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An Integrated Assessment of Water Markets: A Cross-Country Comparison

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Introduction

Many of the world's arid and semiarid regions face the challenge of declining water supplies (Ludwig and Moench 2009) and increasing demand for water resources due to population and income growth (Falkenmark 1999). Without comprehensive efforts to address water scarcity, there will be dire effects on the livelihoods of the poor in water-scarce and low-income countries, especially those with high population growth rates.

Effective institutional arrangements and allocation mechanisms among competing users are needed to mitigate and manage water scarcity. Water markets, which are intended to enhance the economic efficiency with which water resources are utilized, are one such institutional arrangement. The purpose of this article is to develop, for the first time, a comprehensive and integrated framework to assess and compare water markets. This framework is used to identify the strengths and limitations of five water markets: Australia's Murray-Darling

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Basin, the western United States, Chile (in particular the Limarí Valley), South Africa, and China (in particular, the North). These locations are all semiarid and face, to varying degrees, the prospect of reduced water availability associated with climate change. Two of the markets are in rich countries (Australia and the United States), two are in low- to middle-income countries (Chile and South Africa), and one is in a poor, but rapidly developing country (China). However, all five countries (and markets) differ substantially in terms of their water use and reform histories as well as their legal and institutional frameworks.

The framework presented here uses qualitative and quantitative criteria in three key categories—institutional foundations, economic efficiency, and environmental sustainability—to assess and make comparisons across the five water markets. This framework helps identify which of these water markets are currently able to contribute to integrated water resource management, which criteria underpin these markets, and the features of these markets that may require further development.

The following section provides an overview of the integrated framework and the five water markets. The next three sections evaluate the five water markets using the institutional foundations, economic efficiency, and environmental sustainability criteria. The final section summarizes the findings and identifies some general lessons concerning water markets that may be useful in improving water governance.

An Integrated Water Markets Framework

Indicators of water scarcity are typically defined in terms of water availability per person per year or withdrawals as a proportion of water availability and accessible runoff (Postel et al. 1996; Shiklomanov 2003). Sullivan (2002) has proposed a broader measure—a water poverty index—that may include measures of human health, community well-being, and access to safe water and sanitation, as well as water availability. However, as far as we are aware, only Dinar and Saleth (2005) and Saleth and Dinar (2004) have developed a framework to compare water institutions. They use sixteen characteristics of water institutions in three broad categories: law related, policy related, and organization or administration related, but only one of these characteristics is directly related to water markets.

Previous reviews of water markets include Easter et al. (1998, 1999), Howe et al. (1986), and Rosegrant and Binswanger (1994), among others. These reviews provide guidance for improving markets, typically from an economic efficiency perspective. Our goal here is to show how water markets can, and do, function with very different legal and institutional frameworks and what this implies in terms of efficiency and sustainability. In particular, we develop a comprehensive and integrated framework in order to generate a qualitative ordinal rank of the institutional foundations of water markets and their performance in terms of integrated water resource management. While many of these rankings are subjective, we provide evidence to support our judgments and recognize that conclusions drawn from individual basins may not be fully representative of all water markets in a country.

Our integrated water markets framework is designed to (a) assess and compare different water markets, (b) track the performance of water markets over time, and (c) identify ways in which water markets might be reformed to achieve desired goals. The framework assesses and ranks nineteen criteria of water markets in three categories: institutional foundations (eight criteria), economic efficiency (six criteria), and environmental sustainability (five criteria). Equity considerations are included in several subcategories: recognition of public interest, priority of use, initial allocation and reallocation, and dealing with market failures. Many of the criteria are qualitative measures that are derived from primary or secondary data, but some of the economic efficiency criteria are quantitative. The qualitative criteria are ranked on a four-point scale: the highest (three "drops") indicates the criterion is nearly or fully operational; two drops indicates the criterion is mostly satisfied but some further development is required; one drop indicates the criterion is partly satisfied and substantial development is required; and the lowest ranking (X) specifies that the criterion is not operational or is missing. Correlation between criteria is possible given the interwoven challenges of water governance.

We apply the integrated framework to five water markets: Australia's Murray-Darling Basin, the western United States, Chile (the Limarí Valley), South Africa, and China. Limited local water markets have existed in the United States since the nineteenth century, while in China water trading is still very much in its infancy[1] and in South Africa water markets are severely constrained by the lack of full legal recognition of existing use rights. Water rights in Chile's Limarí Valley are, arguably, the most entrenched in terms of legal rights, but this market is small compared to water markets in Australia's Murray-Darling Basin, which were first established in the early 1980s.

For all five markets, we use secondary data sources. These sources have been supplemented by data, first-hand knowledge, and research and water policy experience with three of these markets (Australia, South Africa, and United States) and verified by water experts in the case of China and Chile. The next three sections describe the criteria (by category) in more detail and discuss the findings of the assessments.

Institutional Foundations

The framework uses eight criteria to assess the institutional foundations of the five water markets: (a) recognition of the public interest (legal and practical recognition of multiple interests in water resources); (b) administrative capacity (sufficient administrative authority, resources, and information to manage water resources effectively); (c) well-developed horizontal and vertical linkages (robust and clear institutional relationships, both at a given level of governance and between different levels of governance); (d) legal/administrative clarity (including definition and recognition of water rights and trading rules as well as transparent administrative actions); (e) priority of use (provision of water for basic human needs and the existence of beneficial use requirements); (f) initial allocation and reallocation (transparent processes for allocating water rights and reallocating as priorities evolve); (g) dealing with market failures (recognition of third party effects and appropriate and robust mechanisms for resolving conflict); and (h) adaptive management of institutions (capacity for institutional adaptation). A summary of the rankings for these criteria (by water market) is provided in Table 1. Additional details about the criteria and their status and performance in each of the water markets are presented below.

[1]China's experience with water trading has to date been limited to (a) the "administered reallocation" of water savings from channel lining and (b) several intercounty and interprefecture agreements to reallocate bulk water entitlements (Speed, pers. comm.). There is, however, a directive from the 2006 State Council to develop "a water rights transfer system" (Sun 2010).

Table 1. Assessment of water markets: Institutional foundations

	Recognition of public interest	Administrative capacity	Horizontal and vertical linkages	Legal/administrative clarity	Priority of use	Initial allocation and reallocation	Dealing with market failures	Adaptive management of institutions
Australia	💧💧	💧💧	💧💧💧	💧💧💧	💧💧💧	💧💧💧	💧💧	💧💧💧
U.S. West	💧💧	💧💧	💧	💧	💧💧💧	💧💧	💧	💧💧
Chile	💧	💧💧	💧💧	💧💧	💧	💧💧	💧	💧
South Africa	💧💧	💧	💧	X	💧💧	(pending)	💧💧	(pending)
China	💧	💧	💧	X	💧💧	N/A	X	💧💧

💧💧💧, Nearly or fully satisfied; 💧💧, Mostly satisfied, some further development required; 💧💧, Partly satisfied, substantial further development required; X, Not satisfied/Missing/Not operational; (pending), Pending implementation of espoused policy reforms; N/A, Not applicable.

Recognition of the Public Interest

The public interest refers to beneficiaries from water resources other than direct water users, notably the environment. In the case of Australia, water resource plans are obliged to “establish the intended balance between environmental and consumptive use outcomes, as well as setting out terms and conditions for water access” (National Water Commission 2009a), although in practice this does not necessarily occur (Connell and Grafton 2008).

In the United States, western states own water in trust for their citizens. Individuals hold usufruct rights, or user rights to the water, subject to the requirement that the use is beneficial and reasonable as well as oversight by the state in monitoring applications and water transfers to ensure that they are consistent with the public interest (Gould 1995). The notion of “public interest,” however, has been sufficiently vague to justify state intervention, which has led to uncertainty regarding water rights.

In Chile, the 1981 Water Code specifies “. . . . water is a natural resource for public use” (Hearne 1998), but public interest regulation under the law is constrained by scarce resources, especially with regard to third party losses or environmental services (Oscar Cristi, pers. comm.).

In South Africa, the public interest in water resources is defined under its National Water Act 1998, and the national government is held as the custodian of the public interest (Nieuwoudt and Armitage 2004). However, the national government has failed to prevent major pollution problems, such as acid mine drainage (Water Research Commission 2009), which generate substantial external costs.

China’s constitution provides that water resources are owned by the state on behalf of the people (Speed 2010a), and its 2002 Water Law provides a framework for integrated water resource management and includes sections dealing with planning, conservation, and pollution control (Khan and Liu 2008). Despite these good intentions, however, comprehensive Chinese water resource planning is still in a “developmental phase” (Liu and Speed 2010).

Administrative Capacity

Administrative capacity refers to the capacity to enact government’s stated water policies, and it is most developed in the high-income countries: Australia and the United States. Due to both countries’ historical development as federalist systems, much of this capacity resides at the state level, although in the case of Australia this capacity is rapidly being developed at the federal level following passage of the Water Act 2007. In the United States, each state has a regulatory agency to monitor whether water is held, used, and transferred in ways that are consistent with the requirements of beneficial use and the public interest. These agencies may vary, from the State Engineer in New Mexico and Utah, to the Department of Water Resources in Arizona, to the Department of Natural Resources and special water courts in Colorado.

In Chile, administrative capacity is limited by the human and financial capacity of the government’s water rights agency, Direccion General de Aguas (DGA). Similarly, in South Africa, administrative capacity in the water sector is constrained by a lack of central government support. Attempts to establish effective catchment (river valley) management authorities have also been stalled by the social problems generated under the previous regime (Farolfi and Rowntree 2007). Further difficulties in developing administrative capacity at the national level have emerged from the continued influence of regional offices of the South African Department of Water Affairs, which are, at present, the entities providing local water management. These factors combine to limit the ability of the state to effectively manage and control water resources (Malzbender et al. 2005).

In China, "serious questions about the state's capacity to tackle water problems" remain (Lee 2006), although the establishment of river basin commissions for major rivers and the revision of master basin plans are promising (Speed, pers. comm.).

Horizontal and Vertical Linkages

Well-developed linkages across governments and agencies are necessary to ensure effective water governance if responsibilities are shared. In Australia, cross-government agreements have formed the basis of water reform since the mid-1990s. A willingness to cooperate and cede authority to the federal government in return for financial benefits led to the Water Act 2007, which provides for centralized Basin planning.

In the United States, because water management has been left primarily to the states, vertical and horizontal institutional linkages are relatively weak. For example, water trades may require approval by the relevant irrigation district board, the county where the district is found, the state regulatory body, and, potentially, federal agencies such as the Bureau of Reclamation. These institutional limitations complicate and obstruct water trading, leading to inconsistencies across catchments or river valleys.

In Chile, while horizontal relationships are transparent at lower levels of governance (e.g., between irrigation organizations), significant problems can exist between the DGA and the court system in dealing with water conflicts (Bauer 2004). Chile does appear to have well-developed vertical linkages, although this is partly attributable to the interconnected nature of the Limarí Valley's water infrastructure (Zegarra 2008).

In South Africa, significant interbasin transfers—as well as transfers across national borders—have necessitated functioning horizontal cooperation, and numerous water agreements have been implemented (Turton et al. 2008). The National Water Act 1998 defines the lines of authority between levels of government, but the capacity for local water management still resides largely in the regional offices of the Department of Water Affairs rather than in its catchment management authorities.

China has fragmented horizontal linkages that result in diminished administrative authority and confusion (Lee 2006; Liu and Speed 2010; Zhou 2006). Fractured water management systems have been identified by the World Bank (2002) as "the critical unsolved problem" for China's water resources, including nine separate bureaus with water policy interests (Lee 2006).

Legal/Administrative Clarity

Legal clarity over water rights is a key feature of effective water markets. In Australia, water rights are statutory rights that could, in principle, be revoked or modified without compensation. In practice, governments have sought to protect existing rights holders by purchasing water rights from willing sellers in order to increase environmental flows (Connell and Grafton 2011).

Water rights in the western United States are, typically, based on prior appropriation and diversion (Johnson et al. 1981), with diversions prioritized based on the date of the right. In certain areas, water rights are not well defined, while in others the assurance of junior rights is undermined by overallocation of the available water. There is no single or central water title office. Rights are also conditional upon varying state regulations for beneficial use, preferred uses, area of origin restrictions, and public interest/public trust doctrine mandates (Getches 1997). These requirements vary across states and can raise the transaction costs of transfers and lower the value of water rights.

Chile has the strongest and most broadly defined water rights, based on the Water Code of 1981, whereby the government must pay for the attenuation of water rights (Bauer 1997). Water use efficiency has increased under the system, but there remain some conflicts created by third party effects as well as confusion over the relative priority of consumptive rights and nonconsumptive (mainly hydropower) rights (Brehm and Quiroz 1995). To help avoid this problem, users can register their water rights in registers, a practice that is also underway in China and South Africa.

In South Africa, addressing equity concerns—including through water management—remains the chief national priority, relegating the trading of water rights between farmers to a lower-order concern. Water rights are formally recognized and registered by the Department of Water and Environmental Affairs and are renewable every five years (Pott et al. 2009). Delays in registration and licensing have prevented water users in many catchments from being assured of their existing rights, thus impeding trade (Speelman et al. 2010).

Unclear property rights in China continue to cause significant problems for the management of China's water resources (Speed 2010b). There remains a lack of transparency surrounding water allocation decisions (Lee 2006; Zhou 2006), and the ambiguous legal status of water allocation has led to implementation difficulties (Shen and Speed 2010).

Priority of Use

Priority of use refers to the provision of water for basic human needs (defined as the immediate requirements of households in terms of drinking water and sanitation) and conditions relating to beneficial use (referring to whether, and how, the water is used).

Australia does not have explicit provisions for beneficial use. Basic human needs are defined in terms of water supplies for communities that depend on rivers for their water supplies. Such communities have the highest order priority of access.

The United States has appropriative water rights that are conditional upon placing the water in beneficial use. Most western states define beneficial use in terms of the benefit for the appropriator, other persons, or the public, with corresponding lists of what is considered beneficial use (evolving through time), but should there be extreme water shortages, domestic and municipal uses would take priority over agricultural, industrial, and in-stream uses (Trelease 1955).

Like Australia, Chile has no explicit provisions for beneficial use. There is a general deference to the urban water supply (Hearne 1998), and water availability is such that the provision of basic human needs has tended not to compromise existing water markets and allocations. Increased demand, however, poses allocation challenges in areas where mining activity has been increasing (e.g., Barrionuevo 2009).

The provision of basic water services for human needs—often for free—has been a major priority of the South African government's water policies. This approach is based on the National Water Act 1998, which aims to ensure adequate water for basic human needs and ecological and development purposes (Farolfi and Perret 2002). Beneficial use is also an explicit consideration and is taken into account when licenses are reviewed (Nieuwoudt 2000). However, there is a lack of transparency concerning what this means in practice, and free provision of water may have incentive effects for use and management.

In China, basic human needs for water are met due to the priority given to urban and rural domestic water (Speed, pers. comm.). It may be that beneficial use is taken into account, but because of the centrally administered nature of water allocation in China, it is not clear how this is done.

Initial Allocation and Reallocation

Initial allocations of water rights can be contentious, especially if prior users of water are excluded or provided with a lower share than they had historically. Such allocations may be viewed as inequitable and can contribute to water conflicts that jeopardize the efficient functioning of water markets.

The challenge in Australia has been to reallocate water rights from existing users to the environment in ways that are equitable and meet societal goals. To date, this has been accomplished through federal government purchases of water rights from willing sellers, funded from general tax revenues (Connell and Grafton 2008, 2011).

In the United States, water rights in western states are largely based on the prior appropriation doctrine or "first possession" (Getches 1997; Kanazawa 1998), whereby senior rights holders have first claim to water and junior rights holders bear more risk during drought. While there is no central registry of water rights, rights in each basin generally are well known and transferable separately or with land.

Under Chile's 1981 Water Code, prior users, primarily in agriculture, were allocated consumptive water rights, but nonconsumptive rights such as hydroelectric power generation were also included. There is some confusion as to which of these two rights holders has priority (Bauer 2004). The allocation of return flows to holders of water rights, required under the 1981 Water Code, also may disadvantage customary downstream flow users who previously had access to these flows.

Since the passage of its National Water Act 1998, South Africa has been undergoing a process of compulsory licensing, after which an "initial allocation" of water licenses will occur (Water Research Commission 2009). This process may reallocate water to other purposes, such as to previously disadvantaged individuals, without compensation to prior users/rights holders.

In China, the eleventh five-year plan (2006–2010) requires the development of a national initial allocation system (Sun 2010), but no clear interpretation of this requirement has been provided to date. Large interbasin transfers from the South to the North indicate that past water use does not ensure current access.

Dealing with Market Failures

Market failures can emerge for a variety of reasons, including impacts from third party use, market power, and an inadequate provision of public goods. Market power has yet to emerge as a significant issue in water markets, but third party impacts are important in all markets and arise when water trades impose external costs not accounted for in the water trade.

In Australia, states and irrigation districts have limits on the quantity of sales permissible in water markets so as to protect communities from reduced water diversions. These controls have had a negative effect on water transactions and the efficient functioning of water markets (Productivity Commission 2010). Conflicts and tradeoffs between water uses are resolved primarily at both a basin and catchment level. Where there have been difficult tradeoffs (e.g., water allocations to the environment to the detriment of irrigators), the federal government has provided substantial funding to smooth the transition for those negatively affected.

In the United States, water trades are regulated by states to meet beneficial use and no harm or no injury requirements when they involve changes in location, timing, and nature of use that could affect other rights holders (Getches 1997). There can also be restrictions to limit negative pecuniary impacts of trades. The approach to conflicts in the United States has primarily been one of litigation, including those under the Public Trust Doctrine, a common law notion that emphasizes the public nature of water and other natural resources (Sax 1970; Brewer and Libecap 2009). Because there is no compensation for rights holders who lose water under the doctrine, conflicts over water reallocation can be long lasting (Libecap 2007).

Chile's 1981 Water Code does not specifically address third party effects or environmental impacts. The World Bank considers externalities in Chile's water sector to be of potential concern (Briscoe et al. 1998). As in the United States, Chile's approach to conflicts has primarily been one of litigation, a process that has proved to be time-consuming and costly (Briscoe et al. 1998).

Nieuwoudt (2000) reports that the South African National Water Act 1998 "gives prominence to third party (environment and human) issues," although it is difficult to assess how effective these protections are in the absence of significant levels of water trading. It is clear, however, that conflicts over water are ongoing. Until effective catchment management is implemented, these difficulties are unlikely to be resolved. Some stakeholder-driven water management processes have been developed by the Water Research Commission (e.g., see Farolfi and Rowntree 2007).

In China, water transfers as a result of water "savings" through lining of irrigation channels produce third party effects which, to date, have been inadequately considered (Speed 2010b), especially for surface–groundwater linkages and wetlands (Xie 2008, 76). Importantly, the third party effects of large interbasin transfers from South to the North (Ghassemi and White 2007) have not been fully considered nor have third parties been fully compensated. Regarding conflicts, the 2002 Water Law contains provisions for dispute settlement (Liu and Speed 2010), although shortcomings in the water planning framework have allowed inconsistencies to emerge between regional and local water plans, increasing the potential for conflict in times of water shortage (Liu and Speed 2010).

Adaptive Institutions

Adaptive institutions are able to adjust to unexpected shocks, incorporate new and revised information, and respond in a timely manner to changes in societal preferences over how water is managed and used. Australia's Water Act 2007 represented a radical shift in responsibility for water planning and management and was agreed to by all levels of government and with bipartisan support. This suggests that, at least at the present time, Australia has the most adaptable institutions of the countries in this study, although, as elsewhere, political tensions affect the pace and degree of reform implementation.

In the United States, institutional heterogeneity within and across states provides opportunities for learning and innovation. For instance, many water supply organizations have historically resisted water transfers (Thompson 1993), but as the potential gain from exchange rises, irrigation districts—the largest water supply organizations—have become more responsive to trading potential (Eden et al. 2008).

In Chile, there have been numerous attempts since 1990 to modify the country's water law, and some changes were implemented in 2005 (Bauer 1997, 2008; Zegarra 2008). By contrast, South Africa radically changed its water institutional framework with its National Water Act 1998, which provides for decentralized control of water resources. Since its passage, the focus has been to implement the various reforms rather than embark on further institutional change.

China's recent development of river commissions for its seven major basins is illustrative of adaptability, as is the Water Law 2002, which, on paper, contains many provisions conducive to sound water management. The ability of institutions to adapt in practice, however, has lagged behind the ideals espoused in official laws and regulations. This is at least partly due to the inertia that emerges from the enormity of China's water sector: 1.1 million employees within the institutions of the Ministry of Water Resources and around 1,300 "water affairs bureaus" (Speed, pers. comm.).

Economic Efficiency

The framework uses three quantitative measures of the economic efficiency of water markets: (a) size of the market (volume of water traded from permanent and temporary water rights as a percentage of total water rights); (b) estimates of the annual monetary gains (in U.S. dollars) from water trade; and (c) size of storage (which allows for trades over a longer duration and trades upriver). In addition, the framework includes three qualitative measures of economic efficiency: (d) nature of water rights (the extent to which they are unbundled so that water rights are separated from land rights); (e) breadth of market (capacity for water trading between catchments, including upstream trades, as well as intersectoral trading); and (f) market price formation and availability (predictability of prices given changing water availability and accessibility of price information). The performance of these criteria in the five water markets is summarized in Table 2 and discussed in more detail below.

Size of Water Market

The size of water markets provides a good indication of their ability to facilitate transfers from lower- to higher-value uses. Chile's Limarí Valley (Hadjigeorgalis and Lillywhite 2004) and Australia's Murray-Darling Basin (National Water Commission 2009b) have well-developed

Table 2. Assessment of water markets: Economic efficiency

	Size of market (permanent/ temporary)	Gains from trade (US$ million)	Storage (ratio of average use)	Nature of water rights	Breadth of market	Market price formation and availability
Australia	12.5/20.1%	495	2.0	💧💧💧	💧💧	💧💧💧
U.S. West	I	406	2.3 (Colorado)	💧💧💧	💧	💧
Chile	15/30%	22.1	3.3	💧💧💧	💧💧	💧
South Africa	I	I	I	💧	💧	💧
China	I	I	I	X	💧	N/A

💧💧💧, Nearly or fully satisfied; 💧💧, Mostly satisfied, some further development required; 💧💧, Partly satisfied, substantial further development required; X, not satisfied/missing/not operational; I, Inadequate info; N/A, not applicable.

water markets in terms of the volume traded as a proportion of total water rights available. The annual amount traded is over 20 percent in both locations, including permanent and temporary water rights, which is extraordinarily high. Data are not available across all the western United States to make a similar calculation, but the amount of water traded as a proportion of total water use is much less. Nevertheless, substantial volumes of water are traded in U.S. water markets. For example, between 1987 and 2008, a total of 38,700 gigaliters (GL) were traded in Texas, 27,500 GL were traded in Arizona, and 24,500 GL were traded in California (Brewer et al. 2008).[2] As of 2010, there had been only limited transfers of water rights in South Africa, although this may change after all rights are registered (expected by the end of 2011). Similarly, in China, there are only ad hoc transfers; based on Speed (2010b) and Liu and Speed (2010), these may amount to less than 0.1 percent of the total volumes used.

Gains from Water Trade

Calculating the gains from water trade (in $) requires data on actual transactions. These data are only partially available, at best, for China and South Africa. Calculations of the gains from trade in Chile indicate that the benefits of water markets are substantial, amounting to between 8 and 32 percent of agriculture's contribution to regional GDP (Hadjigeorgalis and Lillywhite 2004). Australian water markets are much larger, with the total volume of trade in the Murray-Darling Basin worth over $1.8 billion in 2009 (National Water Commission 2009b) and the gains from trade in a dry year estimated at $495 million (Peterson et al. 2004). In the western United States, the average annual value of water trading across twelve western states between 1987 and 2008 is estimated at $406 million (in 2008 dollars) (Libecap, forthcoming). Annually, the value of water transactions for all contract types and sectors varies from less than $1 million in Montana and Wyoming, the two least urban western states, to nearly $40 million in Arizona, Colorado, Nevada, and Texas, and more than $223 million in California.[3]

[2]These amounts are based on committed volumes where the annual amounts are projected forward for the term of the contract and discounted back at 5 percent (Brewer et al. 2008).
[3]The high turnover in California is driven by one-year leases within agriculture and a few large multiyear leases that transfer water from agriculture to urban use.

Water Storage

In regions where rainfall is not evenly spread throughout the year, water storage provides a valuable smoothing function. The more variable the climate, the larger is the storage required. In terms of water markets, storage also provides an opportunity for trade over longer periods of time and enables trades upstream, provided the transaction takes place before the water is released from upriver.

In all of the water markets, there is substantial water storage that facilitates water trade. The ratios of total capacity of water storage to average annual water use range from more than 2 in Australia's Murray-Darling Basin to about 3 in Chile's Limarí Valley. The ratios vary substantially for the western United States, but in one case (Colorado) the ratio is 2:3. China has extensive water storage capabilities along all of its major rivers, with approximately twenty thousand GL of storage capacity along the Yellow River alone (Ministry of Water Resources, China 2011).

Nature of Water Rights

In the past fifteen years, water rights in Australia have, more or less, been separated from land rights. Although some riparian rights (stock and domestic use by farmers) still exist, water rights can, in principle, be traded across catchments without also acquiring the land where the water rights were originally located (National Water Commission 2009a). Australia's water market includes two types of trade: a permanent market for the water right (that can vary in reliability across and within catchments depending on factors such as dam levels in public storages and expected inflows) and a seasonal market for the actual annual allocations of water assigned to the permanent water right.

In the western United States, surface water rights are based on the prior appropriation doctrine, which allows water to be separated from the land and moved via canals and ditches to new locations (Getches 1997; Kanazawa 1998; Johnson et al. 1981). Appropriative rights associated with the earliest water claims have the highest priority claim on water.

Chile's water rights system is similar to the system in Australia, featuring both permanent and contingent rights, where the latter provide allocations when availability is above average. In the Limarí Valley, there is also both permanent (title) and seasonal trade, with the latter typically more prevalent (Hadjigeorgalis and Lillywhite 2004; Zegarra 2008; Cristi 2010).

Water rights have been unbundled from land rights in South Africa since the passage of the National Water Act 1998 (Pott et al. 2009), and both temporary and permanent water trading have been observed (Nieuwoudt et al. 2005). In China, despite the 2002 Water Law, water rights remain poorly defined at the regional, irrigation district, and farmer levels (Speed 2010b). Although water access is restricted by the requirement that users hold a water extraction permit, allocations have generally not been granted at the farmer level (Shen and Speed 2010). In addition, land area is often used as a proxy to calculate water charges (World Bank 2002).

Breadth of Market

The breadth of water markets is defined spatially as well as by trades across competing uses. While Australia has well-developed water markets over a very large spatial area within irrigated agriculture, there have been relatively few intersectoral trades between agricultural and urban uses. This is because state governments that control urban water supplies have chosen to avoid, as much as possible, the purchase of water from rural areas in order to protect rural livelihoods and communities.

In the western United States, the majority of water markets are localized, with trades occurring primarily within river basins or subbasins. Regulatory restrictions are one of the main reasons that trading is limited. For example, nearly every western state has laws that protect basins of origin, making it difficult to export water from one basin to another. Consequently, there is virtually no private water trading across states. The lack of conveyance infrastructure and the high capital costs of moving water also limit the geographic scope of water markets. Most short-term trades occur within sectors, especially agriculture. Agriculture-to-urban transactions are dominated by longer-term leases and sales, but patterns vary across states.

Chile's water markets are also dominated by the agricultural sector (Bauer 2004). In the Limarí Valley, there has been limited trade activity by the urban sector because of adequate urban supplies and few conveyance systems between basins (Easter et al. 1999).

In South Africa, the vast majority of water trading has been within the agricultural sector (Pott et al. 2009) despite demands from industry for additional water volumes. While intersectoral transfers from agriculture to mining would be beneficial for both sectors, it could also "challenge the [equity] objectives of government" (Farolfi and Perret 2002) and the priority of providing water to previously disadvantaged individuals. Any intersectoral water trading must also wait for the initial allocation of licenses to be completed (Pott et al. 2009).

China stands out as the one country where there has been substantial transfer of water from agriculture to industrial and domestic uses. However, this has occurred via measures such as lining irrigation channels rather than through a fully operational water market (Speed 2010b).

Market Price Formation and Availability

Stable price formation and the availability of market price information are indicators of a competitive and mature water market. In Australia, water prices are remarkably consistent across catchments in the southern Murray-Darling Basin (National Water Commission 2009b). Where substantial differences exist, they are due to differences in reliability of the water rights or whether the rights are permanent or seasonal. Australia also has the most developed price data, with accessible state registers and a national water register available online in 2011.

In the western United States, markets are both local and "thin," causing considerable annual fluctuation in prices across time, jurisdictions, and sectors. As well as reflecting limited market integration, differences in prices across sectors reflect the opportunity cost of water, adjusted for water quality, conveyance, and the priority of the water right. Price dispersion is also due to the transaction costs involved in trading (Colby et al. 1993; Brookshire et al. 2004).

In Chile, price information is not widely available, which increases transaction costs (Zegarra 2008). In the Limarí Valley, where there is more information, prices of water shares have increased due to economic development across the mining, industrial, and agricultural sectors (Zegarra 2008).

In South Africa, price formation is stable, and information is spread largely by word of mouth (Gillet et al. 2005), with no central notice board. This has led to asymmetries in terms of price information between buyers and sellers (Nieuwoudt and Armitage 2004).

The outlier in terms of price formation is China, where water prices are regulated by the government (Liao et al. 2008). Consequently, water prices are stable, but they do not reflect changing environmental or economic conditions. Prices for water transfers between regional governments, for instance, are determined through direct negotiation.

Environmental Sustainability

Water markets provide a mechanism for the allocation of water between competing water users and market-based consumptive uses. However, unless explicit consideration is given to nonmarket uses or set asides/reserves for the public good, markets may fail to contribute to broader societal goals.

There are several preconditions for meeting environmental sustainability in water management, including adequate information of environmental needs, delivery of water to meet these needs, and an adaptive process to manage these requirements as conditions and circumstances change. Our framework uses five qualitative criteria to capture these preconditions: (a) adequate scientific data to determine hydrological requirements of water-based environmental resources; (b) adequate provisions for environmental flows; (c) adaptive management of environmental flows, including the capacity to monitor the environment; (d) water quality considerations in water planning and markets; and (e) complementary basin and catchment-level planning. The rankings for these criteria in the five water markets are presented in Table 3 and discussed in more detail below.

Adequate Scientific Data

Adequate scientific data are required to ensure that effective water resource planning underpins formal water markets. Australia, the western United States, Chile, and South Africa all have good, though not fully developed, scientific data available. In Australia, much of this data have been developed in the past decade in response to government programs such as the Living Murray First Step (Grafton and Hussey 2007), initiated to increase environmental

Table 3. Assessment of water markets: Environmental sustainability

	Adequate scientific data	**Adequate provisions for environmental flows**	**Adaptive management of environmental needs**	**Water quality considerations in water planning**	**Basin and catchment-level water planning**
Australia	💧💧	(pending)	(pending)	(pending)	(pending)
U.S. West	💧💧	💧	💧	💧💧	💧
Chile	💧💧	💧	💧	💧	💧
South Africa	💧	(pending)	I	I	I
China	X	💧	X	💧	💧

💧💧💧, Nearly or fully satisfied; 💧💧, mostly satisfied, some further development required; 💧, partly satisfied, substantial further development required; X, not satisfied/missing/not operational; I, inadequate information; (pending), pending implementation of espoused policy reforms flows. The data are 'patchy' depending on the catchment and are not always accessible, even to academic researchers, but are used by water agencies for planning purposes.

In the United States, state and federal agencies gather and provide information regarding hydrological data on stream flows, water use, and environmental demands. Environmental requirements are project and river specific, and there is no central clearinghouse. Chile has scientific data for management and some modeling of basins, maintained by the DGA since 2000 (Brehm and Quiroz 1995, Cristi 2010). South Africa has well-developed hydrological models of its major catchments and is developing "ecological reserves" as part of its National Water Act 1998, forcing water planners to improve data collection and monitoring. It is not clear that China has adequate water data for environmental purposes (Shen and Speed 2010).

Provisions for Environmental Flows

Adequate provision of volumes of flows is critically important to maintaining the ecosystem health of rivers and habitats. In Australia and South Africa, there is federal legislation mandating provision of water for environmental and public good purposes. In the case of Australia's Murray-Darling Basin, this will be implemented via a basinwide plan that will determine sustainable diversion limits for each catchment in 2011–2012. At present, water is provided for the environment through both water resource planning processes (Connell and Grafton 2011) and government purchases of water rights from willing sellers (Grafton 2010).

In the United States, all western states recognize that environmental flows are consistent with beneficial use. Quasi-governmental agencies and private organizations, such as The Fresh Water Trust, engage in water leasing or rights acquisition for in-stream flow maintenance (Landry 1998; Neuman 2004; Scarborough 2010). However, there is considerable debate about how much water is needed to achieve specific environmental objectives. Benefit–cost analysis is not expressly required under the Endangered Species Act 1973 or the Clean Water Acts. This means that, in general, a weighing of opportunity costs is not likely to occur when determining environmental flows.

In Chile, because the 1981 Water Code does not directly address third party effects, the primary mechanism for allocating water for environmental purposes is the purchase of existing water rights, although the 2005 code does describes minimum flow requirements. By contrast, South Africa is developing ecological reserves of water for public good purposes that include basic human needs and the environment (Farolfi and Perret 2002), although progress to date has been slow (Pollard et al. 2009). In China, "water is generally not allocated to the environment in any meaningful way" (Shen and Speed 2010), although the government is in the process of amending water basin plans to account for environmental flows in at least seven of its major river basins (Speed 2010b).

Adaptive Management of Environmental Flows

All water markets, to some extent, have elements of adaptive management to facilitate responses to shocks, such as drought, by allowing high-value uses to access water that might otherwise have been denied to them. The challenge is to ensure that water markets can flexibly respond to desired public good benefits of water.

In Australia, water resource plans disproportionately favor water diversions that, typically, decline by a lesser amount than inflows in dry periods (CSIRO 2008). As a result, during extended droughts, environmental flows can become negligible and this can generate widespread environmental degradation (Wentworth Group of Concerned Scientists 2010). A proposed Basin Plan for the Murray-Darling Basin, due to be released in 2011, will attempt to correct this fundamental flaw in water planning.

In the western United States, there is capacity for adaptive management under state and federal environmental legislation. However, the general absence of benefit–cost analysis and reliance upon judicial injunctions under federal endangered species and water quality legislation can result in protracted legal disputes. Consequently, there is potential for greater reliance upon water markets where rights holders are compensated for environmental diversions.

In Chile, adaptive management is in the form of proportional allocation adjustments across all water rights in response to annual variability of inflows. South Africa has also recognized the importance of adaptively managing its water resources. As a key component of the country's ongoing reform process, ecological reserves of water are being identified to meet environmental needs (e.g., Pollard et al. 2009). The status of China's adaptive water planning is that "current approaches to defining environmental flows do not adequately account for complex relationships between flow regimes and ecosystems" (Liu and Speed 2010).

Water Quality Considerations

Water quality is related to flows and how water is diverted and used. Some consideration is given to water quality in all of the water markets assessed. In the Murray-Darling Basin of Australia, there are some restrictions on trade to avoid worsening salinity, and an overall plan for the Basin due for release in 2011 should also include water quality and salinity management actions to safeguard water quality (Murray-Darling Basin Authority 2009). In the United States, water quality is regulated by state and federal legislation and trades can be restricted due to quality concerns. This has been the case, for example, in the Sacramento Delta, where rising salinity levels have contributed to reduced exports of water through the State Water Project.

In Chile, South Africa, and China, there is evidence of major water quality problems, at least in some river basins. The Limarí Valley, however, does not appear to have major water quality challenges (Hearne 1998). In South Africa, the most damaging water quality issue is acid mine drainage that comes from both active and abandoned mines. Despite the fact that these problems have existed for many decades, they remain a major concern in key catchments. China faces the daunting challenge of mitigating severe water quality problems, and although the country is taking steps to resolve water pollution, enforcement remains weak and the problems are "grave and deteriorating" (Lee 2006).

Complementary Basin and Catchment-Level Water Planning

Interlinked and compatible basin and catchment water planning is necessary for integrated catchment management to address downstream externalities. In Australia, a comprehensive Basin Plan for the Murray-Darling Basin is expected to be proposed in 2011 that will specify environmental water requirements and sustainable diversions for each catchment (Murray-Darling Basin Authority 2009).

In the western United States, there is partial basinwide water management regarding environmental flows. Basins often cross multiple political jurisdictions, thus involving differing regulations and agencies, although federal quality regulations generally apply. There has been limited environmental cooperation among the eighteen interstate water basin compacts or agreements, and in California, the Integrated Regional Water Management Plan Program has been expanded to promote water planning outside traditional political boundaries.

Chile has a decentralized planning system where much of the management within basins is done locally. For example, irrigation associations and officials in the Irrigation Bureau effectively manage Limarí's water supply on a year-to-year basis (Zegarra 2008).

South Africa's National Water Act 1998 provides for catchment-level planning for environmental and human needs through reserves. However, slow progress in creating catchment management authorities has meant that water planning remains in its infancy in most catchments. China's seven major river basins all have comprehensive water plans, although they are only now beginning to go beyond a focus on allocation to incorporate more holistic objectives such as water quality, flood control, and environmental protection (Speed, pers. comm.).

Summary and Conclusions: Key Lessons for Water Markets

This article has used an integrated framework to assess and compare the institutional foundations, economic efficiency, and environmental sustainability of water markets in Australia, the western United States, Chile, South Africa, and China. The framework and results presented here reveal important linkages between water market development, institutional constraints, and management goals. Understanding these connections is crucial to good water governance. Applying this integrated framework to other water markets would provide useful information to policy makers about how water markets can be further developed to achieve particular goals.

In closing, we offer ten key lessons from the application of our integrated framework to the five water markets that may be helpful to policy makers, researchers, and other stakeholders as they seek to improve the functioning of water markets. First, institutions matter. This means that what works in one water market may not be as successful in another market that has different institutions. Second, the design of water markets may have purposes other than direct economic efficiency, such as managing third party impacts and equity (e.g., the case of South Africa). Third, markets can be adapted to account for environmental sustainability without necessarily compromising economic efficiency. Fourth, markets can successfully work in small catchments, such as Chile's Limarí Valley, as well as in large basins, such as the Murray-Darling Basin. Fifth, water markets can generate substantial gains for buyers and sellers that would not otherwise occur, and these gains increase as water availability declines. Sixth, there is a need for flexibility in water markets as the benefits of consumptive and *in situ* use change, as has happened in the western United States and Australia. Seventh, there must be a close connection between water markets and water planning to provide certainty to holders of water rights while maintaining desired public benefits. Eighth, history matters. The path and experience of the western United States, with its appropriative rights, has been very different from that of Australia, which has statutory rights. Ninth, differences in regulatory capacity (human and financial), such as those that exist between South Africa and

Australia, help to explain some of the variation in the performance of their water markets. Tenth, performance must match goals. Water markets should be judged not only on economic efficiency grounds but also on equity or environmental sustainability grounds where these aims have been deemed to be important.

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Abstract

This article presents an integrated framework for assessing water markets in terms of their institutional foundations, economic efficiency, and environmental sustainability. This framework can be a tool for (a) comparing different water markets, (b) tracking performance over time, and (c) identifying ways in which water markets might be adjusted by policy makers to achieve desired goals. The framework is used to identify the strengths and limitations of five water markets: (a) Australia's Murray-Darling Basin, (b) the western United States, (c) Chile (in particular the Limarí Valley), (d) South Africa; and (v) China (in particular, the North). The framework helps identify which of these water markets are currently able to contribute to integrated water resource management, which criteria underpin these markets, and which features of these markets may require further development. The findings for each market, as well as comparisons between them, provide general insights into water markets and how water governance can be improved. (*JEL* Q25, Q58)