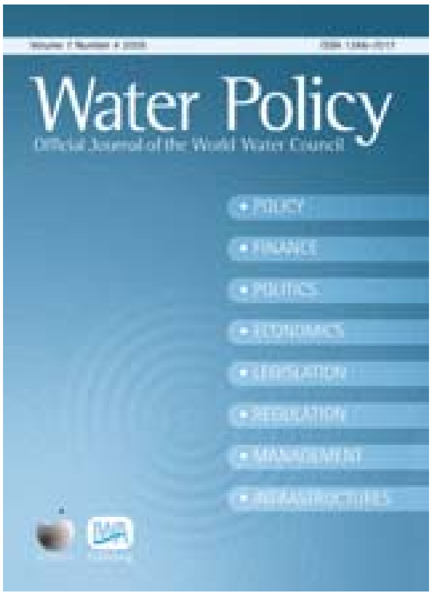
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Water management problems in the Copiapó Basin, Chile: markets, severe scarcity and the regulator

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Abstract

This research focuses on the determination of the factors that led to the failure of water management in the Copiapó Basin in Chile. Interestingly, the existence of full private ownership and free tradability of water rights has not prevented the overexploitation of groundwater resources. In the paper, firstly, water regulation and the role of the regulator in Chile are briefly discussed. Secondly, the evolution of water resources in the Copiapó region is characterized and analyzed, and the granting of water use rights in the basin in the last 30 years is concisely described. Thirdly, we examine and analyze prices and quantities traded in the water market of the Copiapó region. We will argue that this crisis is a consequence first of failure in regulatory implementation and second of an extremely rigid regulatory framework that leaves limited room for adjustment to changing conditions, especially regarding the emergence of new information concerning water availability. We believe this investigation is not only relevant for this case in particular, but also for other regions and countries where water markets are in place.

Keywords: Aquifers; Economic incentives; Regulations; Sustainable water management; Water markets

1. Introduction

Markets are powerful institutions for resource allocation, and water management is not an exception. Water markets facilitate the allocation of resources to their highest valued use through voluntary exchange and the generation of information about relative scarcity and demand (see e.g. Rosegrant & Binswanger, 1994; Easter *et al*., 1999; Freebairn, 2003; Bjornlund & Rossini, 2005). Thus, it has been generally assumed that the transition toward trading through water markets is likely to increase and improve economic efficiency (Brill *et al*., 1997; Calatrava & Garrido, 2005). Usually, these positive economic effects are largely explained by the expansion of more efficient new water users, the adoption of water conserving technologies and the elimination of unnecessary or non-cost-effective uses of water

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(Zilberman & Schoengold, 2005). Indeed, in empirical terms, researchers have shown that water markets have made significant income contributions to many regional and national economies, such as Spain (Lee & Jouravlev, 1998), Australia (Peterson *et al*., 2004; Crase & Dollery, 2006; Brooks & Harris, 2008; Qureshi *et al*., 2009) and the United States (Bjornlund & McKay, 2002; Grafton *et al*., 2012).

Chile is a well-known case of a market-oriented approach to water management. Since the Water Code of 1981, water rights in Chile are fully transferable and separable from land, marketable through negotiations, and independent of final use. The Chilean model was unique not only because it was one of the first to introduce markets to define the allocation of water uses[1], but also because the State had limited powers to intervene in the management of the resources. This can be seen, for example in the inexistence of attributions to define different user rights in order to limit tradability for social or environmental purposes[2].

There have been many works reviewing the water market in Chile. For its history, see Bauer (1997); for economic and financial gains derived, see Hearne & Easter (1997), Briscoe *et al*. (1998) and Hearne (2007); and for normative issues, see Vergara (1998). There are also many other papers reviewing the water market's institutions and functioning: see, for example, Gazmuri & Rosegrant (1994), Ríos & Quiroz (1995), Hearne (1998) and Donoso (1999). More recent reviews can be found in Peña (2001), Galaz (2004), Bauer (2004a, b) and Donoso (2006). In general, the evidence in terms of results is quite mixed regarding water markets. This points to the need for case-by-case analysis.

This paper focuses on the factors that led to the severe overexploitation of aquifers in the Copiapó Basin in Chile's northern region, and the efforts needed to address the challenges arising from intense competition for scarce water resources between mining, agriculture and human consumption. Furthermore, the problem in water management failure has been aggravated due to the recent boom in the mining sector fuelled by high copper prices. This has sharply increased the prices in the water market, whereby even sophisticated fruit production could be at risk of becoming unprofitable. This issue has triggered tensions between stakeholder groups, including mining companies, farmers, water service providers and environmental groups. Interestingly, the existence of full private ownership and free tradability of water rights has not prevented the overexploitation of the groundwater resources.

Doubtless, the over-allocation of water use rights is one of the main factors leading to overexploitation of the aquifer. Nevertheless, this study tries to identify what causes the over-granting of rights: regulatory implementation failures, difficulties in the enforcement of regulation or if it is a broader problem of an inadequate regulatory framework to deal with a very dynamic system with imperfect information. Once the problems that activated the crisis are identified, we will analyze whether the current legislation provides the instruments to solve the situation, considering political, social and economic efficiency aspects. We believe this analysis is not only relevant for this case in particular, but also for other regions and countries where water markets are important. From a local point of view, our conclusions are relevant for most of the aquifers in the center north of Chile, where the resources are currently being overexploited, affecting economic sustainability and agricultural activities in particular.

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[1] The largest intra- and inter-sectorial water markets have been developed in the American West, Chile (1981), and Australia (1983). For a cross-country analysis of institutions and performance see Saleth & Dinar (2004) and Olmstead (2010) for economic and policy issues.

[2] Unlike, for example, the Australian code of 1991, which also establishes a market for water rights.

The paper is structured as follows. Firstly, water regulation and the role of the regulator in Chile are briefly discussed. Secondly, water resources in the Copiapó region are critically depicted, and the granting of water use rights in the basin over the last 30 years is described. Thirdly, we use annual and monthly data to examine prices and quantities traded in the water market of the Copiapó region. Fourthly, based on empirical evidence, we attempt to explain what went wrong in terms of regulatory policy in the basin. Finally, a conclusion is presented summarizing the factors that explain the crisis and arguing the ways forward for sustainable management in water use for Chile and similar markets.

2. Water regulation in Chile

The regulation of water use allocation based on the functioning of the market was introduced in Chile in 1981, with a new Water Law (called Water Code), establishing that although water resources remained as public goods from a legal perspective, water *use rights* can be granted to individuals and firms interested in using the resource. These water use rights are considered private ownership governed by civil law and protected by the Chilean Constitution. Under this framework, rights of use are obtained free of charge, strictly in order of precedence of the application date. Water use rights are therefore traded, inherited and subject to the same rules as real estate. The Water Code was modified by a change in law in 2005, maintaining the essence of the 1981 reform.

The General Directorate of Water (DGA for its Spanish initials) is a public agency in charge of water management and responsible for granting water use rights to private individuals and firms. The DGA has to respond to any request made by interested parties to obtain water rights, with two requirements: (i) the availability of resources and (ii) the consistency of the petition with previously granted rights. According to the law, if there are competing claims for the same rights, DGA should allocate the rights through an auction to the highest bidder. The allocation of water use rights is established in absolute terms, in this case in liters per second. The DGA has limited competence in planning or intervening in water management; water rights allocation is left to the market.

In a situation of extreme scarcity of water, the DGA could, for a limited period of time, apply an extraordinary measure like establishing a reduction in individual water use rights in a proportional manner. This measure has never been used in Chile, despite the critical conditions of many water resources. Also in case of a drought, the DGA could declare a scarcity zone for a period of up to 6 months during which water use rights could be reallocated according with public priorities. Under the original 1981 water code, the DGA could deny the granting of new water use rights in the case of an aquifer only if the aquifer has been declared zone of prohibition. Before the reform of the water code in 2005, the declaration of zone of prohibition could only be requested by water rights owners. Nevertheless, all the water use rights applications that have been submitted prior to the declaration of zone of prohibition have to be granted[3]. If more permanent water user rights have been allocated than resources available, the only option for the DGA according to the law is to buy back the rights at market prices.

[3] There are several rulings of the comptroller office that force the DGA to grant water use rights if they were requested prior to the declaration of prohibition zone regardless of the level of overexploitation.

It is important to point out that the Water Code entrusts water distribution and management functions to associations of water users[4]. In the case of aquifers the law established water user communities as the mechanism for joint management and coordination of users. Once a restriction or prohibition zone has been established by the regulator, the participation in such communities is mandatory for all owners of water use rights. The community is expected to self-regulate to limit extraction in order to restore the level of an aquifer to reduce pumping costs. Therefore, the effective structuring of water user communities is a critical requirement for the management of overexploited aquifers. Nevertheless the process of organizing these communities is subject to free riding, limiting the effectiveness of self-regulation, once the regulator has established the zone of restriction.

A relevant question is whether the law of 1981 gave the DGA the regulatory tools to effectively address the problems of natural variability of aquifers, especially in the north of Chile. The study of this case should shed some light on this question. Regarding the granting of water use rights for underground waters, the water code of 1981 established two types of water use rights: permanent rights and provisional rights. The former is an indefinite water use right, whose overall allocation should be consistent with the long-term recharge capability of the aquifer, and the latter intended for situations when there are uncertainties about the aquifer's resources – provisional water rights can be revoked if impairments of previously granted rights are verified. Nevertheless, in order to be able to grant provisional rights, the DGA must have declared the aquifer a zone of restriction. On the other hand, the declaration of zone of prohibition will prevent the granting of any new water right, permanent or provisional.

Prior to the legal reform of 2005, the declaration of zone of restriction or prohibition could only have been done if requested by water use right holders. The reform of 2005 granted the DGA the right to deny water use rights in aquifers not declared as zones of restriction. Nevertheless, for the DGA to expire provisional rights and to deny granting of new water use rights altogether, it has to demonstrate that third parties, owners of water rights, are affected.

The water code of 1981 was reformed in 2005 after more than a decade of discussion in Parliament. One of the most important elements of the 2005 reform of the water code was the establishment of minimum ecological water flow restrictions. This allowed the State to limit the granting of new rights in order to preserve environmental values. Nevertheless, this regulation was not effective since most water use rights were fully granted prior to 2005. In addition to this, the reforms included: the possibility of creating water reserves under exceptional circumstances; the need of a justification in the water rights application; a fee in the case of non-use of water rights; regulation and enforcement mechanisms for the management of groundwater resources; and the obligation to report transactions on water rights. Most of the changes to the model of allocation of water rights were intended to improve the functioning of the market and to facilitate the regulation of environmental externalities and the management of underground aquifers. In particular, the DGA was authorized to declare a zone of prohibition based on its own judgment. This could be done if, among other factors, there was evidence of overexploitation of an aquifer.

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[4] For this purpose, the boards of directors and managers of user organizations have been granted the legal power, in their capacity as arbitrators, to hear and decide cases involving controversies that may arise among the common users or members of the water associations, or between them and the organization; see Vergara (1998) and Donoso (2006).

3. Water resources management in the Copiapó valley

3.1. Characterization of water resources in the Copiapó Basin

Copiapó is located in an arid area and almost all water resources in the Copiapó Basin come from rivers in the upper mountainous part of the basin (Figure 1). The other contributing areas hardly produce any regular flow and only in case of extreme rainfall. The upper part of the basin receives between 40–60 mm/year of average annual precipitation. The Copiapó River, which crosses the central valley and reaches the sea, receives only between 10–30 mm per year. Although from a hydrological and physical perspective the Copiapó aquifer could be considered a single integrated aquifer, the DGA divided it into six sectors (see Figure 1). Since there are no clear hydrological reasons for dividing the aquifer in these six sections, it has been suggested that the sections were established for administrative purposes. To facilitate the formation of underground water communities, instead of having one such association for the whole aquifer, the regulator expected that it would be easier to form different water associations that would jointly manage extraction in each section. One of the most important flow checkpoints in the Copiapó Basin is in La Puerta, which also marks the boundary between sectors 2 and 3 (Figure 1). Here,

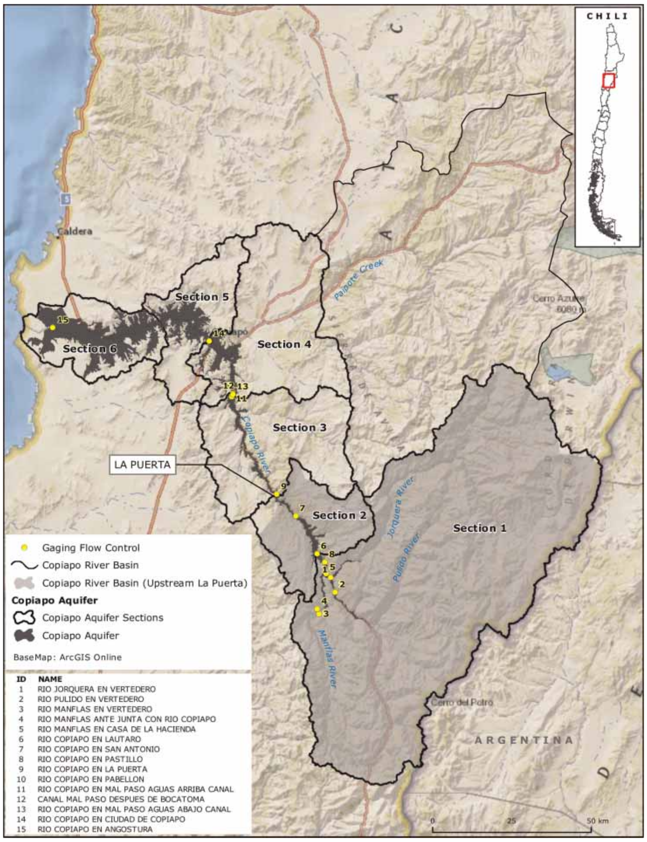

Fig. 1. Rivers and streams of the Copiapó River Basin, flow checkpoints and groundwater.

all runoff coming from the upper side is controlled. Downstream La Puerta, there is virtually no additional runoff, so what is being measured at this checkpoint reflects almost all the water supply for the valley. This runoff is integrated into the aquifers as direct recharge or is consumed or transferred to the coastal section and the sea.

The amount of surface water in the Copiapó River varies significantly depending on the section. The largest flow is found in Section 2, with a long-term average of 1.8 m^3/s. To the west of Copiapó, in Sections 5 and 6, the river is normally dry and the average flow is zero. Ninety percent of water consumption in Sections 5 and 6 is by the agricultural sector and is supplied mainly from wells with a total extraction of about 1 m^3/s. (Figure 2).

While there is only one aquifer related to the Copiapó River and its tributaries, the most important part of the aquifer is located downstream of La Puerta. This is because it concentrates the greatest demand within the aquifer and it is the source of drinking water for the water concessioner[5]. This sector presents the most significant deterioration of its resources, with a steep decline of groundwater levels in recent years.

The annual recharge of the aquifer has a significant variability, with an average value of 2 m^3/s downstream of La Puerta (Figure 3). Years of high recharge are scarce and have values several times greater than the average. Between 1974 and 1993 there were only 7 years when the recharge exceeded this average value and there was only 1 year where 4 m^3/s was exceeded. After 1993, when the aquifer was declared a zone of prohibition, there were only 3 years when values were higher than 2 m^3/s. In the period after 2004 the recharge has been below the average of 2 m^3/s. Recent studies, which have not been published yet, show a reduction of 40% of the infiltration of surface water into the aquifer. This has been attributed to the trading of water rights to more intensive uses and the increase in efficiency in water use in agriculture. This trend is expected to deepen further reducing long-term recharge levels of the aquifer.

3.2. Granting of water use rights in the Copiapó Basin

A study of the aquifer's recharge levels contracted by the DGA at the end of the 1980s (Alamos y Peralta, 1987) concluded that the long-term recharge levels for the whole aquifer was 4.85 m^3/s, of

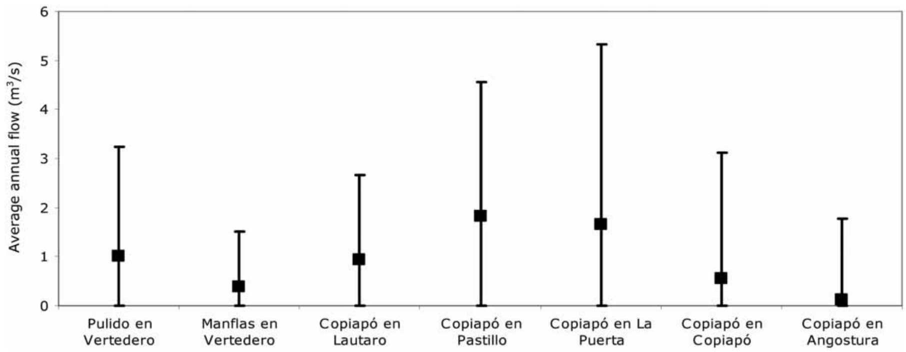

Fig. 2. Average annual flow distribution throughout the basin. From the upper (Pulido on Vertedero) to the lower part (Copiapó on Angostura). *Source:* Authors' calculations based on data from DGA, Atacama Region.

[5] Aguas Chañar is a water and sanitation private company servicing 77,000 people in the Atacama Region.

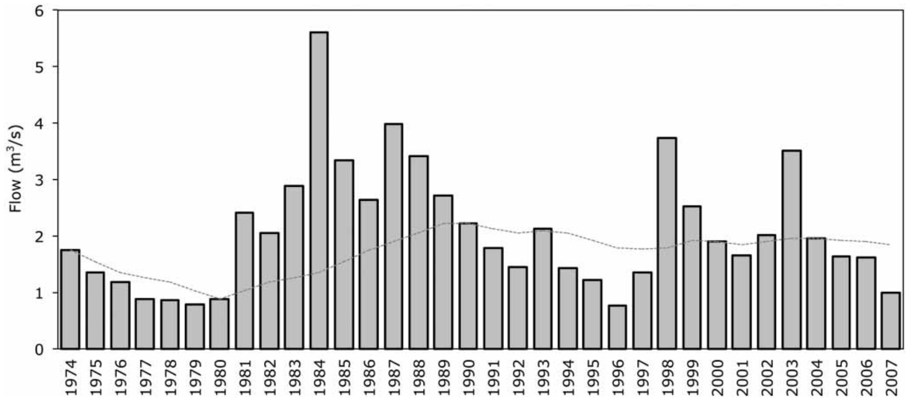

Fig. 3 Annual recharge to the aquifer of Copiapó (downstream of La Puerta). *Source:* DGA (2009).

which at least 3.5 m^3/s should have been available downstream of La Puerta. This study overrepresented the most recent recharge levels, which corresponded to an extraordinary humid cycle, overestimating the long-term recharge flows (DGA/DICTUC, 2010). Meanwhile, water extraction (according to the 1987 DGA study) in the aquifer downstream of La Puerta averaged 1.5 m^3/s until 1984, after which the actual water consumption increased sharply, jumping to over 2.5 m^3/s in 1985. After 1988 average extraction downstream of La Puerta increased to over 3 m^3/s. The water use rights from the aquifer granted until 1987 reached 8 m^3/s, a figure that by far exceeded the overoptimistic recharge level estimation. Nevertheless, actual water consumption was still slightly below the 1987 recharge estimation for the whole aquifer downstream of La Puerta. Thus, there was a widespread perception that the aquifer was still under-exploited, which explains that no water use right holder requested the establishment of restrictions to the granting of new water rights. The DGA continued granting an average of 0.7 m^3/s per year, reaching a total of 11 m^3/s of user rights granted in 1992. It is worth remembering for the purposes of this analysis, that, in order to deny the granting of new water use rights, the DGA had to declare the aquifer a zone of prohibition, which could only be done if requested by water use right holders. In 1993 the DGA finally declared the Copiapó Basin a zone of prohibition for new groundwater exploitation (Resolution of DGA N°193, 27 May 1993), due to the persistent decline in the aquifer levels since 1988 (Figure 4).

When the prohibition was established in 1993, the granted water use rights exceeded, by at least three times, the long-term aquifer recharge levels. In order to reconcile the water rights granted with the recharge levels, the DGA assumed in 1995 that the water use rights granted would be only partially used. The reason for this assumption was that most of the water rights requested were for agricultural purposes; and since agriculture had historically used less than 20% of the nominal water allocated, the DGA established a policy of considering a use factor of 20% for the new allocations of water use rights. With this policy, the DGA was able to solve the contradiction that emerged in that period; with water use rights granted well in excess of recharge levels. In the period previous to the declaration of a zone of prohibition, actual consumption of water from the aquifer was still lower than the long-term recharge level as optimistically estimated by the 1987 study.

Subsequently, in April 1994 the zone of prohibition was modified to exclude the lateral inflows in the recharge zone downstream of La Puerta, allowing the establishment of new water user rights in lateral underground tributaries to the aquifer. The DGA undertook new studies regarding the aquifer in 1995 (known as Alamos y Peralta) and found that the recharge level was reduced from 4.85 m^3/s of the 1987 study to 3.5 m^3/s,

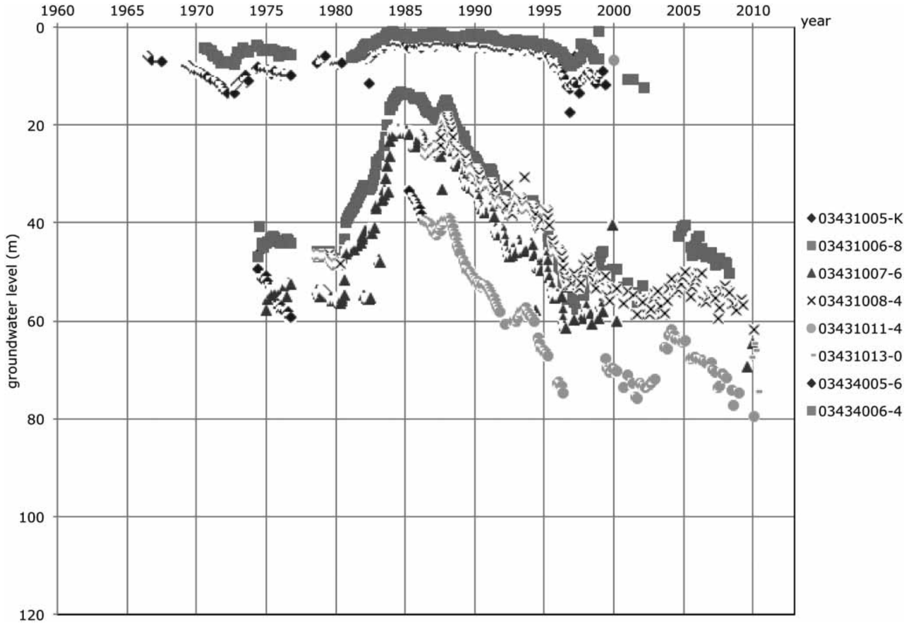

Fig. 4. Levels of the aquifer in the observation wells. *Source:* Authors' calculations based on data from historical records of DGA.

which implied that less than 2.5 m^3/s was available downstream of La Puerta, a reduction of over 25% with respect to the prior estimation. According to the 1995 studies, the aquifer was becoming overexploited, which was consistent with the continuous decline in aquifer water levels. Actual consumption was on average over 3 m^3/s between 1996 and 2000 with only 1 year below 3 m^3/s (in 1997, due to an extreme drought). Therefore, during most of the 1990s, consumption exceeded the long-term recharge levels estimated in the 1995 DGA studies. Nevertheless, after the delivery of the studies and the declaration of the zone of prohibition, between 1996 and 2000, 4 m^3/s of additional water use rights from the aquifer were granted.

Most of these additional water use rights were granted to those that applied for water use rights prior to the declaration of zone of prohibition in 1993. In fact, most of the water use rights granted after 1993 had been requested prior to the declaration of the zone of prohibition. Accumulated applications of this period reached 16 m^3/s, of which almost 12 m^3/s had already been granted. The impact of additional water use rights being granted in the lateral recharge zones of the aquifer, where the ban was lifted, was insignificant. Water use rights granted after the ban reached 5.9 m^3/s, of which 5.1 m^3/s (87%) were applied for before the declaration of zone of prohibition in 1993, reaching 15 m^3/s in 2000. Even with the use factors introduced by the DGA, the forecasted extraction should have exceeded the recharge level estimation of the 1995 studies. The aquifer levels continued to decline in the second half of the decade, although at a slower pace, as we will see later. The years 1998 and 1999 were very humid due to *El Niño*, which generated a partial recovery of the aquifer.

In 2001, restrictions were reduced in Sections 5 and 6, declaring these sectors a restriction zone, instead of a prohibition zone, which allowed the DGA to grant 1.4 m^3/s of provisional rights. Users in the lower end of the basin requested this change in the status of the section. The argument for the request was that in Sections 5 and 6, the level of the aquifer was stable; therefore the conditions for a zone of prohibition were not applicable. Whereas for the aquifer as a whole the conditions for prohibition existed, the fact that the DGA had segmented the aquifer in six zones for administrative and regulatory purpose created the conditions for potential users to question the legality of the prohibition in the lower sections. Water use rights granted increased from 15 m^3/s in 2000 to 20.6 m^3/s in 2006, with rights granted mostly between 2001 and 2003. From 2001 onwards, water use rights have been granted for the following reasons. First, as provisional rights in Sections 5 and 6, since these were restriction zones in which there were no signals of declining in the level of the aquifer. Second, the existence of applications before the declaration of zone of prohibition in 1993. The granting of these water use rights was demanded by law if the requirements valid through the application period were correctly met. Third, with the approval of the 2005 reforms, a provision to regularize rights was established for those who had carried out investments in infrastructural work and had exploited aquifers prior to 2004[6].

After the approval of the 2005 law, enormous pressure was put on the DGA to effectively grant these rights. The DGA granted some of these rights in 2006 as provisional rights. Subsequently, in 2009 a special law was necessary to prevent the DGA from further granting rights requested under this provision. If fully implemented, the regularization of illegal extraction would have implied granting 1 m^3/s of prior unauthorized extractions.

In summary, most of the groundwater rights in the Copiapó aquifer had been awarded in the years following the enactment of the 1981 legislation. The data from the survey conducted by the DGA in 2009 indicate that, in total, water rights of 20.6 m^3/s were granted in the aquifer, with around 1 m^3/s of provisional rights revoked. Of the 19.6 m^3/s of the water use rights effectively granted, approximately 11 m^3/s were granted in Sections 3–5 of the aquifer, and 4 m^3/s were granted upstream of the La Puerta section (Figure 5).

At the end of 2009, most of the provisional water use rights were annulled, reducing them from 1.4 to 0.4 m^3/s. At the end of 2011, the total amount of water use rights granted stood at 19.622 m^3/s, and actual water consumption downstream of La Puerta was 3.9 m^3/s, almost double the long-term recharge level (Figure 6).

The overexploitation of the aquifer became a high profile public policy problem in the summer of 2007. At this time, the decline in water levels of Sections 3 and 4 of the aquifer drastically raised the cost of pumping. Also, low rainfall resulted in the complete emptying of the Lautaro Dam. Given the importance of the Lautaro Dam, built over 70 years earlier for irrigation purposes, the most important economic and social actors started to realize the magnitude of the problem produced by the failure to operate a sustainable water management policy in the Copiapó Basin.

Water users noted this overconsumption due to the lowering of the water levels in pumping wells. Figure 4 shows the persistent decline in groundwater levels of all sections, reaching depths between 50 and 70 meters, far deeper than those observed in previous periods. As a consequence, pumping costs rose considerably. The decline of the water levels of the aquifers started in 1987, 5 years prior to the declaration of a zone of prohibition. Nevertheless, the water use right holders were passive regarding the perceived deterioration of the value of their own assets, despite the existence of mechanisms to stop the granting of new water use rights. Surprisingly, private ownership of water use rights did not play a determinant role in preventing the over-granting of the rights. This is puzzling since private

[6] In other words, a transitory article of the 2005 law allowed the total amount of water permits in the valley to increase, despite of the fact that the problems already present were observed in 1993.

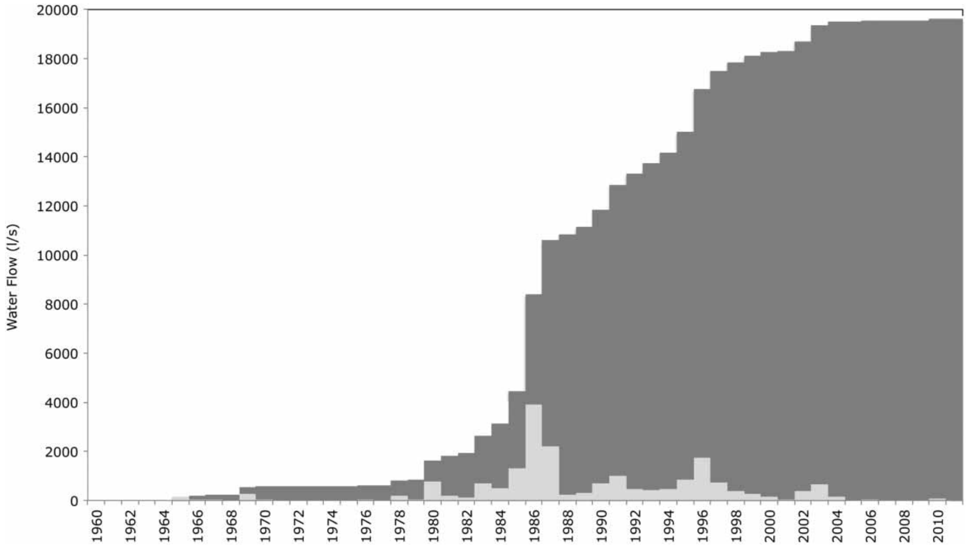

Fig. 5. Water use rights granted in the Copiapó aquifer (granted in light gray, accumulated in dark gray). *Source:* Authors' calculations based on data from DGA (2012).

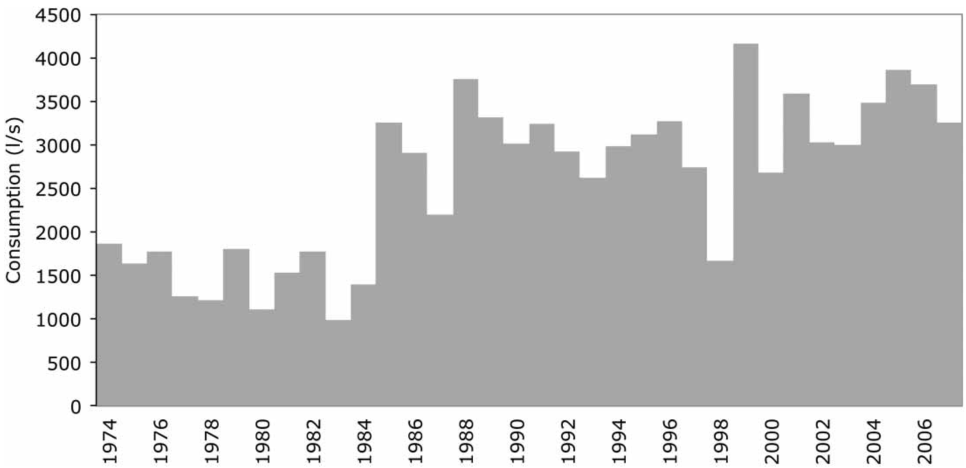

Fig. 6. Annual variation of water consumption in the Copiapó aquifer (downstream of La Puerta). *Source:* Authors' calculations based on data from DGA (2009).

ownership of the right to use a common property resource is considered a tool for preventing the tragedy of the commons (cf. Hardin, 1968). We will come back to this issue in the following sections.

3.3. Water uses in the Copiapó Basin

There is no systematic reporting of water use in the Copiapó River Basin. There are some estimates using different methods in different periods of time. The latest analysis of water use from the aquifer was conducted in 2010 (DGA/DICTUC, 2010) indicating that 4.9 m^3/s was used, 84% for agricultural use, 7% by the mining industry, 8% for drinking water and 1% for industrial use. Results were similar to those collected in 2002 in terms of use distribution across industries. The total use in 2002 was nearly 4 m^3/s for the whole aquifer. Total effective extraction over nearly 10 years has increased by about 1 m^3/s.

Comparing consumption by aquifer section shows that the largest increase between 2002 and 2010 occurred in those sections which were relatively less exploited in 2002. Agricultural use increased in all sections, but especially so in Section 4, which created a critical situation there. Drinking water use was reduced to zero in Sections 3 and 4, and increased in the Andes and coastal areas. Extraction for mining was reduced in one of the most exploited sections and moved toward the mountain range (Figure 7).

A hydrological model was developed by the DGA in 2008 in order to simulate the aquifer flow, considering the sections of Copiapó on La Puerta and the opening in Angostura. With this tool, the DGA simulated the evolution of the volume of water in the aquifer. Considering the same level of withdrawals as in 2008, there is an increasing decline that continues for almost 20 years, almost completely depleting the aquifer.

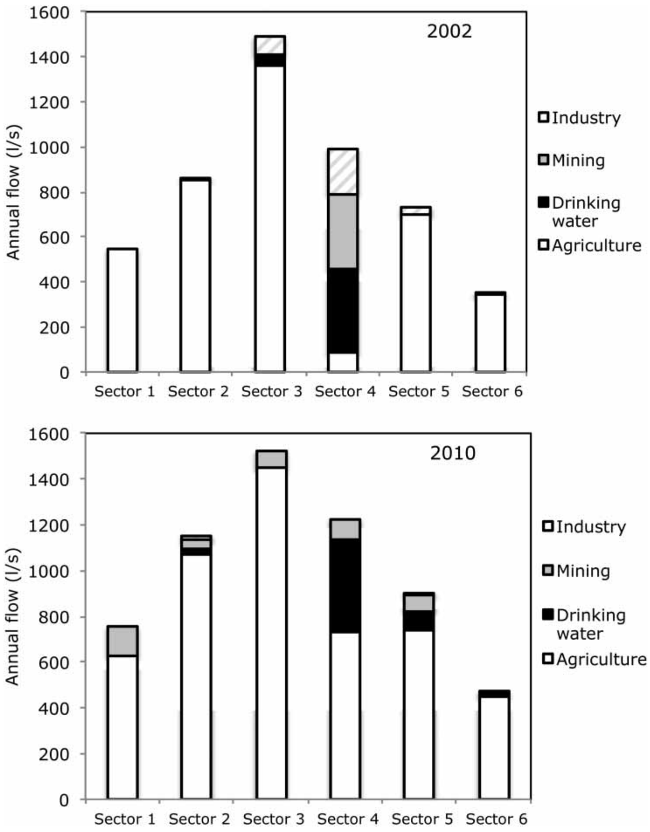

Fig. 7. Groundwater demands in 2002 and 2012. *Source:* Authors' calculations based on data from the study of DGA/DICTUC (2010).

4. The water market in Copiapó

In this section, we use annual and monthly data to characterize and analyze prices and quantities traded in the water market of Copiapó region since the year 2000. Specifically, we have collected disaggregated data describing the water sales price history, considering the source of the water (Tierra Amarilla or Copiapó) and the section of the aquifer where the transactions take place. We also develop an econometric model to estimate the responsiveness of demand to price changes (price elasticity) in the water market, and to evaluate the structural change of the market as a result of the overexploitation crisis. With these analyses in mind, we will have valuable information to characterize the operation, level of efficiency and structural change of the market in Copiapó.

From Figure 8 we can see that the market has been increasingly active. For the period 2000–2006 the average number of annual transactions reached 24, while for the period 2007–2011, it was 33, a 40% increase. After 2008 the number of trades decreased, probably as a consequence of the fact that by that year it had become clear to all stakeholders that the Copiapó aquifer was overexploited and water use rights were dramatically over-granted, creating great uncertainty about the value of the water use rights. Figure 9 shows that the majority of the trades, almost 90%, concerned transactions of less than 50 l/s. This number of transactions and size of volumes traded indicate some level of competition. More than 5% of the total number of rights have been traded in the water market of Copiapó. This figure is above the average for the Chilean water market.

Figure 10 shows the evolution of average price and the volume trade for the period 2000–2011. We can see that the volume traded grew until 2008 and then decreased sharply, just after the crises exploded publicly. The price of water more than tripled in the same period, starting with a value of about US$4,000 /l s^{-1} in 2000, and reaching more than US$14,000 /l s^{-1}. Again, there is a clear structural change in the market starting in 2007. It is important to point out that despite the fact that the participants in the market were aware for quite some time prior to 2007 of the low water levels of the aquifer

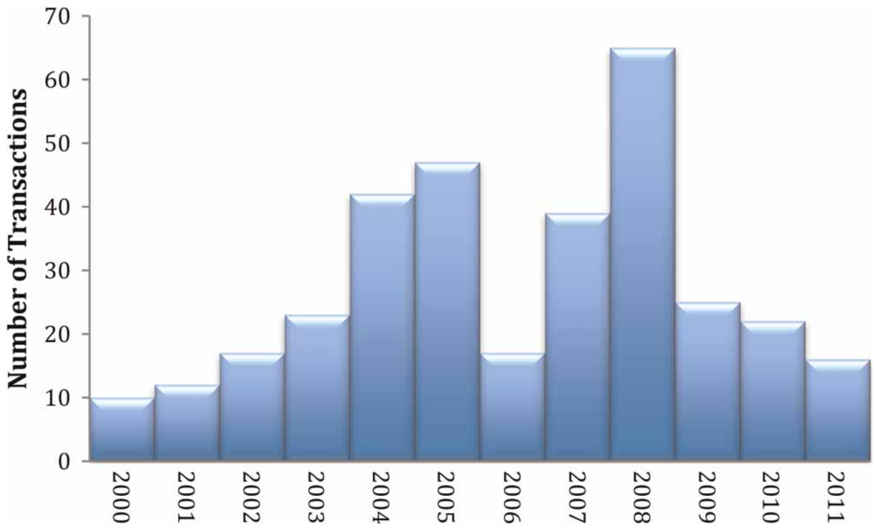

Fig. 8. Evolution of the number of transaction in the water market in Copiapó. *Source:* Authors' calculations based on data from water use rights trades.

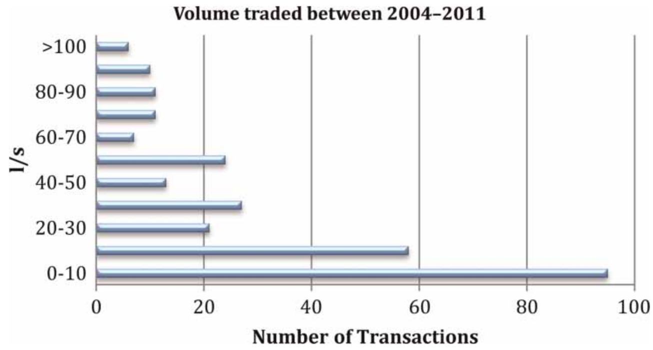

Fig. 9. Volume traded between 2004–2011 in the water market in Copiapó (l/s). *Source:* Authors' calculations based on data from water use rights trades.

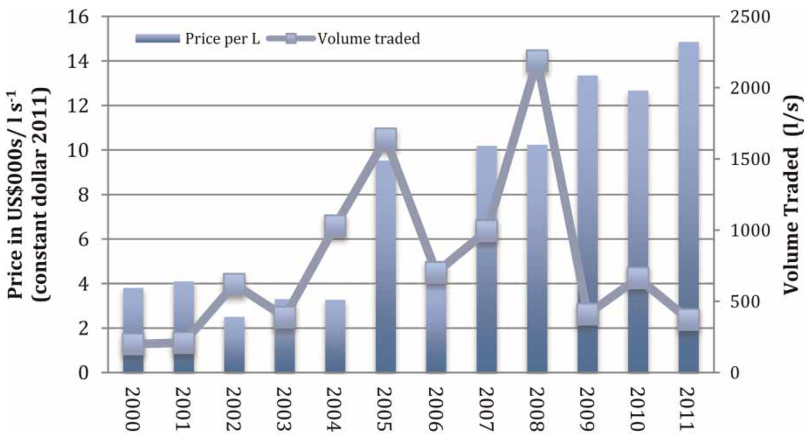

Fig. 10. Price and volume traded in the water market in Copiapó. *Source:* Authors' calculations based on data from water use rights trades.

and the high levels of water consumption, the market reacted several years later. This seems to indicate that the market was very opaque, with low levels of public information and high transactions costs.

It should be noted that there is no electronic market or physical place where these transactions are published. In fact, the real estate register is the only public record of transactions and there is a clear transaction cost for getting fresh information on trading water rights. Besides, the variability of the resource, the uncertainty about its availability and the policy's unpredictability contribute to the lack of information in the market. This lack of transparency undoubtedly promotes speculation regarding the spot and future prices.

In general, we can see an efficient allocation provided by water markets, since the scarcity has increased prices sharply. As we saw in previous sections, this price signal forced consumers to improve the efficiency in the use of the resource. At the same time, activities with higher opportunity cost, and hence greater willingness to pay for the resource, have gained space in the market (Figure 7). We could expect mining companies to buy rights from the agricultural industry in the long term. Unfortunately, there is not a precise record of who the buyers and sellers are. So testing this hypothesis is currently impossible.

From Tables 1 and 2, we can see the average prices and volumes traded in aquifer Sections 3 and 4. Clearly, Section 4 has provided on average more volume during the period, and water price has also been always greater than the price paid for Section 3's water. On the other hand, the prices have also tended to homogenize in recent years for both sources. The fact that prices start to converge is an indication of the market functioning, increasing the efficiency in the allocation of resources.

Summing up, the market price did signal the water scarcity. Indeed, the price of water more than tripled in the period 2000–2011. During this period, transactions were made regularly and in a relatively low volume. Prices have started to converge to a similar magnitude order by 2011, in the different sections of the aquifer, an indication of the market functioning properly. The current differences in prices indicate that arbitrage opportunities are present and hence the interconnection among the aquifers could bring important efficiency gains.

It is important to point out that some of the legal reforms introduced in 2005 have improved market functioning. Particular improvements concern better sources of information about market transactions and water availability, which is a great advance compared with the previous situation. Nevertheless, the problem of too many water rights having been granted for too few resources still remains.

5. What went wrong with water policy and management in Copiapó?

It is relevant to understand what went wrong in the Copiapó Basin regarding water management. Is it a pitfall of the legal framework, or a failure of the regulators? If it is the regulator's fault, is that because of lack of information? Is that due to the regulator's overall incompetency? Or is it the result of political pressure? Understanding the factors explaining the collapse of the aquifer could help in defining public policy and the reform requirements. This analysis is relevant not only for the Copiapó Basin, but also for most of the overexploited aquifers in the center north of Chile, affecting the sustainability of economic

Table 1. Volume traded (l/s) per source.

Source	2004	2005	2006	2007	2008	2009	2010	2011
Section 3	0,416	458	153	428	640	226	284	45
Section 4	614	1183	550	567	1,549	185	380	327
Total	1,031	1,640	703	995	2,189	411	664	372

Source: Authors' calculations based on data from water use rights transactions.

Table 2. Average price per source (constant dollars 2011).

Source	2004	2005	2006	2007	2008	2009	2010	2011
Section 3	2,562	4,793	3,716	7,413	6,189	11,325	11,872	11,826
Section 4	4,211	14,462	4,092	15,751	14,681	18,853	14,799	17,889
Average	3,269	9,525	3,959	10,193	10,239	13,352	12,670	14,857

Source: Authors' calculations based on data from water use rights transactions.

and, in particular, agricultural activities, and for other countries that could be considering the introduction of a water use rights market for the management of aquifers. In order to understand the factors leading to overexploitation we analyze the policy-making and management process of the aquifer since the mid-1980s detailed in Section 3.

In 1987 when the first thorough study of the aquifer was presented the total recharge level for the whole aquifer was set around 4.6 m^3/s. The first problem emerged due to the overestimation of the sustainable recharge level of the aquifer by almost 1 m^3/s, according to recent studies (DGA/DICTUC, 2010). Why the overestimation? There are several hypotheses for this overestimation, first that the study was biased by the very humid period that started in 1981 and lasted until 1990 (Figure 3). Second, the study failed to consider the increased irrigation efficiencies, which generated a systematic reduction in the recharge levels, since less excess irrigation water percolated into the aquifer.

Nonetheless, the main problem in the management of the aquifer was not the overestimation of 25% in recharge levels, but the over-granting by several times of water use rights. In 1987, when the first study was made, total water use rights granted reached 11 m^3/s, more than twice the availability of water resources. Despite this information, the DGA did not establish a zone of restriction which would have allowed the granting of provisional water use rights only, instead of permanent ones, keeping flexibility for future management of the aquifer. The aquifer stayed open to new applications for permanent water used rights until 1993, when total applications exceeded 18 m^3/s and water used rights granted reached almost 13 m^3/s. That year the DGA declared the aquifer a zone of prohibition. The reason for declaring a zone of prohibition was the rapid decline in the level of the aquifer since 1991, which raised the concern of the regulators and some agricultural companies that saw an increase in the pumping cost (Figure 4). Why did the DGA wait so long for declaring zone of restriction or prohibition and stopping the granting of new water rights? According to the information available, the DGA based its estimations on foreseeable use of the rights on historic information. They kept the assumptions from the period when water use rights were non-tradable and used mostly by agriculture producers. The implicit assumption was that only 20% of the water use rights assigned would be effectively consumed. Under this assumption, water use rights granted could exceed 20 m^3/s without overexploiting the aquifer. In 1995, this implicit assumption of low effective use was formalized as a norm by the DGA, in which the water use rights granted would be assumed to effectively use 20% of the allocated rights. This assumption was based in the level of efficiency observed in the 1970s and 1980s in the farming sector, with extensive inefficient irrigation. Extrapolating the water use of a period of relative abundance and without transferability of water rights into a period of increasing scarcity, with fully transferable rights and significant absorption of intensive irrigation techniques is the main factor explaining the delay in the declaration of zone of prohibition until 1993 and the subsequent relaxing of the ban in the lateral tributaries and Sections 6 and 7 of the aquifer. The regulator's overallocation of water use rights is the main reason explaining the near collapse of the aquifer.

The additional granting of water use rights after 1993, of 7.3 m^3/s, with around 1.4 m^3/s of provisional rights of which 1 m^3/s were revoked, is explained to a lesser degree by the decision of the DGA to reopen the aquifer in lateral tributaries and Sections 6 and 7, and to a greater extent (close to 5.1 m^3/s) to the legal interpretation that any application made prior to the declaration of zone of prohibition had to be granted, a factor that was foreseeable for the regulator, which could have been modified through legislative initiative if the regulator had presented the risk of eroding rights to the existing water use right holders.

A puzzle to us is why the water use right owners did not exert their rights to prevent the deterioration of the value of their assets. Why were private owners, who have the legal right to limit the erosion of their rights, not active in front of the regulator and the courts to limit the over-granting of water rights?

The most plausible explanation is that individual farmers had information asymmetries regarding the situation of the overall balance between granted water use rights, rate of use and recharge levels, and that they also trusted the regulator. It was only when the groundwater levels started dropping drastically, that they became worried about the sustainability of the exploitation of the aquifer. This occurred in the early 1990s once too many water use rights had been granted.

Another explanation is that the owners of water use rights were expecting a declaration of the zone of prohibition due to the decline in the level of the aquifer. With the expectation of a proportional rationing, everyone was trying to obtain more rights to improve their situation in case of rationing, but in the end they jointly created an inflation of water rights and eroded their values. Also a significant proportion of wells were illegal, and well owners expected their wells to be legalized once in the possession of a water use right. This expectation may have been informed by the assumption that the grandfathering of rights in case of rationing would consider the existence of actual investment in wells.

6. Concluding remarks and policy recommendations

Based on the evidence presented in this study, our conclusions consist of five points: That the dramatic overexploitation of the Copiapó Basin was the consequence first of failure in regulatory implementation and second of an extremely rigid regulatory framework that left limited room to adjust to changing conditions and the emergence of new information regarding water availability. Third, the government lacked initiative to adjust obvious pitfalls in the regulatory framework for legislation and fourth, the water use right owners, despite having the possibility of closing the market, opted for running a race of over-application and over-investment in water use rights. Finally, it is important to point out that the market price of water more than tripled in the period 2000–2011, consistent with a situation of higher scarcity. During this period, transactions were made regularly and in a relatively low volume. Prices have started to converge to a similar order of magnitude by 2011, in the different sections of the aquifer, an indication of the market functioning properly.

From the Copiapó case a number of recommendations can be drawn. Firstly, we will present some general conclusions and put forward relevant advising ideas for water markets in Chile and the world. Secondly, some specific policy choices for Copiapó are discussed.

6.1. What have we learnt from the water crisis in Copiapó?

The development of an efficient market for water use rights is a critical policy goal for promoting investments and innovation in different sectors that utilized this essential resource. The weakness of property rights, lack of enforcement, asymmetric information and the existence of transaction costs have been considered in many countries as bottlenecks for the development of these markets. Despite that in Chile property rights are well established in law and in the Constitution, the market for water use rights has been limited. It has been found that increased water scarcity promoted the development of the market. Nevertheless, the granting of too many water rights has eroded the rights of prior holders, and has created uncertainty regarding what the rights effectively mean, in terms of rights to extract water in the future.

In this context, to sustain an efficient competitive market is a much more complex task than just distributing permits and rights, especially if the resource could be affected by the tragedy of the commons and if regulation is not coherent with the nature of the activity. To function efficiently, a market requires a variety of other systems, institutions, social norms and procedures, and infrastructures whereby parties engage in exchange. If the market can achieve these requirements, it will effectively facilitate trade and it will enable the allocation of resources in a society in an economically efficient manner.

Thus, there are a number of points that have to be ensured in order to guarantee the correct functioning of any water market, as in Copiapó.

Firstly, a very dynamic water system with imperfect information, as the Copiapó, requires more flexible market regulations such as the regulation of fisheries or pollution right markets that usually work with aliquots. A good example of this type of regulation is the surface water use rights in Chile, which in practice works also with aliquots. Indeed, in fisheries, for example, the government allocates individual tradable quotas as a percentage of a total available quota, which is periodically recalculated based on scientific evidence. In surface water rights, the surface water flows are measured at specific points of the river and the extraction rights adjusted proportionally to the availability. The case of underground water is closer to fisheries, where several economic agents are extracting resources from a common pool. In that regard, the preferred approach for a water market would be the individual tradable quota model of fisheries.

Secondly, the role of the Water Authority, in this particular case the DGA, has to be consistent with the fact that they are regulating a market. In this scenario, the main policy instrument of the authority should be to have the power of defining the real amount of the resource in a periodical manner. The Water Authority should also be able to define the value of the aliquot of water rights in a consistent manner, based on periodic and regular studies of water availability.

Thirdly, some measures have to be taken in order to avoid the opportunistic and speculative behavior of some players in the market. Specifically, when the water price is increasing significantly, the cost of keeping the right will also have to increase accordingly. Otherwise, the vicious circle of scarcity, higher cost, speculative behavior, more scarcity, more increase in cost, and so on, will end in the tragedy of the commons.

Fourthly, the problem of lack of information present in the market, regarding transactions, prices, resource allocation and availability should not be allowed. The current problem in Copiapó could have been avoided or alleviated if all the market's agents had had better information. The lack of transparency promotes speculation about the spot and future prices, creating very damaging consequences. Public records should be available for displaying relevant information such as water availability, prices and transactions, in order to reduce speculation and create a more transparent market.

6.2. Some specific policy recommendations for Copiapó

To gain economic efficiency in Copiapó's water market, it is necessary to restore the aquifer. This can only be accomplished with a sharp reduction in water use. Thus, the main problem that the water market in the Copiapó Basin currently faces is an inflationary one. There are 'too many water use rights chasing too few water resources'. Clearly, the responsibility of the Water Authority (Government) is to correct this situation.

In this context, one way to restore the optimal equilibrium is to take out some water use rights. Doing this is similar to the implementation of a tight monetary policy. We believe that there are three ways that will allow us to take out some water use rights, maintaining the market mechanisms in place.

Firstly, the government could buy permits. This is an easy way out of the situation, taking advantage of the market mechanisms in order to solve this complex problem. Nevertheless, there are three problems with this approach. First, the potential speculative behavior of some right owners, who will see this as an opportunity to take advantage of the government, charging higher prices. Second, the government will have a political problem, having to compensate in monetary terms, and probably paying again great amounts of money, for resources that the agents got free of charge in the first place. Finally, the amount of permit that should be acquired in order to restore the equilibrium is very significant (more than three-quarters of all water use rights), which implies significant fiscal resources.

Secondly, the user association could play an important role in solving the excess of water use rights by achieving an agreement between the right owners. Specifically, the association could implement a grandfathering mechanism, similar to the ones used in environmental emission permits systems or the already mentioned individual tradable quotas for fisheries, that keeps the market share of every original right holder, but it reduces the total volume of committed water resources. Obviously, this *Solomonic* decision will not be welcomed by those water use right holders who use their rights for efficient exploitation, because it will immediately give a considerable amount of power to agents that are currently not using their water rights. In any case, the main problem of user associations, as explained in the paper, is the high transactional costs and the free riders problem that generate a lack of incentives to reach an agreement. The main incentive will be that this is the most realistic option to save the market mechanism for water management in the Copiapó Basin, which gives assets of some value to existing players; otherwise the only way out will be the definite changing of the law in favor of non-market-oriented water management regulation. This second option will also prove whether or not the user associations can have a major role to play in the water markets or if their intervening was only wishful thinking of the legislator. Until now, the role played by the user association before, during and after the crisis has been very limited. So far, there are only a couple of water communities in Sections 5 and 6 of the aquifer, and these do not include all water use right holders. Thus, it appears to be difficult for users to organize themselves in all sections of the aquifer.

The third option is to redefine the regulatory framework to resemble the regulation in fisheries as described above. Specifically, the individual tradable quota model of fisheries is a good model. This, without doubt, requires reassessing the role of the regulator in the water market. Distinguishing the water use rights being used from those unused will have to be addressed in the regulation; the same problem has been faced in fisheries. In fisheries, most of the countries consider historic rights based on past effective investment and captures. This should be a guide for the water sector. Nevertheless, as in fisheries, a cost should be charged for using a common or public resource when given in exclusivity.

Finally, in the central-north of Chile, we could expect mining companies to buy rights from the agricultural industry in the long-run. Given the high prices of copper in particular and mining commodities in general, this could create a scenario where the agricultural sector could shrink, due to the competition for water and human resources from mining. In terms of economic efficiency, this situation could be the 'right' one, but only in the absence of any externality. The fact that mining is a non-renewable resource and that there is hysteresis in trade suggests that the eventual withdrawal from sophisticated fruit export markets due to the mining boom, could have dynamic efficiency costs. Clearly, there are several positive externalities from agriculture, such as local employment and the avoidance of erosion, among others. As such, some interventions would be needed to ensure that these are internalized. The same could be said about using water for household consumption (e.g. typically large benefits in terms of health) or the use of water for ecological purposes (e.g. maintaining the local flora and fauna).

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