The likelihood of a water market in Brazil

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Abstract: The paper examines the likelihood of a water market in Brazil. The US water market, probably the oldest and most well-documented case, is initially analyzed. In the American West, water permits were transformed into property rights more than 140 years ago. However, mainly due to high transaction costs, only recently the trading became regular. Analyzing the Brazilian case, it is clear that the country does not have the problem of water availability that the American West has. On the other hand, Brazil has poor water infrastructure. As such, more than 35% of cities had no water for months in 2012, although the country possesses 12% of the world's fresh water. To implement a water market, the first step would be to change the water diversion entitlements in keeping with the property rights. It is argued that this would be an opportunity to force users to invest in water infrastructure. Thus, a model is built to study the conditions under which the market would lead to a Pareto superior situation. **Keywords:** water right, water market, Brazilian water law.

Resumo: O artigo examina os indicativos de um mercado de água no Brasil. O caso dos EUA, provavelmente o mais antigo e bem documentado, é inicialmente analisado. No Oeste Americano, as outorgas foram transformadas em direitos de propriedade há mais de 140 anos. Todavia, devido principalmente aos altos custos de transação, apenas recentemente o comércio se tornou regular. Analisando caso do Brasil, fica evidente que o país não tem um problema de disponibilidade hídrica como tem o Oeste Americano. Por outro lado, o Brasil tem uma pobre infraestrutura hídrica, de modo que mais de 35% das cidades tiveram falta de água por meses em 2012, embora o país tenha 12% da água mundial. Para iniciar um mercado, primeiro seria necessário transformar as outorgas em direitos de propriedade. Argumenta-se que isso seria uma oportunidade para forçar os usuários a investir em infraestruturas hídrica. Assim, um modelo é construído para estudar as condições em que o mercado levaria a uma situação Pareto superior. **Palavras-chave:** outorga de direito de uso de recurso hídrico, mercado de água, lei das águas do Brasil.

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1 Introduction

In 1997, Brazil established a national plan to manage water resources with three main elements[1]: water diversion entitlements ("outorgas de direito de uso de recurso hídrico," in Portuguese), contributions and basin committees. Under this approach, the water users need permits from the government, and they must contribute financially to watershed preservation. The aim of the basin committees is to monitor the permits, establish the contributions, and invest in water conservation.

In 2015, the Organization for Economic Cooperation and Development (OECD) published an evaluation of the Brazilian plan. The report indicates that the users rarely contribute financially, as outlined by the law. In fact, only 4 in 174 committees had implemented the policy by 2012 (ANA, 2013), mainly because there is much resistance from users against the contributions. In conclusion, the report suggests that the diversion entitlements could be converted to tradable property rights, and the taxation on trading could finance watersheds maintenance. According media reports, the Brazilian Water National Agency (ANA) is considering this possibility in response to the water crisis[2]. Although this is not a new discussion in Brazil; a law project with this purpose was debated between 2002 and 2013 in the National Congress.

The establishment of financial contributions and primitive markets for water diversion entitlements, often called "water rights," has been promoted since Roman times. Scott and Coustalin (1995) show that the idea came up several times throughout history, motivated by many different causes, but always as to balance different uses in dry times and in arid places. Today water markets in some form exist in the United States (US), Mexico, Australia, South Africa, Chile, India, China, Israel, Portugal, and Spain.

Among these countries, the US case is probably the oldest and best documented. According Anderson and Hill (1975) and Littlefield (1983), the modern idea of tradable water permits started in the 1850s with the California gold rush, where river fractions were allotted by the miners themselves by date of first use, giving them an early form of the water rights. At the end of the gold rush period, farmers started buying these water rights, and during the following years they started a primitive marketplace among the settlers. During the 20th Century, activity in this market was reduced by the popularization of groundwater exploitation as a substitute source. However, in the later years, it has restarted because there are not more options to supply water in the American West – water availability is being redistributed by the market.

The literature in economics began to take a special interest in this issue in the 1980s. There seems to be a consensus that the market is a good way to force the efficient water use under a scarcity situation, provided that there are ways to reduce transaction costs and negative externalities[3]. In this sense of scarcity, the data show that Brazil has a "functional" lack of water, i.e., the country has a considerable lack of water infrastructure and does not have an issue of availability. In fact, Brazil has 12% of the world's fresh water, but more than 35% of the cities lacked water in 2012 because there were not ways to adequately management the watersheds (OECD, 2015).

Given the likelihood of a water market in Brazil, or at least a more frequent discussion of the idea, this paper has two purposes. First, it produces a literature review to contribute to a clearer

[1]See the history of the Brazilian Water Law in ANA (2002).

[2]See: Folha de São Paulo, November 8, 2015, "Agência federal propõe criação de um mercado da água no Brasil;" Veja, October 19, 2014, "O novo pensamento econômico sobre a água;" or Valor Econômico, October 30, 2013, "Criação de mercado é saída para equacionar a escassez."

[3]See The Economist, May 22, 2010, "Trade and conserve."

debate about this issue. It points out what has been learned about the historical development of water rights, the formation of a marketplace, and the situations in which it has become beneficial to society. Second, this article analyzes at what point the conversion of permits to water rights (i.e., tradable property rights) can be an opportunity to solve water problems in Brazil – for this, an economic model is developed to study how the market would lead to a "Pareto superior" situation.

In this way, the second section presents water market development and current data, with special attention to the US case. Section 3 discusses the hydric situation, the imminence of the water market and the distribution possibilities of water rights in Brazil. Final remarks conclude the paper.

2 The US water market

Gleick (1993) describes many conflicts related to droughts, and the reason for this is quite simple: water is a fundamental resource, integral to all ecological and societal activities, including food and energy production, transportation, waste disposal, industrial development, and human health. In any inhabited place where water becomes scarce for a long time, some kind of human conflict emerges. Among these quarrels exists a special case in the US during the second half of 19th Century. It is emblematic because from it comes up with the idea of water rights as property rights separate from land rights (Anderson and Hill, 1975; Littlefield, 1983; Scott and Coustalin, 1995). This section first presents this history, and later some data of the market that has emerged from it.

2.1 The history

The 1848 California discovery of gold caused a massive immigration movement to the American West (what is today the states of Arizona, California, Colorado, Idaho, Montana, Nevada, New Mexico, Oregon, Texas, Utah, Washington, and Wyoming). Besides mining, many economic activities suddenly emerged, especially those related to agriculture to provide food. As most of the territory is semi-arid, and water is an essential input for mining and agriculture, the conflicts among users were inevitable.

While the state presence was growing, a court system was installed. At that time the notion of justice in relation to water was the "riparian doctrine" of British law. Its main principle was that the land ownership gives the right to use the water inside and adjacent of property. However, with few water endowments in a vast territory, poorly defined property rights and conflicts emerging everywhere, this principle did not make sense – and a new doctrine was needed to establish order.

In 1855, the California Supreme Court judged a case known as Irwin v. Phillips that became a turning point for water laws. Irwin's mining was exploiting a creek while Phillips started another mining operation downstream. Eventually there was not sufficient water for both, and neither had land rights. After much debate, the court ruled "first in time, first in right" and that the rights over water and land can be separated. As such, Irwin gained the water-use priority, even without having the land rights. This was the first principle of the "priority doctrine" that would be established in the following years.

During the 1860s, mining was in a decline, and farmers were claiming the water that had been used in now-abandoned mines. So, the courts began deciding which water uses were more important to communities. This was called the "beneficial use" principle, and it helped to prioritize water use. But, often ditches were needed to divert water from mining points to farms, frequently complicating land uses (i.e., creating negative externalities). So, the water right transfers were conditioned with the presentation of a plan for ditches as well as neighbourhood agreements – this was called the "third-party" principle. From these three principles (first in time, beneficial use, and third-party), the modern water rights concept was born. However, the idea of a market had not yet emerged.

In the 1870s, with the end of the civil war, a new massive immigration movement to the American West had begun, and these new settlers needed access to water. In this way, the government gave the water rights to news users under the three principles of the priority doctrine. These entitlements recorded the source and way of diverting water, authorized use, and priority number in case of shortages (older users first). But the key point of these papers was that water rights were considered property rights, so they could be sold, leased or exchanged. At this time, the possibility of a marketplace was born.

Since the end of the 19th Century, new users were required to apply for a new right from a government agency or look for an existing right in the marketplace, both of which were challenges. If a new user was applying for a new right, the law required that existing users not be negatively affected, which was a difficult condition to meet. And in the marketplace, besides being rare to find a seller and set a fair price, there could be a high transaction cost to properly divert the water from properties. But these challenges had begun to be less important with the proliferation of water wells – because they were free of water rights. In this way, the substitution between surface water and groundwater stopped market development for many years.

In the first half of 20th Century, a countless number of water wells began operating throughout the American West, while water shortage problems began to worsen in rivers and creeks. With the development of geological sciences, it was possible to show that the groundwater exploitation was drying the surface sources because the aquifers were partially recharged by the infiltration of surface water. But the worst discovery was that these aquifers were filled over geologic time, and they could not be fully recharged by the hydrological cycle. These sources were as exhaustible as oil reserves[4]

Gopalakrishnan (1973), Garner (1997), and Hobbs (1999) show the perception that it was only a matter of time before the "water chaos" forced sweeping changes to laws during the 1960s. By the mid-1970s, all US western states had developed specific rules for groundwater use, and this forced a revision of all water rights. To illustrate the issue, Table 1 shows the number of permits and population in Colorado by decades. By the middle of 20th Century, there were close to 20,000 water rights awarded with a population of nearly 1.5 million. In other words, there were almost 14 rate permits per thousand people. Under the new law, more than 55,000 wells with specific water rights were recorded and monitored in the 1970s, increasing the rate to 35 per thousand people.[5]

[4] In addition, Burness and Quirk (1979, 1980) and Saleth et al. (1991) have investigated theoretically and empirically the effects of the "first in time, first in use" principle in regards to water management. They found indications that this principle has not encouraged investment in infrastructure because the users with greater economic power could buy the priority rights rather than making new investments. So, the presence of this principle would aggravate the problem of shortages.

[5] In the Colorado case, virtually all permits awarded after the 1980s are related to the drilling of small wells. In other words, new surface water permits were rarely awarded. Nowadays, all catchment systems above 15 gallons (56.8 liters) per minute must to be supported by a water right (regardless of the source), being that 86.5% of the rights are used for agriculture, 6.8% are used for industrial and mining purposes, and the remaining 6.7% are for municipal use, which is the treatment and distribution of water for residences and business.

Table 1: **Water rights and population in Colorado.**

Decade	New water rights awarded	[a] Number of water rights	[b] Population (in thousands)	[a]/ [b]
1880s*	2,374	2,374	194.3	12.22
1890s	3,612	5,986	413.2	14.49
1900s	2,750	8,736	539.7	16.19
1910s	2,558	11,294	799.0	14.13
1920s	1,604	12,898	939.6	13.73
1930s	2,036	14,934	1,035.8	14.42
1940s	855	15,789	1,123.3	14.06
1950s	2,968	18,757	1,325.1	14.16
1960s	2,416	21,173	1,753.9	12.07
1970s	**56,944**	**78,117**	**2,209.6**	**35.35**
1980s	16,258	94,375	2,889.7	32.66
1990s	14,091	108,466	3,294.4	32.92
2000s	17,240	125,706	4,301.3	29.23
2010s**	3,649	129,355	5,029.2	25.72

*Between 1863 and 1889; **Until 2015. Data source: Colorado Division of Water Resources. Elaborated by the author.

Howe et al. (1986), Lyon (1986), Swaney (1988), and Shupe et al. (1989) report that the new laws created difficulties for a groundwater market, but also created new possibilities to incentivize the development of surface water markets with the purpose of reallocating water availability between agents with bigger marginal values of use. The main idea possibly is the "water bank" – it can be broadly defined as an institutional mechanism that facilitates the transfer and market exchange of various types of surface and storage entitlements. In effect, the bank can act as an intermediary that brings together buyers and sellers. In addition, this figure can provide a host of administrative and technical functions to reduce transactions costs. For example, it can implement a derivative market where farmers have an option to buy or sell water in case of a future drought, or it can implement an auction system for storage volumes.

Even with the new institutional framework developed over the 1970s, Howe (1998), Howe (2005), and Whitford and Clark (2007) show that the water markets worked poorly at least until the 1990s – only some isolated business occurred. In most cases, the reason was that the transaction costs remained high and inflexible. Besides the engineering problems (piping, pumping, evaporation, contamination etc.), there was also: the difficulty of finding buyers and sellers close enough to transfer water; the speculative movements frequently hampering price negotiation; and, the possibility that a neighbour would create a judicial problem.

As described by Donohew (2009), in all western states in order to change aspects of a water right (the owner, point of diversion, type of use etc.) a government agency needs to approve it. In most states, the applicant has to hire a certified examiner to study the case and report it to the agency. The agency must then determine if the change will negatively affect wildlife and other users. Furthermore, a public announcement of the proposed trade is made, usually in a newspaper, and a comment period is opened to allow the public to raise objections to the transfer. If the transfer is protested, a hearing is held by a water court and both sides present their cases. If there is potential harm, the agency accepts or denies the application, or may attach conditions, such as a reduction in the total water transferred. And, by law, the potential buyer or leaseholder pays all costs – which discourages a lot of trading.

On the other hand, Howe and Goemans (2003) and Lepper and Freeman (2010) also show examples between the 1990s and 2000s where the marketplace worked well. Specifically, this happened where there is an institution, like a water bank, that provided: low transaction costs (efficient administrative and engineering procedures); access to information (databases to find buyers, sellers and prices); and, sufficient market scope (some concentration to create a range of transactions). The reference market in this sense is the Northern Colorado Water Conservancy District (NCWCD), where a public agency administrates the water distribution and acts as a water bank, using 12 reservoirs and more than 200 km of tunnels and canals. The system provides supplementary water for more than 260,000 hectares of irrigated agriculture and 900,000 people.[6]

Analyzing the most recent years, Donohew (2009), Iseman et al. (2012), and Culp et al. (2014) report examples of other places that are trying to operate like the NCWCD. This stems from the fact that historically many projects were developed in the American West to augment water supplies by building dams, reservoirs and canals to capture, store and transmit water. But nowadays, most areas in the water basins have been claimed, and environmental objections to new projects further reduce supply growth as a feasible way to meet increasing demand. Consequently, meeting the needs of new users via new sources has been largely replaced by the reallocation of existing supplies using the water markets.[7]

Furthermore, irrigators consume more than 80% of the fresh water in the American West, frequently for the production of low-valued crops such as hay and alfalfa (Brewer et al., 2008). Urban uses and high-valued crops have far greater marginal water values. Therefore, a combination of scarcity and application in low-valued production are creating a new opportunity for markets to reallocate water to higher valued uses. As will be seen below, as in the past when water rights were moved from mining to agriculture, today they are going from agriculture to urban uses.

2.2 The contemporaries data

The best source of information about water markets in the US is the "Journal of Water", because it produces a regular survey of the transactions in the state agencies[8]. However, even this dataset underestimates the reality in at least two ways (Hansen et al., 2014). First, there are informal leases that are not included in its surveys. And second, frequently the transactions recorded do not have all data disclosed by the agencies, such as prices, because the disclosure depends on state laws. Despite this, the University of California, Santa Barbara provides a comprehensive compilation of these surveys between 1987 and 2009.[9]

As Table 2 displays, there were at least 4,608 transactions over 23 years observed in the American West, and they moved more than 43 billion m^3 in assets – as a point of reference, in Brazil the maximum volume of the Cantareira System in São Paulo is close to 1 billion m^3. Colorado had almost half of the transactions due to the operations in the NCWCD, and California had the greatest volumes traded[10]. Table 2 shows also the populations[11], pointing

[6] See northernwater.org.

[7] See The Economist, February 22, 2014,"The drying of the West."

[8] See journalofwater.com.

[9] See bren.ucsb.edu.

[10] Hansen et al. (2008) provide an empirical analysis of this case.

[11] The number of water rights awarded is not publicly available in all states. In Colorado and Oregon there were 129,355 and 88,379 rights, respectively, in 2015. Comparing these numbers with the populations, it is possible to

that even in relative terms Colorado has the most transactions (443 per million inhabitants) – which corroborates with the idea presented earlier that the figure of a water bank is fundamental to increase the trading by reducing the transaction costs.[12]

Table 2: **Water rights transfers between 1987-2009 (numbers and assets), and population in 2010.**

State	[a] Number of transfers	[b] Assets (billions of m^3)	[c] Population (millions)	[a]/[c]	[b]/[c]
Arizona	238	10.3	6.4	37	1.61
California	692	15.5	37.3	19	.41
Colorado	2,228	1.9	5.0	443	.38
Idaho	148	8.1	1.6	94	5.16
Montana	59	0.1	1.0	60	.11
New Mexico	153	0.7	2.1	74	.36
Nevada	402	0.4	2.7	149	.16
Oregon	130	1.5	3.8	34	.39
Texas	346	3.4	25.1	14	.13
Utah	87	0.5	2.8	31	.16
Washington	59	0.4	6.7	9	.54
Wyoming	66	0.4	0.6	117	.79
Total	4,608	43.2	95.0	48	.46

Data source: Journal of Water Surveys and Iseman et al. (2012). Elaborated by the author.

Also in Table 2, note that despite the fact that Colorado has had more transfers, the assets have relatively had less volume. This reflects the fact that in Colorado most of the transfers are among irrigation farms, while in Arizona, California and Idaho, for example, most transfers are from agriculture to municipalities – with the purpose of protecting the cities from lacking water (Brookshire et al., 2004).

Table 3 shows the origins and destinations of the transfers considering agriculture zones, urban areas, and the environment (Donohew, 2009). The numbers show that 16.4% of the transfers have had origin and destinations inside the agriculture zones. Moreover, 82.9% of all transfers originated in this sector, and the main destinations were the urban areas, followed by the environment (basically the recharge of degraded watersheds). This reflects the fact that the irrigators have the highest number of water rights in the American West. On the other hand, as it was discussed earlier, urban users have greater marginal values for water, thus they are looking for farmers to try reallocating resources. This movement involves a lot of money too – despite less than 2/3 of the observations having values recorded in the dataset, the total was more than 5.6 billion of dollars.

estimate that there are around 25 rights per 1,000 inhabitants in the American West. In these terms, there would be more than 2 million rights in this region, and the trading of 4,608 rights could be less than 0.5% of the total.

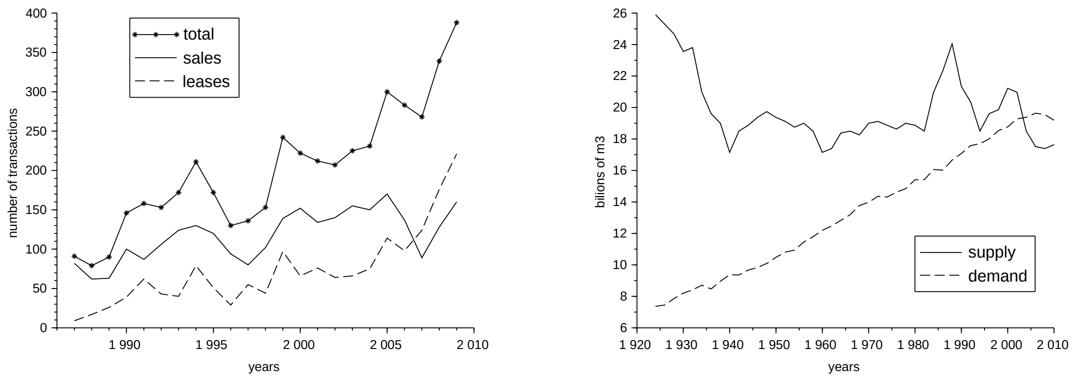
[12] Payne et al. (2014) provide an empirical analysis for this point in the Colorado case.

Table 3: **Origins and destinations of water rights transfers: % of the total.**

		Destinations			
		Agriculture	Urban	Environment	Total
Origins	Agriculture	16.4	56.5	10.0	82.9
	Urban	1.2	13.8	1.9	16.8
	Environment	0.0	0.0	0.2	0.2
	Total	17.6	70.4	12.1	100.0

Data source: Journal of Water Surveys and Donohew (2009). Elaborated by the author.

Ahead Figure 1(a) shows that the transactions have had an ascending trend during the period analyzed, and that the leases' operations have had as much presence as sales[13]. This ascending trend can be justified by the drought risk. To illustrate the situation, Figure 1(b) is showing the supply and demand in the Colorado River Basin system between the 1920s and 2000s – the basin provides approximately 42% of the fresh water in the American West. While the supply historically offered by the hydrological cycle is around 18 billion m^3 per year[14], the average demand for water in the basin has exceeded this level every year since 2003. This is forcing the users to get water from other systems, using the marketplace as a solution (Culp et al., 2014; Iseman et al., 2012; Pullen and Colby, 2008).



(a) Water rights transferred. (b) Colorado River Basin system.

Figure 1: **Number of water rights transferred by year (1987-2009), and supply and demand of the Colorado River Basin system (1920s-2000s).**
Data source: Journal of Water Surveys and United States Bureau of Reclamation. Elaborated by the author.

In short, the marketplace in the US has been asleep for almost 100 years (between the 1890s and the 1990s), but the lack of new water resources and an increasing demand are waking it up. Moreover, the data corroborate that in a situation of shortage, the market for water-access entitlements can be a tool of reallocation to sectors with larger marginal values of use if transaction costs are low enough, which depends on the available infrastructure and legislation.

[13]In addition to these operations, there were also exchanges (not plotted) representing less than 5% of transactions.

[14]The supply concept is of the “hydric availability”.

On a global scale, the literature shows the idea of water markets as a tool to deal with shortages is becoming more popular. However, there is not a common model; each country is working with its own arrangements and different motivations[15]. But even in the US, which apparently has the oldest and most experience with water markets, what is to come is not very clear. The market still is very immature, and nobody seems to predict with some certainty how this marketplace will be throughout the 21st Century.

3 The likelihood of a water market in Brazil

OECD (2015) presents a detailed evaluation of the contemporary Brazilian water governance[16]. Among its many contributions, the report summarizes the literature that describes the basin committees' difficulties introducing the users' contributions system, as set by law in 1997. Consequently, there are few financial resources to improve water management.[17]

The report also describes the government's advances in controlling access to hydric resources by emission and supervision of water diversion entitlements. However, this control is still too weak to enforce an efficient allocation and utilization among the users. According ANA (2013), there were 204,607 permits recorded in 2012 in Brazil, which is not significant for a country with more than 200 million people. To compare, in Colorado, a state with 5 million residents, there were 129,355 permits recorded in the same year.

In short, OECD (2015) pointed that there is ample resistance from the system of contributions, many challenges in the controlling and planning of the use of watersheds, and significant issues related to the lack of infrastructure and management of water availability. In conclusion, the report suggests that the transformation of permits into water rights (i.e., entitlements with tradable property rights) could be a complementary tool for governance, and perhaps even replace an ineffective system of contributions.

The OECD proposal is in line with the law project #6979/2002 that was under discussion in the National Congress until 2013. In this project, the general idea was that a market could reallocate water between users during droughts or in the Brazilian semi-arid, and a percentage of traded value could increase the contributions to the watersheds' management. Moreover, insofar as the market maturing, possibly there would be greater interest on behalf of the economic agents to fund large storage and distribution infrastructures.

But regardless of the proposals, looking at the US case, it has been evident that the birth of a water market is determined fundamentally by four variables: water scarcity, heterogeneity in water endowments, different values of use, and transaction costs. In the absence of a threshold of these magnitudes, it may not make much sense to talk about a market. Thus, to analyze the likelihood of a marketplace in Brazil, these points will be considered in sequence.

[15] See the cases in Mexico (Garner, 1997; Rosegrant and Binswanger, 1994), Australia (Easter et al., 1999; Garner, 1997; Harris, 2013), South Africa (Bjornlund and McKay, 2002; Garner, 1997), Chile (Bjornlund and McKay, 2002; Easter et al., 1999; Garner, 1997; Rosegrant and Binswanger, 1994), India (Easter et al., 1999), China (Bjornlund and McKay, 2002), Israel (Berck and Lipow, 1994), Portugal (Easter et al., 1999), and Spain (Garner, 1997).

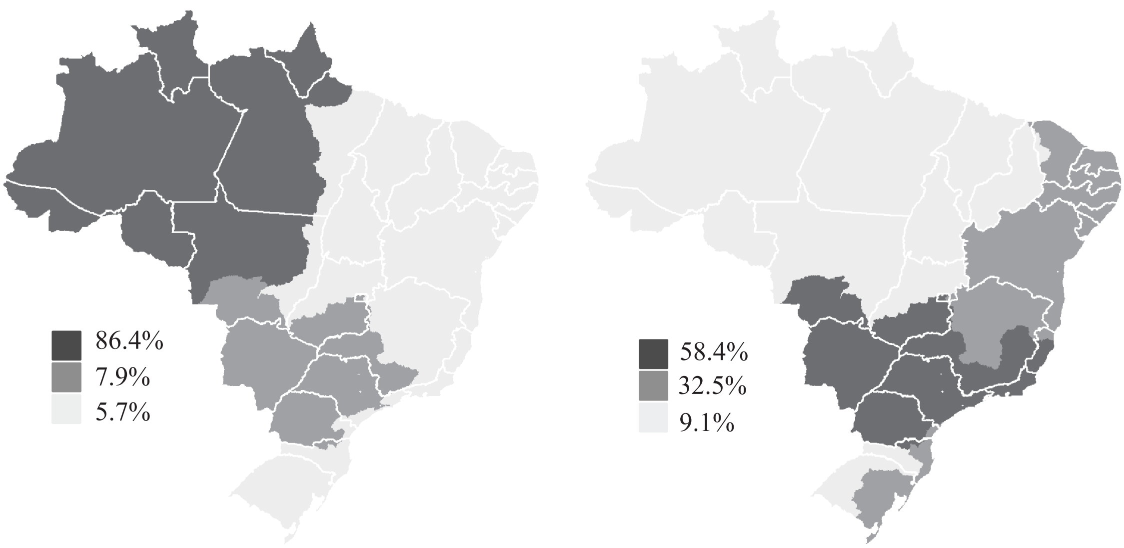
[16] The history of water governance in Brazil is in ANA (2002).

[17] See a detailed discussion of this point in Carrera-Fernandez and Garrido (2000), Lemos and De Oliveira (2004), Campos (2005), Abers and Keck (2009), Leite and Vieira (2010), Malheiros et al. (2013), and Freitas (2015).

3.1 The Brazilian hydric availability

As OECD (2015) points out, Brazil has 12% of the world's "hydric availability," i.e., the amount of water that can be removed from watersheds without substantially altering the hydrologic cycle and the opportunities for future use. But this fact does not imply that the country is operationally abundant in water, because the abundance does not mean much without the existence of ways to exploit it.[18]

To illustrate that it is not easy to exploit this abundance, Figure 2 shows the spatial distribution of the hydric availability and of the urban consumption[19]. The left map shows that 86.4% of Brazilian water is in the Amazonic hydrographic region (the darker area), 7.9% is in the hydrographic regions of Paraguai and Paraná (the less dark area), and the rest is spread throughout the area closer to the coast[20]. On the other hand, Figure 2(b) shows that the urban consumption is on the opposite side of the country – thousands of km away from the Amazon region. The maps are like an inverse mirror of each other, and it can be concluded that almost all urban needs must rely solely on 13.6% of available water there.



(a) Hydric availability. (b) Urban consumption.

Figure 2: **Spatial distribution of hydric availability and urban consumption by hydrographic regions and among states in 2010.**
Data source: ANA. Elaborated by the author.

But, even without considering the Amazon region, the data indicate that Brazil still will have water availability, though not necessarily water access. Table 4 displays the water use by sectors to illustrate the distance from a chronic problem. According the ANA surveys in 2006 and 2010, the total consumption increased from 54.1 to 72.3 billion m^3 between these years. In terms of water availability, the numbers indicate that was used 14.5 and 19.4% of the limit

[18]See The Economist, April 26, 2014, "Water in Brazil: Nor any drop to drink."

[19]To be consistent with the data shown for the US case, the sum of urban and industrial uses recorded in ANA (2013) are considered urban consumption.

[20]Some readers may be surprised that the area of the São Francisco River is not darker in color, but it must be remembered that the map is showing water availability, and that this basin was at the limit of its use capacity in the recent years.

to do not compromise the set of watersheds. To compare, as Figure 1(b) displayed previously, the majority of the American West is above 100% in this indicator. Consequently, even without counting the Amazon region, there is a good water supply, although there is an indication of increasing consumption.

As can be seen too in Table 4, the agricultural use increased from 31.6 in 2006 to 44.5 billion m^3 in 2010 – meaning an increase of 40.8%, while the increase in the urban use was 23.5%. This indicates that agriculture is significantly increasing water consumption, and there are at least two explanations for it (ANA, 2013). First, besides being a larger water user by nature, the sector is performing economically better than urban sectors in recent years. And second, irrigation activities are growing faster than other agricultural activities.

Table 4: **Water use by sectors agriculture and urban – without consider the Amazonic region.**

Use,	billions m^3		% of the hydric availability	
and year	2006	2010	2006	2010
Agriculture	31.6	44.5	8.5	12.0
Urban	22.5	27.8	6.0	7.5
Total	54.1	72.3	14.5	19.4

Data source: ANA. Elaborated by the author.

However, despite the water availability in Brazil, drought problems are frequent. Table 5 shows more than 10% of the municipalities of the country frequently have intense or moderate scarcity problems. And, more than 35 percent of the cities lacked water in 2012.

Table 5: **Percentage of Brazilian municipalities with an intense or a moderate lack of water (2003-2012).**

Year	Intense	Moderate	Total
2003	2.46	11.81	14.27
2004	3.11	10.16	13.27
2005	4.49	21.67	26.16
2006	1.58	11.83	13.41
2007	1.33	14.02	15.35
2008	0.88	9.41	10.29
2009	0.65	12.87	13.52
2010	1.67	8.69	10.36
2011	0.04	2.28	2.32
2012	0.97	34.67	35.64

Data source: ANA. Elaborated by the author.

At any rate, as pointed out by OECD (2015), the fact is that there are not water problems due to a widespread drought, like in the case of the American West. The water problems in Brazil are more connected to a lack of infrastructure. And under the imminence of water market implementation, a more basic issue must be pointed out: the permits need to be transformed on tradable rights. In this way, this transformation can be explored like an opportunity, and a mechanism for the distribution of water rights can be useful in aligning incentives and to take advantage of water availability. This is addressed in sequence.

3.2 An economic model to analyze incentives and transaction costs

To better understand when the market can be a solution for water problems (and when it cannot), a simple model is developed here. In this way, as Figure 3 describes, nature might reveal a "normal time" (i.e., water availability at least equal to the sum of volumes in all permits), or a "dry time" – when the government needs to reduce the volumes of all the water diversion entitlements (e.g., in a river).

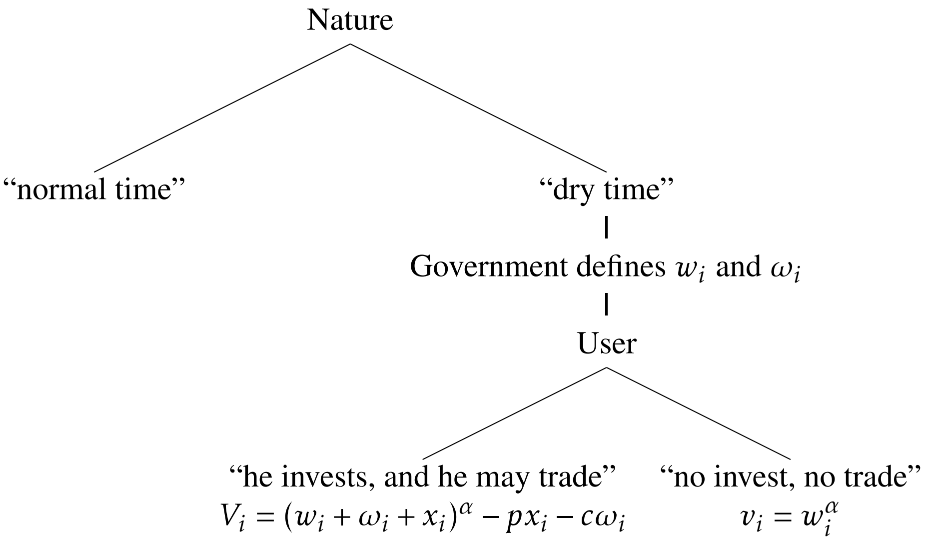


Figure 3: **Model description.**

In this scenario, each user indexed by i has a permit to divert w_i with no cost. Moreover, during a normal time, each user could invest in some infrastructures for storage ω_i at the marginal cost c (including all engineering and transaction perspectives). The government wants to enforce all possible hydric infrastructures to use in dry times, and the maximum ω_i that each user can offer is supposed to be known[21]. For that reason, the government is analyzing an "if invest you may trade" rule – i.e., if the user invests to reach ω_i, he will have the right to trade water. Therefore, in this model the water rights are granted for the users that built water storage infrastructures determinate by the government.

Consider that the water value of use is a_i^α for any volume $a_i \geq 0$, with $\alpha > 0$. Then each user has two options: "invest," which gives him a payoff $V_i = (w_i + \omega_i + x_i)^\alpha - px_i - c\omega_i$, where p is

[21] Although this is not a trivial task in reality, because the geography (and other aspects) does not permit a specific rule. Consequently, each case needs to be analyzed separately.

the market price and x_i is the choice of water fraction to trade (if $x_i > 0$ he chooses to buy, and if $x_i < 0$ he chooses to sell); or "no invest," which gives him a payoff $v_i = w_i^\alpha$, that represents the value of use only of the permit. The price and potential volumes traded are determined by a static game of complete information among the users, then the strategies are: "invest" and trade $x_i \in [-(w_i + \omega_i), \sum_{j\neq i}(w_j + \omega_j)]$; or, "no invest".

If n players choose "invest," the market equilibrium is the price and n supplies and/or demands for supplementary water that solve the system formed by: reaction curves $p = \alpha(w_i + \omega_i + x_i)^{\alpha-1}$, indicating that the marginal benefits are balanced (otherwise some users are willing to continue trading); and, the market clearing condition $\sum_i x_i = 0$. If diminishing marginal returns are valid (i.e., if $\alpha < 1$), the equilibrium price is $p^* = \alpha/(\overline{w})^{1-\alpha}$ and the equilibrium trading is $x_i^* = \overline{w} - (w_i + \omega_i)$, given the average hydric available to trade $\overline{w} = \sum_i(w_i + \omega_i)/n$. The net payoff is defined by $U_i = V_i - v_i$, and considering U_i^* as the value in market equilibrium, the Nash equilibrium in this game happens when n users choose "invest" and trade x_i^* if $U_i^* > 0$ and other users choose "no invest" if $U_i^* \leq 0$.[22]

From the government perspective, with a dry future certain, the rule "if you invest you may trade" is considered feasible if occurs $\sum_i \omega_i > 0$ in the Nash equilibrium. Consequently, the rule can be implemented when $U_i^* \geq 0$ for all i and $U_i^* > 0$ for at least one user i (i.e., when the Nash equilibrium implies in a Pareto superior situation). To identify the determinants of this situation, conveniently the permits can be written as deviations of the average hydric available to trade: $w_i = q_i\overline{w}$, for any $q_i \geq 0$. Then U_i^* can be written by:

$$U_i^* = \overline{w}^\alpha \left(\Big[1 + \alpha q_i\Big] - \Big[\alpha + q_i^\alpha\Big] \right) + \Big[(p^* - c)\omega_i\Big] \tag{1}$$

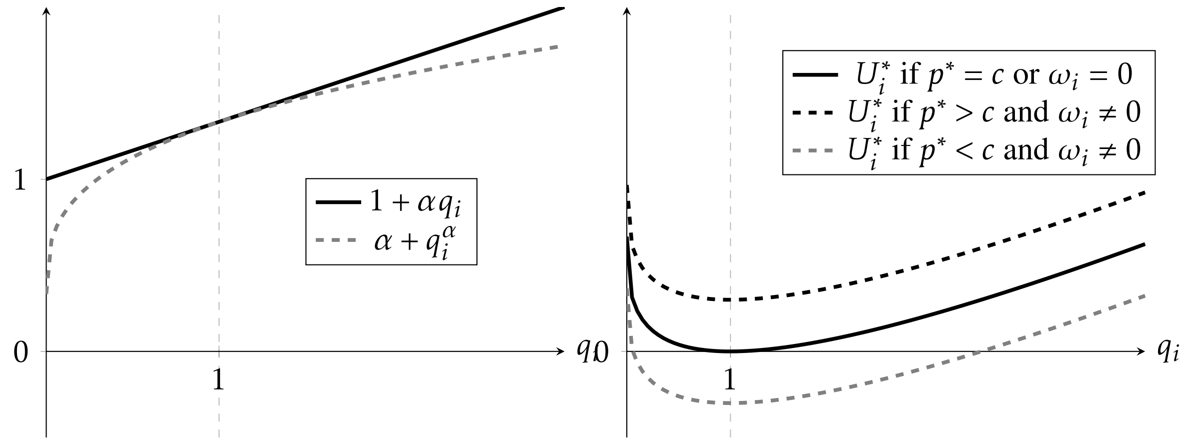
In the equation (1), note the net payoff is essentially determine by the differences $[1+\alpha q_i] - [\alpha + q_i^\alpha]$ and $p^* - c$. Moreover, note that when $\omega_i = 0$ for all i, and the trading is permitted, there is a "pure exchange economy." Therefore, U_i^* is the sum of two outcomes: one resulting from a pure exchange economy; and, other resulting from a potential profit when there is the production of supplementary water.

Because $\alpha < 1$, it occurs that $\overline{w}^\alpha > (w_i^\alpha + w_j^\alpha)/2$ for any $w_i \neq w_j$, and consequently $w_i^\alpha - \overline{w}^\alpha \neq \overline{w}^\alpha - w_j^\alpha$ without trading. This means that, if there are decreasing returns, the marginal water value is different between users because the permits are not equal, and it implies that trade in a pure exchange economy puts the users in a Pareto superior situation – a known result by economic theory in the absence of market failures. Complementary, the potential profit of the water production is positive ever the market price is larger than the marginal cost involving the investment. Moreover, $U_i^* > 0$ occurs even if the profit is negative, provided that it is smaller (in absolute value) than the pure exchange economy outcome. Putting this together, Figure 4 illustrates all net payoffs possible in the Nash equilibrium.

The left graph in Figure 4 illustrates the difference between $1 + \alpha q_i$ and $\alpha + q_i^\alpha$. It is 0 only when $q_i = 1$, i.e., when the user permit is exactly equal to average hydric availability. This is reflected by the solid line in the right graph, that is plotting U_i^* if $p^* = c$ or $\omega_i = 0$ (i.e., when price and marginal costs are equal, or in a pure exchange economy situation). If the user permit is smaller than the average hydric availability (i.e., $0 \leq q_i < 1$), he desires to buy water because he has a bigger marginal value of use. On the other hand, if $q_i > 1$ he desires to sell because he has a smaller marginal value of use. With infrastructure construction, if $p^* > c$ the results are

[22] Subjectively, it is considered when the net payoffs are equal the decision "no invest" prevails.

potentially bigger even if $q_i = 1$ (the black dashed line), because the user can sell or use himself the water stored – then the strategy "invest" is strictly dominant for all players only if $p^* > c$ and $q_i \neq 1$ for all i. Additionally, if $p^* < c$ the trading can be a good option or not for the user. Ultimately, the strategy of "no invest" has a threshold evolving p^* and c.



Cases	$0 \leq q_i < 1$	$q_i = 1$	$q_i > 1$
$p^* = c$ or $\omega_i = 0$	$U_i^* > 0$	$U_i^* = 0$	$U_i^* > 0$
$p^* > c$ and $\omega_i \neq 0$		$U_i^* > 0$	
$p^* < c$ and $\omega_i \neq 0$	$U_i^* \geq 0 \Leftrightarrow q_i \to 0$ and $(1-\alpha)\overline{w}^\alpha + (p^* - c)\omega_i > 0$	$U_i^* < 0$	$U_i^* \geq 0 \Leftrightarrow q_i \to +\infty$

Figure 4: **Net payoffs possibilities in the Nash equilibrium.**

Considering the US case, where it is well documented that the transaction costs are high and there are a lot of investments in infrastructure, the possibilities where $p^* < c$ and $\omega_i \neq 0$ seem to be closer to the reality. The point is that if the user has very little water ($q_i \to 0$), the marginal benefit to have more water is very high. Consequently, some financial loss in the present investment is acceptable to get benefits in a potentially future dry, if this loss is not greater than a threshold – in the model, the result $(1 - \alpha)\overline{w}^\alpha + (p^* - c)\omega_i > 0$ needs to happen (i.e., the pure exchange economy outcome when $q_i = 1$ needs to be bigger than the potential loss of the investment in infrastructure). On the other hand, if the user has much water ($q_i \to +\infty$), the market is an even better result for him – because he can sell the excess volume.[23]

In short, in the model developed here there are four points (not mutually exclusive) involving a Pareto superior scenario. First, a shortage situation needs to exist to adjust the permits w_i and/or motivate the offer of supplementary water ω_i. Second, this situation needs to create some heterogeneity in the endowments – i.e., $q_i \neq 1$. Third, the marginal benefits for water use needs to be different between users – in the model, $\alpha < 1$ permits this. Finally, there is a threshold when the absence of profit in the production of supplementary water precludes the market – i.e., p^* can be smaller than c until a limit.

In its simplicity, the model developed here can explain some facts observed in the US case, as the prevalence of market operations at the same time where there are high transaction costs.

[23]The numbers of this movement trade were discussed previously for the US case in the analysis of Table 3.

In addition, the model is also potentially useful for a deeper discussion about the possibility of the implementation of a water market in Brazil. And thus, it may also be useful as a basis for the development of other economic models that include aspects closer to reality.

The model can be expanded in many ways. First, some dynamics can be included, and thus can be considered a probability distribution of the risk of dry times in future – the game gains an aspect of incomplete information. Second, ω_i can be considered a private information of players, where the government and other players have only partial information on how much supplementary water each user can offer – the game gains an aspect of imperfect information. Third, other types of infrastructure can be incorporated in addition to the storage capacity, such as a system of channels that may reach different users or transport water of differing qualities and evaporation levels. Fourth, other transaction costs and externalities may be incorporated in the model, such as the judicial costs and other aspects discussed in Donohew (2009). Fifth, it can imcorporate the simultaneity of the market and the system of contributions, as well as the resistance from the users to exchange governance models as discussed in OECD (2015). Sixth, bargaining rules may be implemented in the case that the Nash equilibrium is not Pareto superior, but at the same time the social gain is large enough to implement the market – i.e., if $U_i^* < 0$ for some $i = 1, ..., I < n$ and $\sum_{i=1}^{n} U_i^* > 0$, there is space to bargain the social benefits and implement the market.

Regardless of the potential expansions, using the model in the simplest version, a forthcoming example is developed to show how the transformation of permits into water rights can be explored as an opportunity to take advantage of Brazilian hydric availability. Specifically, the idea is to better understand how the government could define the levels ω_i (which has hitherto been considered exogenous). To do this, illustratively, a real case is considered.

3.3 The water bank example and the ω determination

To exemplify the possibility of aligning the incentives to have a better hydric infrastructure, the case of the interconnection between the Paraíba do Sul river and the Cantareira system in São Paulo is examined. It is a construction of 20 km, at cost of 140 million of dollars, funded by the state government to mitigate future water crisis, that could be a water bank[24]. Downstream there are about 1,100 users with permits to divert a total of almost 2 billion m^3 per year, and in the Cantareira side the SABESP[25] is allowed to divert another billion. While the river flow is above the sum of the permits, the bank could be filled. In the future, during dry times, the floodgates could be opened to supply water. So, this project could be funded by a private agent (a water banker) in exchange for some kind of water rights. In this case, the law could give the right for the banker encash these users for the water recharging services.

The potential banker could be a big economic player among the river users, such as the CSN. This firm is the second largest steel-maker company in Brazil, and its permits represents more than 12% of the total volume of diverts allowed in Paraíba do Sul. As such, this firm is one of the most interested users in the functioning of a safe system to supply water, and it has ways to fund the project.

[24] See *Folha de São Paulo*, Dec. 10, 2015, "SP, MG e RJ fecham acordo de gestão do rio Paraíba do Sul para beneficiar Cantareira."

[25] It is the largest utility company in the world by market capitalization, providing water and sewage services to residential, commercial and industrial users in the city of São Paulo and in 363 of the 645 municipalities in São Paulo state.

In this scenario, suppose that with certainty of a dry future occurs $w_i = 0$ for all i – i.e., the river's hydric availability is at its limit, and nobody can divert anything more. On the other hand, consider that there is an user indexed by b (the banker) funding a infrastructure upstream with capacity ω.

In the model terms, this situation implies $\omega_b = \omega$ and $\omega_i = 0$ for all $i \neq b$. The banker can open the floodgates to supply x_i for each user i downstream diversions (including himself). Moreover, it is considered that all users are honest – i.e., nobody diverts if he does not pay, and when somebody diverts the volume is exactly equal to what it is paid. In this case occurs: $x_i^* = \overline{w} = \omega/n$ for all $i \neq b$; $x_b^* = \omega/n - \omega$; and, $p^* = \alpha/(\omega/n)^{1-\alpha}$. Since $q_i = 0$ for all i, including the banker, substituting this results in equation (1), the net payoffs are:

$$U_b^* = \left(\frac{1+\alpha(n-1)}{n^\alpha}\right)\omega^\alpha - c\omega \tag{2a}$$

$$U_{i\neq b}^* = \left(\frac{1-\alpha}{n^\alpha}\right)\omega^\alpha \tag{2b}$$

With these net payoffs, if $\omega \leq ([1+\alpha(n-1)]/[cn^\alpha])^{1/(1-\alpha)}$, the government can enforce any ω to implement the market in a feasible way – i.e., to establish a Pareto superior situation (the limit in ω is illustrated in the left graph of Figure 5). To choose ω, the government can use a rule to maximize some social welfare function subject to restriction $U_b^* > 0$, e.g., $\sum_{i\neq b} U_i^* + U_b^*$ (this objective function is illustrated in the right graph of Figure 5).

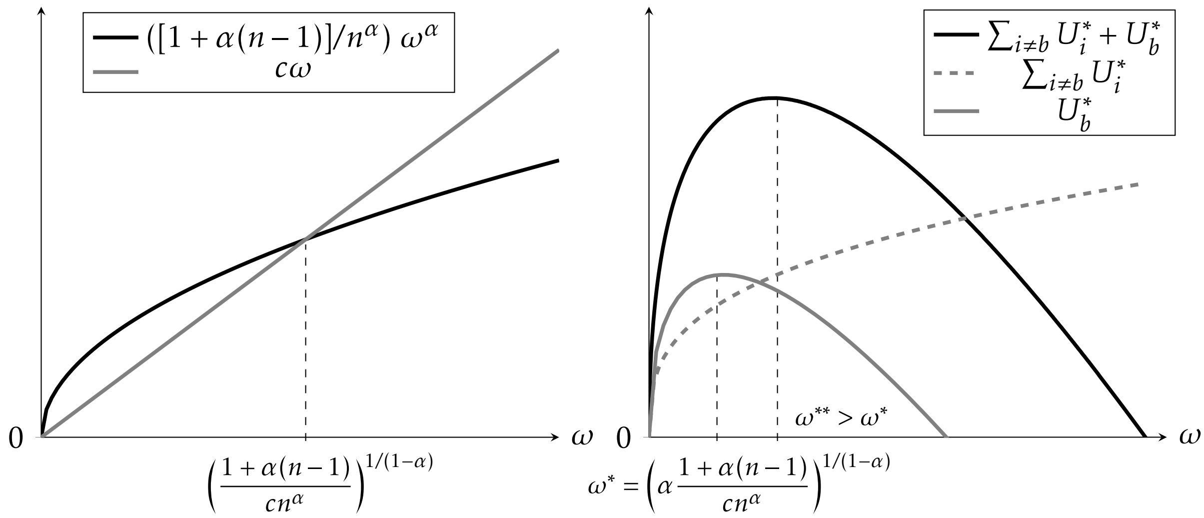


Figure 5: **Net payoffs possibilities in the Nash equilibrium in the water bank example.**

In this example, the optimum point in the social perspective is $\omega^{**} = n(\alpha/c)^{1/(1-\alpha)}$, while the optimum point in the banker perspective is $\omega^* = (\alpha[1+\alpha(n-1)]/[cn^\alpha])^{1/(1-\alpha)}$. As illustrated in Figure 5, $\omega^{**} > \omega^*$, meaning the government could enforce a supply bigger than the monopolist offers. Therefore, all users can be in a better situation if the government implements this water market, changing only the banker water diversion entitlements in keeping with the property rights.

4 Final remarks

This paper has been analyzing the likelihood of a water market in Brazil, accordingly with what the media has published in recent months. As this issue is still an uncommon discussion in economic literature of Brazil, this analysis has started by looking at the history of these markets – in particular the US market, which is potentially the oldest and most well-documented case.

In the American West, water access entitlements were transformed into property rights more than 140 years ago, and they are known today as "water rights". Despite the water rights trading be possible for many years, a marketplace began to operate regularly just a few years ago, because the transaction costs are too high. In fact, the increased water demand and the non-existence of new sources are becoming the market a feasible option to allocate endowments.

Analyzing the Brazilian data, it is easily noted that the country does not have a water availability problem – as is the case in the American West. On the other hand, Brazil has a considerable lack of infrastructure to store and distribute water. Hence that a fact with no sense is regularly observed: the country has 12% of the world's fresh water, while more than 10% of the cities frequently lack water.

To implement a water market, the first step is to change permits to divert water within one's water rights. In this paper, it was argued that this can be an opportunity to align the incentives of economic agents to build new water infrastructures. Using an economic model, it was shown that a game can be implemented to put society in a Pareto superior situation. This outcome intrinsically depends on the transaction costs, expected water availability in the future, and different marginal benefits of water use among players.

Lastly, this research observed that water markets are increasing all around the world, and this is a relatively new research agenda in many countries. But even in the US, which has the most experience in this type of trading, the market is still very immature. There are few data to analyze, and many challenges wanting answers from economy theory.

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