cell FE	Yes	No	Yes	No	Yes	No	Yes	No
Sub-basin FE	No	Yes	No	Yes	No	Yes	No	Yes
Observations	24,437	24,435	24,437	24,435	54,032	54,031	54,032	54,031
R-squared	0.249	0.280	0.560	0.572	0.231	0.286	0.557	0.561
Mean Dependent Var.	0.448	0.448	-0.048	-0.049	0.457	0.457	0.202	0.202

Table 24: Summary Statistics: parcel level dataset, by distance to the Coast

	1					
	Mean	SD	p10	p90	Min	Max
Water Consumption per area	3.62	1.3	1.9	5.4	0.1	7.4
Total (Estimated) Water Consumption	253.81	619.1	8.9	664.5	0.2	23368.2
EVI (max over Summer)	0.45	0.1	0.3	0.6	0.1	0.9
Area (m2)	57697.51	131852.7	3494.0	146577.1	127.4	3977456.0
Latitude	-34.74	1.4	-36.8	-33.0	-37.6	-29.8
Longitude	-71.51	0.4	-72.2	-71.1	-73.0	-70.8
Precipitation (year, plot)	1939.78	790.8	979.1	2973.0	478.1	4267.5
Precipitation (Summer)	56.29	20.8	29.2	83.9	15.9	99.7
Mkt. Acc. (Santiago)	239.44	149.9	65.7	485.6	24.3	613.8
Mkt. Acc. (Valparaiso)	294.99	178.0	88.8	579.1	15.8	707.2
Mkt. Acc. (San Antonio)	236.14	156.6	59.5	493.3	20.4	621.4
Distance to Coast (location in basin)	87.61	31.9	31.7	122.8	0.9	131.8
Dist Upstream Capital	69.66	21.6	50.0	101.2	50.0	179.6
Observations	26780					

	2					
	Mean	SD	p10	p90	Min	Max
Water Consumption per area	4.04	1.1	2.6	5.4	0.3	7.0
Total (Estimated) Water Consumption	328.84	717.2	14.2	852.2	0.2	22422.0
EVI (max over Summer)	0.47	0.1	0.3	0.6	0.0	0.9
Area (m2)	70285.51	147771.5	4057.0	174246.4	47.6	4168568.5
Latitude	-34.83	1.4	-36.7	-32.8	-37.6	-29.9
Longitude	-71.30	0.5	-71.9	-70.8	-72.6	-70.6
Precipitation (year, plot)	1578.97	741.1	793.3	2792.3	449.3	3274.8
Precipitation (Summer)	46.19	15.7	28.8	68.7	16.5	93.1
Mkt. Acc. (Santiago)	236.86	155.8	48.9	475.5	9.4	596.1
Mkt. Acc. (Valparaiso)	315.74	164.8	124.9	548.4	44.6	689.6
Mkt. Acc. (San Antonio)	257.33	142.7	100.9	483.2	73.2	603.8
Distance to Coast (location in basin)	123.26	27.3	81.2	150.3	11.4	159.9
Dist Upstream Capital	70.01	13.0	56.4	88.2	50.0	88.2
Observations	26138					

	3					
	Mean	SD	p10	p90	Min	Max
Water Consumption per area	3.66	1.1	2.1	5.0	0.1	6.7
Total (Estimated) Water Consumption	294.48	656.3	14.4	758.8	0.3	23274.3
EVI (max over Summer)	0.44	0.1	0.3	0.6	0.1	0.9
Area (m2)	68699.35	145405.0	4746.7	165233.6	129.6	5350225.5
Latitude	-34.88	1.6	-36.9	-32.8	-37.8	-29.9
Longitude	-71.23	0.5	-72.0	-70.6	-72.9	-70.5
Precipitation (year, plot)	1350.98	557.7	770.2	2038.9	0.0	2881.2
Precipitation (Summer)	41.03	14.2	24.2	58.4	2.6	74.8
Mkt. Acc. (Santiago)	247.92	179.9	33.3	515.9	9.4	616.5
Mkt. Acc. (Valparaiso)	334.72	181.2	124.9	609.3	33.2	709.9
Mkt. Acc. (San Antonio)	284.51	153.5	124.5	523.6	72.8	624.1
Distance to Coast (location in basin)	157.06	27.1	120.7	188.4	31.1	219.8
Dist Upstream Capital	70.05	13.1	56.4	88.2	50.0	88.2
Observations	25539					

Table 25: Heterogeneous effects: farm size

	Small farms				Large farms			
	(1) ETa (mm) per surface	(2) ETa (mm) per surface	(3) log(total water consumption)	(4) log(total water consumption)	(5) ETa (mm) per surface	(6) ETa (mm) per surface	(7) log(total water consumption)	(8) log(total water consumption)
Board x Downstream	0.124	0.207	0.0339	0.0274	0.0934	0.156	0.0370	0.0198
	(0.126)	(0.144)	(0.0511)	(0.0592)	(0.0828)	(0.0984)	(0.0273)	(0.0306)
Board x Midsection	-0.118	0.0412	0.0233	0.0773	0.0137	0.0929	-0.00343	0.0387
	(0.0949)	(0.0976)	(0.0496)	(0.0562)	(0.0747)	(0.0756)	(0.0276)	(0.0262)
Board x Upstream	-0.412	-0.353	-0.126	-0.0648	-0.312	-0.282	-0.139	-0.0926
	(0.143)***	(0.0810)***	(0.0580)**	(0.0419)	(0.133)**	(0.0819)***	(0.0542)**	(0.0322)***
Downstream	0	0	0	0	0	0	0	0
	(.)	(.)	(.)	(.)	(.)	(.)	(.)	(.)
Midsection	0.371	0.138	0.0667	-0.00321	0.161	-0.0373	0.0745	-0.0251
	(0.0980)***	(0.0959)	(0.0501)	(0.0446)	(0.107)	(0.0976)	(0.0344)**	(0.0301)
Upstream	0.329	0.00604	0.0999	-0.0158	0.0675	-0.198	0.0622	-0.0682
	(0.117)***	(0.0944)	(0.0448)**	(0.0352)	(0.127)	(0.0951)**	(0.0455)	(0.0312)**
Area (polynomial)	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Precipitation (pol.)	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Prec. Summer (pol.)	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Soil quality	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Market Access	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
(lat, lon) cell FE	Yes	No	Yes	No	Yes	No	Yes	No
Sub-basin FE	No	Yes	No	Yes	No	Yes	No	Yes
Observations	35,204	35,203	35,204	35,203	19,872	19,870	19,872	19,870
R-squared	0.455	0.528	0.829	0.844	0.509	0.565	0.799	0.816
Mean Dependent Var.	3.610	3.610	2.974	2.974	3.985	3.985	6.467	6.467

	Small farms				Large farms			
	(1) (mean) evi_maxB	(2) (mean) evi_maxB	(3) log(total EVI)	(4) log(total EVI)	(5) (mean) evi_maxB	(6) (mean) evi_maxB	(7) log(total EVI)	(8) log(total EVI)
Board x Downstream	0.00925	0.00911	0.0250	0.00993	0.0285	0.0230	0.0646	0.0288
	(0.0115)	(0.00982)	(0.0273)	(0.0226)	(0.0105)***	(0.0106)**	(0.0217)***	(0.0211)
Board x Midsection	-0.00717	0.00447	0.0426	0.0758	0.000737	-0.000946	-0.00487	0.00938
	(0.00864)	(0.00874)	(0.0401)	(0.0432)*	(0.00702)	(0.00848)	(0.0207)	(0.0246)
Board x Upstream	-0.00686	-0.00919	0.0156	0.0410	0.00416	-0.000384	-0.0174	0.00853
	(0.0105)	(0.00867)	(0.0290)	(0.0276)	(0.00765)	(0.00704)	(0.0261)	(0.0198)
Downstream	0	0	0	0	0	0	0	0
	(.)	(.)	(.)	(.)	(.)	(.)	(.)	(.)
Midsection	0.00855	-0.0120	-0.0309	-0.0758	0.00803	-0.000925	0.0322	-0.0194
	(0.00983)	(0.00815)	(0.0425)	(0.0342)**	(0.00878)	(0.00851)	(0.0211)	(0.0193)
Upstream	-0.00118	-0.0266	-0.0227	-0.0945	-0.0132	-0.0199	0.00193	-0.0560
	(0.0134)	(0.0117)**	(0.0335)	(0.0254)***	(0.0129)	(0.0110)*	(0.0308)	(0.0241)**
Area (polynomial)	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Precipitation (pol.)	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Prec. Summer (pol.)	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Soil quality	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Market Access	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
(lat, lon) cell FE	Yes	No	Yes	No	Yes	No	Yes	No
Sub-basin FE	No	Yes	No	Yes	No	Yes	No	Yes
Observations	35,211	35,210	35,211	35,210	19,873	19,871	19,873	19,871
R-squared	0.330	0.374	0.885	0.890	0.283	0.308	0.814	0.822
Mean Dependent Var.	0.497	0.497	-1.167	-1.167	0.522	0.522	2.267	2.267

Table 26: Heterogeneous effects: location within canal

	Farms close to river				Farms far from river			
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
	ETa (mm) per surface		log(total water consumption)		ETa (mm) per surface		log(total water consumption)	
Board × Downstream	0.107	0.267	0.180	0.300	0.265	0.398	0.359	0.282
	(0.145)	(0.154)*	(0.0882)**	(0.0893)***	(0.153)*	(0.200)**	(0.121)***	(0.132)**
Board × Midsection	-0.126	-0.0260	-0.160	-0.117	-0.0229	0.200	0.206	0.248
	(0.0958)	(0.0791)	(0.0752)**	(0.0748)	(0.101)	(0.0881)**	(0.157)	(0.153)
Board × Upstream	-0.302	-0.302	-0.0509	-0.100	-0.467	-0.395	0.0526	0.0557
	(0.109)***	(0.110)***	(0.0888)	(0.0872)	(0.172)***	(0.0846)***	(0.0827)	(0.0910)
Midsection	0.405	0.194	0.495	0.412	0.325	0.0524	0.181	0.0940
	(0.0981)***	(0.102)*	(0.0906)***	(0.0740)***	(0.137)**	(0.120)	(0.105)*	(0.113)
Upstream	0.266	0.0339	0.434	0.358	0.344	-0.0310	0.302	0.175
	(0.128)**	(0.120)	(0.101)***	(0.105)***	(0.167)**	(0.124)	(0.105)***	(0.107)
Area (polynomial)	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Precipitation (pol.)	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Prec. Summer (pol.)	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Soil quality	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Market Access	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
(lat, lon) cell FE	Yes	No	Yes	No	Yes	No	Yes	No
Sub-basin FE	No	Yes	No	Yes	No	Yes	No	Yes
Observations	24,432	24,430	24,432	24,430	54,025	54,024	54,025	54,024
R-squared	0.468	0.505	0.568	0.580	0.463	0.552	0.567	0.572
Mean Dependent Var.	3.652	3.652	4.222	4.221	3.825	3.825	4.505	4.505

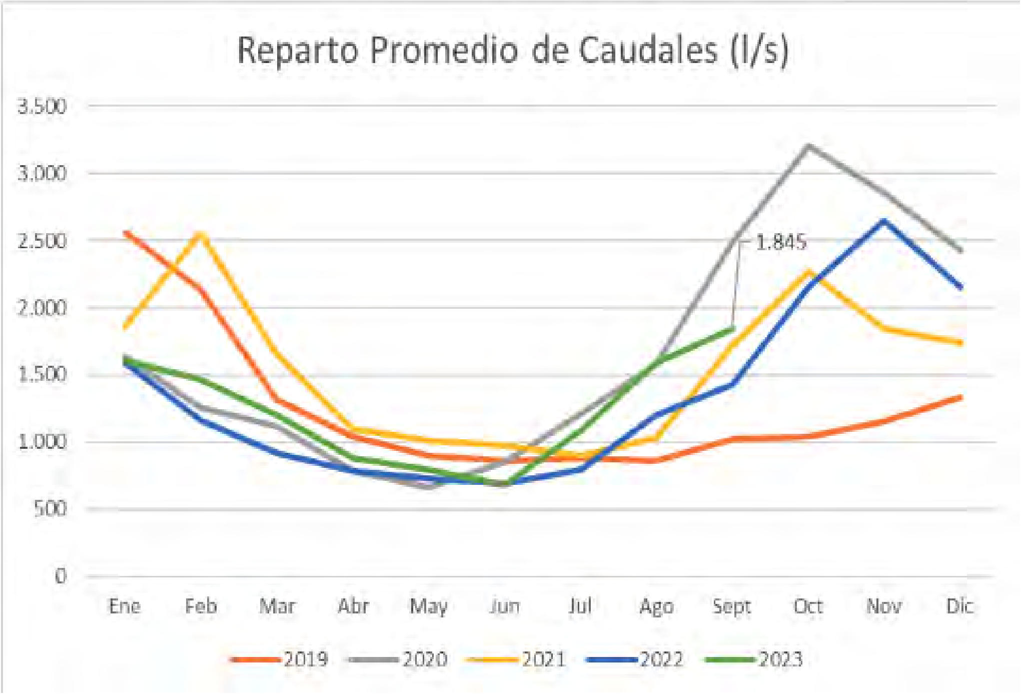
	Farms close to river				Farms far from river			
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
	EVI per area		log(total EVI)		EVI per area		log(total EVI)	
Board × Downstream	0.0107	0.0183	0.174	0.271	0.0424	0.0408	0.378	0.272
	(0.0121)	(0.0129)	(0.0833)**	(0.0753)***	(0.0189)**	(0.0248)	(0.115)***	(0.123)**
Board × Midsection	0.00144	0.00566	-0.124	-0.0905	0.00269	0.0145	0.219	0.222
	(0.00839)	(0.00910)	(0.0710)*	(0.0754)	(0.0112)	(0.0105)	(0.156)	(0.151)
Board × Upstream	-0.0176	-0.0193	-0.00526	-0.0560	-0.0147	-0.0140	0.192	0.167
	(0.0114)	(0.0108)*	(0.0847)	(0.0783)	(0.0159)	(0.00942)	(0.0722)***	(0.0860)*
Midsection	0.0123	-0.00259	0.386	0.332	0.0160	-0.00656	0.116	0.0628
	(0.0106)	(0.0105)	(0.0864)***	(0.0727)***	(0.0121)	(0.0104)	(0.0986)	(0.104)
Upstream	0.000384	-0.0153	0.330	0.286	0.00842	-0.0266	0.212	0.120
	(0.0132)	(0.0124)	(0.0952)***	(0.0959)***	(0.0159)	(0.0119)**	(0.0967)**	(0.0995)
Area (polynomial)	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Precipitation (pol.)	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Prec. Summer (pol.)	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Soil quality	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Market Access	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
(lat, lon) cell FE	Yes	No	Yes	No	Yes	No	Yes	No
Sub-basin FE	No	Yes	No	Yes	No	Yes	No	Yes
Observations	24,437	24,435	24,437	24,435	54,032	54,031	54,032	54,031
R-squared	0.249	0.280	0.560	0.572	0.231	0.286	0.557	0.561
Mean Dependent Var.	0.448	0.448	-0.048	-0.049	0.457	0.457	0.202	0.202

Table 27: Heterogeneous effects: farm size

	Small farms				Large farms			
	(1) ETa (mm) per surface	(2) ETa (mm) per surface	(3) log(total water consumption)	(4) log(total water consumption)	(5) ETa (mm) per surface	(6) ETa (mm) per surface	(7) log(total water consumption)	(8) log(total water consumption)
Board x Downstream	0.124	0.207	0.0339	0.0274	0.0934	0.156	0.0370	0.0198
	(0.126)	(0.144)	(0.0511)	(0.0592)	(0.0828)	(0.0984)	(0.0273)	(0.0306)
Board x Midsection	-0.118	0.0412	0.0233	0.0773	0.0137	0.0929	-0.00343	0.0387
	(0.0949)	(0.0976)	(0.0496)	(0.0562)	(0.0747)	(0.0756)	(0.0276)	(0.0262)
Board x Upstream	-0.412	-0.353	-0.126	-0.0648	-0.312	-0.282	-0.139	-0.0926
	(0.143)***	(0.0810)***	(0.0580)**	(0.0419)	(0.133)**	(0.0819)***	(0.0542)**	(0.0322)***
Downstream	0	0	0	0	0	0	0	0
	(.)	(.)	(.)	(.)	(.)	(.)	(.)	(.)
Midsection	0.371	0.138	0.0667	-0.00321	0.161	-0.0373	0.0745	-0.0251
	(0.0980)***	(0.0959)	(0.0501)	(0.0446)	(0.107)	(0.0976)	(0.0344)**	(0.0301)
Upstream	0.329	0.00604	0.0999	-0.0158	0.0675	-0.198	0.0622	-0.0682
	(0.117)***	(0.0944)	(0.0448)**	(0.0352)	(0.127)	(0.0951)**	(0.0455)	(0.0312)**
Area (polynomial)	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Precipitation (pol.)	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Prec. Summer (pol.)	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Soil quality	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Market Access	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
(lat, lon) cell FE	Yes	No	Yes	No	Yes	No	Yes	No
Sub-basin FE	No	Yes	No	Yes	No	Yes	No	Yes
Observations	35,204	35,203	35,204	35,203	19,872	19,870	19,872	19,870
R-squared	0.455	0.528	0.829	0.844	0.509	0.565	0.799	0.816
Mean Dependent Var.	3.610	3.610	2.974	2.974	3.985	3.985	6.467	6.467

	Small farms				Large farms			
	(1) (mean) evi_maxB	(2) (mean) evi_maxB	(3) log(total EVI)	(4) log(total EVI)	(5) (mean) evi_maxB	(6) (mean) evi_maxB	(7) log(total EVI)	(8) log(total EVI)
Board x Downstream	0.00925	0.00911	0.0250	0.00993	0.0285	0.0230	0.0646	0.0288
	(0.0115)	(0.00982)	(0.0273)	(0.0226)	(0.0105)***	(0.0106)**	(0.0217)***	(0.0211)
Board x Midsection	-0.00717	0.00447	0.0426	0.0758	0.000737	-0.000946	-0.00487	0.00938
	(0.00864)	(0.00874)	(0.0401)	(0.0432)*	(0.00702)	(0.00848)	(0.0207)	(0.0246)
Board x Upstream	-0.00686	-0.00919	0.0156	0.0410	0.00416	-0.000384	-0.0174	0.00853
	(0.0105)	(0.00867)	(0.0290)	(0.0276)	(0.00765)	(0.00704)	(0.0261)	(0.0198)
Downstream	0	0	0	0	0	0	0	0
	(.)	(.)	(.)	(.)	(.)	(.)	(.)	(.)
Midsection	0.00855	-0.0120	-0.0309	-0.0758	0.00803	-0.000925	0.0322	-0.0194
	(0.00983)	(0.00815)	(0.0425)	(0.0342)**	(0.00878)	(0.00851)	(0.0211)	(0.0193)
Upstream	-0.00118	-0.0266	-0.0227	-0.0945	-0.0132	-0.0199	0.00193	-0.0560
	(0.0134)	(0.0117)**	(0.0335)	(0.0254)***	(0.0129)	(0.0110)*	(0.0308)	(0.0241)**
Area (polynomial)	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Precipitation (pol.)	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Prec. Summer (pol.)	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Soil quality	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Market Access	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
(lat, lon) cell FE	Yes	No	Yes	No	Yes	No	Yes	No
Sub-basin FE	No	Yes	No	Yes	No	Yes	No	Yes
Observations	35,211	35,210	35,211	35,210	19,873	19,871	19,873	19,871
R-squared	0.330	0.374	0.885	0.890	0.283	0.308	0.814	0.822
Mean Dependent Var.	0.497	0.497	-1.167	-1.167	0.522	0.522	2.267	2.267

Figure 25: Average Liters per second distributed by El Arrayan Water Board to Canals, by month



Source: `https://jmapocho.cl/reparto-total/`. Captured in November 7, 2023

B Appendix: Instrumental Variable Analysis

B.1 Tables

Table 28: Total Water Consumption: Instrumental Variables estimation at the parcel level.

	IV, ETa (mm) per surface		
	(1) Downstream	(2) Mid section	(3) Upstream
Board	1.999	1.848	-0.605
	(0.863)**	(1.517)	(0.149)***
Area (polynomial)	Yes	Yes	Yes
Precipitation (pol.)	Yes	Yes	Yes
Prec. Summer (pol.)	Yes	Yes	Yes
Soil quality	Yes	Yes	Yes
Market Access	Yes	Yes	Yes
(lat lon) bin FE	Yes	Yes	Yes
Observations	26,780	26,138	25,539
R-squared	0.242	0.129	0.574
Mean Dependent Var.	3.545	4.085	3.665
First Stage F-stat	16.523	2.472	59.731
p-value Under Id LM test	0.001	0.131	0.002
Effective F-stat	16.523	2.472	59.731

Notes:

Table 29: Agricultural Production: Instrumental Variables estimation at the parcel level.

	IV, EVI (yield index)		
	(1) Downstream	(2) Mid section	(3) Upstream
Board	0.209	0.209	-0.0365
	(0.0851)**	(0.159)	(0.0181)**
Area (polynomial)	Yes	Yes	Yes
Precipitation (pol.)	Yes	Yes	Yes
Prec. Summer (pol.)	Yes	Yes	Yes
Soil quality	Yes	Yes	Yes
Market Access	Yes	Yes	Yes
(lat lon) bin FE	Yes	Yes	Yes
Observations	26,792	26,138	25,539
R-squared	-0.017	-0.146	0.315
Mean Dependent Var.	0.445	0.470	0.438
First Stage F-stat	16.509	2.472	59.731
p-value Under Id LM test	0.001	0.131	0.002
Effective F-stat	16.509	2.472	59.731

Table 30: Inequality and Average Water Consumption: Instrumental Variables estimation at the parcel level.

Notes:

	Smaller Farms, ETa (mm) per surface			Larger Farms, ETa (mm) per surface		
	(1) Downstream	(2) Mid section	(3) Upstream	(4) Downstream	(5) Mid section	(6) Upstream
Board	1.711	3.490	-0.770	3.375	1.082	-0.278
	(0.956)*	(3.558)	(0.191)***	(1.506)**	(0.863)	(0.149)*
Area (polynomial)	Yes	Yes	Yes	Yes	Yes	Yes
Precipitation (pol.)	Yes	Yes	Yes	Yes	Yes	Yes
Prec. Summer (pol.)	Yes	Yes	Yes	Yes	Yes	Yes
Soil quality	Yes	Yes	Yes	Yes	Yes	Yes
Market Access	Yes	Yes	Yes	Yes	Yes	Yes
(lat lon) bin FE	Yes	Yes	Yes	Yes	Yes	Yes
Observations	14,561	12,021	11,386	6,270	7,427	7,447
R-squared	0.286	-0.759	0.561	-0.252	0.396	0.626
Mean Dependent Var.	3.279	3.963	3.585	4.031	4.295	3.833
First Stage F-test	10.968	1.285	55.657	8.423	3.765	61.042
p-value Under Id LM test	0.004	0.255	0.003	0.009	0.091	0.001
Effective F-stat	10.968	1.285	55.657	8.423	3.765	61.042

Notes:

Table 31: Inequality and Average Water Consumption: Instrumental Variables estimation at the parcel level.

	Smaller Farms, EVI (yield measure)			Larger Farms, EVI (yield measure)		
	(1) Downstream	(2) Mid section	(3) Upstream	(4) Downstream	(5) Mid section	(6) Upstream
Board	0.124	0.301	-0.0420	0.300	0.132	0.00632
	(0.0869)	(0.310)	(0.0169)**	(0.139)**	(0.0907)	(0.0236)
Area (polynomial)	Yes	Yes	Yes	Yes	Yes	Yes
Precipitation (pol.)	Yes	Yes	Yes	Yes	Yes	Yes
Prec. Summer (pol.)	Yes	Yes	Yes	Yes	Yes	Yes
Soil quality	Yes	Yes	Yes	Yes	Yes	Yes
Market Access	Yes	Yes	Yes	Yes	Yes	Yes
(lat lon) bin FE	Yes	Yes	Yes	Yes	Yes	Yes
Observations	14,571	12,021	11,386	6,270	7,427	7,447
R-squared	0.164	-0.496	0.446	-0.520	0.090	0.382
Mean Dependent Var.	0.486	0.518	0.503	0.530	0.530	0.506
First Stage F-test	10.970	1.285	55.657	8.423	3.765	61.042
p-value Under Id LM test	0.004	0.255	0.003	0.009	0.091	0.001
Effective F-stat	10.970	1.285	55.657	8.423	3.765	61.042

Notes: