**Universidad Austral de Chile**

Facultad de Ciencias Económicas y Administrativas

# IDENTIFYING THE DETERMINANTS OF WATER RIGHTS PRICE: THE CHILEAN CASE

TESIS DE MAGÍSTER

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VALDIVIA-CHILE

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# IDENTIFYING THE DETERMINANTS OF WATER RIGHTS PRICE:

# THE CHILEAN CASE

Tesis presentada a la Facultad de Ciencias Económicas y Administrativas de la Universidad Austral de Chile en cumplimiento parcial de los requisitos para optar al Grado de Magíster en Desarrollo a Escala Humana y Economía Ecológica.

por

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DEDICATORIA

*A mi esposo y a mis hijos; A mi madre y mis hermanos. Que siempre se busquen alternativas para comunicar lo que de otro modo no sería entendido.*

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# RESUMEN

Este estudio investiga los mercados de derechos de agua en diversas regiones de Chile, abarcando una amplia gama de climas. Utilizando 10,345 registros de transacciones desde la década de 1990 hasta 2014, proporcionados por la autoridad reguladora nacional de servicios públicos, este conjunto de datos cubre información de 12 de las 15 regiones de Chile en ese momento y 26 cuencas a través del país.

La naturaleza integral de este estudio, que no se ha logrado previamente con un conjunto de datos tan fiable y extenso, tiene como objetivo analizar la dispersión de precios en estos mercados. Las consideraciones clave incluyen variables climáticas como la precipitación anual y las temperaturas máximas, el PIB regional per cápita y factores como el nivel de industrialización minera, categorías de tamaño de transacción, tendencias de cambio de uso de la tierra y la existencia de decretos de escasez. Empleando modelos hedónicos, particularmente modelos cuantílicos con errores robustos, la investigación evalúa el impacto de estas variables en los precios observados.

Los hallazgos revelan que la precipitación, las características geopolíticas y demográficas, la industrialización y el volumen de transacción influyen significativamente en los precios de los derechos de agua. Curiosamente, los decretos de escasez de agua, destinados a minimizar los daños por sequía, resultaron paradójicamente en precios más bajos de los derechos

de agua. El estudio también destaca una presencia corporativa predominante y patrones geográficos de compra específicos del sector, particularmente en los sectores agrícola y minero. Estas percepciones son críticas para la valoración de los servicios ecosistémicos y para informar la gestión sostenible de los recursos hídricos frente al cambio climático y los desafíos de gobernanza de los recursos naturales.

Palabras clave: *Asignación de agua; gestión integrada de recursos hídricos; dispersión de precios; desempeño del mercado.*

## ABSTRACT

This study investigates water rights markets across various regions of Chile, encompassing a wide range of climates. Utilizing 10,345 transaction records from the 1990s to 2014, provided by the utility's national regulatory authority, this dataset covers data from 12 of the 15 regions of Chile at the time and 26 basins across the country.

The comprehensive nature of this study, which has not been previously achieved with such a reliable and extensive dataset, aims to analyze price dispersion in these markets. Key considerations include climatic variables such as annual precipitation and maximum temperatures, regional GDP per capita, and factors like mining industrialization level, transaction size categories, land-use change trends, and the existence of scarcity decrees. Employing hedonic models, particularly quantile models with robust

errors, the research assesses the impact of these variables on observed prices.

The findings reveal that precipitation, geopolitical and demographic characteristics, industrialization, and transaction volume significantly influence water rights prices. Interestingly, water scarcity decrees, intended to minimize drought damages, paradoxically resulted in lower water right prices. The study also highlights a predominant corporate presence and sector-specific purchasing geographic patterns, particularly in the agricultural and mining sectors. These insights are critical for ecosystem services valuation and for informing sustainable water resource management in the face of climate change and natural resource governance challenges.

Keywords: *Water allocation; integrated water resources management; price dispersion; market performance.*

# 1    INTRODUCCIÓN GENERAL

El agua, elemento vital para la vida y el desarrollo económico, enfrenta una creciente presión debido al aumento de la demanda, la disminución de los recursos y la contaminación. El cambio climático intensifica esta presión, especialmente en regiones áridas y semiáridas como Chile. Este estudio analiza el mercado de derechos de agua en Chile, con el objetivo de identificar los determinantes del precio de estos derechos y evaluar su poder explicativo. Se hipotetiza que diversos factores, incluyendo características climáticas, indicadores socioeconómicos y dinámicas del mercado, influyen en el precio de los derechos de agua en Chile, y que estos factores pueden explicar en conjunto una porción significativa de la variación observada en el precio.

Existe amplia literatura en torno a los desafíos de la escasez de agua y las complejidades de la gestión de los recursos hídricos. Ostrom (1990) y Gleick (1993) resaltan la creciente presión sobre los recursos hídricos por la competencia de diversos sectores. Boretti y Rosa (2019) advierten sobre una posible subestimación de la escasez de agua para el año 2050.

El enfoque particular adoptado por Chile para la gestión de los recursos hídricos, establecido a través del Código de Aguas de 1981, involucra un sistema de mercado para la asignación de derechos de agua (Bauer, 2004; 2010). Donoso (2017) y Hearne y Easter (1997) reconocen el rol de este

sistema en la lucha contra los desafíos de la escasez de agua al tener como objeto la optimización de la distribución y uso.

Sin embargo, aún no se cuenta con una comprensión completa de los factores que influyen en el precio de los derechos de agua en Chile. Si bien Coase (1960) postula que los precios en mercados competitivos deberían reflejar el valor marginal, la evidencia empírica que respalda esta afirmación en el contexto del mercado de agua chileno es limitada y fragmentada (Donoso, 2006). Esta brecha de conocimiento se vuelve crucial ante el cambio climático, que amenaza la disponibilidad de agua y los mecanismos de fijación de precios (Caretta et al., 2022; IPCC, 2014, 2018).

Este estudio busca cerrar esta brecha de conocimiento utilizando un conjunto de datos completo que abarca 10.345 transacciones de derechos de agua para identificar los determinantes del precio de estos derechos en Chile. Se utiliza un modelo de precios hedónico para analizar cómo factores como las variables climáticas (precipitación, temperatura), las características regionales (PIB per cápita) y las dinámicas del mercado (tamaño de la transacción, industrialización) influyen en el precio de los derechos de agua.

Comprender estos determinantes del precio tiene importantes implicaciones:

- Formulación de políticas: Esta investigación puede informar el desarrollo de marcos regulatorios robustos y mecanismos de distribución equitativa del agua, especialmente cruciales en el contexto del cambio climático.

- Gestión sostenible del agua: La identificación de los factores que influyen en el precio de los derechos de agua es fundamental para fomentar prácticas de gestión del agua sostenibles en Chile, como lo han enfatizado Araral y Wang (2013), Biswas y Tortajada (2010) y Liu y Liang (2023).

- Valoración de los servicios ecosistémicos: Los datos del mercado de derechos de agua se utilizan para valorar servicios ecosistémicos como la provisión de agua (Pastén et al., 2023). Comprender los factores que influyen en el precio es altamente relevante para asegurar la precisión de estas valoraciones.

Además, este modelo de gestión ofrece valiosas ideas para otras regiones que enfrentan desafíos análogos en la gestión del agua. Esta investigación contribuye a una comprensión más completa de los mercados de derechos de agua y su papel en la gobernanza del agua, entregando información relevante para las decisiones en un marco de cambio climático y disminución del recurso.

# 2  CAPÍTULO 1: IDENTIFYING THE DETERMINANTS OF WATER RIGHTS PRICE: THE CHILEAN CASE

## ABSTRACT

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The findings reveal that precipitation, geopolitical and demographic characteristics, industrialization, and transaction volume significantly

influence water rights prices. Interestingly, water scarcity decrees, intended to minimize drought damages, paradoxically resulted in lower water right prices. The study also highlights a predominant corporate presence and sector-specific purchasing geographic patterns, particularly in the agricultural and mining sectors. These insights are critical for ecosystem services valuation and for informing sustainable water resource management in the face of climate change and natural resource governance challenges.

# 1   INTRODUCTION

Water, as the lifeblood of ecosystems and a cornerstone of human survival and economic development, faces increasing pressure from various competing demands (Gleick, 1993; Ostrom, 1990). Rising demand, diminishing resources, and pollution, compounded by population and economic growth, may lead to an underestimation of the severity of water scarcity by 2050 (Boretti & Rosa, 2019). In Chile, a country characterized by its diverse climatic regions and faced with the challenges of water scarcity, particularly in its arid and semi-arid areas, managing this vital resource has been complex and evolving (Bauer, 2004; 2010). The nation's unique approach to water resource management, through the establishment of a market for water rights, stands as a critical component of its strategy in addressing these challenges (Donoso, 2017; Hearne & Easter, 1997).

Despite the integral role of this market in Chile's water management framework, a comprehensive understanding of the various factors influencing water rights pricing remains elusive. Traditional economic theories posit that prices in a competitive market should reflect the marginal value of a commodity (Coase, 1960). However, in the context of Chile's water rights market, empirical evidence to support this assertion has been limited and fragmented (Donoso, 2006). This knowledge gap acquires heightened significance in the wake of climate change, which presents formidable risks to water avail ability and, by extension, the

mechanisms of its pricing (Caretta et al, 2022; IPCC, 2014, 2018). Addressing this crucial need, our study embarks on an exploration to decipher the determinants of water rights pricing in Chile, placing a particular emphasis on the role of climatic and socioeconomic variables. Utilizing a comprehensive dataset encompassing 10,345 water rights transactions, we implemented a hedonic pricing model, rooted in multiple linear regression analysis (Rosen, 1974). This model will allow us to scrutinize how variables such as maximum temperature, precipitation, and regional GDP intricately weave into the fabric of pricing dynamics within the water rights market.

The importance of understanding these pricing dynamics transcends academic curiosity, bearing significant implications for policy formulation, especially in the context of an escalating climate emergency (Loch et al, 2013; Stern, 2007). By identifying and elucidating the variables that markedly influence water rights pricing, our research aspires to contribute to the formulation of more robust regulatory frameworks and equitable water distribution mechanisms. Such advancements are imperative for fostering sustainable water management practices in Chile, a necessity underscored by several authors (Araral & Wang, 2013; Biswas & Tortajada, 2010; Liu & Liang, 2023).

In this vein, Chile's model of water rights, operational since the early 1980s under the Water Code, represents a pivotal case study (Bauer, 2010; Donoso, 2006). The Water Code, by segregating water from land property,

instituted a market-based system for water allocation, a concept that has seen diverse outcomes and criticisms over time. This research aims to dissect these outcomes considering the current climate crisis, examining how historical and projected climatic changes might reshape the water rights landscape in Chile (Alvarez-Garreton et al, 2023; Taucare et al, 2024). This exploration is not only pertinent to the Chilean scenario but also offers insights for other regions grappling with analogous challenges in water resource management.

Understanding the factors influencing water rights prices is crucial not only for related decision making but also for its impact on valuing ecosystem services like water provision. Recent research has used the water rights market as a direct valuation methodology for these ecosystem services (Pastén et al, 2023). However, it is important to recognize that this approach might be more accurate only if the influencing factors are primarily environmental. Otherwise, the valuation of ecosystem services could encompass unrelated elements, like industrialization or the types of stakeholders involved in transactions.

Furthermore, the growing demand for information related to ecosystem services, as reflected in their inclusion in Chilean legislation (Law No. 21.600 of 2023), could also impact the water rights market. This trend highlights the connection between water provision and the environment, as well as the threats and uncertainty the annual water 'stock' may face under climate change scenarios and land-use changes.

## 2 WATER RIGHTS IN CHILE

In Chile, water rights are governed by a legal framework that permits their ownership and trade independently from the land where they are located. Chilean law declares water as a national public good, yet grants appropriation rights to individuals, companies, and organizations. These rights are primarily acquired through applications to the state and once granted, can be bought, sold, and leased in a free market (CNR, 2023).

The 1951 Water Code established water rights as a real right, centered on the use and enjoyment of water resources. Initially granted through concessions known as 'mercedes', these rights functioned as the concessionary title. The 1967 Agrarian Reform Law No. 16.640 marked a significant shift by revoking the privatization of water rights and reclassifying them as state-administrative rights. This legal framework was again altered with the 1981 Water Code, which reinstated private property rights for water, ensuring their security against the expropriation practices permitted by the previous Agrarian Reform Law. After this modification, water rights could be acquired and retained indefinitely, whether they were actively utilized or not (Hadjigeorgalis & Riquelme, 2002).

A significant amendment to the Water Code was enacted in 2005, aiming to address the issues of water rights speculation and hoarding (Bauer, 2015). This reform introduced a mechanism known as 'non-use fees,' which mandates the holders of water rights to pay a fee if their rights are not

utilized over an extended period. The primary objective of this measure was to promote the efficient use of water resources and to discourage the practice of retaining water rights purely for speculative purposes. However, it is worth noting that water rights can still be leveraged at their source without extraction in cases where they are declared as part of projects linked to the permanence of water, such as conservation or tourism purposes. In these instances, well-being continues to be provided in non-consumptive forms, primarily associated with cultural ecosystem services.

The non-use fee is established based on verifying the existence of structures associated with water use, penalizing those holders (both individuals and legal entities) of water rights who have not constructed the necessary works for the capture and conveyance of water. This system specifically targets those who fail to develop the requisite infrastructure to utilize their water rights effectively, thus ensuring that rights holders are actively engaged in the management and use of their allocated water resources. This fee can be avoided f the water rights are relinquished (General Directorate of Water (DGA), 2023).

The Superintendency of Sanitary Services (Superintendencia de Servicios Sanitarios, SISS) in Chile plays an important role in collecting and refining information on water rights transactions, which are also publicly managed by the DGA. The data, initially registered with the Real Estate Conservators (CBR), undergoes a rigorous validation process by the SISS, ensuring its high reliability and accuracy (Cristi, 2014). This process is particularly

pertinent in the context of determining water tariffs, where the SISS utilizes these transactional records to define key pricing parameters. However, it is important to acknowledge a limitation in this approach: the information predominantly pertains to consumptive water use values and may exclude data not required for the specific purposes of water tariff setting by the SISS. This distinction aims for a comprehensive understanding of the water rights market in Chile, as it may lead to the omission of certain transaction details not directly linked to the SISS's tariff regulatory framework, as could happen also with transactions that are only registered in notary offices but do not complete their registration with the CBR.

## 3  CONTEXT OF PRICE ANALYSIS IN CHILE

As explained, the Chilean water market, as structured by the 1981 Water Code and its subsequent amendment in 2005, exemplifies a market-centric approach to the allocation of water rights. This framework, distinct in its reliance on market mechanisms, has garnered attention and critique, especially concerning its efficacy and the consequences it holds for equitable water distribution (Bauer, 2010; Prieto, 2016). The challenges posed by water scarcity in Chile, exacerbated by climate change and increased demand from various sectors, underscore the intricate link between water resource governance and broader socio-economic dynamics (Aghakouchak et al., 2015; IPCC, 2018; Mehran et al., 2015). The increasing frequency of heatwaves and a robust drying trend in central Chile (30°S–48°S) have been observed, with significant impacts on water

resources and exacerbating existing challenges in water management (Castellanos et al, 2022).

Water crises in Chile are not only environmental but also governance crises, reflecting the complexities of effectively managing this critical resource in a manner that is both efficient and equitable (Ocampo-Melgar et al, 2022; OECD, 2015). The market-based allocation system, while providing a mechanism for water rights trading, has been criticized for contributing to social inequality and environmental degradation. Geographical studies reveal inherent contradictions in market models for water allocation, particularly their adverse effects on both the environment and social equity (Bakker, 2004; Budds, 2004; Perreault, 2008). The performance of Chile's water market is heavily influenced by the dominant agricultural demand and well-developed Water User Associations, leaving significant gaps in understanding its impact in areas with conflicting demands, such as between mining operations and indigenous communities (Bauer, 2010).

The role of the mining sector in Chile's water market is particularly noteworthy. Mining municipalities collect taxes to offset the negative externalities of resource extraction, but studies indicate that these financial mechanisms do not necessarily translate into improved quality of life in these communities, especially concerning public education indicators (Oyarzo & Paredes, 2021). This raises critical questions about the socio-economic impact of water market dynamics in regions dominated by

mining activities.

Water Scarcity Decrees have emerged as a crucial governmental response to drought conditions in Chile, highlighting the complexities of water allocation under scarcity. These decrees disproportionately benefit larger agricultural producers who can afford the investment in underground water extraction, thus influencing their issuance and duration. This phenomenon points to the interplay between political power and market outcomes in water allocation, especially under conditions of climatic stress (Perez-Silva & Castillo, 2023). The water sector in Chile shows a very high vulnerability due to weak water governance focused on market aspects, leading to uneven distribution of water, particularly in rural communities. The spatial differences in water availability are further enhanced by strong population growth, economic development, mining activities, and the high dependence of agriculture on irrigation (Castellanos et al, 2022).

The implications of climate change are profound, as evidenced by the "megadrought" affecting Chile. This sustained drop in precipitation has intensified water scarcity, exacerbating conflicts and amplifying disparities in water access. The situation is particularly dire in regions that are poles of mining and agricultural development, where the bulk of Chile's river basins have been declared as suffering from water scarcity (Center for Climate Research and Resilience (CR2), 2015; Perez-Silva & Castillo, 2023; Reyer et al., 2017). Droughts in these regions are a major threat to water security as river streamflow are highly dependent on the interannual to

decadal climate conditions, snow melting processes, and rainfall events, and impacted by land uses and changes in irrigated agriculture (Castellanos et al, 2022). The Chilean experience thus offers valuable insights into the challenges of water justice in the face of market-based water allocation, underlining the need for strategies that ensure equitable and sustainable water governance.

## 4   METHODS

This study was conducted in two main stages: 1) acquisition and preparation of the water rights transactions database from the Superintendency of Sanitary Services (SISS); and 2) data analysis to assess the influence of climatic and socioeconomic variables on the dynamics of the water rights market in Chile.

### 4.1   ACQUISITION AND PREPARATION OF THE SISS DATABASE

The initial database provided by the SISS comprised a comprehensive record of over 15,000 water rights transactions spanning from 1993 to 2014. After an extensive process of data validation and cleansing, which included the removal of duplicate entries and clarification of any confusing or contradictory information, the refined dataset consisted of 10,345 transactions.

The refined database encompasses a comprehensive range of geographic and transactional diversity. It includes data from 12 out of 16 regions of

Chile, covering 150 communes (municipalities) and 26 river basins. This represents a substantial portion of Chile's climatic variability, although it excludes the extreme climatic zones such as the Atacama Desert, the Southern Patagonian Ice Fields and the Patagonian Steppe.

Each transaction in the database was quantified in terms of flow rates, measured in liters per second (L/s), and the value of each transaction. Regardless of the original transaction currency (Chilean pesos, Unidad de Fomento (UF), or US dollars), the transaction values were standardized and converted to unitary price, UF per 1 L/s, based on the date of the transaction. UF is a unit of account used in Chile, which is constantly adjusted by inflation, this ensures a consistent and comparable economic analysis across all transactions. The transactions in the dataset involve various types of parties, including natural persons, juridical persons, and combinations thereof, reflecting a wide spectrum of transaction values and amounts.

### 4.1.1 Integration of Geopolitical characterization

Following the acquisition and preparation of the SISS database, each transaction was further characterized to enrich the analysis. This involved assigning a commune based on the location of the water source, along with coordinates of the centroid for precise geographical identification. Additionally, information regarding the corresponding basin and the nearest meteorological station for each observation was integrated. This allowed for the association of climatic data and socioeconomic data.

To accurately characterize each transaction within the dataset, a systematic approach was employed for assigning communes, which are political-administrative units in Chile, also referred to as municipalities. The assignment process was anchored on the precise location of the water source associated with each transaction. For this purpose, national databases of 'canal associations' and 'surface water communities', both registered with the General Directorate of Waters (DGA, 2023), were extensively utilized.

### 4.1.2  Integration of Transactional Agents Characteristics

Based on the original records from the SISS, a search for terms indicative of corporations was conducted, aiming to discern if there are significant differences in market behavior based on the nature of the transacting agent.

Specific terms were used to classify legal entities, including Public Limited Companies, Stock Companies, and Limited Liability Companies, among others. This classification allowed for a clear distinction between transactions carried out by natural persons and those executed by corporate entities. Furthermore, the categorization of companies was deepened based on their sector of activity, focusing on identifying terms related to key industries such as mining, agriculture, and real estate/investment. This approach allows us to identify if any of those categories are either buyer or seller in any transaction.

### 4.1.3 Integration with Demographic and Economic Context

Data were acquired from the Central Bank of Chile (2023) and the Library of Congress National (2023), which included annual Regional Gross Domestic Product (GDP) per capita. This approach involved analyzing annual Regional Gross Domestic Product (GDP) per capita to account for regional population differences and incorporating total municipal income per capita for a broader economic view, in CLP and MCLP respectively (2023).

To understand the impact of mining activities, an indicator was created to identify 'Mining Communes.' This was based on the percentage of income from mining patents, with a threshold of more than 2.5% as suggested by Oyarzo and Paredes (2021).

Demographic and political dimensions were also considered. An index of rurality for each commune was calculated using the percentage of the rural population from the year 2017 census. While this data is not the most current, it provides a reasonable representation of rural proportions. In the climate related and political issues, the study examined records of scarcity decrees from the DGA (2023). These decrees were linked to specific areas, such as communes, basins, or rivers. The number of scarcity decrees in each area was used as an indicator.

### 4.1.4 Integration with Climatic Context

Climatic data were integrated with the water rights transaction dataset to examine the impact of environmental conditions on market dynamics. Monthly mean maximum temperatures and annual precipitation levels for each river basin were sourced from the CAMELS-CL platform of the Center for Climate Science and Resilience (CR2, 2023). This information was obtained for the nearest climatic station and averaged across stations within each basin. The data were then matched with the year and location of each transaction, establishing a link between market activity and climatic factors.

The CAMELS-CL platform provides a comprehensive set of hydrometeorological information across Chile, facilitated by the Watershed Explorer tool developed by the Climate Research and Resilience Center (CR2).

In addition to absolute climatic measures, this study incorporated variables to capture variations in maximum temperature and precipitation. These variables were defined as the difference between the annual value and the average of the preceding three years. This approach aims to discern not only the objective level of precipitation or temperature but also how these levels might be perceived based on recent weather patterns. The inclusion of variation variables acknowledges that recent climatic events can influence perceptions of water scarcity or abundance, and consequently, decisions in the water rights market. This analysis was conducted at the

basin level, recognizing that while climatic patterns can vary from year to year, significant changes over a large area, such as a river basin, could be indicative of broader climatic and/or land-use changes.

By considering both direct and relative climatic variables, the study seeks to understand how short-term changes in weather patterns may affect water rights trading behaviors.

## 4.2   ECONOMETRIC MODEL AND DATA ANALYSIS

The empirical analysis of this study is conducted using Quantile Regression (Koenker and Bassett, 1978), which allows for assessing the impact of independent variables on different quantiles of the dependent variable distribution, offering a more comprehensive understanding than average effects as in ordinary least squares (OLS) regression. Unlike OLS regression, which minimizes the sum of squared residuals and thus provides an estimate of the conditional mean of the dependent variable, Quantile Regression minimizes the sum of weighted absolute residuals, providing estimates of the conditional median or other quantiles of the dependent variable. This approach is particularly beneficial when dealing with non-normal and heteroskedastic error distributions prevalent in large datasets (Chen et al, 2017).

In addressing the multifaceted nature of water rights pricing, this study employs a Quantile Regression framework, diverging from the traditional Ordinary Least Squares (OLS) regression to allow for a nuanced

understanding of the impact of covariates across the entire distribution of transaction prices. Unlike OLS, which targets the conditional mean, Quantile Regression estimates the conditional median or other quantiles, offering a robust analytical perspective particularly pertinent for distributions that exhibit non-normality or heteroscedasticity. Moreover, the model accords with the assumption of heterogeneity in the error distribution, an assumption reflective of the complex and varied nature of water right transactions. The Quantile Regression is formalized as follows, where $Q\tau\ (y|x)$ denotes the $\tau$-th quantile of the dependent variable $y$, given the covariates $x$, and $\beta(\tau)$ represents the quantile-specific coefficients to be estimated:

$$Q_\tau(y|x) = x'\beta(\tau) + \epsilon_\tau \qquad [1]$$

Here, $\epsilon\tau$ is the error term for the $\tau$-th quantile, and $x'$ encompasses a vector of independent variables that include transactional characteristics, buyer demographics, and environmental factors, all of which are theorized to influence the unit price of water rights. This quantile-specific modeling enables the determination of how covariates affect different points of the price distribution, thus providing a comprehensive view of the pricing dynamics within the water rights market.

Also, the data was subjected to normality test appropriate for large datasets –Shapiro-Wilk test–, to ascertain the distribution characteristics of the variables. Kurtosis and skewness assessments provided further

insights into distribution symmetry and tail behavior. Heteroskedasticity was tentatively evaluated using the Breusch-Pagan and White tests within an OLS model as a preliminary step, since these tests are not applicable directly to Quantile Regression. For the Quantile Regression model itself, heteroskedasticity was assessed by examining the scatter plot of residuals versus fitted values. Multicollinearity was initially assessed using Variance Inflation Factor (VIF) analysis within an OLS framework, as direct multicollinearity tests for Quantile Regression are not standard. Additionally, correlation matrices and pairwise correlations were employed to further investigate the relationships between variables for the Quantile Regression model. The model's fit and the assumption of independent errors were examined through Quantile-Quantile (Q-Q) plots and residual scatter plots.

The study's dependent variable is the natural logarithm of the unitary price of each transaction in Unidad de Fomento (UF). The independent variables are categorized into several groups to comprehensively capture the dynamics of water rights pricing. Firstly, product characteristics are considered, which include the quantity and type of water rights involved, represented by the quartile classification of transaction volume and the nature of the water source (surface or subterranean). Secondly, buyer characteristics are assessed, focusing on the sector of the buyer, whether it be mining, agricultural, or real estate/investment companies. Thirdly, the contextual characteristics of the transaction's location are examined. This

includes demographic, political, and economic factors, quantified through the Rurality Index, Municipal Income per capita, Regional Gross Domestic Product

(GDP) per capita, identification of mining-related municipalities, and the count of Accumulated Scarcity Decrees. The fourth category involves climatic context, encompassing annual precipitation and maximum monthly mean temperature data from the nearest meteorological station to the transaction site, as well as variations in these climatic factors relative to previous years in the corresponding basin. Lastly, the temporal factor is integrated by including the year of the transaction to identify potential effects over time, such as modifications in the Water Code or other time-related influences.

## 5   RESULTS AND DISCUSSION

The statistical analysis of the variables and the model validated the use of quantile regression with robust errors. This was due to the results from normality and heteroskedasticity tests, which demonstrated significant variance dispersion, previously reported by other authors in the water market context (Cristi, 2014; Donoso, 2015; Hadjigeorgalis & Riquelme, 2002; Hearne & Donoso, 2014).

The results of our analysis, focusing on the price dispersion in WR markets in Chile, are systematically presented in Table 1 and further elucidated through Figure 1. The econometric model deployed in this study

incorporates a diverse array of independent variables, spanning transactional factors, resource characteristics, and contextual and climatic variables (Table 2).

*Table 1. Descriptive statistics of the variables in the model (n=10,345).*

| Group | Subgroup | Variable | Mean | Standard Deviation |
|---|---|---|---|---|
| Transactional factors | Buyer | Real State | 0.094 | 0.292 |
| | | Mining | 0.006 | 0.079 |
| | | Agricultural | 0.093 | 0.291 |
| | | Individuals and Other Industries | 0.812 | 0.391 |
| | Resource | Quartile 4 | 0.245 | 0.430 |
| | | Quartile 3 | 0.273 | 0.445 |
| | | Quartile 2 | 0.247 | 0.431 |
| | | Quartile 1 | 0.235 | 0.424 |
| | | Subterranean | 0.192 | 0.394 |
| Contextual factors | Demographic, geopolitical and economic | Rurality Index | 0.288 | 0.214 |
| | | Ac. Scarcity Decree | 0.400 | 0.895 |
| | | Mining Municipality | 0.287 | 0.452 |
| | | Municipal Income per capita | 203.30 | 124.70 |
| | | Regional GDP per capita | 8,627,590 | 2,575,966 |
| | Climatic | Annual Precipitation | 338.43 | 295.32 |
| | | Max. Temperature | 21.37 | 5.370 |
| | | Precipitation Variation | - 39.89 | 73.450 |
| | | Max Temperature Variation | 0.170 | 0.280 |
| | Temporal | Year | 2,011 | 1.76 |

*Table 2. Quantilic (P50) Hedonic model of prices in Chile.*

| Group | Subgroup | Variable | Coefficient | 95% Confidence Interval |
|-------|----------|----------|-------------|--------------------------|
| **Transactional factors** | Buyer | Real State*** | 0.397 | [0.322, 0.473] |
| | | Mining*** | 1.024 | [0.929, 1.119] |
| | | Agricultural*** | 0.748 | [0.655, 0.841] |
| | Resource | Quartile 4*** | -2.201 | [-2.300, -2.102] |
| | | Quartile 3*** | -1.674 | [-1.755, -1.594] |
| | | Quartile 2*** | -0.752 | [-0.841, -0.663] |
| | | Subterranean*** | 0.307 | [0.227, 0.388] |
| **Contextual factors** | Demographic, geopolitical and economic | Rurality Index* | -0.204 | [-0.393, -0.016] |
| | | Ac. Scarcity Decree* | -0.040 | [-0.072, -0.008] |
| | | Mining Municipality | 0.024 | [-0.070, 0.118] |
| | | Municipal Income per capita*** | 0.001 | [0.000, 0.001] |
| | | Regional GDP per capita*** | 0.000 | [0.000, 0.000] |
| | Climatic | Annual Precipitation*** | -0.001 | [-0.001, -0.001] |
| | | Max. Temperature | 0.005 | [-0.003, 0.012] |
| | | Precipitation Variation*** | 0.001 | [0.001, 0.002] |
| | | Max Temperature Variation*** | -0.198 | [-0.307, -0.088] |
| | Temporal | Year | -0.001 | [-0.024, 0.021] |
| **Constant** | | | 7.948 | [-37.396, 53.291] |

*Number of Observations: 10,345. Pseudo $R^2$: 0.2027. * p value under 5%. ***p value under 0,1%*
*Source: Authors own elaboration.*

Figure 1 presents a quantified visual analysis of the percentage changes in the unitary price of WR due to variations in specific market and environmental variables. The bar chart distinguishes the effects of sectoral participation, size of the trade, and local economic and demographic conditions, as well as climatic and temporal characterization.

Of the variables presented, all those linked to buyer characteristics and the resource itself (B and R), as well as the variable indicating a mining-related municipality (G3), are binary. This means the increase or decrease in water rights prices occurs when the specified condition—such as the presence of a buyer from a particular sector or the transaction involving a certain type of water source—is met. Other variables operate on a continuous scale. For instance, the temporal variable (T1) increments annually (by 1 year). The coefficients suggest that sectorial involvement (real estate, mining, agriculture) and higher transaction volumes significantly drive price adjustments, with the binary nature of these variables indicating a direct correlation with the presence of the condition. Variables such as the Rurality Index (G1) and Acute Scarcity Decree (G2) have an inverse relationship, where an increase in the variable's presence or condition results in a decrease in the price of water rights.
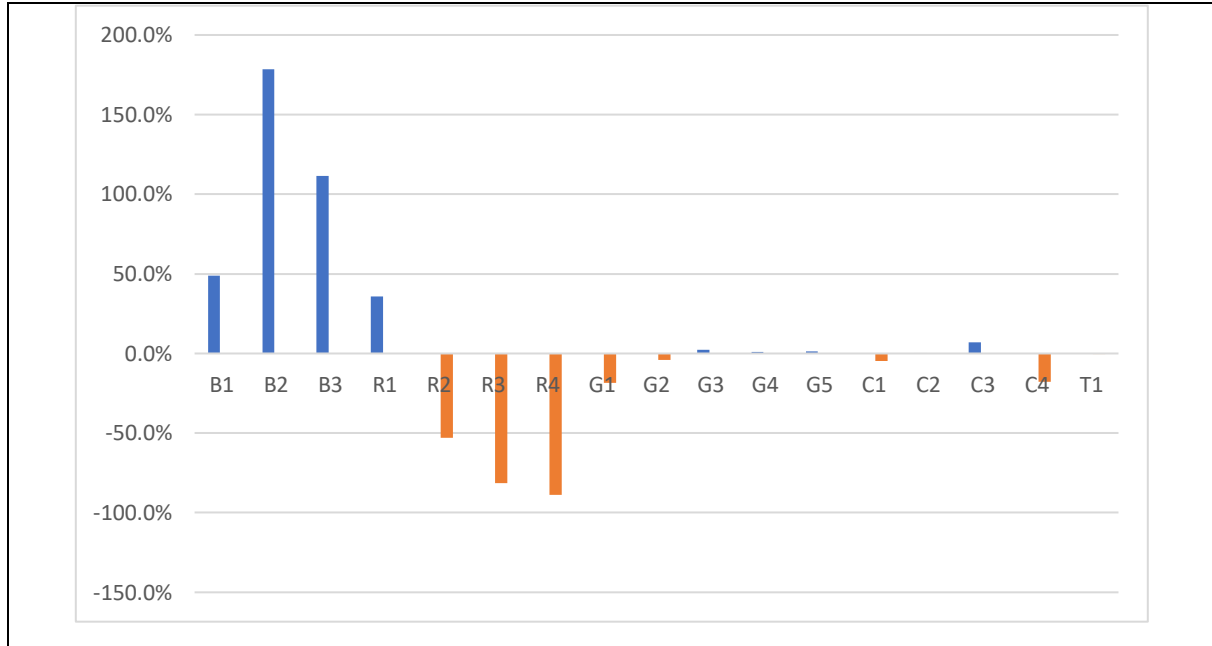
*Figure 1. Relative Change in Unitary Price of Water Rights*

Relative Change in Unitary Price. This figure displays the percentage change in unitary price across different subgroups categorized under Transactional, Product, Contextual, and Temporal variables. For Transactional variables, the indicators B1, B2, and B3 represent buyers from the real estate, mining, and agricultural sectors, respectively. Under Resource variables, P1 to P4 denote the quartiles of the amount of water involved in the transaction, with P4 being the highest (Quartile 4) and P1 representing subterranean water source. Contextual variables are divided into two categories: Geopolitical, demographic, and economic factors are represented by G1 to G5, where G1 is the Rurality Index, G2 is the Acute Scarcity Decree, G3 indicates a Mining Municipality, G4 is the Municipal Income per Capita, and G5 is the Regional GDP per Capita. Climatic variables, labeled C1 to C4, refer to Annual Precipitation, Maximum Temperature, Precipitation Variation, and Maximum Temperature Variation, respectively. The Temporal variable, T1, indicates the Year.

## 5.1 IMPACT OF TRANSACTIONAL CHARACTERISTICS

This section examines the influence of commodity and buyer characteristics on water rights pricing. It analyzes the relationship between transaction size, water source type, and buyer sector, focusing on their direct impact on prices. The main findings reveal that every variable within these categories shows high statistical significance in influencing water rights prices.

### 5.1.1  Resource Characteristics

A significant and explanatory relationship between the transaction size and source characteristics (see Table 3), and water rights pricing is established, with all variables demonstrating high statistical significance ($p < 0.001$).

In the analysis of transaction sizes within water rights markets, it is instructive to contextualize the quartile distribution of transaction volumes. The quartiles are distributed as follows: the 25th percentile (Q25) at 0.18 liters per second (L/s), the median (Q50) at 0.5 L/s, and the 75th percentile (Q75) at 2.26 L/s. To comprehend the practical implications of these volumes, we refer to the Chilean Government's estimate (2015) that an average individual in Chile consumes approximately 200 liters of potable water per day. It is important to note that the transactions pertain exclusively to raw water, yet this comparison offers an illustrative perspective on the magnitude of the traded volumes. Accordingly, the volume at Q25 is adequate to meet the daily potable water needs of up to 78 individuals, equating to about 20 households. The median volume (Q50) can serve up to 216 individuals, or over 50 households, which is comparable to the student population of 6 classrooms. The volume at Q75 is sufficient for the daily requirements of approximately 1,123 individuals, akin to the size of a full school. Transactions in the fourth quartile, representing the highest volumes, exceed the daily potable water needs of 500,000 individuals, indicative of significant water quantities being traded,

likely catering to the requirements of larger communities or for industrial applications.

The findings corroborate previous research, illustrating a 'bulk discount' effect in water rights transactions. This economic principle manifests as a decreasing marginal price per unit with increasing transaction size. The results highlight a substantial price reduction when moving from the first to the second quartile, with a 53% decrease in unitary price. This trend persists, albeit at a diminishing rate, across higher quartiles, with additional decreases of 29% and 36% for the third and fourth quartiles, respectively. This implies a non-linear, decreasing marginal price effect as transaction volume increases.

Regarding the type of water rights, delineated as surface or subterranean, a noteworthy influence on pricing is observed. Specifically, the price increases by 36%, ceteris paribus, for subterranean water rights.

*Table 3. Impact of Resource Characteristics in Percent Change in Unitary Price of Water Rights.*

| Variable | Coefficient | Unit of Change | Change in Unitary Price |
|---|---|---|---|
| Quartile 4 (P1) | -2.201** | Binary | -89% |
| Quartile 3 (P2) | -1.674** | Binary | -81% |
| Quartile 2 (P3) | -0.752** | Binary | -53% |
| Subterranean (P4) | 0.307** | Binary | 36% |

*Number of Observations: 10,345. * p value under 5%. ***p value under 0,1%*

*Source: Authors own elaboration.*

### 5.1.2 Buyer Characteristics

The sectors under consideration include mining, agriculture, and real estate/investment firms, each having distinct operational water needs and valuation approaches.

The empirical results presented in Table 4 elucidate the premium that different sectors are willing to pay for water rights. Real estate entities, often dealing with development projects requiring substantial water supplies, are willing to pay a 49% premium on water rights. Mining companies, whose operations are heavily dependent on water resources, exhibit the highest willingness to pay, with a premium of 178%. The agricultural sector, which traditionally relies on water for irrigation, shows a willingness to pay a premium of 111% for water rights. This sectoral disparity in water rights pricing may reflect the strategic importance of water to each industry, the differential ability to pay, or the varying levels of dependency on water for business operations.

Moreover, these premiums reflect the value of water in supporting the direct activities of each sector, which can have significant economic ramifications (Hearne & Easter, 1995). It is also crucial to consider the broader market context in which these transactions occur. Donoso et al. (2021) provide an in-depth analysis of the Chilean water market, highlighting the complexities and challenges of establishing an effective water allocation mechanism. Their insights into the water market's

efficiency and regulatory environment can help in understanding the underlying factors influencing these sectoral pricing disparities.

Also, transaction volumes typically associated with these sectors should be considered. For instance, agricultural firms, despite paying a premium, often engage in transactions involving large volumes of water, potentially triggering 'bulk discount' effects. Thus, a large agribusiness purchasing in excess of 2.6 L/s might initially face a price 111% above the baseline. However, due to the bulk discount associated with larger transaction volumes, this could effectively reduce to a net premium of only 22% above the baseline price for smaller volume transactions.

*Table 4. Impact of Buyer Sectoral Characteristic in Percent Change in Unitary Price of Water Rights.*

| Variable | Coefficient | Unit of Change | Change in Unitary Price |
|:---:|:---:|:---:|:---:|
| Real Estate | 0.397** | Binary | 49% |
| Mining | 1.024** | Binary | 178% |
| Agricultural | 0.748** | Binary | 111% |

*Number of Observations: 10,345. * p value under 5%. ***p value under 0,1%*

*Source: Authors own elaboration.*

## 5.2 IMPACT OF CONTEXTUAL CHARACTERISTICS

### 5.2.1 Demographic, Geopolitical, and Economic Factors

This section scrutinizes the influence of demographic composition, geopolitical context, and economic indicators on the pricing of water rights. As can be seen in Table 5, most of the variables included, such as the Rurality Index, Accumulated Scarcity Decrees, and Municipal Income per Capita, have shown significant impacts on pricing. However, except Mining related Municipalities, which exhibit an ambiguous effect that is not significant on the unitary price.

The findings indicate that an increase in the rural population ratio leads to a significant decrease in water rights prices ($p<0.05$). This may reflect the marginal productivity of water across different municipalities, where areas with higher rurality potentially have lower levels of industrialization. Moreover, the urban-rural dichotomy in water rights valuations is further evidenced by Burns et al. (2022), who observed that urban buyers typically pay a premium over their rural counterparts, likely due to differing intended uses of the water rights acquired. In such regions, the opportunity cost of water is likely more closely linked to human subsistence and daily living rather than to economic productivity. This suggests that the value of water is intertwined with local socio-economic activities, where less industrialized rural communities may prioritize water for essential living needs over commercial or industrial uses. It underscores the necessity to understand water valuation within the context of marginal productivity

theory and to consider the implications for rural development and resource allocation (Cristi, 2014).

The results pertaining to Scarcity Decrees reveal a counterintuitive dynamic: regions with a higher number of scarcity decrees exhibit lower unitary prices for water rights ($p<0.05$). This raises two critical points of discussion. First, there is a need to reassess whether the tools designed to mitigate drought impacts are appropriate for addressing long-term challenges. The lower pricing in response to scarcity decrees might inadvertently promote consumptive overuse, potentially degrading ecological flows and diminishing environmental resilience, thereby initiating a self-perpetuating cycle of long-term water scarcity (Cornelis et al, 2019; Hoover et al, 2021). Second, the decrees appear to distort the water rights market, creating a paradox where water's value decreases as it becomes scarcer, which could have profound effects on political and economic decisions related to water resource management and governance.

The analysis of mining-related municipalities revealed that their correlation with water rights pricing was statistically non-significant ($p > 0.6$), exhibiting an ambiguous effect as indicated by a confidence interval spanning both positive and negative values. This suggests that the influence of mining on water rights prices is not directly associated with the economic contribution of mining to the municipalities. Instead, it is hypothesized that water rights pricing is more intricately linked to the

attributes of the buyers from the mining sector. Consequently, the relationship between the mining industry and unitary water rights prices is more precisely examined in the context of buyer characteristics (see section 5.1.2), which can provide a clearer understanding of the market dynamics.

The analysis of economic variables at the transaction site reveals a more nuanced effect on pricing. Regional GDP per capita and municipal income per capita, while highly significant, exert a more modest influence on unitary price changes.

The coefficients of the economic factors were adjusted to reflect a change in a perceptible unit, as their original unit, the Chilean peso (CLP), is not practically applicable in economic terms. Therefore, the unit of change was adjusted to a level consistent with the units of measure of the price and the magnitude of the values—3 UF (approximately 120 USD) for regional GDP per capita and 0.3 UF for municipal income per capita.

An increment of one perceptible unit in either regional GDP per capita or municipal income per capita is associated with an approximate 1% increase in the unitary price of water rights. This observation is consistent with demand theory, which posits that an augmentation in purchasing power typically heightens the willingness to pay for a commodity. Hence, a higher aggregate of communal or regional wealth correlates with an increase in the transaction price for water rights.

*Table 5. Impact of Demographic, Geopolitical, and Economic variables in Percent Change in Unitary Price of Water Rights for given units of change.*

| Variable | Coefficient | Unit of Change | Change in Unitary Price |
|---|---|---|---|
| Rurality Index | -0.204* | % | -18.5% |
| Ac. Scarcity Decree | -0.040* | 1 decree | -4.0% |
| Mining Municipality | 0.024 | Binary | 2.5% |
| Regional GDP PC | 0.000** | 3 UF | 0.8% |
| Municipal Income PC | 0.001** | 0.3 UF | 1.2% |

*Number of Observations: 10,345. * p value under 5%. ***p value under 0,1%*

*Source: Authors own elaboration.*

## 5.2.2 Climatic Context

In this analysis, as it is illustrated in Table 6, climatic variables pertaining to temperature and precipitation are evaluated, both at the absolute level of the year and in terms of their variation over the preceding three years. Except for the annual maximum temperature, all variables emerged as highly significant.

Consistent with expectations, absolute annual precipitation exerts a negative effect on the price of water rights, indicating that higher precipitation levels correlate with lower prices. This finding is not only useful for comparing transactions across different years but also across various locations. It suggests that in regions with higher rainfall levels, characterized by abundant rivers and lakes, water rights are generally traded at lower values compared to areas where water scarcity is more

pronounced. This observation is particularly relevant given that a significant portion of the transaction records in the database pertain to the semi-arid regions of central Chile. The implication here is that in a given location, increased rainfall could lead to lower water rights prices, potentially due to an augmented supply or greater willingness to sell rights if water scarcity is not perceived as an immediate issue.

Conversely, the average maximum monthly temperature appears to positively affect water rights prices, although this effect is not statistically significant. This could be due to the complex interplay of various factors influencing water rights prices, such as the specific requirements of industries like mining, commonly situated in areas with higher temperatures, as seen in Chile's arid zones.

Variations in climatic conditions over time, however, exhibit a contrary effect on prices. This aspect of the study sheds light on the market's response to deviations from climatic norms, highlighting its sensitivity to both immediate and perceived long-term environmental changes. Intriguingly, in years that are particularly dry, prices decrease significantly. For instance, a 50 mm hydrological deficit relative to the previous three years correlates with a 7% decrease in the price of water rights. This could be attributed to uncertainty and risk economics considerations, where diminished water flows might compromise the certainty of fully utilizing water rights, thereby devaluing them due to increased risk (Hadjigeorgalis & Riquelme, 2002). Nevertheless, while certain studies have reported

minimal or ambiguous effects concerning the certainty of water right utilization, the consensus under stable conditions suggests a potential increase in value with greater certainty of use (Brent, 2016). This aligns with findings of a positive linear relationship between precipitation variability and value, interpreting an increase in the former as a rise in certainty of use. In the case of temperature, a 1°C increase compared to the three-year average leads to a substantial 17.9% decrease in the unitary price. This decrease might reflect concerns over higher evaporation rates and reduced river flows, affecting the actual availability of water despite legal entitlements.

Notably, these findings primarily establish correlations rather than causal relationships. While significant correlations between climatic variables and water rights prices are evident, it is important to recognize that these relationships might be influenced by a myriad of other factors, both climatic and non-climatic.

*Table 6. Impact of Climatic variables in Percent Change in Unitary Price of Water Rights for given units of change.*

| Variable | Coefficient | Unit of change | Change in Unitary Price |
|---|---|---|---|
| Annual Precipitation | -0.001** | 50 mm/yr | -4.9% |
| Max. Temperature | 0.005 | 1°c | 0.5% |
| Precipitation Variation | 0.001** | 50 mm/yr | 7.0% |
| Max. Temperature Variation | -0.198** | 1°c | -17.9% |

*Number of Observations: 10,345. * p value under 5%. ***p value under 0,1%*
*Source: Authors own elaboration.*

### 5.2.3  Temporal Factors

The temporal analysis within the model indicates a negligible impact of time on the unitary price of water rights. The coefficient associated with the year variable is -0.001, with a 95% confidence interval ranging from -0.02 to 0.02. This confidence interval spans zero, suggesting that the effect of time on price is statistically indiscernible from no effect at all, as evidenced by a p-value approaching 0.9.

Even if this temporal effect were to be considered significant, the practical implications would be minimal. To illustrate, a 40-year span would be necessary to accumulate a -4% change in the unitary price of water rights, which is marginal when compared to same price change brought on by the addition of a single scarcity decree, according to this model.

### 5.3  GEOGRAPHICAL CHARACTERIZATION

### 5.3.1  Distribution of Unitary Price

The unitary price, representing the average market value for the right to utilize one liter of water per second, exhibits a pronounced regional disparity across Chilean municipalities. Analysis of the compiled data indicates a trend of elevated prices in the central and northern zones (see Figure 2). Particularly notable are municipalities such as Los Vilos in the Coquimbo Region, Vitacura in the Metropolitan Region, alongside Los Andes and San Esteban in the Valparaíso Region. These municipalities exhibit mean unitary values surpassing 3500 UF (141 MUSD), suggesting

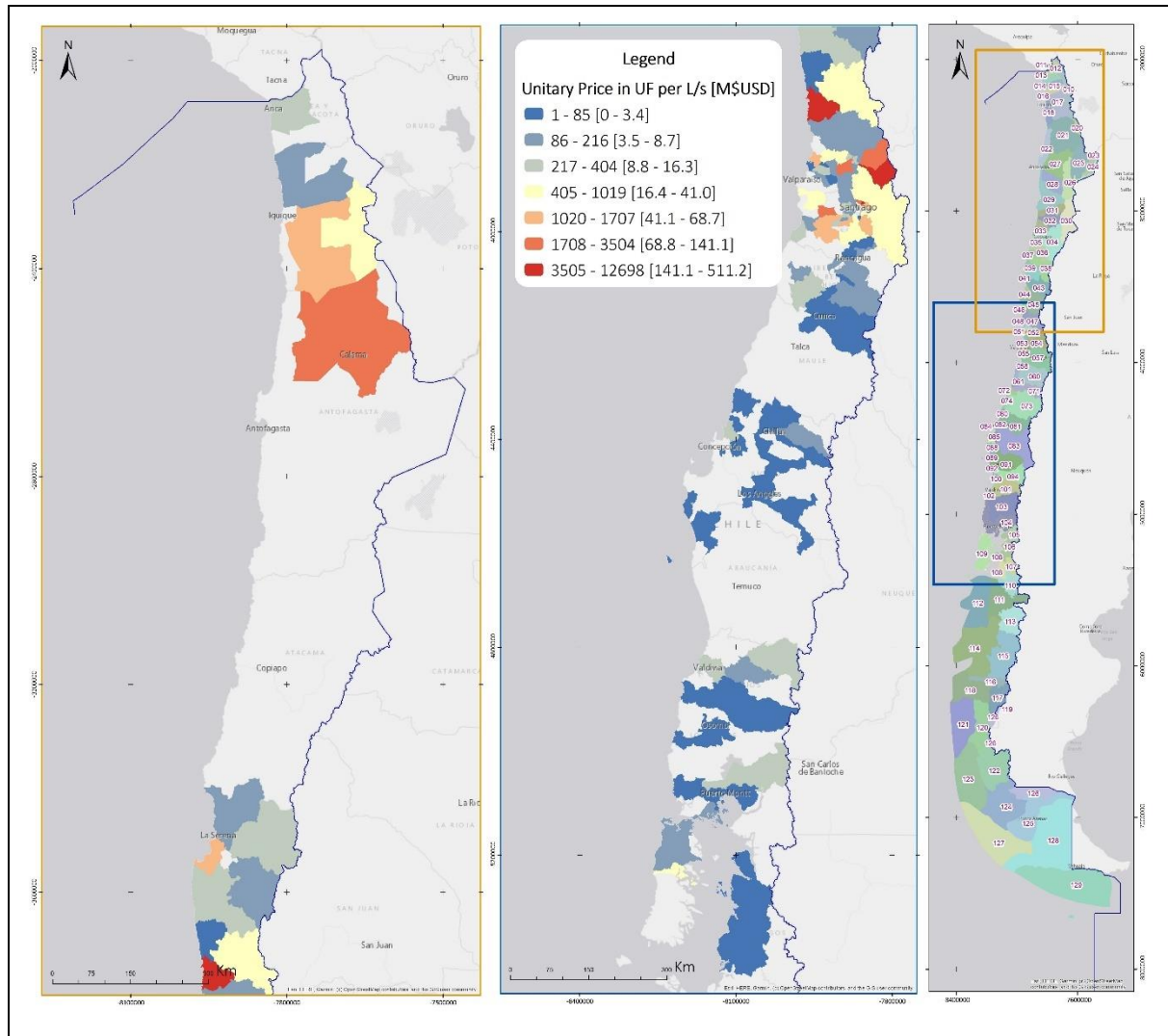the emergence of high-value clusters proximate to metropolitan locales and regions with intensive mining activities.



*Figure 2. Geographical distribution of Unitary Prices among Municipalities from Chile.*
*Source: Authors own elaboration.*

This spatial price distribution may be attributed to varying levels of industrialization and intensive agricultural practices prevalent in the central regions, contrasted with the mining-dominated economy of the northern regions (Comisión Chilena del Cobre, 2022). The Metropolitan

Region, as a hub of industrial and economic activity, alongside the agriculturally rich areas of the Valparaíso Region, aligns with the observed price concentration.

In contrast, the southern region of Chile demonstrates a markedly lower and more stable price range, fluctuating between 1 and 400 UF/L/s (0 to 16 MUSD). This valuation consistency is reflective of the abundant water supply, attributed to the voluminous flow rates of southern rivers and the less uncertainty about water provision.

## 5.4 CONCENTRATION OF DEMAND FOR WATER RIGHTS

As shown in Figure 3, the dataset delineates a pronounced corporate dominance in the water rights market, with entities accounting for 60% of the total transaction volume. This substantial corporate footprint in the market suggests that, despite the numerosity of individual actors, the aggregate corporate acquisition of water rights is predominant. On the other hand, individual purchasers, while numerous, collectively account for 40% of the market's volume.

Disaggregating corporate acquisitions further elucidates sector-specific behaviors. The agricultural and fruticulture sectors emerge as the primary corporate purchasers, responsible for 33% of the total volume of water rights acquired. This substantial figure underscores the critical role that water plays in supporting Chile's robust agricultural industry.
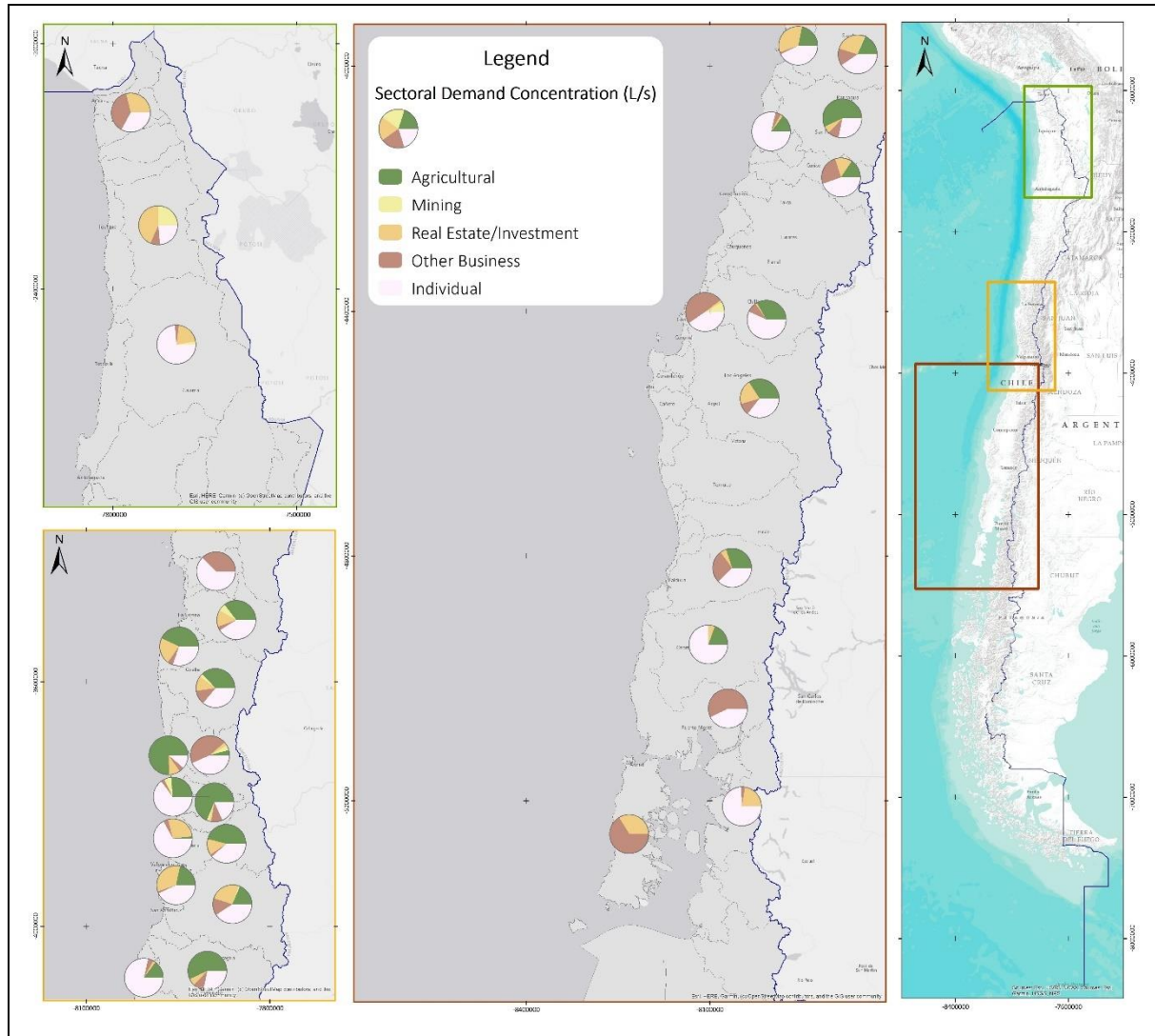
*Figure 3. Geographic distribution of Water Rights Concentration of Demand.*
*Source: Authors own elaboration.*

Spatially, the demand distribution is characterized by distinctive regional trends. Mining companies, as anticipated, dominate the demand in the northern regions, reflecting the area's mineral-rich geology and the water-intensive nature of the mining industry. Conversely, real estate investments show a significant presence in both northern and southern regions, albeit with a consistent presence throughout the nation. The central and southern

regions, however, see a predominance of agricultural enterprises in the water rights market.

It is imperative to comprehend the sectorial participation within the water rights market to inform the development of regulatory instruments. Such tools are essential to manage the implications of market concentration adequately and to uphold ecosystem resilience in the face of consumptive resource use.

Accompanying this analysis, a time-series graph delineates the relative sectorial participation from 2009 forward, encapsulating 98% of the data points (see Figure 4). This temporal focus is due to the statistical robustness of the period, with preceding years presenting unstable and less reliable distributions. The graphical analysis reveals that individual participation—representing natural persons—fluctuates between 37 and 52%, without a discernible trend towards either an increase or a decrease. However, it is crucial to note that this analysis pertains to annual demand and may not directly reflect the distribution of water right ownership.
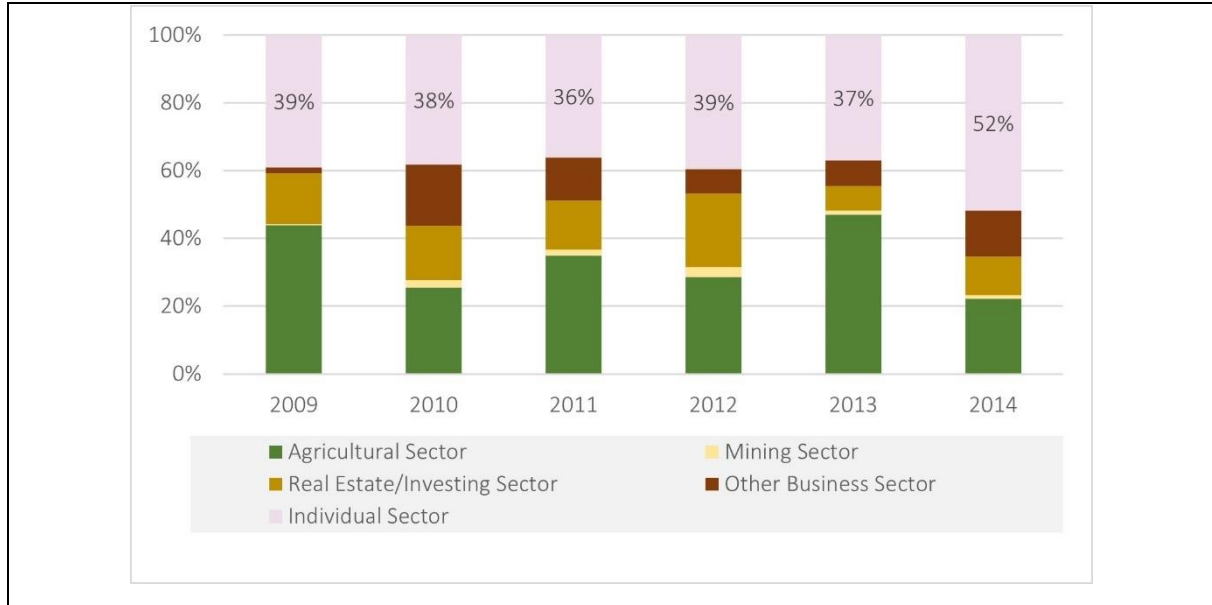
*Figure 4. Temporal Distribution of Water Rights Concentration of Demand.*
*Source: Authors own elaboration.*

## 5.5 KEY INSIGHTS AND LIMITATIONS

This section elucidates the pivotal contributions of this study to the existing body of knowledge on water rights markets in Chile, particularly in filling critical information gaps pertinent to the influence of climatic and socioeconomic factors on market dynamics. Concurrently, it acknowledges the inherent limitations and the specific contextual parameters within which the findings are most applicable. Recognizing these boundaries is essential for a nuanced understanding of the study's implications and for guiding future research directions in this domain.

This study represents a significant advancement in understanding Chile's water rights market, primarily by leveraging a comprehensive database of over 10,000 transaction records from 12 of the 15 regions. This extensive

data collection offers a nuanced view of the market, revealing the influence of various factors on water rights pricing. The research demonstrates that transactional characteristics, particularly those related to demographic, political, and climate contexts, significantly impact pricing. These insights are crucial for ecosystem services valuation and inform sustainable water resource management practices. The study also contributes to the field of public policy, especially concerning climate change and natural resource governance, by highlighting the potential of water rights market data for informed decision-making.

While understanding the general effects of various variables on water rights pricing is beneficial, there is a pressing need to delve deeper into future studies on water rights dedicated to conservation and their connection with ecological flows. Research, such as that conducted by Netusil & Summers (2009), has identified positive associations between the value of a water right and its environmental conservation potential, particularly in vulnerable settings. Expanding research in this direction would not only augment our comprehension of water rights market dynamics but also underscore the significance of incorporating ecological considerations into water resource management strategies.

An intriguing aspect of the study is the identification of market anomalies and correlations that defy conventional expectations. For instance, public policies such as scarcity decrees have a statistically significant and market-distorting effect, paradoxically leading to a decrease in water rights prices

relative to resource scarcity. While serving as a short-term drought mitigation measure, these decrees could mask long-term complexities and overlook the importance of ecological flows and inadvertently undermine ecosystem resilience. This cyclical dynamic suggests that each decree potentially increases the likelihood of needing subsequent ones.

The study examines how agents perceive climatic conditions, both as absolute variables and in terms of local variations. This approach uncovers a paradox where absolute climatic conditions (such as general rainfall levels) influence water rights prices based on resource availability, while temporal variations are perceived in terms of the risk associated with the actual use of the resource. Hadjigeorgalis and Riquelme (2002) elucidate this concept by explaining that the variability in water availability over time, especially in high-profit or export-oriented agricultural operations, adds a cost to the market. Rights yielding more consistent water flows are valued higher, particularly among risk-averse farmers.

While the study's use of a large, validated database allows for a broad-scale analysis of influences on water rights pricing, it also introduces certain limitations. The diverse geographic, political, and contextual characteristics present in the dataset can lead to outliers and unexpected factors that challenge a generalized analysis. This diversity necessitated data standardization and the use of models to minimize internal variations.

In this analysis, factors concerning water quality, which are typically influential in price determination according to economic theory, have not been included. Future research could benefit from a focused examination of water quality metrics, assessing their effect on pricing when other conditions are homogenous or have been statistically controlled. This additional layer of analysis could provide deeper insights into the nuances of water rights valuation. Additionally, while the model shows a high degree of correlation across variables, it is essential to approach the interpretation of causality with caution. Correlations, particularly in the context of climatic variables, may not always imply causation. For instance, the relationship between precipitation and latitude, as well as the influence of industrial areas on local climates, illustrates the complex interplay of factors affecting water rights pricing. Therefore, distinguishing between correlation and causation remains a critical consideration in the analysis of market dynamics and environmental factors.

The research represents a subset of the total market transactions. Not all transactions are captured in the dataset, as some may remain unregistered or undigitized, or excluded from the SISS database despite being present in DGA records. This situation could lead to an overrepresentation of entities capable of registering transactions in all required instances, potentially obscuring smaller transactions and those between individuals.

# 6 CONCLUSIONS

This analysis of Chile's water rights markets, covering climatic, economic, and transactional factors, reveals intricate and at times unexpected dynamics. It highlights the complex relationship between market behaviors and environmental factors, pointing to essential areas for policy interventions and future research.

Significant price variation in water rights transactions reflects market heterogeneity. The mining and agriculture sectors, with their strategic reliance on water, showed a willingness to pay premiums of 178% and 111%, respectively, for water rights. The Real Estate and Investment sector also displayed a readiness to pay 49% above the baseline price. Such disparities raise concerns about equitable access and sustainable water utilization, particularly considering the lower prices in higher-volume transactions.

The study sheds light on the role of climatic variables. A direct inverse relationship between annual precipitation levels and water rights prices indicates market sensitivity to perceived water abundance, suggesting potential undervaluation in rainier regions. The decrease in prices following scarcity decrees, intended as drought mitigation measures, might inadvertently distort the market and impact long-term ecosystem resilience, necessitating a reevaluation of these regulatory interventions.

The relationship between precipitation and water rights pricing was quantitatively established. A 50 mm increase in annual precipitation led to a 4.9% decrease in unitary water rights prices, reflecting market reactions to perceived abundance. In contrast, climatic variations had a contrasting effect, suggesting that market responses are more aligned with perceptions of risk due to climatic variability than with general perceptions of water availability. Years with atypical climatic patterns, particularly drier conditions, might lead to a higher perceived risk of water scarcity, decreasing the value assigned to water rights.

These findings highlight the need to thoroughly examine market responses to scarcity decrees and other regulatory measures. Policymakers must strike a balance between immediate water needs and long-term resource stewardship. The study emphasizes the need for multifaceted policies that align with environmental and sustainability objectives. Future research should focus on the complex interactions between market dynamics and climatic conditions to inform the development of equitable and sustainable water policies.

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## 3 DISCUSIÓN GENERAL Y CONCLUSIONES

Este estudio analizó el mercado de derechos de agua en Chile considerando factores climáticos, económicos y transaccionales. Los resultados revelan dinámicas complejas y, en ocasiones, inesperadas, que resaltan la relación intrincada entre el comportamiento del mercado y los factores ambientales. El análisis de las variables y el modelo validaron el uso de la regresión cuantílica con errores robustos, confirmando la gran variabilidad del precio por unidad de caudal transada, previamente reportada en el mercado del agua (Cristi, 2014; Donoso, 2015; Hadjigeorgalis & Riquelme, 2002; Hearne & Donoso, 2014).

Se observó una variación significativa en el precio de las transacciones de derechos de agua, lo que refleja la heterogeneidad del mercado. Sectores como la minería y la agricultura, cuya actividad depende críticamente del agua, exhibieron una disposición a pagar primas del 178% y 111% respectivamente, en comparación con el precio base. El sector inmobiliario y de inversión también mostró una disposición a pagar un 49% más. Estas disparidades plantean preocupaciones sobre el acceso equitativo y el uso sostenible del agua, especialmente considerando los precios más bajos en transacciones de mayor volumen.

Con relación a las variables climáticas, se identificó una relación inversamente proporcional entre los niveles de precipitación anual y el precio de los derechos de agua, lo que indica la sensibilidad del mercado a

la percepción de abundancia hídrica. Esto sugiere una posible subvaloración en regiones con mayor precipitación. La disminución del precio tras la implementación de decretos de escasez, pensados como medidas de mitigación de sequías, podría distorsionar el mercado de manera involuntaria e impactar la resiliencia del ecosistema a largo plazo.

Sin embargo, el análisis también reconoce limitaciones metodológicas importantes. La base de datos empleada no representa todas las transacciones de derechos de agua en Chile, lo que podría sesgar los resultados hacia transacciones de mayor tamaño y con una mayor proporción de participación corporativa. Además, el modelo econométrico utilizado, a pesar de su robustez, simplifica la complejidad del mercado al no incorporar todas las variables posibles, como la calidad del agua. Estas limitaciones sugieren la necesidad de futuras investigaciones que utilicen conjuntos de datos más amplios o ahonden en las características propias de cuencas o regiones.

A pesar de estas limitaciones, el estudio aporta contribuciones significativas al desarrollo del tema, siendo el primero en analizar un conjunto de datos de tan amplia magnitud y distribución geográfica en Chile. Identifica factores clave que influyen en el precio del agua y examina el impacto de políticas públicas, como los decretos de escasez, en el mercado de derechos de agua. Estos hallazgos apoyan la hipótesis de que existen determinantes significativos del precio de los derechos de agua en Chile y son cruciales para la formulación de políticas que busquen un

equilibrio entre la demanda inmediata y la gestión sostenible a largo plazo del recurso hídrico.

Este estudio no solo valida la hipótesis de que hay determinantes significativos en el precio de los derechos de agua en Chile, sino que también destaca la necesidad de políticas públicas bien informadas y estrategias de gestión que armonicen los objetivos de sostenibilidad y equidad. Los hallazgos subrayan la complejidad del mercado de derechos de agua y la importancia de considerar una gama amplia de factores, desde climáticos hasta económicos, en su análisis. Futuras investigaciones deberán abordar las limitaciones identificadas, ampliando la comprensión del mercado y contribuyendo a la gestión sostenible del agua en contextos de cambio climático y presión creciente sobre la tan preciada agua.

# 4  ANEXOS

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