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Water Markets and Climate Change Adaptation: Assessing the Water Trading Experiences of Chile, Australia, and the U.S. with Respect to Climate Pressures on Water Resources

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WATER MARKETS AND CLIMATE CHANGE ADAPTATION:

Assessing the Water Trading Experiences of Chile, Australia, and the US with Respect to Climate Pressures on Water Resources

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PREFACE

To add to the complexity of assessing the many implications of any water management strategy, water markets carry with them a philosophical debate over the significance of water as a human right or economic good, and an association with the blind application of neoclassical economic theory. The politics of this debate and association can hardly be separated from the academic and policy literature on water markets of the last few decades. We see, on the one hand, recommendations for the creation of water markets as the most sophisticated tool for water allocation coming from development organizations in some of the early literature. On the other hand, when acknowledging the mixed and complex results of water markets throughout the world, other research qualifies the recommendation of water markets with enough concerns to suggest that markets may be better left untouched. Climate change is then added to the picture, often showing up as a final consideration that further confuses the role of water markets in effective water management. With this understanding of the literature and academic consensus (or lack thereof) on water markets and climate change in mind, I have spent a semester seeking to position the vast literature on water markets' outcomes against a set of questions that about climate change adaptation goals.

INTRODUCTION

Climate change is no longer just a future threat to be mitigated through reducing greenhouse gas emissions, but must also be addressed through aggressive adaptive measures. Many effects of climate change are and will increasingly be manifested through water. Predictable cycles and sources of freshwater will become more volatile and already-unpredictable water-driven forces such as tropical storms will increase in intensity and frequency. As defined by the International Panel on Climate Change (IPCC), adaptation is defined as “the process of adjustment to actual or expected climate and its effects. In human systems, adaptation seeks to moderate or avoid harm or exploit beneficial opportunities. In some natural systems, human intervention may facilitate adjustment to expected climate and its effects” (IPCC 2014). Because of the strain climate change is and will increasingly place on water resources for all uses, it is crucial to examine the adaptation options available today and past experiences with different models. Though the effects of climate change remain uncertain and adaptation options will bring significant costs to society, it is more certain that the cost of inaction on climate change and addressing freshwater scarcity is higher.

Water markets, touted by economists as a sophisticated approach to water resource management, are currently implemented to various degrees in several parts of the world. The possibility of applying water markets as a policy tool for climate change is appearing in current research, though only recently. While the literature explicitly exploring water markets as a climate adaptation tool is limited, there is extensive literature on the cases of water markets throughout the world and their outcomes under different climatic conditions. If academics give a qualified “yes” to using water markets for management of water scarcity, what do these qualifications mean in practice? Where in the world may water markets be successful adaptation tools? What does the institutional structure, water rights system, economic and political history, and physical environment need to look like for water markets to become useful? Based on existing markets throughout the world, can we expect them to address the increasing variability in water supply that climate change will present? The scholarly literature answers portions of these questions empirically and anecdotally, and together begins to make a set of recommendations for the use of water markets in climate change adaptation. As water markets have only recently been added to the list of possible climate change adaptation policy tools, the answers to these questions are found throughout water market and water management literature. While new empirical investigations into water markets and climate variability will be necessary, there is a great deal of insight on this topic that can be gleaned from existing studies of water markets, and particularly those that address the effects of drought on market performance. This thesis attempts to make the most out of existing research by comparing experiences among three international water market cases.

In the Western United States, Chile, and Australia, water rights have been traded for a number of years, though these countries demonstrate considerable variety in market design, physical infrastructure, and historical context. In considering whether markets could be effective tools for addressing the effects of climate change, these cases provide a rich body of literature and set of comparisons to be made among their experiences. The Western US, with its highly developed infrastructure for freshwater transportation and relatively powerful regulatory institutions, has shown the importance of infrastructure in water trading, as well as the need for low transaction costs in forming an active water market. Chile has been an international example of a free-market approach to water management. However, without much regulatory oversight, communication among water users, or physical infrastructure for trading, Chile has seen few active markets with many conflicts resulting from the lack of governance. Australia has shown the most long-term and wide-spread devotion to developing and improving water markets, with many promising results. Though the Australian case has historically been simplified with a small presence of municipal water users compared to irrigators in the markets, Australia has demonstrated the benefits of continually reforming trading policies to include environmental considerations. When applied to the adaptation goals of accommodating increased variability in freshwater resources and greater frequency and/or length of drought in an equitable and sustainable manner, we can take many conclusions from these cases. The presence of physical infrastructure for storage and transportation of water is integral to many trading programs. Markets with low transactions costs and timely transfers are most equipped to help address the short-term needs that will arise under climate change. Water trading programs are highly successful when they closely approximate cap-and-trade policies, and facilitate constant reform to internalize third-party effects and address environmental needs. Some of the most successful programs are small and designed to address specific local needs. This set of conclusions from studying three cases results from first understanding the climate pressures on freshwater resources, the theory of water markets and cap-and-trade, and the frameworks used for assessing water management policies.

Effects of Climate Change of Freshwater Resources

Freshwater resources, a key economic input and necessity for human life, will be strained and variable under the effects of climate change. According to the latest IPCC report, the sources of most climate change effects on freshwater are increases in temperature and sea level, changes in precipitation, and greater variability in these changes (Jiménez Cisneros et al. 2014).

Indirectly, these changes will adversely affect water quality, as there will be longer and more frequent periods of reduced water quantities. Arid and semi-arid regions are particularly vulnerable to these effects, which is a consideration for water markets and their ideal locations. Significant changes from historical measures have been documented in the categories of glaciers, precipitation, evapotranspiration, soil moisture, permafrost, streamflow, groundwater, water quality, soil erosion and sediment load, and extreme events. Evidence for the effects of anthropogenic climate change on these elements of the water cycle varies from weak to strong, often limited by our inability to separate climate-drive changes from natural variability. These changes will be exacerbated by anthropogenic, but non-climate, factors such as increasing population, land use changes, new socioeconomic conditions, and technological developments (Jiménez Cisneros et al. 2014).

Despite the challenge in modeling the water cycle and climate system to quantify their interactions, there are many reliable and highly likely expectations to base adaptation plans on. Potential evapotranspiration is “very likely” to increase with climate change, causing the water cycle to accelerate (WGI AR5 Chapter 12). Glaciers will continue to lose mass and the period of peak runoff is projected to move from summer towards spring (Huss 2011). Generally, runoff is likely to increase at high latitudes and decrease nearer to the equator, though significant uncertainty exists for China, south Asia, and much of South America (Jiménez Cisneros et al. 2014). Groundwater recharge has been shown to follow the same trend as runoff, increasing where runoff is expected to increase and decreasing where runoff will decrease (Kundzewicz and Döll, 2009). Unconfined aquifers near the coast will be at risk of saltwater intrusion (Werner et al. 2012). Since heavy rainfall is likely to increase in many parts of the world, greater soil erosion will occur as a result (Seneviratne et al, 2012). This effect will be extreme in semiarid regions due to extreme rainfall and flood events. There are two kinds of drought, both of which are projected to increase in frequency and/or length by the end of the 21st century. Drought includes meteorological droughts, meaning less rainfall, and agriculture droughts, meaning drier soil. Regions particularly vulnerable to drought are southern Europe and the Mediterranean, central Europe, central and southern North America, Central America, northeast Brazil, and southern Africa (Jiménez Cisneros et al. 2014).

Global water security is already a serious issue, and climate change projects show significant declines in freshwater availability in coming years. According to IPCC projections, "each degree of global warming is projected to decrease renewable water resources by at least 20% for an additional 7% of the world population." Water security is defined by the UN as "the capacity of a population to safeguard sustainable access to adequate quantities of acceptable quality water for sustaining livelihoods, human well-being, and socio-economic development, for ensuring protection against water-borne pollution and water –related disasters, and for preserving ecosystems in a climate of peace and political stability". Only 20% of the world population is water secure (Vörösmarty et al. 2010). From a variety of global analyses of freshwater resource availability under climate change conditions, a broad set of conclusions can be drawn in global trends. Water availability is expected to follow trends in rainfall, though the models contain a wide range of spatial results. There is regional consensus that availability will decline in the Mediterranean and parts of southern Africa, while models differ when projecting results for south and East Asia. For an increase in the global mean temperature of under 2^{o}C above preindustrial, it is expected that water availability will be more greatly affected by population increase than climate change (Jiménez Cisneros et al. 2014). However, population change will not be homogenous across the globe and both drivers of scarcity will interact. A global estimate by Schewe et al. (2013) shows a 1^{o}C temperature rise leading to a severe decline in water resources, meaning a reduction in runoff greater than 20% or more than one standard deviation of current runoff, for 8% of the global population and 2^{o}C rise resulting in a 14% decline, and 3^{o}C translating to 17%. These reductions will force management decisions among the many important human and non-human users of water as scarcity increases.

A decline in freshwater resource availability will impact many water uses including agriculture, energy, freshwater ecosystems, human consumption, and others. With respect to agriculture, there is high confidence that demand for irrigation water will increase by more than 40% in Europe, the USA and some of Asia (Jiménez Cisneros et al. 2014). Some of this demand could be mitigated by increased atmospheric CO_2 concentrations, which aids in crop production. Gerten et al. (2011) concludes that population growth is likely to yield greater effects on irrigation demand than climate change. Meza et al. (2012) model the effects of climate change on irrigation demand and streamflow in the Maipo Basin in Chile, finding that irrigation water demands increase by 60-80% under climate change conditions during peak irrigation seasons. Under these conditions, it is much less probable that water rights holders can receive their allocated volumes, posing significant challenges for irrigation and agriculture. The effect of climate change on water used in energy production will depend on the infrastructure in place. Run of river dams will directly experience the increased runoff variability and some systems, such as the Lake Mead Hoover Dam, may become inoperable if reservoir levels fall too low. Water is also a crucial component of thermal power plants as it is used for cooling. Because of lower flows and increased river temperatures, there will likely be more frequent occurrences of reduced usable capacity for power plants. Municipal water users will also need to adapt to many effects of climate change that impact human consumption of water. Due to rising temperatures, snow volumes are expected to decrease and evaporation from lakes and aquifers will increase, taking away from the water sources that many municipalities rely on (Jiménez Cisneros et al. 2014). Possible intense and frequent episodes of drought will increase the need for water storage. There are also many water quality risks associated with rising temperatures, and specific coastal risks where rising sea levels could intrude into coastal aquifers.

Climate Change Adaptation

In the context of freshwater resource management, adaptation must be focused on addressing the risks presented by climate change. The World Bank (2007) lists the following goals for freshwater resource adaptation:

> "Involving all stakeholders, reshaping planning processes, coordinating the management of land and water resources, recognizing linkages between water quantity and quality, using surface water and groundwater conjunctively, and protecting and restoring natural systems are examples of principles that can beneficially inform planning for adaptation."

There is strong consensus that the principles of Integrated Water Resource Management, based on the four Dublin Principles presented at the World Summit in Rio de Janeiro (1992), are pillars that every water management plan should embrace.

1. Fresh water is a finite and vulnerable resource, essential to sustain life, development, and the environment.
2. Water development and management should be based on a participatory approach, involving users, planners and policy-makers at all levels.
3. Women play a central part in the provision, management and safeguarding of water.

4. Water has an economic value in all its competing uses and should be recognized as an economic good (Dublin Statement 1992).

These principles achieve widespread support, though partially through their vagueness. In practice there is no set of management techniques advanced by all. The Dublin Principles can be embodied in many different management and adaptation plans without dictating the specifics.

Adaptive measures for freshwater scarcity range in goal, scope, physical infrastructure, and cost. Solutions for climate change adaptation are split into two categories: "hard" infrastructural and "soft" institutional solutions. Most adaptation programs will combine both categories (Jiménez Cisneros et al. 2014). Climate change adaptation literature shows efficient irrigation and water storage development as the two most common suggested measures (World Bank 2009). This thesis is focused on the ability of water markets to serve as an adaptive measure for freshwater scarcity. Increased seasonal and annual variability in runoff is one result of climate change that we must prepare for without being able to predict which seasons or years will be wet or dry. Thus, an adaptive measure for variability must be responsive to changing conditions. Water markets provide a potential tool for addressing variability, and they may be more successful at this in some regions over others. The rationale for considering water markets as a theoretical solution for climate change adaptation comes from background in the microeconomic theory of water markets, which indicates that markets could help allocate water efficiently among users and bring the price of water up to reflect its scarcity.

Theory of Cap and Trade and Markets for Environmental Goods

Markets for environmental goods and cap and trade policies are the result of applying market theory to environmental management. Given the intuition that a market can help allocate resources towards their highest valued and most efficient use, using a market in management of a natural resource should yield these desirable outcomes as well. The buying and selling of an environmental good can be complemented with an overall market cap, or limit on the use of some good or production of some form of pollution. Examples of trading in environmental goods exist for water, sulfur dioxide, carbon dioxide, and other pollutants. These examples provide insight into the workings of such a market, the conditions that allow them to yield desirable results, and the outcomes that come from trading. In the most well-known application of cap-and-trade policies, total carbon dioxide emissions are limited for a given region and pollution allowances are allocated among emitters, who may then trade these allowances. The polluters who can most easily accommodate pollution reductions will sell their allowances to polluters who depend most strongly upon being able to emit carbon dioxide. The cap can be incrementally lowered based on environmental needs. While trading in an environmental “bad” such as carbon dioxide addresses an over-abundance of the pollutant, trading in an environmental “good” such as water can help manage scarcity. Water rights are analogous to CO_2 allowances in that they may be defined as portions of a larger cap or extraction limit. Within this cap on water diversions, water users must decide whether they will be made better off by using the volume of water associated with their water rights, or by selling the rights to another user. With a clear, defined price associated with a given quantity of water, users are encouraged to make efficient use of the resource. As a scarce resource that will become even more so with climate change, it is important that municipal, agriculture, and energy production processes for using water are as efficient as possible. Also, based on the notion that markets can lead to optimal resource allocation, water markets can help direct water quantities towards their highest-valued uses.

There are many reasons why a market for water may not behave like the optimal perfectly competitive market that economists speak of. Water is a quintessential example of a resource that does not behave as a normal private, tradable good. It exhibits many characteristics of a common-pool resource that is rival but non-excludable. Rival refers to the fact that consumption of water by one user means that another use cannot consume as much, and non-excludable means that it is difficult to prevent anyone from using the good. To complicate this definition of water as a common-pool resource, water also has properties of a public good, where its use by one party does not interfere with its use by another. This occurs, for example, in the environmental roles of water where it supports habitats and humans at the same time. Both public goods and common-pool resources differ from traditional, private goods in that a competitive market may not properly allocate these goods without outside regulation. Common-pool resources commonly suffer from excessive use, "congestion," and quality degradation. Public goods fall victim to the same troubles, as well as the "free-rider" problem where some users of the good do not pay. However, effective markets for public and common-pool resources can exist through careful management by some outside regulatory body.

Water markets specifically must address many unique historical, economic, and physical properties of water and water rights that make this good different from the ideal private good. Creating a market of water rights is challenging for many of the following reasons: water rights are often tied to land rights, conveyance of water can be costly and even impossible, many third-party effects can occur, and there may be an unequitable initial allocation of water rights. Competitive markets hinge on clearly defined property rights, meaning that implementing water markets often involves involving or standardizing water rights. Trading water away from its original location means having water rights that are separate from land rights. In places such as the US, there are many types of water rights based on different legal systems, making trading among users difficult to administer without extensive litigation. In the three case studies presented in this thesis, there are several forms of water rights encountered. Under a system of riparian water rights, land-owners have a right to use the water on or adjacent to their property. In a system of prior appropriation, a right is created with initial diversion of water in more of a first-come, first-serve manner. Some places in the world have "use it or lose it" provisions where water rights cannot be idly held, but must be actually used. With this variety in legal structure, implementing a water market often involves making challenging legal changes.

The physical transfer of water is determined by the existence of infrastructure such as reservoirs, dams, and canals. Without hydraulic infrastructure, water trading is limited to natural movement of the resource. Externalities occur when third parties other than the buyer and seller of a good are affected by the transfer and the market in general. There are many ways externalities can result from water trading. Because water is simultaneously a good for consumption and a necessity for the natural environment, the movement or use of water will necessarily affect the hydrology of a region, and thus the other water users in the area. For instance, the extraction of groundwater under one land segment will impact the height of the water table in neighboring regions. Finally, market outcomes depend on who begins with possession of the good. These are all considerations in the design of a water market and areas of strength or weakness that appear in the experiences of Chile, Australia, and the US.

Two views exist on the legal structure of water rights: more traditional neoclassical views on water markets specify that rights must be legal in nature, while contemporary research points out the existence of more informal contracts that are traded (Easter et al. 1999). The broad advantages of implementing a market in any industry include reaching the most efficient allocation of resources, sending goods to their most highly valued use, and encouraging private innovation. Where informal water markets exist, they help in sending water to its highest-valued use and encouraging some conservation and efficiency, but they lack the institutional strength to fund infrastructure development or support long-term transfers. Formal water markets, which are the focus of this thesis, require greater planning and institutional resources, but can increase the benefits seen in informal markets by reducing the negative outcomes associated with illegal markets (Thobanl 1997). These markets help direct the price of water to reflect its scarcity, or opportunity cost. Formal water markets allow for seasonal leases and spot market transactions, and regulatory agencies can be more involved in monitoring operations and outcomes (Thobanl 1997). Examples of water trading exist in Mexico, Chile, Australia, the southwestern United States, South Africa, areas in South Asia and some of Spain. The most famous examples exist in the Western United States, Chile, and Australia. These case studies will be the focus for answering the questions laid out in this thesis.

Assessing Water Institutions and Markets: Theory and Literature

Evaluating the possibility of water markets as a policy tool for climate change adaptation requires a framework for understanding the desired outcomes of a water management strategy, or specifically, a water market. Both academics and policy institutions have created such frameworks, which are briefly reviewed here to guide later analysis of regional water market cases. Developing these frameworks has often been a matter of translating broad normative statements, such as those laid out in the Dublin Principles, into more specific outcomes. The Water Institutions Health Index (WIHI) created by Saleth and Dinar (2005) and Saleth and Dinar (2004) introduces a ranking system for institutional quality based on legal, policy, and organizational criteria. The Index ranks 43 countries based on its criteria, but the authors also acknowledge several perverse results that occur from simplifying water policies into a ranking system.

In the most water market-specific set of guidelines, Grafton et al. (2011) lay out an Integrated Water Markets Framework for assessing markets worldwide in four areas: institutional underpinnings, economic efficiency, equity, and environmental sustainability. Within the category of institutional underpinnings, Grafton et al. identify eight criteria: recognition of public interest, administrative capacity, well-developed linkages among institutions and water users, legal and administrative clarity, conflict resolution, adaptive management of institutions, and registration/titling. Economic efficiency criteria include size of the market, estimates of the annual gains from trade, size of storages, legal nature of water rights, quality of titles, breadth of market, stability of price formation, and availability of market price information. In terms of equity, markets should address beneficial use of water extractions, provision of basic human needs, limits on market power, recognition of third-party impacts, and initial allocation mechanisms that include equity considerations. Environmental sustainability under water markets requires five preconditions according to Grafton et al. (2011): adequate scientific data to determine hydrological requirements of water-based environmental resources, adequate provisions for environmental flows, adaptive management of environmental needs, water quality considerations in water planning and markets, and complementary catchment and basin-wide planning and trading.

As this thesis is concerned with the necessary preconditions for successful implementation of a water market, the criteria related to pre-existing systems are most relevant. These include administrative capacity, linkages among water users and institutions, legal nature of water rights, size of storages, initial allocations, availability of scientific data, and adaptive management of environmental needs. While a water market can be created to provide for many of the institutional, environmental, equity, and efficiency goals of water management, these elements depend strongly upon the infrastructure in place before the creation of a water market. In adding climate change adaptation to the list of outcomes that a water market could attain, it becomes important to consider water markets' abilities to address climate pressures. This thesis is primarily concerned with the use of water markets to accommodate increased seasonal and annual variability in water supply, as well as how a market might react to lengthy or severe drought.

THE WESTERN UNITED STATES

Water trading in the US West[1] has arisen through a wide variety of local water right transfers and water trading programs that vary widely in their formality and flexibility. The makeup of water rights and existence of infrastructure for water transfer throughout this region varies widely, providing for many local market examples to be compared with one another. While local water management organizations differ in structure and purpose, two influences on trading remain constant throughout the West: the presence of large-scale infrastructure for the storage and transportation of water, and strong institutional and legal support for environmental water needs. These factors have certainly reduced third-party effects and transactions costs in water transfers, though local regions display a large disparity in transaction frequency and freshwater ecosystem health. Localized programs designed to address specific economic, water management, and environmental goals such as the Texas Edwards Aquifer market show the most promising results for climate change adaptation.

Historical and Legal Context

Water management in the Western United States is defined by the resource's scarcity in the region and the expansive hydraulic infrastructure developed by states and by the Bureau of Reclamation. Excluding the Pacific Northwest, the western states are arid and semi-arid. This fact has defined the region's development ever since the 1879 publication of John Wesley Powell's *Report of the Lands of the Arid Region.* This text spurred an idea that the wild west could be "reclaimed" for beneficial uses, and today the transportation and control of water resources within and among states makes the US southwest stand out worldwide. Much of the

[1] "West" in this thesis encompasses all states in the US where significant water trading occurs: Arizona, California, Colorado, Idaho, Montana, New Mexico, Nevada, Oregon, Texas, Utah, Washington, and Wyoming

history of this hydraulic development lies in the creation of a federal agency devoted to spreading the region's limited water resource throughout. The Bureau of Reclamation, formed after the 1902 Reclamation Act called for southwestern irrigation infrastructure, is responsible for many of the early and impressive hydraulic feats of the West, including Hoover Dam, Glen Canyon Dam, the Colorado River Aqueduct, and Grand Coulee Dam. Thus, from the earliest stage of western water management, infrastructure for the transfer of water was a central vision. The more than 600 Bureau of Reclamation dams and reservoirs, as well as state water projects, are at the center of many water markets in the West, providing conveyance necessary for transferring water (Howitt and Hansen 2005). Such extensive federal sponsorship for water transportation infrastructure is no small consideration in explaining the transfers we see today.

Water rights in the West are defined in several ways, but predominately by prior appropriation, nicknamed "first in time, first in right." A right is created with the diversion of water for "beneficial use," and assigned a date corresponding to initial diversion. Priority in water use goes to the holders of older rights, which are called senior rights. As water availability fluctuates from year to year, senior water rights are always protected over junior, or newer, water rights. These rights are divorced from land property rights, and ultimately in the control of governing water agencies, meaning that they are weaker than typical property rights (Brewer et al. 2006). The water associated with a right must be put to use every year, or the owner risks losing the right. This creates a perverse incentive to direct water towards low-valued uses (Grafton et al. 2010). Conservation of water can result in an individual loss because this water will simply pass to the next-priority user (Brewer et al. 2006). Markets have helped address this mal-incentive by providing a way for conserved water to become valuable and transferable. This is an important result to consider in a water market's role in climate change adaptation.

Managing increased scarcity will require eliminating any incentives for wasteful or low-valued water uses. Under prior appropriation, there is overlap in water use among rights-holders in the same geographical area (Libecap 2010). Many junior rights depend upon the return flows of more senior users who divert a quantity of water but return some of it. Junior rights holders become increasingly dependent upon these return flows in years of drought, meaning that a transfer away from a basin could have significant third-party effects. This requires special attention, considering that many transfers move water long distances from agriculture to urban uses, as will be discussed later.

A second form of water rights, which appears alongside prior appropriation in California, Texas, Oregon, and Washington, is the riparian right, which grants land-owners access to water in or alongside their property for reasonable use (Getches 1997). All rights are reduced in quantity during times of drought (Libecap 2010). Trading can only occur among right-owners of adjacent properties, which seriously inhibits the formation of a water market. Riparian rights, which developed from English common law, are abundant in the Midwest and East Coast of the United States. Long distance imports of water to cities like Denver and Los Angeles would not be possible under a riparian right system because water must remain with its associated land (Kenney 2004).

Groundwater rights are much less homogenous across the western states and extractions are regulated to varying degrees throughout this region (Getches 1997). Some states have adopted groundwater management plans in recent years, and if a system of rights is in place, it is likely to be based on prior appropriation. As will be discussed below, one of the more advanced water trading systems, the Texas Edwards Aquifer market, includes groundwater trading. However, groundwater trading is a much rarer than surface water trading. Groundwater regulation and management plans are important in concert with markets for surface water, since the diversion of surface water has implications for local aquifers. When water is temporarily diverted from a surface water source or withdrawn from an aquifer, but partially returned after use, the water may continue to serve local environmental purposes such as recharging aquifers and contributing to healthy stream flows. Long-distance diversion of water through trading eliminates the potential for beneficial return flows, putting local aquifers at risk. Furthermore, groundwater is a critical source of fresh water in the southwest. In California, groundwater provides 30% of the state's water in normal years and 40% in dry years (Legislative Analyst's Office 2008).

Water trading in the West is often confined to individual states, which may or may not align with natural, ecological divisions. Because states have different legal rules for appropriation and trade of water rights, states have turned to the courts for long-term water allocation. These compacts are negotiated by state officials, ratified by the states involved and the U.S. Congress, and often involve extensive litigation. Such compacts appear for many of the main rivers in the West. Therefore, interstate trading is highly constrained. Despite these limitations, trading occurs throughout Western states to various degrees of market maturity and success.

Institutions

Water transfers have been promoted since 1986 by the Western Governors' Association, which was created to increase collaboration in water management among Western governors. The Western States Water Council policy says "western states have primary authority and responsibility for the appropriation, allocation, development, conservation and protection of water resources" (WSWC Resolution #331). Roughly 70% of freshwater withdrawals in the west are used for irrigation. The Association's 2012 report projects that "in an era of limited water supplies and growing demands, water transfers will be an increasingly important tool for water supply management in the western states. Many rivers are fully appropriated or over appropriated, meaning that newer water rights will yield water only during limited periods or not at all." At the federal level, transfers in the West are viewed as a tool to be increasingly used as water becomes scarcer. A survey of 17 states by the Western States Water Council shows that three-quarters of these states think that transfers will be used to meet future water demand, especially since some of the simpler conservation measures have been exhausted.

There are over 1,100 water supply organizations in 17 western states, some of which hold water rights for users. These organizations include irrigation districts, mutual ditch and reservoir companies, water conservancy districts, municipal water districts, and water companies (Libecap 2010). The range and sheer number of organizations involved in water rights contributes to high transaction costs in water markets (Bretsen and Hill 2009). Libecap (2010) notes that within irrigation districts, which are the most common water supply organizations, governing bodies maybe elected by organization members or local communities, and these decisions may determine the local politics of water transfers. Trading can require approval if there may be injury to other rights. Gathering this approval involves a petition for trade that must specify water quantity, contract duration, type of right, consumptive use, and hydraulic or other legal information (Libecap 2010). The applicant carries the burden to prove that their proposed trade will not injure other rights-holders, and likelihood of approval often depends on the local water supply organization, making some place more favorable for trading.

Given the institutional, historical, and legal background presented above, the outcomes of water markets in the Western United States can answer the following questions about the role of water markets in climate change adaptation:

(1) Which differences among regional markets determine the transaction costs involved in water trading, ultimately affecting a market's ability to accommodate increased seasonal variability?

(2) Can localized, highly-structured trading and banking programs achieve environmental sustainability and efficient water allocation with greater success than more free-market transfers?

(3) How does extensive physical infrastructure for storage and transportation of water underpin trading?

Outcomes

The most comprehensive collection of data on water transfers in the West originates from a monthly trade journal called the *Water Strategist* and its original publication, the *Water Intelligence Monthly*. This dataset begins with transfers from 1987 and extends through February 2010, and is made available by the University of California, Santa Barbara Bren School of Environmental Science and Management. While this dataset does not contain every transfer during its time period, it provides the largest collection of transfers available and it can be assumed that missing transfers are random. The data includes transfers from Arizona, California, Colorado, Idaho, Montana, New Mexico, Nevada, Oregon, Texas, Utah, Washington, and Wyoming. The main limitation of this dataset is that short-term transfers within irrigation districts may frequently occur and would be missed by this dataset (Grafton et al. 2010). Research on water trading in the US is limited by the fact that all empirical papers on the topic use the same *Water Strategist* data. However, results from this dataset have been confirmed repeatedly by this body of research.

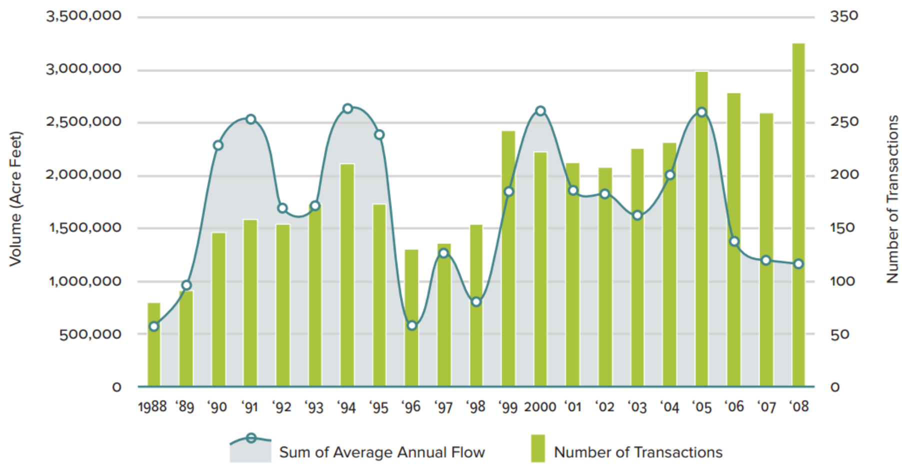
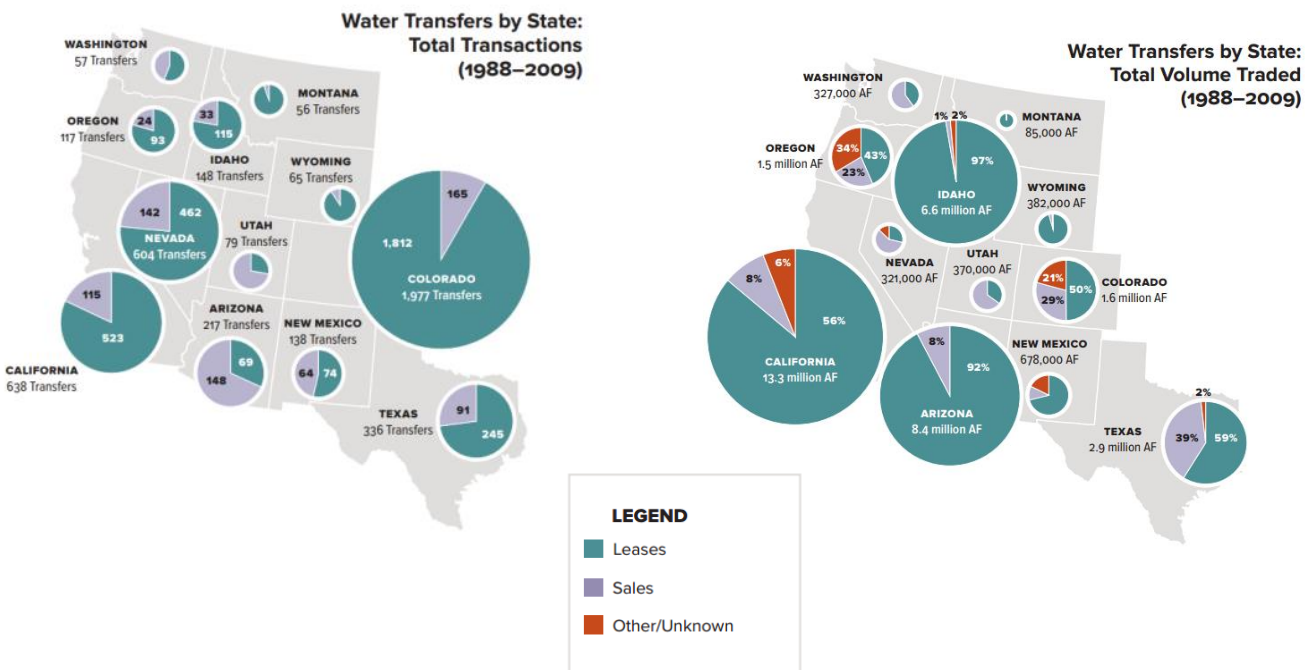


Figure 1: Water transfers by volume and number of transactions according to *Water Strategist* data. Image from "Water Transfers in the West," Western Governors' Association.

Grafton et al. (2010) present summary statistics that begin to explore the nature of water trading in the West. They note that the agriculture sector is by far the largest point of origin for traded water rights, with 77% of all water transactions coming from agriculture sector, and 62% by volume. Many subsidized and low-value crops like alfalfa, cotton, and rice appear in the West, indicating the potential for gains from trade that direct water towards more highly-valued uses (Grafton et al. 2010). Over half of transfers occurred from agriculture to urban uses over the span of the dataset. Significant gains from trading among sectors are indicated by the fact that the median price of water leased from agriculture to urban uses is over four times higher than prices of trades within the agricultural sector. This statistic becomes double when looking at sales rather than leases, and the price differences are confirmed within regional markets. In a particularly dramatic case, farmers from the Imperial Irrigation District paid $13.50 per acre-foot for Colorado River water, while a development near the South Rim of the Grand Canyon spent

$20,000 per acre-foot for the same water (Glennon 2002). The stark price differences between prices in transfers from agriculture to urban uses and transfers within agriculture indicate that a market can serve as an indicator of where water is most highly valued. While farmers are accustomed to paying for pumping or conveyance costs of water, farmers are still willing to pay much less compared with municipal water agencies (Brewer et al. 2006).



Figures 2 and 3: Total transactions by state 1988-2009 and total volume traded by state 1988-2009.

The number of trades has drastically increased over the course of the dataset, with 91 trades reported in 1987 and 287 trades in 2008. In terms of volume, there were under 1,000,000 acre-feet of water traded in 1987 and over 3,000,000 in 2008. Despite this growth, however, the amount of water traded is only a small fraction of total water diversions in the region. A 2004 US Geological Survey of water diversions by state in 2000, when compared with the volume of trades in *Water Strategist* in that year, shows that trades amounted to 2% of the USGS total. This indicates great potential for growth in Western water markets. As climate change causes increased competition for scarcer water resources, there must be a mechanism for allocating water among sectors. What remains to be shown is whether the market can support a highly variable climate where a market must operate quickly enough to accommodate this variability. Brewer et al. 2008 observe that when measured by water quantity contractually committed in a year, it appears that trades are increasing over time, whereas when measured by by annual flow of water traded, markets show signs of stagnation. *Water Strategist* data also shows that transactions are increasing over time mainly due to increased numbers of agriculture-to-urban transfers, and that sales and multiyear leases are increasing in frequency but 1-year leases are not. Arizona, California, and Texas are the leading states in water quantity traded. The growth of transfers from agriculture to urban uses again confirms the notion that markets are opening up new movements of water towards more efficient uses. The disparity in water quantity traded among Western states indicate that varying legal, institutional, and historical conditions influence the success of a water market. This will be further explored by looking at specific basin-wide markets in several US states.

Despite the fact that much of the Western water trading research analyzes the entire *Water Strategist* dataset, additional insight can be gleaned by treating the data as a group of individual markets that may be compared with one another. These comparisons can be used to address the question of which institutional differences foster an active trading market within the same broad nation-wide legal framework. Brookshire et al. (2004) study water prices in the three major markets of Arizona, Colorado and New Mexico: the Central Arizona Project in Lower Colorado basin, the Colorado Big Thompson market associated with Northern Colorado Water Conservancy District in the Upper Colorado Basin, and the Middle Rio Grande Conservancy District market in Rio Grande basin. Legal and administrative differences among these markets appear to explain their differing relative levels of market maturity, revealing several conditions that facilitate water market operation. While several types of rights exist simultaneously in Arizona and New Mexico, Colorado reaps the advantage of having proportional surface water rights throughout the market. These rights consist of “shares” of the annual water supply, and the only limitation is that rights must remain within the Northern Colorado Water Conservancy District. Furthermore, the Colorado Big Thompson market receives institutional trading advantages over the other two markets, where transactions can take between 1 and 18 months to complete (Brookshire et al. 2004). Based on these advantages of expedited transactions, lower fees, and homogenous water rights for Colorado, it is expected that the Colorado market would reach the highest level of maturity among these three markets. Analysis of prices in these three markets confirms the intuition that the Colorado market is most mature. From 1990 to 2001, there were 35 trades in the Lower Colorado (Arizona), 89 in the Rio Grande, and 490 in the Upper Colorado. Higher prices and more frequent trades in Colorado reflect greater market maturity, which can be explained by its legal and institutional conditions. The maturity of the Colorado market indicates a strong potential for the market’s ability to respond to variability in water availability. In fact, across all three markets, water prices were lower in wetter periods, which confirms that US markets are accommodating for variable scarcity, no matter how mature. In their conclusion, Brookshire et al. (2004) note that all three of these markets are made possible by Bureau of Reclamation infrastructure, underscoring the need for central support of transportation projects in successful water markets.

One of the more advanced trading systems in the West applies the principles of cap and trade to groundwater in the Texas Edwards Aquifer. The cap was created after several years of conflict resulting from an Endangered Species Act lawsuit, as well as from the Aquifer’s importance in local water supply (Sugg 2013). It is the principle water source for nearly two million people and underlies the health of many regional rivers and local species (Votteler 2004). This conflict culminated in legislation that put a cap on total aquifer withdrawals, converted rights into private, tradable rights, and created the Edwards Aquifer Authority (EAA) to manage the trading. Sugg (2013) analyzes 14 years of transfers collected by the EAA from 1998 to 2012, which includes the most severe drought in Texas historical record in 2011. The Authority followed environmental recommendations for a maximum safe yield in establishing the 400,000 acre-foot per year cap of withdrawals. Trading records show that the market responded in a predictable manner to the 2011 drought. Both 2011 and 2009, which was another drought year, had the most transfers, suggesting that the market allowed for flexibility in responding to variable environmental and climatic conditions (Sugg 2013). By basing the cap on scientifically-determined minimum aquifer levels, the market is ensured to meet basic environmental needs. Such close monitoring of groundwater extractions is necessary for environmental protection, and there are extreme regional differences across the West in the degree to which groundwater is regulated. Markets based on regional caps, such as the Texas Edwards Aquifer market, show incredible promise for addressing variability due to climate change while meeting environmental requirements.

As evident by some of the regional water market examples in the US, environmental protection can be ensured through a number of institutions and policies. The Endangered Species Act is the source of many federal court rulings in favor of allocating water for environmental uses, specifically for habitat protection and maintenance of minimum stream flows. This act is found at the crux of many of the most powerful decisions that protect the environment in the face of competing uses. Such a framework is critical in the establishment of water markets, which won't inherently place value upon environmental uses for water without legislation or institutional encouragement. Brewer et al. (2006) find that nine percent of trades in the *Water Strategist* data move water towards environmental uses, showing that markets can and are being used to provide water for non-human needs. The institutions most frequently involved in habitat protection are the US Fish and Wildlife Service and state departments of fish and game (Grafton et al. 2010). Without such governing bodies, markets would be less likely to meet environmental needs, especially as climate change is likely to increase competition among uses.

There are several examples of emerging water markets for environmental protection such as banking and trading programs in California's Kern River and Oregon's Deschutes River and in the Idaho Water Supply Bank. These programs demonstrate other options for the use of markets in water allocation that can address increasing scarcity. While they may not fall directly under the category of a water market, banking and trading programs similarly address variability in water availability and water needs among a group of users, including environmental users. In Idaho, the Water Resource Board facilitates a Water Supply Bank where water is collected by pools to be rented by users depending upon their present demand.[2] Water rights holders may sell their water to the bank when unused, and buyers without rights or with insufficient rights may purchase this water. The bank also integrates surface water rights and groundwater rights by making both available for sale, and it has grown steadily over its lifetime, with over half a million dollars in revenue paid to water rights holders who rented their rights in 2014 (Water Supply Bank 2014). 494 applications for lease or rental were processed in 2014, indicating a highly active market. While this Idaho banking example could be considered a market of its own, water banks in other places serve more precautionary and environmental measures than as markets. In Kern County, California, water banking is the norm across local water agencies. The

[2] https://www.idwr.idaho.gov/water-supply-bank/overview.html

Kern Water Bank, under the Kern Water Bank Authority, "provides an efficient, reliable and environmentally sound water source for both local urban water supplies and hundreds of thousands of acres of essential crops."[3] Without facilitating an active market, the Kern Water Bank achieves many of the adaptation outcomes desirable in a water policy. The Bank will provide a safeguard against increasing variability in water supply due to climate change and includes considerations for agriculture and the environment in its core statement. Such example suggest that a highly regulated market designed for long-term human and environmental water supply is an effective tool for climate change adaptation, rather than a more free-market approach.

More sophisticated market products have appeared in the state of California, where examples of options in water trading exist. Howitt and Hanak (2005) document developments in the California water market, arguing for the "central role of institutions in facilitating market development." Options contracts allow a transfer to be guaranteed given a certain level of scarcity, which offers a method to manage the risk of uncertainty and variability in water supply. A somewhat recent example of an option agreement involves the Metropolitan Water District of Southern California (MWD), which is constantly tasked with reducing its reliance on Colorado River Water. As part of these efforts, MWD reached a number of agreements with individual agencies in 2002-2003 (Howitt and Hanak 2005). Eleven agreements were made with Sacramento Valley Districts involving 206 million cubic meters of water depending on the flow of four major rivers. The mutual agreement show in these negotiations shows promise for the growth of options markets in the US, as well as an effective way to manage increasing variability in water supply.

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[3] http://www.kwb.org/

Water trading in the Western United States shows several important results for designing markets to facilitate climate change adaptation. With examples of successful programs designed for environmental protection and overall sustainable yield, it is clear that markets specifically created to address certain goals have strong potential to achieve these goals. This advocates for clear decision-making in the design of markets so that specific outcomes are integral throughout the process, as well as localized programs designed to meet specific, local needs. The widespread use of Bureau of Reclamation infrastructure in US water markets points to the need for federally-sponsored support in water transportation and storage. This is no small consideration in the implementation of water trading in new settings. Markets in Colorado show us that minimizing transaction costs will be crucial for using water markets to accommodate short-term water needs. There is, however, a balance to be struck between minimizing transaction costs and maintaining sufficient market regulation, which will become more apparent in studying the Chilean case.

CHILE

Chile saw several radical changes in government in the second half of the 20th century, which were manifest in the country's various approaches to water resource management. The Chilean case is fundamentally different than that of Australia and the United States because of the economic development and political shifts that occurred while water markets were forming throughout the country. National policy transitioned from treatment of water as a public good to a privatized, market-based system with the creation of the 1981 Water Code during the military dictatorship of Pinochet. This Code provided for the establishment of tradable, private water rights to encourage the exchange of the resource towards efficient allocation. While the tide is currently turning towards an understanding of the need for more integrated river basin management and the incorporation of groundwater management, changes to the 1981 Code have been slow to reach local implementation, and water continues to be treated largely as a private good. Empirical and qualitative research in the fields of economics, politics, and the natural sciences since 1981 has addressed the success of the Code, drawing a wide range of conclusions. Generally, however, the initial assessments lauded the privatization of water rights as the best strategy for other developing countries, while more recently researchers have uncovered environmental and social costs associated with the 1981 policy. While there are certainly some active water markets that help allocate water among users in specific basins of Chile, the broader results of Chilean markets show a lack of market activity, social equity, and environmental sustainability, indicating that water markets can only serve the purpose of climate change adaptation with greater environmental protection and river basin management planning.

Historical and Legal Context

The Chilean model for water marketing attempts the most neoclassical and deregulated water management strategy worldwide. The Water Code was implemented during a highly tumultuous period in the country's history. Water rights in Chile were loosely defined through the mid-20th century, where private water rights existed but were influenced by government regulation. The government gained greater authority over water in a 1967 water law, when Chile was under socialist leadership. This government was then overthrown by the authoritarian military regime of Pinochet in 1973, which passed the 1981 Water Code near the end of its run (Bauer 2005). In accordance with this regime's preference for neo-liberal, free market policy solutions, the Water Code made water rights separate from land rights and tradable (Hearne and Easter 1995). Furthermore, the government backed out of water resource management and did little to explicitly establish a market, only altering water rights to make them private and tradable (Bauer 2005). The Code is supported by Chile's Constitution, which came a year before the Code and had to be maintained for the military regime to step down in 1990. A principle reason why Chile's water rights system is the most *laissez-faire* strategy in the world is the fact that there is no "use it or lose it" rule, meaning that water rights may be held idle for years (Hearne and Easter 1995). Thus, private speculation remains unfettered, which has been the topic of continuing conversation over reforms to the Code in the 21st century (Bauer 2005).

The market in Chile is historically different than in other countries because of the order in which the market and associated institution were established. Carl Bauer, a leading Chilean water policy scholar, points out the essential historical difference between Chilean water markets and those of other countries such as the US and Australia:

> "In other countries that have allowed or encouraged water markets, in varying degrees and circumstances, these markets have been a policy instrument within the larger context of water law and regulation. In Chile this order is reversed: water resources management takes place in an institutional context that has been shaped by and for water markets. The Chilean Water Code is so *laissez-faire* that the overall legal and institutional framework has been built in the image of the free market, with strong private property rights, broad private economic freedoms, and weak government regulation" (Bauer 2013).

The Code was championed by a group of neo-liberal economists, who achieved most of the provisions they suggested, barring an annual water right tax. A tax, according to these economists, would send proper price signals to water users and create the incentives necessary for markets to achieve an efficient allocation of water. The tax was blocked by agricultural parties, likely hindering the development of markets (Bauer 2005). It is Bauer's argument that the lack of outstanding water management law and regulation has led to unsatisfactory social and environmental consequences, as well as relative inactivity in the market. This thesis will further argue that without sufficient institutional support for using markets to address some of the effects of climate change, the Chilean markets, and therefore other similar water management systems, cannot perform as adaptation tools in an effective, equitable, or sustainable manner.

Water rights in Chile are divided into categories based on two criteria: use and priority. Rights may either be permanent or contingent, where permanent rights are assigned to unallocated water sources, and contingent rights can only be redeemed in years of excess water flow. Based on use of water, rights in Chile are divided up into consumptive rights and non-consumptive rights (Hearne and Easter 1995). Consumptive rights are primarily used for agriculture and human consumption, while non-consumptive rights serve hydropower and aquaculture. The existence of markets in non-consumptive rights makes Chile unique in the world.

Institutions

The governing agency over water rights is the Dirección General de Aguas (DGA), or General Water Directorate, which does little resource management but must administer water rights when requested for no fee (Bauer, 2004b). Despite the fact that the Water Code deems water a form of inalienable public property, the law in fact makes the DGA weaker in governing water management in previous legislation. When water is physically and legally available, the DGA must grant rights without knowing the intended use of these rights (Bauer 2005). Only the market and its water prices may give preference to certain uses over others. If new users apply for rights where the quantity available is insufficient to meet all applications, the agency holds a public auction to determine the highest bidder. However, these auctions have been rare in practice (Bauer 2005). After rights have been granted by the DGA, they become recognized as general forms of real estate, which underscores that water is truly treated as any other good or property under Chilean law. Conflict must be resolved privately, as the DGA has no power to address injury to other rights or competition among rights holders.

The Code does not contain any provisions for environmental sustainability or river basin management, which certainly limits its ability to accommodate any possible new measures for climate change adaption. This lack of institutional management plays out in the empirical results of Chilean water markets, and will indicate that strong regulation and oversight is a necessary prerequisite to a successful water market. In comparison with United States, for example, water marketing in Chile began with far less institutional support for equitable and sustainable water management as well as exchanging of information among water users, which has lasting implications for the outcomes of these markets. It is clear that Chile's water policy was created to approximate a market for a private good, rather than a cap and trade system, which highlights its inability to manage a scarce resource. Given the clear differences in the vision for water trading in Chile compared with the United States, the following questions can be addressed using Chile's experience:

(1) What are the implications of Chile's *laissez-faire* approach to water trading for market success and climate change adaptation? Are Chile's markets active enough to become adaptation policy tools?

(2) Is Chile equipped to reform its markets to specifically address the effects of climate change?

Outcomes

An early group of papers, largely written by development experts, and lacking empirical analysis, laud Chile's policy as an example for water resource management reform in other developing countries (Bjornlund and McKay 2002). Rosegrant and Binswanger (1994), from the International Food Policy Research Institute and The World Bank respectively, list Chile's water policy as a leading management strategy resulting in efficient water allocation and reducing the number of water conflicts that reach courts. Later research questions both of these claims. Taking a more cautionary approach, Brehm and Quiroz (1995), in a World Bank technical paper, argue that the 1981 code has performed "satisfactorily" and that it is the best option for water management reform in other developing countries. They recognize that effective water trading policies must address the externalities of water quality and consumptive versus non-consumptive uses, speculative buying of water rights, groundwater, return flows, infrastructure and conflict resolution. The paper ultimately concludes that addressing these flaws in the Chilean system would merely require minor policy changes. This conclusion, as will be explored later, has proved inaccurate given the country's inability to alter the Code in any significant ways.

Another series of papers empirically address the level of activity in water markets throughout the country, finding active local markets in some river basins, and relative inactivity in others (Donoso 1999; Gomez-Lobo and Paredez 2001; Hearne and Easter 1995; Hadjigeorgalis and Lillywhite 2004). Hearne and Easter (1995) examine trading characteristics in four river valleys: the Elquí, the Limarí, the upper Maipo, and the Azapa, finding most activity in the Limarí and Elquí valleys. They note the strong presence of water transfers away from agriculture, concluding that water markets are important for efficient allocation of the resource, and that improved transportation infrastructure reduces barriers to trade. Their paper finds highly disparate results among the four basin case studies, which it attributes to varying institutional and physical infrastructure for trading. Both the Upper Maipo and Azapa valleys showed an infrequency of transactions that lead Hearne and Easter to omit these from analysis. The Elqui valley similarly showed infrequent transactions due to a lack of infrastructure, but did demonstrate intersectoral transfers and transfers within agriculture. The case that stands out in this study, as well as many others, is the Limarí Valley. Hearne and Easter find that buyers of water rights for profitable crops or municipal water supplies received the highest rents, and that specifically grape producers in the Limarí Valley received the highest rents. Gaines from trade in this basin were triple the transaction prices for 4,250 cubic meters of water from the Cogotí Reservoir. Hearne and Easter attribute the relative activity in this basin to the development of irrigation infrastructure and the organization of local Water User Associations (WUAs).

Hadjigeorgalis and Lillywhite (2004) focus in further on the Limarí basin to examine institutional constraints on trade. The Limarí River Valley is in a semiarid region in central Chile 400km north of Santiago. Agriculture in this region is diverse both in terms of crop mix and farm size, and most trades occur among agricultural water users (Hadjigeorgalis and Lillywhite 2004). The market involves both permanent water rights transfers and spot water trades, the latter of which is only constrained by physical water trading infrastructure. They use field-collected data on water rights and spot market transactions to examine price differences between permanent water right trades and unconstrained spot market trades, finding significant welfare losses from trade barriers in permanent water rights transactions. Secondly, the analysis reveals significant heterogeneity in price behavior across irrigation districts. Within one growing season, prices rose in some districts and fell in others, showing a degree of segmentation within what is known as the most active and developed water market in Chile (Hadjigeorgialis and Lillywhite 2004). Based on their results, Hadjigeorgialis and Lillywhite make important hypotheses about the effects of reducing barriers to trade among irrigation districts. They predict that further trades from low-valued crop sectors to high-value export crop sectors would not eliminate the presence of low-valued crops, though this result would not necessarily apply to water markets in other countries, such as the US.

Generally, the empirical water trading literature concludes that active markets exist in locations of relative scarcity, but that active markets are the minority among basins throughout the country (Hearne and Donoso, 2005). Dourojeanni and Jouravlev (1999) use this scarcity of markets to conclude that water is not allocated efficiently throughout the country. In an attempt to explain why active markets remain absent in the majority of the country, Bjornlund and McKay (2002) list the following barriers: an inflexible water distribution system, legal barriers, cultural ties to irrigation for small farmers, and efficiency alternatives cheaper than trading, such as drip irrigation and channel lining.

In response to the collection of empirical analyses of Chile's water trading, Bauer (1998; 2004a; 2004b; 2005) leads the call for a more interdisciplinary look at the impacts of the 1981 Code in economic, social, and environmental terms. His papers qualify the success of water allocation success with research on the social equity and water quality costs apparent in Chile. Bauer compares the outcomes of the Code to both its stated goals upon creation and implementation, and more modern tenants of effective water resource management. Though the Code has met its intended goals of reducing government regulation, allowing for trade, and increasing the autonomy of local water user associations, it has missed the mark in terms of fostering overall irrigation efficiency, financing infrastructure, leading to the formation of markets nation-wide, and helping poor farmers gain access to water supplies (Bauer, 2005). With respect to newer criteria for effective water management, Chile's policy falls short in the management of basins and multiple water users, the protection of environmental goods and ecosystems, and the provision of aid to poor farmers, among other shortcomings. The critique of social equity results of the water markets is continued in Galaz, 2004, which uses game theory and empirical data to argue that Chile's system provides incentives for the exploitation of less powerful water users. From an environmental justice standpoint, Larrain (2012) assesses examples of conflict within watersheds and highlights the places where Chile's policy is at odds with United Nations principles of sanitation and water access as human rights, recommending that Chile recognize water as a public good.

Reform to Chile's Water Code has been an ongoing debate for over a decade, yielding few meaningful results. This reform story can begin to answer the question of whether markets could be adapted to address climate change. Without a “use-it-or-lose-it” provision of Chilean water rights, many parties have worried for years about the speculative purchasing of water rights for later sale during times of relative scarcity. Years of debate over whether to address this issue culminated in a 2005 fee for non-use, which has proved to be fairly inconsequential in the market (Valenzuela et al. 2013). Given that this single reform took years to come to fruition and proved to be of little use in discouraging non-use, it is difficult to imagine the timely passage of reforms that gear Chile’s markets towards climate change adaptation. Australia’s experience will show that ongoing and regular reform is effective in moving water markets towards new goals as changing needs arise.

Other than the general lack of market activity, Chilean markets have led to an increasingly visible array of water conflicts, and institutions have demonstrated an inability to govern these conflicts. Some of the more high-profile instances of conflict have occurred among water users of different sectors within a single river basin. Notoriously, the Maule River Basin in south-central Chile has been host to conflict among irrigation and hydropower for over two decades (Bauer 2015). Though many individual conflicts have occurred over the construction of hydropower infrastructure that affects irrigators’ water supplies, they have generally centered on lack of governance when consumptive and non-consumptive water rights exist simultaneously. A 1993 Supreme Court ruling gave non-consumptive water rights users the power to develop a river with no consideration for the effects on irrigators or other consumptive users, setting a precedent for reduced communication among water users and standing in the way of any kind of integrated basin management (Bauer 2015). Another type of conflict has occurred where complete allocation of surface water has led to groundwater overdraft. In the Copiapó River Basin, where growth in copper mining of the 1990s and 2000s was accompanied by population growth and increased fruit production, the DGA responded by granting far more groundwater rights than the annual volume recharged. The river remains in extremely poor health today and Bitran et al. (2014) attribute the overuse of the Basin to an inability of the DGA to regulate and adapt its regulation to new conditions. The fact that the DGA was obligated to grant rights "if certain formalities were met" under the Water Code, meant that it had little power to intervene in the rising overuse. The Copiapó Basin case suggests that under the current Water Code and DGA, the Chilean system will be unable to handle increasing scarcity and competitive pressures among water users in a sustainable manner.

The examples of water markets in Chile that are relevant to climate change adaptation are those that are active. These active markets, such as the Limarí Valley market, coincide with the places where Water User Associations and other user organizations are strong. This is strong evidence that institutional participation in water markets is critical for healthy markets. While it may be hard to claim that Chile's Water Code has proved worse than an alternative at responding to water resource scarcity and variability, it can be said that the overall lack of activity and presence of widespread conflict are not improving water management in Chile. The single reform seen over the course of water trading in Chile will appear in stark contrast to the dedication to constant improvement seen in Australian water market policy.

AUSTRALIA'S MURRAY-DARLING BASIN

Australia's Murray-Darling Basin (MDB), located in southeast Australia, is home to the quintessential success story of water markets. Water use in this region is predominantly agricultural. The Basin produces nearly 40% of Australia's food supply and almost 90 million hectares of the 106 million hectare basin are devoted to agriculture, underscoring the importance of water security in this region for human consumption and for food security (Hafi et al. 2009; NWC 2011). The Snowy Mountain Scheme, which consists of 16 major dams, 145 kilometers of tunnels, 80 kilometers of aqueducts, provides the infrastructure that makes trading in this arid region possible (Quiggin et al. 2010). Establishment of water trading in southeast Australia began in the 1980s, and today Australian markets are often described as the most effective water trading scheme worldwide (NWC 2011). Ongoing amendments to water market structure and increasing devotion to environmental sustainability have contributed to its success. Furthermore, with little involvement of urban water users in water markets, trading has been focused on water allocation among irrigators, and thus the specific needs of irrigators have been met more fully. The development of water trading policy in Australia deserves and will receive extra attention because Australia has most extensively wrestled with the politics and institutional design of water markets. While the United States has seen local policy design decisions, and Chile has left trading to the free market, Australia's experience represents the most wide-spread and conscious effort to design a market that minimizes third-party effects and operates as smoothly as markets of private goods.

Historical and Legal Context

Though water rights in Australia first formed under English common law, where land owners could use water adjacent to their property, it eventually became clear that a different system was needed to address variability in supply. Beginning with the Victorian *Irrigation Act 1886*, a number of policies in the late 19th and early 20th centuries brought centralization to water resource management under public organizations (NWC 2011). Further reform occurred as states competed over the waters of the River Murray, and some of these conflicts were resolved in the River Murray Waters Agreement, which began to provide for the construction of irrigation and storage infrastructure.[4] Water resource management remained more cooperative from then on. Infrastructure continued to expand through most of the 20th century, with the first few instances of water trading occurring during this time period, notably during the droughts of the 1940s. Early fears about the development of water barons or large irrigation or agriculture corporations led to limitations on farm size in public irrigation developments and irrigated land area (NWC 2011). Furthermore, water rights were intentionally tied to land rights to protect the power of small farmers, which would eventually create extra work in the formation of water markets. To summarize the development of water markets in Australia, the National Water Commission (2011) claims that “reservations about the treatment of water as an economic good led to a very gradual and closely controlled approach to introducing water trading.” The Commission describes a slow realization that further infrastructure development for water management was become increasingly costly and most of the “low-hanging fruit” in terms of water efficiency had already been picked.

Water management strategies backed in economic arguments were taken more and more seriously as the environmental costs of water extraction became more apparent in the 1970s

[4] http://www.mdba.gov.au/what-we-do/basin-plan/development/history

(Musgrave 2008). Local governments began replacing area-based water licenses with volume-based rights and ending the appropriation of new waters to protect ecosystems (NWC 2011). Thus, with embargos on the issuing of new licenses and water rights tied to land property, obtaining new water rights involved purchasing land, which made adaptation to the widespread drought of 1982-83 challenging. Legislation allowing for water trading was implemented at different times and through different measures among states, and land rights were slowly separated from water rights. The period from the mid-1990s to the mid-2000s saw a number of reforms such as the Murray-Darling Basin Agreement of 1992, the Council of Australian Governments Water Reform Framework in 1994, and the National Water Initiative in 2004, which increased trading and integrated programs for environmental sustainability. A cap on extractions for the entire Murray-Darling Basin was established from 1995-1997 (NWC 2011). The implementation of these reforms saw an important debate over whether compensation should be given to water entitlements holders when volumes are reduced for environmental reasons. The issue of security of tradable water rights was addressed by making rights into open-ended shares of the larger portion of a particular water resource and defining risk associated with water availability for all rights (NWC 2011). Using water trading to reallocate water towards environmental uses began under the Living Murray program, which was initially unpopular both within irrigation communities and outside.

More recent reforms occurred in the 2007 National Plan for Water Security and later in that year under the *Water for the Future* program (NWC 2011). These programs addressed environmental sustainability in a more consequential manner. The Water for the Future program contains three main elements: a Basin Plan for the integrated management of the MDB under maximum safe withdrawal limits, government purchases of water rights for conservation, and investment in irrigation efficiency. The plan greatly increased the government's role in Australian water markets, including a $3.1 billion commitment over 10 years to purchase water rights and commit this water to ecosystem health. Environmental goals were further addressed through provisions for address salinity in MDB ecosystems. States in the Basin created a Basin Salinity Management Strategy requiring states to address trade-induced salinity impacts and introducing a fee for trades that impact salinity in a negative way. Other barriers to trade exist where transferring water out of one physical region could hurt local irrigation communities or the physical environment. For example, the State of Victoria has a 4% limit on annual trade of water out of an irrigation district, and a maximum of 10% of the volume of water entitlements can be held by parties outside of the district. There are also termination fees for when an irrigator gives up the right to water delivery by an irrigation utility and exit fees for when water entitlements are sold outside of an irrigation district (Grafton et al. 2010). In this way, reforms to water trading in Australia have slowly begun to internalize effects of trading not ordinarily captured in the market.

Today there are two principle types of water rights that are traded among users. As defined by the National Water Initiative, a water access entitlement is a "perpetual or ongoing entitlement to exclusive access to a share of water from a specified consumptive pool as defined in the relevant water plant," and a water allocation is "[t]he specific volume of water allocated to water access entitlements in a given season, defined according to rules established in the relevant water plan." Water allocations are always tradable separate from land, whereas water access entitlements may only be tradable separate from land in certain unbundled systems. A key difference in Australian water rights and water rights in the United States is that there is no "use it or lose it," beneficial use law in Australia. This helps create incentives to conserve water and sell unused water entitlements or even carry unused water over to the next irrigation season (Grafton et al. 2010).

Institutions

Water management occurs at a variety of institutional levels in Australia, beginning with the states, as well as interstate organizations. The Murray-Darling Basin Authority and Murray-Darling Basin Ministerial Council were created in 1985 to oversee water trading in the Basin (Turral et al. 2005). The Authority is an independent government agency under the Minister for Agriculture and Water Resources, which collaborates with a Basin Officials Committee of Basin Government officials and a Basin Community Committee of community members, including water users, irrigators, environmental water users, and indigenous peoples. [5] Within the basin, there are irrigation infrastructure operators, which are collectives or companies that have an interest in keeping water rights tied to the land where their infrastructure is used to cover the fixed costs of conveyance. Accordingly, they charge members a fee for selling water rights to users outside of the district. These fees are typically 15-20% of the water entitlement price, but can be as high as 80% (ACCC, 2006:45).

Australia's historical and legal context for trading lead to the following questions that apply the results of the Murray-Darling Basin to climate change adaptation:

(1) Evaluating Australia' markets as a program designed for environmental protection, how has it succeeded?

(2) How has Australia performed in terms of non-environmental outcomes and can Australia's success be a reflection of a water market's ability to allocate among consumptive uses where more urban users are involved?

[5] http://www.mdba.gov.au/about-mdba/governance

Outcomes

The strong correlation between market growth and activity in Australia and periods of drought suggests that trading has provided a useful scarcity-management tool. During the severe drought of 2002-03 the proportion of water allocations traded of total allocations rose from 7% to 15%, Then, in the next severe drought of 2007-08, this proportion of southern MDB allocations more than doubled to reach 41% (NWC 2011). Price data also confirms the expectation that prices should be highest during years of scarcity. The most severe drought years of 2006-08 show peak seasonal allocation prices (Grafton et al. 2011). The Australian Bureau of Agriculture and Resource Economics irrigation survey indicates that 43% of surveyed irrigation farms in southern MDB traded allocations in the three years leading up to 2010-11, while 15% traded water access entitlements. Aggregate economic modeling for the Commission estimates that water trading in the southern MDB increased Australia's GDP by $220 million and its gross regional product by over $370 million in 2008-09. Annual trading in the MDB reached a turnover of $3 billion in 2009-10 (NWC 2011).

Comparing water prices in the US southwest with those in Australia, Grafton et al. (2011) find much more consistent prices in Australia, as well as a smaller difference between prices for water in agriculture and in urban uses. Estimating the costs of transporting and disinfecting drinking water, they show that there is no difference in water price for urban water users and irrigators. Australia's market has involved substantially less urban users than the US, though this is likely to change under increasing scarcity pressures. In obtaining future water supplies for cities, it will be far cheaper to purchase rural water than to take on alternative projects such as desalination (Grafton et al. 2010). This will force Australia to more directly confront the challenges of trading among sectors that the US has encountered. With fewer urban water users involved in the Australian water markets, gains from trade often accrue to irrigators who receive smaller seasonal allocations than necessary. Grafton et al. (2011) find that perennial-crop farmers with orchards and vineyards required extra water in drought years and were able to keep their crops alive by purchasing seasonal allocations. The sellers of these allocations received a source of income that may have been their sole source of income during severe drought. These results highlight the potential of markets to alleviate some of the extreme effects of drought, which we expect to occur more frequently. Broad trends among agricultural water users reveal that water generally moves downstream from rice growers to horticulturalists, who have less flexibility in the their long-term irrigation needs (NWC 2011).

Figure 4: Volumes of allocation and entitlement trades in the southern MDB, 1983-84 to 2009-10

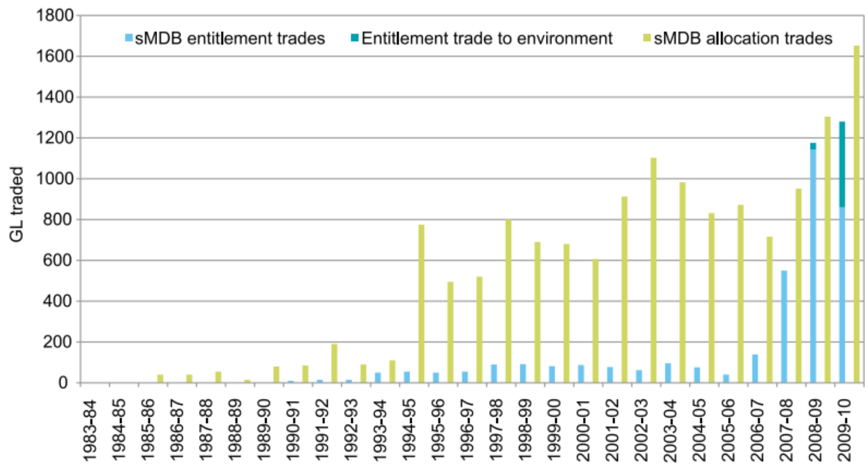


Figure 5: Water allocation sales as a percentage of water allocated in the southern MDB 1998-99 to 2009-10

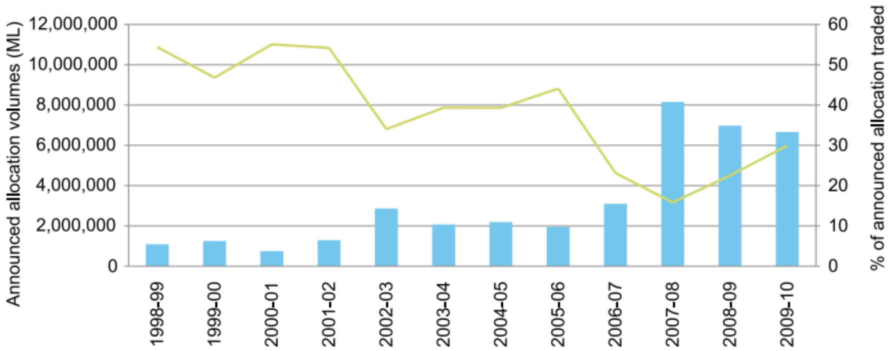
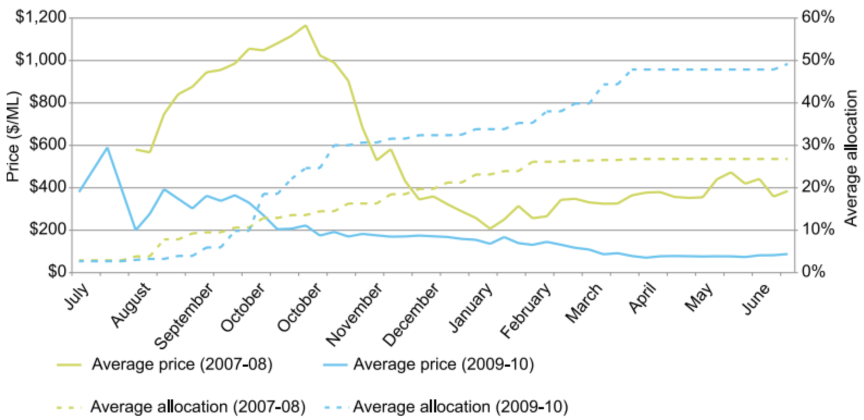


Figure 6: Average water allocations and average allocation prices in the southern MDB, 2007-08 and 2009-10



Though efforts are ever-increasing to address environmental sustainability in the MDB, conditions are less than ideal throughout. A 2008 audit found that of 23 river valleys in the MDB, only three are in good or moderate health, and 20 in poor or very poor health (Grafton et al. 2010). Drought years have seen considerably higher reductions in environmental water provisions than in consumptive water quantities. For instance, the State of Victoria saw a one third reduction in water share of the Murray River from 2000-2010, which led to a diversion reduction of 10% and environmental water allocation reduction of 50% (Connell and Grafton 2008). Separating the effects of drought, intense irrigation, and water markets on ecosystem health in the region is challenging, as is drawing conclusions about any positive environmental impacts from the buyback program. There are nearly 200,000 acre feet worth of entitlements registered by the Australian Government as part of environmental buyback program and efforts to address poor environmental conditions in the Basin are ever-increasing.

As Australian markets continue to mature, the National Water Commission (2011) expects the MDB to face more trading involving urban water uses spurred on by drought, and a need for more water rights devoted to exclusively environmental purposes. These challenges are expected to be complemented with more advanced decision-making processes as water users grow accustomed to trading and markets. Bjornlund and Rossini (2008) see an additional possibility in the increasingly mature MDB market. They claim that Australian water markets are reaching a level of maturity that could support the entry of investors and new market products. These risk sharing products, including options, futures, and contingent contracts, could further alleviate the effects of water supply variability since water entitlements vary based on water availability for a given year. The results of increased municipal water user participation in the market, as well as potential new market products, will make the Australian case even more telling of the potential of water markets to facilitate adaptation.

Australia's Murray-Darling Basin is often lauded as the leading example of a successful water market, and part of this success can be attributed to the relative simplicity of having one large basin where nearly all water is devoted to irrigation. This reality makes designing a basin-wide trading program a simpler task than in the US, for instance, where many more types of water users are involved and the physical geography is more variable. However, the MDB program deserves credit for constantly reforming and improving the market in the midst of severe drought and making ongoing efforts to internalize environmental needs for the region.

The evidence that trading helped provide crucial income for irrigators during periods of drought is a promising example for the potential role of water markets in climate change adaptation. The Australian case further indicates that similar settings around the world (large basins where water use is primarily devoted to one sector) may be successful sites for water markets designed to facilitate climate change adaptation.

CONCLUSIONS

The experiences of the Western United States, Chile, and Australia’s Murray Darling Basin speak to a number of questions regarding the role of water markets and climate change adaptation given their respective settings and outcomes. Though these experiences cannot be compared directly because of the wide disparity in context, their collective results given these contexts can be accumulated into a set of conclusions about the prospect of using water markets in adaptation in these and other places. In generalizing the analyses of the US, Chile, and Australia presented in this thesis, the following may be argued:

(1) Federally-sponsored water storage and transportation infrastructure connecting water users underlies the market activity found in Australia and the Western United States. Such activity will be necessary to accommodate increasing water resource variability under climate change.

(2) Water markets facilitate environmental sustainability to the degree that they are designed to do so, or to the degree that legal environmental protection already exists. Markets can and must be continually reformed to internalize third-party effects of trading.

(3) Water markets can most effectively allocate water under situations of scarcity when they are designed to approximate “cap-and-trade” policies rather than free markets.

(4) Scarcity and variability have, in fact, proven to be healthy for water markets, supporting their viability as a successful tool under climate change conditions.

(5) Local institutions involved in managing water markets are attuned to local climate, economic, and social concerns, allowing them to help design water markets that address these issues.

> (6) In using markets to address increasing short-term variability in water supply, it will be crucial to minimize transaction costs so that markets may accommodate changing water needs quickly.

Australia's National Water Commission echoes several of these claims in listing "universal physical and economic characteristics that suggest where water trading will be most beneficial," which include places where with the following characteristics:

> "resources are fully developed for consumptive use, there is variability in seasonal water availability and variability between connected systems within seasons, there are a large number of connected water users, users have varying demands and degrees of flexibility to respond to water shortages, water users are exposed to the cycles of global agricultural markets, demands for urban and environmental water are increasing, and there is pressure for change in the existing structure of water-using industries" (NWC 2011).

This final characteristic is perhaps as important as any in the consideration of water markets as an adaptation tool. Though climate change will likely present pressures for change in water management styles, considering the implementation of water markets must involve a conversation about the alternatives. While the merit of alternative adaptation strategies lie outside the scope of this thesis, the above six considerations are presented as evidence to be part of this conversation.

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