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Water Trading: Innovations, Modeling Prices, Data Concerns

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Abstract: This article examines policy innovations and data concerns related to water trading in Colorado, and develops econometric models of transactions occurring over two distinct time periods. The Punctuated Equilibrium Theory (PET) of policy adaptation is used to examine shifts in Colorado water trading policy paradigms. Creating better policy frameworks for water trading is a key concern for agricultural, urban, and environmental water interests, given hotter temperatures and more variable precipitation patterns in the western U.S. Contractual arrangements of varying types are being used to engage farmers in providing reliable water supplies for ecosystem and urban needs through changes in farm water use practices. While various pieces of information about changes in water use can be gleaned from public databases, transaction price information is notably lacking. Recent Colorado policy innovations related to water trading emphasize reducing on-farm consumptive use and making water available for other purposes without permanently drying up irrigated cropland. The use of econometric models analyzing water rights transactions provides insight into how changes in key external factors affect transaction prices. The econometric models developed here focus upon Colorado's urbanizing Front Range and examine the effect of demographics, housing prices, drought indicators, and agricultural profitability on prices at which water is traded. Volume traded, drought measures, housing prices, alfalfa prices, and water source characteristics are statistically significant in these models. The article concludes by discussing factors that contribute to water trading policy innovations and the broader relevance of Colorado's innovative trading arrangements to water management challenges in arid regions.

Keywords: *water transactions, trading, risk*

Water trading policies and water-management agreements have become more complex as timing and volume of supplies are made more uncertain by climate change (Jones and Colby 2010). Transaction programs in many regions have matured from local water trusts conducting one-on-one negotiations with farmers, to strategic regional water-sharing agreements involving agricultural, municipal, industrial, energy, and environmental sectors. Economic impetus for water trading among different water users grows when water shortages threaten to impose high costs. When policies that enable water trading are lacking, the threat of shortage costs spurs innovations to accommodate creative water trading approaches and work around existing impediments. Identifying ideal policies to enable trading has deservedly been a classic emphasis over 40 years of research on water markets. However, this has tended to overlook valuable innovations that occur despite institutional obstacles and lack of enabling conditions. This article examines such innovations in Colorado, uses econometric modeling to analyze patters in water trading over two distinct time periods, and concludes with broader implications for water management and policy.

Colorado provides an ideal setting in which to examine changes in water transaction activity over time. It is unique among the U.S. states in its reliance on a specialized judicial system (Water

Court) to oversee its formal water right transfer process. Its vibrant economy provides impetus for water trading among active agricultural regions, mining and other large industrial water users, growing municipalities, and public agencies and Non-governmental organizations (NGOs) seeking water to support stream flows and habitat.

Colorado also stands out in high costs and delay associated with its formal change of water right process. While there are no recent quantitative studies of transaction costs (TC) for trading water in Colorado, previous studies indicate that Colorado TC far exceed those of neighboring states. Colby (1990) found, for instance, that TC were about 12% of prices paid in Colorado compared to 6% in Utah and New Mexico. MacDonnell, Howe, and Rice (1990) found similar patterns. Time delays to achieve formal approval of a water right transfer also are much higher than in neighboring states (Colby 1990; MacDonnell, Howe, and Rice 1990). These costs and delays create economic impetus to stimulate water transfers across use sectors and locations and to consider mechanisms to facilitate a more cost-effective process for trading water.

The evolution of water transactions in Colorado usefully illustrates a process of water policy change in response to economic impetus. Transaction activities in Colorado have moved well beyond the customary transaction of the 1960s - 1990s; permanent changes in the place and purpose of use of a water right. More complex arrangements are occurring to simultaneously meet demands of agricultural and municipal users as well as the environment (Aylward et al. 2016). Many transactions of the "low-hanging fruit" variety already have been realized, those cases where simple outright purchases benefit both parties and impose minimal third-party effects. Thus, more complex transactions are becoming the norm as large municipal and industrial users seek to secure a reliable water supply while complying with Colorado's labyrinthine water laws. The Colorado innovations discussed here spring from state legislative and administrative policies, water court officials, and federal-state collaborations.

Examples include Colorado's Alternative Agricultural Transfer Mechanisms Grant Program (ATM Program), the interstate System Conservation Pilot Program (SCPP), Substitute Water Supply Plans (SWSPs), and other programs that pay farmers to implement deficit irrigation and on-farm management practices that provide water for urban and environmental uses.

Related Literature

Literature comparing water markets and transactions across time periods and regions typically considers more conventional type of transactions, leases, and sales that change the place and purpose of use of a water right. These have been the dominant type of transaction for many decades, and state water agencies maintain some publically available data on these changes in water right processes. However, pressures of climate change and values for preserving agricultural economies spur a need to consider a much wider range of transactions.

A number of recent publications examine water trading programs. Aylward et al. (2016) developed a framework for considering cost-effectiveness in Environmental Water Transaction (EWT) programs. Stanford's Woods Institute Water in the West program issued a draft report and score card on EWTs for the seven Colorado River Basin (CRB) states (Stanford 2017). A Science for Nature and People Partnership (SNAPP) project directed by The Nature Conservancy has developed a framework for assessing EWT programs, focusing on small basins needing seasonal improvements in streamflow regimes (Kendy et al. 2018).

In this article, we use the term water transactions to encompass a wide range of voluntary agreements to reduce water consumption, application, or diversion in order to make water available for a different location and/or use. Transactions encompass traditional water-right sales and leases, irrigation forbearance agreements, dry-year options, deficit irrigation contracts, agreements to shift crop mix to reduce consumptive use, split-season leases, groundwater banking, and switching to alternative water sources.

Colorado Water Trading Innovations

The forms in which water trading occurs is a dynamic mix which varies over time as public policies governing trades adapt to accommodate new concerns. Colorado's experience exemplifies this, in the four programs briefly summarized here. SWSPs provide an interim means by which water use moves out of crop irrigation. The ATM and Instream Flow (ISF) Acquisition Programs are other examples of innovative activities administered through the State of Colorado. Development of these mechanisms has been stimulated by costs and delays in the formal change of water right process, as well as by special considerations for EWTs. The CRB SCPP is an example of an interstate program, with NGO, municipal, state, and federal partners, that alters agricultural water use to make water available for other purposes.

Conventional Trading: Change in Water Right

Changes in use of a water right from irrigated agricultural use to other uses occur through the Colorado Division of Water Resources (CDWR) and Water Court process (see Table 1). This category of transaction has been the dominant means to transfer water from agricultural uses in Colorado. The CDWR maintains a Water Transactions Database that can be analyzed to identify changes in water rights that move water from irrigated agriculture to other uses. The CDWR Water Transactions Database includes *many other* types of water rights changes, not relevant to this evaluation project, and multiple layers of data analysis are necessary to identify relevant transactions. Water right changes typically involve multiple ditch rights. However, they are tracked by the CDWR (and in this publication) under a unifying case number.

In 2007 the Colorado Supreme Court responded to requests voiced in various public processes for expediting the change of water right process. Many commentators criticized the costly length of delays between filing and final approval for changes in water rights. Following a lengthy study and public comment period, the Colorado Supreme Court in 2009 adopted rule changes that included specific timelines and created a clear and more coordinated path to timely decisions. Under the revised rules, judicial officers are active case managers from the outset of every water court filing and CDWR engineers coordinate with the water judges. The rule changes have had a positive, measurable impact in reducing unnecessary delay and uncertainty (Hobbs 2014).

Substitute Water Supply Plans (SWSPs)

SWSPs provide temporary administrative approval of plans for changing location, use, and/or timing of a water right (and for water augmentation plans) without first having to obtain a Water Court decree. Legislation in 2002-03 gave the Colorado State Engineer authority to approve SWSPs, an important innovation in Colorado transaction opportunities.

SWSPs are utilized to quickly accomplish a change in place/use/timing of a water right for a duration of less than five years. The Colorado State Engineer verifies that the proposed change will not cause injury to other water rights, typically limiting water quantity in the new use to the 'historical consumptive use' of the water right. The CDWR maintains a public database containing the most recent 20-24 months of currently active SWSPs. Statewide there are several hundred SWSPs active at a given point in time, concentrated in the eastern portions of Colorado. Some water users file for both a traditional transfer through water court, and file for a SWSP (Colorado Department of

Table 1. Changes in water rights from crop irrigation to other use, 2010-2017. Number of transactions and volumes by year decree entered.

	2010	2011	2012	2013	2014	2015	2016	2017	Total
Transactions	0	3	4	14	11	22	18	3	75
Volume (AF)	0	508	417	4,177	16,891	34,199	30,966	26,241	113,397

Source: Colorado Information Marketplace 2017b
Notes: "Transactions" is the number of unique case numbers that decreed/settled in the respective years. Three transactions did not have a quantity measure noted in the CDWR database. For these, CDWR documents were reviewed to produce a volume estimate.

Natural Resources n.d. (a); Colorado Information Marketplace 2017a). In this case, the SWSP allows the water to be utilized for its new use immediately, while the traditional, slower water right transfer works its way through the Water Court process.

ATM Grant Program Projects

Colorado implemented the Alternative Agricultural Water Transfer Methods Grants Program to develop alternatives to "buy and dry" transfers of agricultural water. Funded projects vary from actually implementing an ATM to analyzing different ATM methods. Since its inception, the grant program has funded many studies of ATMs and pilot implementation projects.

The number of ATM projects that move water from crop irrigation to another use is relatively small, two to five projects of this type funded per year over 2013-16. Typically, ATMs are temporary or intermittent, and leave the ownership of the water right with agricultural interests.

Despite their small numbers, ATM projects are essential for showcasing promising approaches. An ATM consists of several features: a) a method to reduce agricultural water consumption (such as fallowing, deficit irrigation, crop switching); b) a mechanism to make that water available to another user (such as a lease or Interruptible Water Supply Agreement (IWSA)); and c) financial compensation to the agricultural water users for reducing their use. Over the period 2013-16, annually there were an average of three active ATM projects that reduce water consumption in irrigated agriculture to be available to other uses. The volume of water made available is not readily obtainable. ATMs have the potential to provide municipalities, habitat protection programs, and industrial operations with water, without permanently drying up farmland. While permanent changes in water rights still are the dominant type of transfer in Colorado, ATMs are now an ongoing part of Colorado transaction activity (Colorado Department of Natural Resources n.d (b); WestWater Research 2016).

ATMs include the following strategies to make irrigation water available for another use:

- Fallowing: farmer stops irrigation for all or part of the irrigation season.
- Deficit Irrigation: farmer applies less water than usual.
- Crop Switching: farmer grows less water-intensive crop mix available for another use.
- Infrastructure Agreements: an outside party finances an infrastructure project beneficial for the farmer's operation, in exchange for use of a portion of the farmer's water rights.

Some common mechanisms of transferring the water made available include: IWSAs under which water right is used for agriculture in normal conditions, but transferred if certain shortage circumstances arise; and regular leases in which a farmer leases a portion of now unused water to a new use in exchange for payment. In some cases, a SWSP has been utilized as part of an ATM, such as to allow a long-term transfer to proceed while waiting for Water Court approval, and for ATM leasing agreements lasting fewer than five years.

Colorado Water Conservation Board Instream Flow (CWCB ISF) Acquisitions

The CWCB ISF program is responsible for appropriation, acquisition, and protection of instream flow water rights and acquires water through direct purchase, donation, lease, exchange, and other transaction types. CWCB acquisitions provide more senior ISF water rights than those coming from the appropriations process. The CWCB conducts hydrologic modelling for each water right acquired to determine historic consumptive use of the right and identify potential issues arising from a proposed change to ISF use. Over 2013-16, the annual average number of new stream segments protected varied from one to seven. Despite the small annual numbers, CWCB ISF acquisitions are an important feature of Colorado water transaction activity. Counting stream segments is not ideal for representing achievements of the ISF acquisition program. Yet these indicators are more readily available than more sophisticated measures that would account for ecological improvements and seasonal flow considerations.

System Conservation Pilot Program (SCPP)

The SCPP was developed in response to long-term reservoir declines. The SCPP was initiated in the summer of 2014 through an agreement between the Bureau of Reclamation (BOR) and four major southwest U.S. urban water suppliers (Central

Arizona Water Conservation District, Metropolitan Water District of Southern California, Southern Nevada Water Authority, and Denver Water). SCPP projects active in 2015-17 encompass a variety of conservation techniques, including fallowing (both full and partial season), deficit irrigation, and crop switching. The SCPP is an important innovation to reduce water consumption in irrigated agriculture to make water available for other purposes.

Initiated in the summer of 2014 through an agreement between the BOR and four major urban water suppliers, the parties committed to funding pilot projects. Pilot projects have been implemented in the upper basin (2014-17). Over 2014-17, several dozen projects were active in Colorado, New Mexico, Utah, and Wyoming with annual water savings of 2,500 – 11,500 acre-feet (AF).

Ranching and farming water users demonstrated increased interest through a steady increase in applications to participate. Some participating Colorado farms and ranches used program payments to fund a transition to organic farming, helping cover the loss of income from the required three-year hiatus from pesticide spraying (Tory 2017). The SCPP is regarded as a successful water trading venture and a good example of collaboration across diverse interests. It was recognized by the White House in 2016 as a positive example of "cooperation, collaboration, and innovation in long-term water management." Funding has not yet been made available for future rounds of projects beyond 2017.

Summary: Colorado Innovations

The programs described above are not an exhaustive list of water trading innovations in Colorado. Rather they are illustrative and convey a sense of the variety of approaches and the level of interest in making water trading less reliant on permanent dry-up of cropland and more responsive to water user needs. In the next section, econometric models explore Colorado transaction price patterns in two different time periods.

Econometric Models

Econometric models have the potential to provide insight into how changes in key external factors affect transaction prices, including changing policies governing water trading. Two data sources are utilized to model pricing patterns in transactions that have occurred in Colorado's Front Range over two different time periods. The Front Range (located on the east side of the Rockies surrounding the Denver metro area and extending to cities located north and south of Denver) is Colorado's most active area for water trading. These data sources are referred to here as 'The Water Strategist' (TWS) and AcreValue. Colorado does not require water transaction price to be reported, and the data for TWS and AcreValue are collected by private firms surveying transaction participants. These data sets may not include all transactions that have occurred, and there is no comprehensive registry of water transactions against which they can be compared. TWS has been widely used for past statistical analyses of water trading, and it is valuable to compare it to the new AcreValue data source. Due to the methods of acquisition, quality of these data cannot be observed directly. However, it is considered the best publically available water transaction data and the companies that procure it rely upon it as an integral part of their business.

There is a relatively small body of studies that have applied econometric analysis to data on water transactions. Prior U.S. studies generally have relied upon TWS data, made available by paid subscription for the years 1990 - 2009 and then discontinued (Stratecon Inc. n.d). Loomis et al. (2003) examined water transactions for environmental purposes in the western United States over the period 1995-99, finding that prices paid for environmental uses exceeded agricultural values for water in specific locations. Brookshire et al. (2004) analyzed statistical patterns in water trading in Arizona, New Mexico, and Colorado. They found that population change, per capita income, and drought have a statistically significant effect on the price at which water is traded, with higher trading prices in drier years. Brown (2006) examined water sales and leases and included transactions in 14 western states, finding higher lease prices in drier time periods in counties with larger populations, and for municipal and environmental uses. For water sales, Brown (2006) found that higher sales prices are associated with municipal use, surface water, smaller county populations, and smaller volumes of water traded. Pullen and Colby (2008) identified water right seniority and components of agricultural profitability (such as hay prices) as key influences on transaction prices. Jones and Colby (2010) found lease prices to be statistically linked to per capita income, drier weather, and population growth. Basta and Colby (2012) found statistical relationships between price and urban housing prices, urban population, and drought. Drought in the area of a city's water supply origin had a more consistent influence on transaction price than drought in the urban area itself (Basta and Colby 2012). Hansen, Howitt, and Williams (2014) found that agricultural production levels and land values influence annual volumes of water traded, as do measures of drought and water supply variability.

TWS data used in this analysis were published in *The Water Strategist* based on data compiled by Stratecon Inc. on price/AF, quantity transacted, and other transaction and buyer/seller characteristics. Each observation was accompanied by a description of the transaction, usually detailing where it took place and additional terms of the sale/lease. For this analysis, 321 Colorado Front Range transactions from 2002-09 were analyzed.

The AcreValue data originate from a web-based application of the same name, managed by Granular Inc., an agricultural technology company. Granular Inc. recently partnered with WestWater Research to provide water transaction data as a part of their AcreValue platform. The web application consists of a Geographic Information Systems (GIS)-based map with transactions "placed" on the map. Price, volume, sale/lease, and locational information is available. Data from this application yield 288 Front Range observations from 2012-16.

The variable Colorado Big Thompson (CBT) Service designates a transfer of rights to Colorado Big-Thompson (C-BT) units. These units are fundamentally different from typical Colorado water rights. C-BT units possess attributes that make transfer of these units much quicker and cost-effective, within the CBT service area, compared to transfer of water rights. Consequently, C-BT units typically sell/lease at a higher price than water rights transferred around the CBT service area. Data on whether a transaction involved C-BT units were not available for the AcreValue data, so a proxy was used based on location as described in Table 2. C-BT unit transfers (actual or by proxy) make up a majority of all transfers in the data.

The price variable shows a minor negative skew, while quantity shows a moderate positive skew. These trends are caused by a handful of transactions where a relatively large quantity of water is transferred for a relatively low price per acre-foot. For the AcreValue data, permanent purchases and surface water transactions make up the majority of observations in the AcreValue data, at 78% and 96% of the observations respectively.

Using these two data sets, three separate models were developed. In all models, the dependent variable is *Ln_Price_16*. The first "TWS" and second "AcreValue" models incorporated all the variables that are common among both datasets, allowing for direct comparison between the two models. In the AcreValue dataset, additional information on whether the transaction was a sale or lease, and whether the water right was for surface water or groundwater was available. To make use of this additional information, a third model, "AcreValue Modified" was estimated with two dummy variables for sale/lease and surface/ground characteristics. Note that TWS data do contain information on the sale/lease characteristic, but all observations in our chosen sample were sales. Table 3 provides summary statistics for variables used in econometric models. Table 4 shows the results of the econometric analysis. With respect to model specification, the "TWS" and "AcreValue Modified" models tested positive for heteroscedasticity; therefore, White's Standard Errors were utilized to run a Feasible Generalized Least Squares (FGLS) model. Results from the heteroscedasticity tests are presented in Appendix A.

Discussion of Econometric Results

All three models confirm ex ante hypotheses for water trading variables. Considering the two models containing identical variables, "TWS" (R^2=0.505) had higher explanatory power of price compared to "AcreValue" (R^2=0.389). When lease and groundwater dummies were included in "AcreValue Modified," explanatory power doubled compared to "AcreValue."

There are two perspectives regarding the expected effect of quantity transacted on price.

Table 2. Econometric model variables and definitions.

Variable	Definition
Ln_Price_16	Natural log of the price per acre-foot of the transaction. Adjusted to 2016 dollars.
Ln_Quantity	Natural log of the quantity transacted.
CBT_Service	TWS: Dummy variable with a value of 1 if the water rights transacted were C-BT units, and 0 otherwise. AcreValue: Dummy variable with a value of 1 if the water rights transacted were located within the service boundary of Northern Water.
SPI_SNOW_V5	Variance of the 12-month Standard Precipitation Index (SPI), over the last 5 years, in Colorado climate division 2.
HPI (Base=1995)	HPI for the Denver metropolitan statistical area (MSA), with a base year of 1995.
Alfalfa_16	Price of alfalfa hay, measured in $/ton. Adjusted to 2016 dollars.
Lease	Dummy variable with a value of 1 if the transaction was a lease, and 0 otherwise.
Groundwater	Dummy variable with a value of 1 if a groundwater right was transacted, and 0 if surface water was transacted.

Table 3. Summary statistics of econometric models.

	TWS Model			AcreValue Model		
Variable	**Mean**	**Median**	**Standard Deviation**	**Mean**	**Median**	**Standard Deviation**
Price_16	16,085	17,920	4,195	21,110	25,760	15,073
Quantity	46.33	9.10	136.99	101.78	13.40	381.58
CBT_Service	0.93	1.00	0.26	0.78	1.00	0.42
SPI_SNOW_V5	0.46	0.45	0.20	0.72	0.81	0.24
HPI (Base=1995)	189.76	190.68	6.19	235.08	225.09	31.99
Alfalfa_16	138.11	151.94	24.80	201.27	208.66	36.27
Lease				0.22	0.00	0.41
Groundwater				0.04	0.00	0.19

The first is that a higher volume transacted will result in a lower price/unit of water, consistent with economies of scale. The second is that larger transactions are associated with large TC due to more opposition to larger transactions, with the price/unit expected to be higher for larger transactions. In both "TWS" and "AcreValue" models, the sign of *ln_quantity* is negative, which supports the economies of scale view. The relationship between price and ln_quantity is marginally insignificant for the "TWS" model. For the "AcreValue" models, a coefficient range of -0.14 to -0.35 means that a 1 acre-foot increase in the transaction quantity produces a $3.15 to $4.14 decrease in price per acre-foot. Looking at the variable *CBT_Service*, the coefficient is positive, and it is significant for the "TWS" and "AcreValue" models. This particular type of water right is well established as more highly valued than other rights in the region due to clear, low cost trading procedures and the desirable location in which these rights are tradable.

An additional four variables are statistically significant in the "TWS" model, but not in the "AcreValue" model. First, our measure of climate variability, *SPI_SNOW_V5* is positive and

Table 4. Econometric model results.

Variable	**TWS**	**AcreValue**	**AcreValue Modified**
Intercept	9.17***	8.52	7.89
ln(quantity)	-0.01	-0.35***	-0.14***
CBT_Service	1.15***	1.80***	0.15
SPI_SNOW_V5	0.24*	0.29	0.26
HPI (Base=1995)	-0.001	0.0003	0.0007
Alfalfa_16	-0.003***	-0.0005	0.003
Lease			-3.74***
Groundwater			-0.86
R-Square	0.505	0.389	0.840
N	321	288	288

*p-value = 0.010; ***p-value = 0.001

significant in the "TWS" model, indicating that when there is more uncertainty in the amount of precipitation in the region that supplies surface water to users, buyers tend to pay a premium for water rights. Second, when the price of alfalfa hay increases, prices for water rights decrease, but this relationship is only significant for "TWS," where a $1/ton increase in the price of alfalfa causes roughly a $1/acre foot reduction in price. Interestingly, the effect of the Housing Price Index (HPI) is not significant in any of the models.

In the "AcreValue Modified" model, when the *lease* and *groundwater* dummies are added, the explanatory power of the model increases significantly, from 0.4 to almost 0.85, indicating that these variables together play a large role in explaining price variation. A coefficient of -3.74 for the lease dummy indicates that lease prices are around 40 times lower than sale prices. The sign for groundwater is negative, but is marginally insignificant.

Importance of Improving Water Trading Data Availability

The models utilized available, but somewhat limited, data on water trading collected by two private water information businesses in two time periods. In general, data on price and volumes traded are not reported as part of the transaction approval process, and this information is not publically available in the various locations in the U.S. where water trading occurs.

In Colorado, despite the innovations occurring, the most common type of transaction is still a change in water right from one use to another. However, verifying that a change in water use has occurred from public data takes considerable care to sort through. Purchase or lease of a water right may occur before or after formal filing for a change in place and/or purpose of use. Consequently, what we generally think of as a water right transaction (lease or purchase) can occur months to years before or after an entry in the state records system. Once filing occurs, public records emerge through publication of a Water Resume and creation of a CDWR case number. Contractual agreements to purchase or lease a water right are not recorded in a public database. The CDWR transaction database only indicates that a lease or purchase *may* have occurred when the holder of the water right files for a change in place and/or purpose of use, and the vast majority of entries in the CDWR database are *not* transactions in the general usage of that term. Agreements that involve acquisition of agricultural water often involve nondisclosure agreements. Parties do not talk about them publically and there are no reliable data to track them in real time. In the CDWR transactions database, the word "transaction" is used to refer to a wide variety of administrative changes in water rights including corrections to the records. The CDWR database "Water Rights Transactions/Water Rights Transactions in Colorado" contains "the court decreed actions that affect amount and use(s) that can be used by each water right." (Colorado Information Marketplace 2017b).

Improving transaction data is essential, both to stimulate development of water trading systems and to improve evaluation of trading and its effects. Australia recognized the importance of transparent water trading information, and now requires that price, volume, and other basic transaction information be reported. Database management and weekly updates are provided by the Australian Bureau of Agricultural and Resource Economics and Sciences. Transaction data are posted online and updated regularly (Australian Bureau of Agricultural and Resource Economics and Sciences 2017).

In the U.S., poor access to transaction price information means that urban and environmental water managers only learn what others have been paying informally. Price information is imprecise and sporadic. Agricultural interests also rely on hearsay and out-of-date information. Lack of easily accessible and reliable price information discourages participation in transactions. For those cities and environmental programs desiring to acquire water, it is difficult to develop a program budget for acquisitions and to get organizational buy-in when price is not known and hard to predict.

Ideally, the following information would be publicly available for each transaction:

- Price paid per unit of water and volumetric measures of water traded.
- Location and type of use before and after transaction.
- Change in seasonal pattern of use due to transaction.

Access to such information would greatly reduce informational barriers for those wishing to participate in transactions as buyers, sellers, lessors, and lessees. And, these data would allow examination of water transaction pricing patterns over time, price dispersion patterns (an indicator of market maturity), and price paid for water compared to farm net returns per unit of water (one indicator of how agricultural sellers and lessors fare in transactions). Information on changing seasonal patterns of use assists in identifying effects on stream flows that provide environmental and recreational benefits.

Transparent transaction information allows comparison of price paid for water to farm net returns, which is useful in understanding how farmers selling or leasing water are faring in transactions, vis a vis urban and environmental buyers and lessees. This also provides insight into the bargaining power between water using sectors and into the market's ability to reflect changes in the regional agricultural economy. Analyzing transaction pricing patterns over time allows consideration of how regional markets are performing. Econometric models are able to sort out the influence of many simultaneous factors on price and transaction activity and assess whether the market is maturing as evidenced by: prices responding rationally to shifting supply and demand factors and effectively conveying information about changing water values across agricultural, urban, and environmental uses.

Factors Influencing Water Policy Change

The Punctuated Equilibrium Theory (PET) is a body of work proving useful for considering how and when significant shifts in policy paradigms occur (Brock 2006). The PET has been applied to complex shifts in water policy paradigms. Experience with water transaction policies in Colorado suggests the following PET themes apply to facilitating emergence of new policy paradigms.

Economic Impetus for Policy Innovation

How high are the costs and how "broken" is the current system? For whom is it broken? Pressure for innovation comes from high costs of the status quo imposed on important stakeholders who influence whether a new policy can be successfully implemented. High costs provide the impetus needed to move a policy innovation from its gestational core of supporters into an adopted policy (Baumgartner 2006; Jones and Baumgartner 2012).

This cycle of pressure-building impetus followed by a big shift shows up repeatedly in Colorado water transaction policy. While breakthroughs in Colorado policy often come through new legislation, the judicial branch has been key as well. In 2009, the Colorado Supreme Court adopted amendments to procedural rules for State Water Court Divisions in response to extensive criticism of costly delays in achieving final decree. Judicial officers were authorized to become active case managers from the outset of every water court filing and division engineers were required to conduct consultations with water referees and water judges. The rule changes had a positive, measurable impact in reducing unnecessary delay and uncertainty (Hobbs 2014).

Pilot Programs Create Economic and Cultural Shifts that Assist Policy Change

Pilot runs of a new policy approach are set up with a specific end date that can deter naysayers from mounting significant opposition. Those who are opposed assume the new policy will fail and are reassured by its expiration date. New pilot programs to facilitate water transactions for environmental needs make payments to irrigators that create a shift in the regional agricultural economy and culture. Farmers come to appreciate the role of these revenues in their income portfolio, as well as the contributions of healthy streamflows in rural economies. This broadens support for permanent policy changes to improve environmental access to water.

Key Roles for Entrepreneurial NGOs and Researchers.

The PET suggests that NGOs are central in water transaction breakthroughs (Ingram and Fraser 2006; Laird-Benner and Ingram 2011), and Colorado experience bears this out. NGOs have been instrumental in advocating for new pathways to acquire and dedicate water for environmental purposes, as well as for improving opportunities to conserve and transfer water. The PET notes that researchers develop innovative policy concepts that await opportunities to enter public dialogue, with data and scientific studies ready to inform policy debate so that timely ideas are ready and substantiated. The Colorado water trading policy innovations described here involved substantial participation and idea-seeding from researchers at the state's universities, and continue to rely on research to improve implementation and measure program effectiveness.

Summary and Conclusions

This study of innovations related to water trading in Colorado joins a small but growing number of studies that find the PET a valuable approach in understanding water policy. The PET perspective suggests policy emphases on pilot programs of the type described early in this article, on assessing support for new initiatives by weighing effects of current water policies on stakeholder groups, and on inviting active NGO and university research participation in water policy dialogue, design, and implementation.

Based on analysis of limited available data on transactions, it appears that transaction prices along Colorado's Front Range respond rationally to factors expected to influence water supply and demand. A recent water transaction data source (AcreValue) compares reasonably well, in econometric modeling, with a longstanding (but discontinued) data source (TWS). Most importantly, innovative water trading arrangements are being actively explored and applied to address water management challenges in Colorado. Initiatives underway there can provide ideas for other regions juggling agricultural, urban, and environmental water needs in the face of increasingly variable supplies.

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Acronyms and Abbreviations

AF – Acre Feet
ATM – Alternative Transfer Mechanism
BOR – U.S. Bureau of Reclamation or Reclamation
CBT/C-BT – Colorado Big Thompson Project
CDWR – Colorado Division of Water Resources
CRB – Colorado River Basin
CWCB – Colorado Water Conservation Board
EWT – Environmental Water Transaction
FGLS – Feasible Generalized Least Squares
GIS – Geographic Information Systems
HPI – Housing Price Index
ISF – Instream Flow
IWSA – Interruptible Water Supply Agreement
MSA – Metropolitan Statistical Area
NGO – Non-Governmental Organization
NW – Northern Water
PET – Punctuated Equilibrium Theory
SCPP – System Conservation Pilot Program
SNAPP – Science for Nature and People Partnership
SPI – Standard Precipitation Index
SWSP – Substitute Water Supply Plans
TC – Transaction Costs
TWS – The Water Strategist

Appendix A: Econometric Models Tests for Heteroscedasticity

Table A1. TWS Model

Equation	Test	Statistic	DF	Pr > ChiSq	Variables
ln_price	White's Test	87.96	19	< 0.0001	Cross of all vars
	Breusch-Pagan	36.88	1	< 0.0001	1, CBT_service

Table A2. AcreValue Model

Equation	Test	Statistic	DF	Pr > ChiSq	Variables
ln_price	White's Test	12.94	16	0.6773	Cross of all vars
	Breusch-Pagan	1.78	1	0.1824	1, CBT_service

Table A3. AcreValue Modified Model

Equation	Test	Statistic	DF	Pr > ChiSq	Variables
ln_price	White's Test	117.3	29	< 0.0001	Cross of all vars
	Breusch-Pagan	15.44	1	< 0.0001	1, CBT_service

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