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Key Points:
- Water market transaction costs are uncertain, and this uncertainty depends upon legal procedures for water rights transfers
- Transaction costs are higher in water-scarce regions, for higher-conflict transfers, and for senior water rights, and show scale economies
- Transaction costs have grown over time due to increased competition for scarce water and more complex water rights operations

Supporting Information:
- Supporting Information S1

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Water Markets, Water Courts, and Transaction Costs in Colorado

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Abstract Water markets increasingly facilitate adaptation to water scarcity, but transaction costs can be barriers to expanded water marketing, particularly under water rights law in the western United States. However, transaction costs are rarely measured, and existing research commonly overlooks how transaction costs differ across individual water transfers and uncertainty in those costs. We collected hundreds of estimates of procedural transaction costs—costs incurred by transfer proponents for legal and hydrologic experts—by surveying 100 water professionals in the state of Colorado. There, water markets are among the most active in the United States, convey perhaps the most clearly defined private property rights of any state, and, unique to Colorado, require approval from specialized water courts. We elicited costs for water transfers with differing physical and legal characteristics, and we elicited separate assessments of (i) probabilities of legal outcomes for water transfers and (ii) transaction costs conditional on those outcomes. Then, we estimated expected transaction costs with a statistical model that combines (i) with (ii). The model reveals systematic differences in transaction costs, with scale economies and higher transaction costs for water-scarce regions, senior water rights, and higher-conflict legal outcomes. It also shows substantial transaction cost uncertainty, which itself can discourage trading. Our novel survey and estimation procedure develops a replicable approach for measuring transaction cost heterogeneity and uncertainty. Additionally, qualitative survey data we collected indicate transaction costs have increased over time due to growing competition for scarce water and that, despite high transaction costs, specialized water courts offer unique benefits.

1. Introduction: Markets and Courts as Water Allocation Mechanisms in the Western United States

Water markets are often proposed as institutional mechanisms for reallocating water among competing users amidst water scarcity, accommodating urban population growth, agricultural and industrial change, restoration of water for ecosystems, and adaptation to climate change (Culp et al., 2014; Garrick et al., 2013; Garrick & Aylward, 2012; Thompson, 1993; Thompson et al., 2012). Formal water markets that trade water rights or entitlements exist in diverse nations, including Australia, Chile, Spain, South Africa, and the United States (Bauer, 2004; Bjornlund & McKay, 1998; Brown, 2006; Nieuwoudt & Armitage, 2004; Palomo-Hierro et al., 2015; Thompson et al., 2012). Within the United States, water marketing is particularly active in the state of Colorado: Brewer et al. (2008) report that over half of the number of water transactions in 12 western U.S. states recorded from 1987 to 2005 occurred in Colorado (1,707 of 3,232 transactions). Colorado was fourth among the 12 states in committed water traded (14.9 million acre-feet of 78.1 million acre-feet traded; committed water values discount purchases or multiyear leases to their first year) (Brewer et al., 2008). During this time period, Colorado's market had the highest percentage of permanent transactions of any state (1,599 of 1,707 transactions), and 75% of the committed water traded consisted of agricultural-to-urban transfers (Brewer et al., 2008). More recently, in 2015, Colorado exhibited the second-most water market activity by monetary value of any western U.S. state, totaling $79 million (WestWater Research, 2017). Colorado's market was second by value despite reporting the fourth-highest volume traded because water rights are particularly valuable in Colorado, and the market still mostly consists of permanent rights sales (WestWater Research, 2017).

Formal water marketing occurs within legal frameworks for water rights, which in the United States vary from state to state. Both the substantive law that defines water rights and the legal procedures

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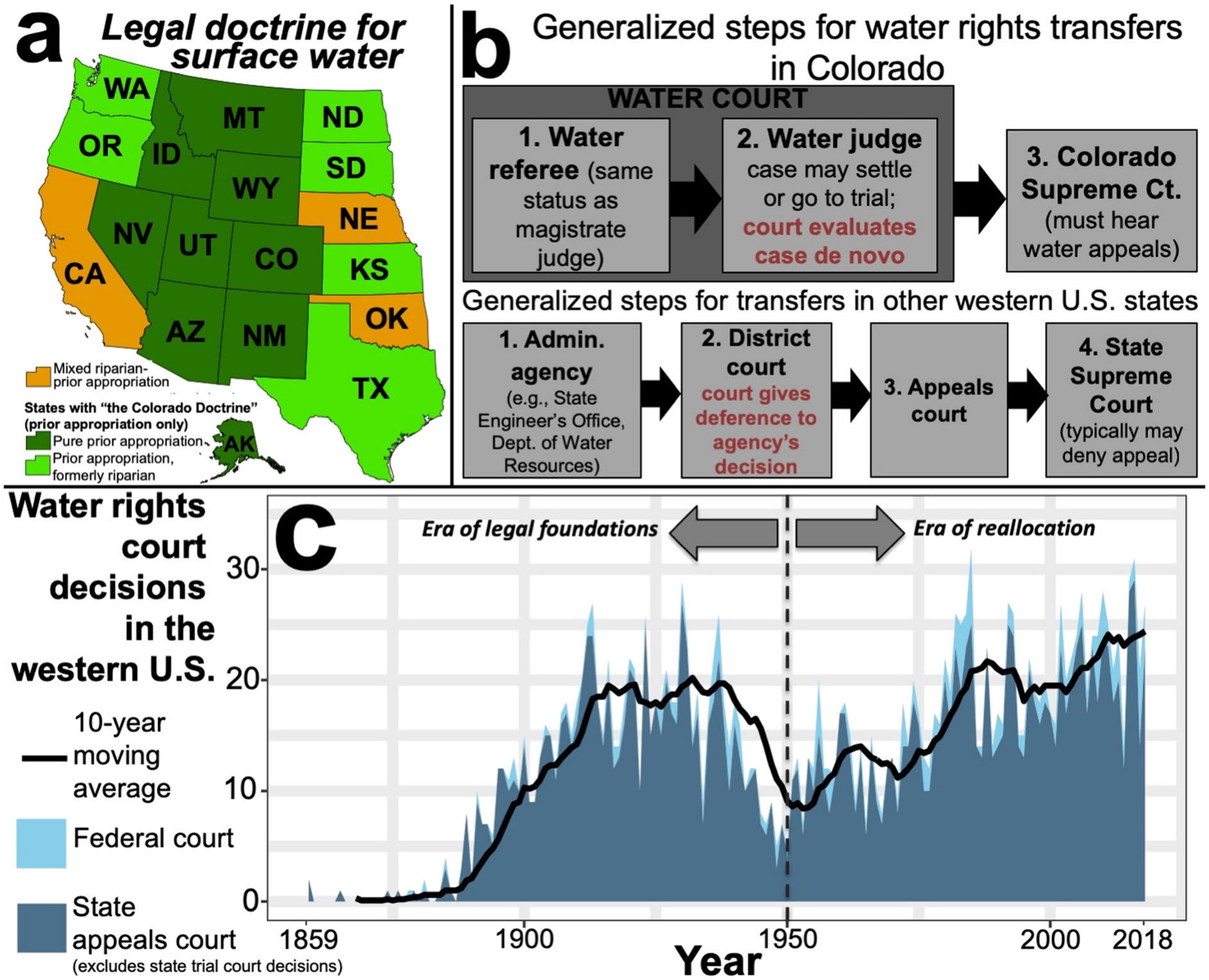

Figure 1. (a) 14 of 17 western U.S. states and Alaska apply the so-called "Colorado Doctrine" for surface water rights, relying on prior appropriation and not riparian rights. (b) Comparison of procedure for Colorado's judicial approach for water rights transfers versus administrative agency approaches used in other western U.S. states. (c) Water rights litigation is increasing in the western United States. After early water rights litigation largely defined foundational aspects of western U.S. water law—for example, which water allocation doctrines governed in different states—growing and new demands from municipal, industrial, and environmental users have contributed to a renewed and increasing judicial presence in western U.S. water allocation. Data in (c) come from Westlaw; see supporting information.

for administering and transferring them affect the robustness of a water market. Colorado, like all 17 western U.S. states, applies the prior appropriation doctrine for water rights (Thompson et al., 2012; Trout et al., 2011; Womble et al., 2018). Prior appropriation first emerged in California, with the California Supreme Court acknowledging it in 1853, and in 1866, Nevada's Supreme Court applied prior appropriation principles (MacDonnell, 2015). In 1882, however, Colorado's Supreme Court became the first to rule that prior appropriation was the only water rights doctrine in the state and that riparian rights, which apply in the eastern United States and some western states, did not exist in Colorado (MacDonnell, 2015). Riparian rights systems allocate water rights for reasonable use on riparian lands bordering a water body and require that all water users share shortages equally, while prior appropriation allocates water rights to the first riparian or non-riparian user that puts water to beneficial use, allowing older, more senior users to fulfill their entire water right before junior users receive any water in times of shortage (Thompson et al., 2012; Trout et al., 2011). The pure prior appropriation doctrine without riparian rights, which today is effectively followed in 14 of 17 western states and Alaska, is labeled "the Colorado Doctrine" (Figure 1a; Christian-Smith et al., 2012; Schorr, 2012).

Colorado probably has the most clearly defined private property rights to water of any state in the western U.S. Colorado law largely recognizes prior appropriation water rights as the only type of water right, unlike

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other states (e.g., California) where riparian rights to surface water still exist or different types of water rights exist for groundwater versus surface water (Thompson et al., 2012; Trout et al., 2011). Unlike some western states, Colorado legally integrates management of rights to surface water and hydrologically connected groundwater, protecting surface water rights from impacts of groundwater pumping and vice versa (Trout et al., 2011). Colorado has the most restrictive public rights in water of any western U.S. state, increasing security of private rights: it is the only state that does not consider public interests while evaluating transfers of water rights or applications for new rights, and it recognizes no public trust doctrine (Craig, 2010; Leonhardt & Spuhler, 2012; Myers, 2016). Finally, as the only state that continuously adjudicates water rights throughout the state, where transferred and new water rights are directly and immediately incorporated into state water rights records, Colorado avoids general stream adjudications, which are used in the other western U.S. states to define water rights for entire hydrologic systems. General stream adjudications can last decades, occur infrequently, and, in many states, do not cover all of a state's surface or groundwater systems (MacDonnell, 2015).

Colorado is also the only state with a permanent, specialized water court system (Thorson, 2016). Colorado's water courts handle water disputes, including performing initial reviews of water rights transfers (Trout et al., 2011). In other western states, government agencies conduct initial review of water rights transfers, and agency decisions may subsequently be appealed to court (Figure 1b). Judicial courts play a growing role in resolving water disputes in the western United States, with court litigation over water rights increasing over time and most of this litigation occurring in state courts (Figure 1c). In most states, the courts that handle water rights lawsuits are generalist courts that hear diverse legal matters (Thorson, 2016). However, interest has grown in specialized water courts. Montana and Idaho have operated long-term water courts for general stream adjudications (Thorson, 2016), and permanent water courts like Colorado's have been suggested for California, Idaho, and New Mexico (Fluckiger, 2016; Thorson, 2016; Valentine, 2003).

While Colorado water law has unique characteristics, transfers of prior appropriation water rights must satisfy similar substantive standards and follow similar procedures across the western U.S. states (Figures 1a and 1b). For example, water rights transfers may not result in unlawful enlargement of water use; under conventional prior appropriation law, transferred water rights must be limited to their historical beneficial use before the transfer (Trout et al., 2011). Also, because transfers may modify the timing, location, and amount of return flows, the no-injury rule of western U.S. water law implements absolute protections against these third-party impacts to other water rights holders (Thompson et al., 2012). In all western U.S. states, after an applicant submits their transfer application, third parties may formally object to transfers on the basis of enlargement, injury, or other reasons. In Colorado, objections are filed in water court, while in other states, objections are initially filed with an agency but may be appealed to court (Figure 1b; Colby et al., 1989). Third-party objections sometimes prompt extended negotiations, hearings, and litigation (Colby, 1990).

Due to the heavily legal and technical nature of transfers, applicants and objectors in the western U.S. commonly hire lawyers and hydrologic experts (Colby et al., 1989). These transaction costs help to clarify and protect property rights not only for buyers and sellers but also for potentially affected third parties. Water rights are highly heterogeneous, often poorly defined, and can be very intertwined, with downstream users dependent upon upstream return flows (Colby, 1990). Applicants commonly hold asymmetric information about rights they propose transferring and transfer approval procedures share that information with agencies, courts, and third parties (Trout et al., 2011). Also, protections against enlargement or injury offer security for existing water users so they can invest in and develop their property rights (Colby, 1990).

However, transaction costs impede some socially beneficial transfers. Socially optimal transaction costs would only allow transfers with greater social benefits than costs, but western U.S. water law performs no such balancing. In Colorado and many other western states, the no-injury rule precludes *any* impact to third-party water rights, no matter how small or far in the future. Banks and Nichols (2015) relay one instance in Colorado where this rule was said to protect a downstream water right from a stream depletion of less than a cup of water more than five years in the future. Accordingly, proving no injury "can lead to costly engineering and expensive and lengthy litigation" (Banks & Nichols, 2015).

A substantial academic literature identifies transaction costs as barriers to water marketing (Carey & Sunding, 2001; Challen, 2000; Donoso et al., 2014; Garrick et al., 2013; Howe et al., 1986; Howe et al., 1990; Meyers & Posner, 1971; Nieuwoudt & Armitage, 2004; Ruml, 2005; Schorr, 2012; Thompson, 1993;

Trelease, 1961). Nevertheless, few studies have actually measured such transaction costs, and the existing studies evaluate limited numbers of transactions or measure aggregate costs over many separate transactions (Brown et al., 1992; Colby et al., 1989; Garrick & Aylward, 2012; MacDonnell et al., 1990).

Here, we estimate a statistical model for determinants of transaction costs for individual water transfers in Colorado. We also develop qualitative understanding of factors driving trends in transaction costs over time and the perceived benefits of specialized water courts.

2. Legal and Institutional Context for Trading Water Rights in Colorado and the Western United States

We examine transaction costs associated with state approval of transfers of prior appropriation water rights in Colorado. State approval for transfers (formally, "changes") of water rights is required in all western U.S. states for water rights transactions that change a water right's type, place, or time of use (Thompson et al., 2012).

Procedures and standards differ for water trading that does not change prior appropriation water rights, such as trading of allocations within a water distribution institution like the Colorado-Big Thompson Project (C-BT) (Howe et al., 1986; Maas et al., 2017). Water trading within such institutions generally does not modify the institutions' underlying water rights, so it do not trigger transaction costs associated with state review of water rights transfers.

In the specific case of the C-BT water market, though economists often identify it as a model (Carey & Sunding, 2001; Howe et al., 1986), the institutional conditions are unique and not readily replicable elsewhere. Unlike transfers of prior appropriation rights, the C-BT market trades homogenous water contracts to which the no-injury rule does not apply. The C-BT market trades water imported via transmountain diversion from the Colorado River Basin in western Colorado to the Northern Colorado Water Conservancy District in eastern Colorado (Carey & Sunding, 2001). Because prior appropriation treats transmountain diversions as fully consumptive to the basin of origin and assigns ownership of return flows to the diverter (Thompson et al., 2012), once water is taken for the C-BT under prior appropriation water rights, it is no longer subject to the prior appropriation system. Only District approval, not state approval, is required for within-district trades (Carey & Sunding, 2001). Thus, a permanent trade of C-BT water can be accomplished within four to six weeks with minimal transaction costs, and seasonal trades can be completed by internet or postcard (Northern Colorado Water Conservancy District, 2018; Michelsen, 1994). Despite these favorable conditions, however, the volume and number of transactions for prior appropriation water rights in Colorado's South Platte River Basin alone still exceed the entire C-BT market (Payne et al., 2014).

Colorado law divides the state into seven water divisions that mostly match major river basin boundaries, with one water court in each division (Figure 2a). Trading between divisions is uncommon, making each water division a distinct market region. Water scarcity is most acute in two divisions in eastern Colorado, which contain nearly 90% of Colorado's population and 55% of its irrigated lands but less than 20% of the state's average annual water supply (Figure 2b). These two divisions experience the most prior appropriation water rights transfer activity and the highest prices for permanent water rights acquisitions (Figures 2c and 2d). The South Platte River Basin (Division 1), which contains over 70% of the state's population and has the most irrigated acreage, has by far the most transfer activity and the highest prices for water rights (Figures 2c and 2d). The Arkansas River Basin (Division 2), which contains the city of Colorado Springs and is just south of the South Platte Basin, has the second-highest transfer activity and prices for water rights (Figures 2c and 2d). Most of the water marketing in eastern Colorado has been from agriculture to cities (Payne et al., 2014). A moderate level of transfer activity and moderately expensive water rights exist in the Upper Colorado River Basin (Division 5), which contains ski resorts and growing municipalities (Figures 2c and 2d). Also, because transmountain diversions from this basin to eastern Colorado export annual averages of over 355,000 acre-feet to the South Platte Basin and over 127,000 acre-feet to the Arkansas Basin, major eastern Colorado water users commonly file objections in Division 5 water court cases to protect their water rights there (Colorado Water Conservation Board, 2015; Water Education Colorado, 2014). Moderate transfer activity and slightly less expensive water rights are found in the Rio Grande Basin (Division 3), while other water divisions on Colorado's West Slope exhibit relatively low transfer activity and prices (Figures 2c and 2d).

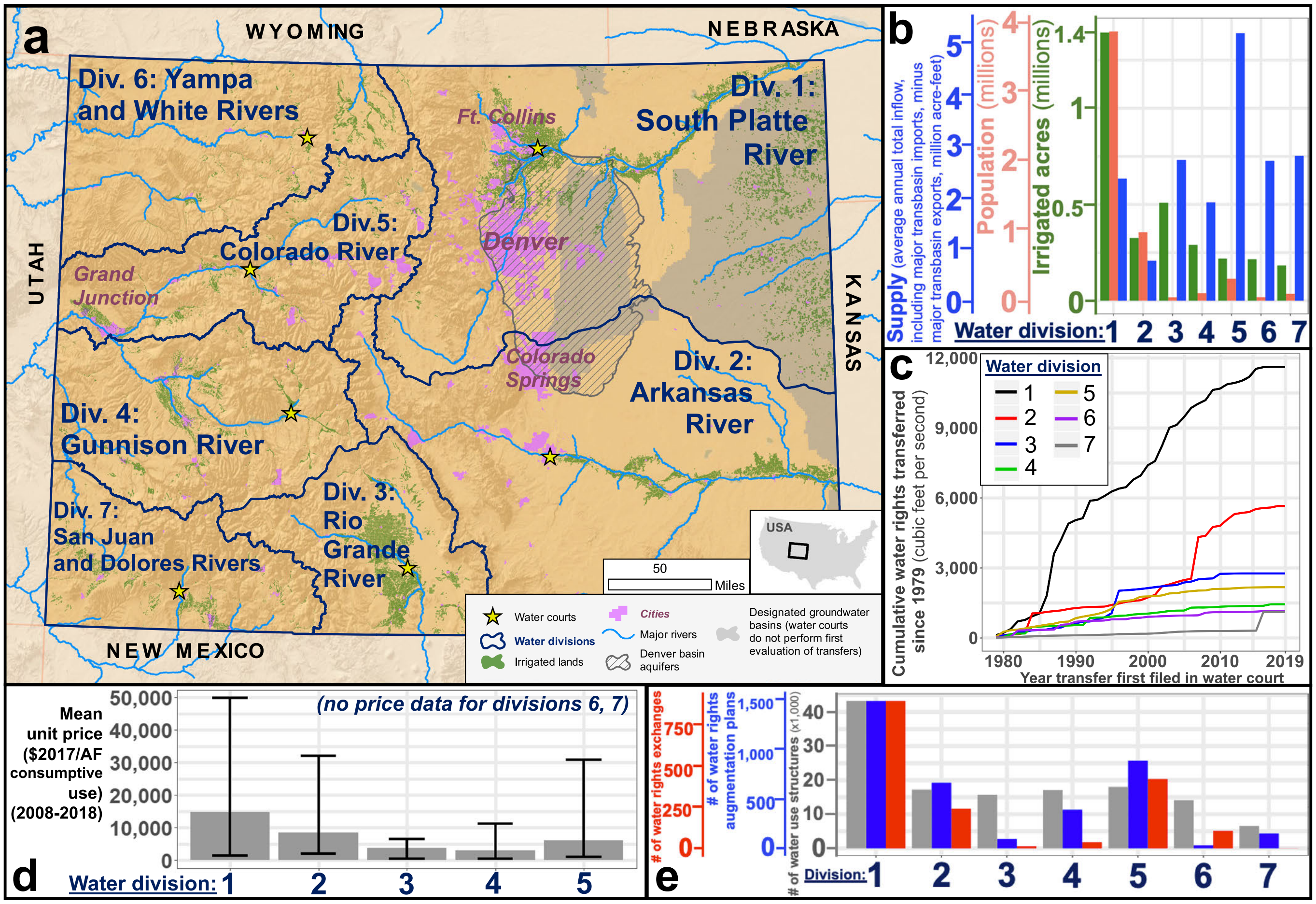

Figure 2. (a) Colorado's seven water divisions. Colorado operates seven water courts, with one in each division. (b) Average annual water supply, population, and irrigated acreage by water division. (c) Cumulative water rights transfers by water division (1979–2019). (d) Mean unit price for permanent acquisitions of water rights whose transfer could require water court approval in Divisions 1–5 (2008–2018). (e) Complexity of water rights administration and operations by water division, as indicated by the number of water use structures, exchanges, and augmentation plans. Water rights pricing data shown in (d) are from WestWater Research, LLC, which maintains the most comprehensive modern database of these prices in Colorado. See Supporting Information for more information on data sources and analysis for Figure 2.

Colorado's water divisions also vary in their complexity of water rights administration and operations. In Figure 2e, we show this variation in complexity with several metrics: the number of water use structures, like diversions, reservoirs, and wells, and the prevalence of complicated water rights delivery arrangements like exchanges or augmentation plans. Exchanges occur when an upstream water user supplies water to a downstream senior water user and then takes an equal amount upstream (Trout et al., 2011). Augmentation plans offset a junior water right's out-of-priority depletions; these plans commonly offset surface water impacts of junior groundwater pumping (Trout et al., 2011). More exchanges or augmentation plans in a division signal that injury to third parties is a prevailing concern there, which can make transfers more complex. More water use structures in a division may also signal greater potential for third-party injury. Figure 2e suggests that water rights administration and operations are most complex in the South Platte River Division but are also complex in the Arkansas and Upper Colorado River Divisions.

Colorado's water courts approve transfers of rights to surface water and hydrologically connected groundwater. The Colorado Supreme Court appoints one district court judge as the water judge in each of the seven water courts, and a water referee assists the water judge (Trout et al., 2011). After a transfer applicant applies, third parties may allege injury to other water rights or other legal deficiencies. Next, the water judge refers all transfers to the referee for initial review. Lower-conflict cases may be resolved before the referee without opposition or via settlement. Referees often re-refer more complex cases to the judge. Some cases that are re-referred to the water judge are settled before trial, while others go to trial. Finally, Colorado allows direct appeals of water court decisions to the Colorado Supreme Court, which must hear these appeals (Trout et al., 2011).

3. Literature Review: Transaction Costs in Western U.S. Water Markets

Broadly speaking, transaction costs have been defined as any "resources used to define, establish, maintain, and transfer property rights" (McCann et al., 2005). Transaction costs may be divided into two categories: (1) static transaction costs: all non-water costs to trade and enforce water rights within a given institutional framework, and (2) dynamic transaction costs: costs of effecting institutional change and institutional lock-in costs (costs imposed by current institutional decisions that limit future flexibility) (Challen, 2000; Garrick et al., 2013; Marshall, 2005). In water markets, static transaction costs encompass, for example, costs for finding trading partners, information gathering, negotiation, brokerage, government review and hearings, application filing, public notification, monitoring, and enforcement, as well as externalities of transfers (Colby et al., 1989; Garrick & Aylward, 2012; MacDonnell et al., 1990; McCann et al., 2005; McCann & Easter, 2004). As Howe et al. (1990) asserted, "[w]hich of these costs are 'relevant' depends upon the question being asked. If one wants to carry out a social benefit-cost analysis of a transfer, all of the above costs are relevant. If the objective is to predict whether or not a particular transaction will take place (an evaluation of the transaction from the private buyer-seller viewpoint), then only the costs borne by the buyer and seller will be relevant."

To improve understanding of whether and how particular transactions take place, our objective is to statistically model private static transaction costs borne by water transfer applicants (typically buyers) based on various determinants of those costs. Because an applicant's ex ante understanding of their static transaction costs drives their decision-making in a water market, we estimate these costs ex ante. Specifically, we measure a subset of static transaction costs that we label the "procedural transaction costs." These are the legal and hydrologic expert fees incurred to satisfy state approval of water rights transfers in Colorado. We focus on these costs because Colorado's water court system prompts nearly all applicants and third-party objectors to retain attorneys and hydrologic experts to complete water transfers. Across 10 Colorado water transfers investigated by Colby et al. (1989), legal and hydrologist fees constituted on average 85% and at most 99.9% of applicants' total transaction costs.

Past studies suggest some determinants of static transaction costs for individual transfers. After gathering monetary transaction costs for 19 transfers in Colorado, New Mexico, Nevada, and Utah, Colby et al. (1989) qualitatively compared the transfers and suggested the following factors raised transaction costs: cross-cultural conflicts, more complex or novel transfers, small transfers lacking economies of scale, transfers over a greater distance or across jurisdictional boundaries, transfers involving less sophisticated applicants, more regional competition for water, and politically sensitive interests. Based on transaction cost data for nine transfers in Colorado, MacDonnell et al. (1990) also observed scale economies, along with higher transaction costs for transfers opposed by third parties or near cities. In New Mexico, Brown et al. (1992) reported summary statistics from 87 transfers showing variation in transaction costs across basins. More recently, Hagerty (2019) studied water marketing in California using individual data for many transfers. Instead of measuring transaction costs directly, he inferred them from water market prices, and he assessed how they vary when water is transmitted across the San Francisco Bay-Delta (which incurs significant conveyance losses) and whether or not any water rights review was required. Meanwhile, in our paper, we directly measure transaction costs across different outcomes of legal review that have different stringencies in Colorado.

Other studies evaluate aggregate basin-wide transaction costs per year instead of static transaction costs for individual water transactions. Garrick (2015) and Garrick and Aylward (2012) performed such an analysis of revealed, public transaction costs incurred by conservation buyers and water resource agencies for environmental water recovery across the Columbia River Basin from 2003 to 2010. They found that transaction costs varied substantially across subbasins with differing levels of institutional capacity and volumes of water purchased.

By contrast, we measure and then statistically model procedural transaction costs and completion times for hundreds of individual water rights transactions with differing characteristics. We did this based on a survey of 100 legal and hydrologic experts who work in Colorado's water rights markets.

4. Methods

We estimate a hedonic cost function for procedural transactions costs for water transfers in Colorado. A hedonic cost function represents the unit price of a commodity as a function of its various attributes, including quality characteristics. The underlying notion is that different versions of the same commodity (e.g., cars, houses, real estate) might command different prices if they are of different quality, and an empirical hedonic cost function can produce a quality-adjusted price index for the commodity (Court, 1939; Griliches, 1961). Here we apply the concept not to a commodity (water) but to transaction costs associated with acquisition of that commodity.

In conventional estimation of a hedonic cost function, the researcher knows costs and characteristics of different versions of the commodity, making estimation fairly straightforward. In our case, data on transaction costs associated with water market transfers are generally not publicly available. These costs must be elicited. For this purpose, we draw on stated preference modeling methodologies, widely used in various fields in economics including environmental economics, market research, and health economics.

In stated preference modeling, the researcher seeks to elicit respondents' willingness to pay for some item and represent how it varies as a function of characteristics of the item and perhaps the individual (Arrow et al., 1993; Louviere et al., 2003). The elicitation can be done via open-ended valuation questions ("what is the most you be willing to pay for X?"), closed-ended valuation questions ("if X cost $Z, would you want it?" where Z is varied across respondents), or choice experiment questions, which present respondents with several different outcomes with different prices and ask respondents which outcome they prefer or how they would rank the outcomes. We draw on variants of these stated preference methods to elicit our survey respondents' assessment of the transaction costs associated with water transfers possessing various alternative characteristics.

The U.S. National Oceanic and Atmospheric Administration's Blue Ribbon Panel endorsed using well-designed stated preference surveys for government decision-making (Arrow et al., 1993; Johnston et al., 2017). Issues to be tackled in designing stated preference surveys can include hypothetical bias and strategic behavior by respondents. Stated preference surveys typically elicit respondents' maximum willingness to pay for an item, and empirical evidence suggests that respondents tend to understate willingness to pay and instead offer estimates anchored on what they think the item would cost (Brown, 2005). In this study, however, we elicited assessments of cost, not willingness to pay, from informed respondents for whom such assessments are a daily reality, not a hypothetical matter.

We identified relevant water transfer characteristics based on the transaction cost literature described above and pretest interviews conducted with five attorneys and five hydrologists. The pretest respondents had diverse experience working in all Colorado water divisions. Based on this, we identified key determinants of transaction costs in water rights transfers: the (1) volume of average annual consumptive use being transferred, (2) seniority of the water right being transferred, and (3) Colorado water division where the transfer occurred.

In addition, we identified a fourth determinant of transaction costs in Colorado: the legal outcome of water court actions. We identified five alternative legal outcomes: a referee's ruling with no opposition (the lowest-conflict outcome), a referee's ruling with some opposition, a case settled on the judge's docket before trial, a water court trial, or an appeal to the Colorado Supreme Court (the highest-conflict outcome). By way of an example, in one recent transfer appealed to the Colorado Supreme Court, the Central Colorado Water Conservancy District applied to change the use of senior water rights with an 1882 priority date in the Jones Ditch Company; this ditch is located in the South Platte River Basin. After Central and third-party objectors failed to reach a settlement, a water court trial and then a Colorado Supreme Court appeal centered on how much water could be transferred, in this case litigating the lawful historical use of the Jones Ditch water right. Although Central initially claimed that the Jones Ditch water right included all water historically used to irrigate over 700 acres, because this acreage included irrigated lands supplied by the Jones Ditch but not contemplated in the 1882 court decree for the Jones Ditch water right, the Colorado Supreme Court limited the water right to water for approximately 344 acres (Central Colorado Water Conservancy District v. City of Greeley, 2006).

Although legal and hydrologist fees for a water transfer may vary depending on which water court outcome occurs, this outcome is not known ex ante: it depends on the strength of opposition, specific details of offers to settle the case before trial, and dispositions of referees and judges, among other factors. In our survey, therefore, we first elicit respondents' expectations of the legal outcome and then, conditional on a particular legal outcome, we elicit their assessment of transaction costs. Our final estimate of transaction costs associated with any particular type of transfer combines the two elicitations; the expected cost is calculated as

$$E(\text{cost}) = \sum_{j=1}^{J} P\left(\text{outcome}_j\right)^{*}\text{cost}_j \quad (1)$$

where j represents the alternative legal outcomes

This two-stage structure represents an innovation. MacDonnell et al. (1990), for example, estimated an unconditional transaction cost function. In rare instances where hydroeconomic modeling studies include transaction costs, they also commonly assume deterministic transaction costs (Du et al., 2017; Erfani et al., 2014; Wang, 2012; Zhu et al., 2015). In contrast, we estimate a transaction cost function conditional on the outcome of legal proceedings.

4.1. Survey Structure

The survey consisted of an in-person interview followed by an online survey. The in-person interview started with some information about the respondent's experience and then, following some introductory material, moved into a type of choice experiment (Table S2 and Figures S2–S5 in the supporting information). We first presented respondents with one particular water transfer, characterized in terms of its volume of consumptive use, seniority, and water division, and then we asked them to assess the probability of each of the five legal outcomes for that transfer. Possible options were 0%, <1%, 1–5%, 5–10%, 10–20%, 20–40%, 40–60%, 60–80%, 80–90%, 90–95%, 95–99%, >99%, and 100% (Figures S2 and S3). Next, we told the respondent which legal outcome had occurred, and we asked them to consider two alternative versions of that transfer with that outcome—a simple version and a complex version. For both the simple and complex versions, we asked respondents to provide open-ended estimates of the applicant's legal fees, hydrologist fees, and water court completion times assuming typical costs based on reasonable market rates for legal and consulting services. We told participants to evaluate fees and completion times from when a client first asked them to work on a transfer until the water court issued a decree. While we told participants that they could draw on their own past experience charging fees, we asked them to consider typical fees that they and their colleagues would charge.

After the in-person interview, we invited respondents to complete a supplemental online survey. The online survey presented five more water transfer scenarios like the one scenario in the in-person survey, again requesting probabilities of alternative legal outcomes and then, for a given outcome, the applicant's legal fees, hydrologist fees, and completion times (Table S3). For the in-person and online choice experiment scenarios, we varied characteristics of water transfers—the volume of water traded, seniority, water division, and water court outcome—using a fractional factorial *D*-efficient experimental design (Sawtooth Software, 2017; Table S2). However, we began the in-person and online surveys by asking respondents to indicate water divisions and volumes of water that they felt comfortable evaluating, and where the experimental design assigned a different division or volume, we randomly replaced the value with one that fell within their experience or comfort. In the in-person and online choice experiment, we also repeated the elicitation questions described above but accompanied by specific proposed changes to Colorado law. Those responses, which incorporate another important determinant of transaction costs, whether the water right has been transferred before or is being transferred for the first time, are analyzed separately in Womble and Hanemann (2020).

4.2. Survey Sample

We measured a water transfer applicant's legal and hydrologist fees, and we surveyed attorneys and hydrologists who advise these applicants rather than the applicants themselves. These subjects generally have more experience with diverse transfers across different water divisions than any individual applicant.

Including the 10 pretest participants, 100 respondents completed the in-person survey. Of these, 71 completed the online survey. Initial participants were identified by first sending survey advertisements to subscription lists maintained by Colorado's water courts, the State Engineer's Office, the Colorado Bar Association, the Colorado Water Congress, and the American Water Resources Association. Second, additional interviewees were identified through references from earlier participants and internet searches for Colorado water attorneys and hydrologic experts. We directly contacted prospective participants in this second group by email or phone. All respondents donated their time. The in-person interview required about 1 hour, and the online survey about 30 minutes.

The sample is described in Table S1. Sixty-three of the respondents were lawyers, and 35 were hydrologists. The other two were a water planner and administrator. Overall averages for respondents were 26.2 years of experience, 15.3 transfers per year, and a lifetime experience of 159 transfers. 80.6% of the respondents had worked in Division 1 (South Platte River) and 76.5% in Division 2 (Arkansas River), the divisions with the most transfer activity.

Because there is no comprehensive database of water lawyers and hydrologic experts in Colorado and the population is small, we interviewed as many participants as possible rather than a representative sample. A sampling approach combining convenience and snowball sampling is common in surveys of expert communities (Fink, 2003). Such surveys may incur bias where the survey sample differs from the population. However, we found little evidence of bias toward lower- or higher-paid experts in our sample (Figure S1).

4.3. Econometric Methods

As indicated in equation (1), our model for predicting water market transaction costs in Colorado has two components: an equation predicting probabilities of water court outcomes and an equation predicting transaction costs conditional on particular court outcomes. The two equations raise different statistical issues.

Responses to survey questions on water court outcomes are a set of five proportions—one for each outcome—with the proportion representing the probability with which that outcome is expected to occur. Except for the case where the assessed probability is 0 or 1, the response is a range of proportions. Technically, one would apply the Dirichlet distribution to model a set of proportions, and there are several ways to elicit Dirichlet proportion estimates (Zapata-Vázquez et al., 2014). One approach elicits point estimates of each probability; however, this approach is problematic when significant uncertainty exists about the probabilities. Indeed, ample evidence from the psychology literature demonstrates that people poorly judge probabilities (Daneshkhah, 2004). Accordingly, another practice is to elicit respondents' confidence intervals around their point probabilities (Chaloner & Duncan, 1987), or, more simply, to elicit an interval in which they believe the probability falls (Garthwaite et al., 2005), known as the variable interval method. We observed uncertainty in the elicitation of probabilities in pretest interviews, so we elicited ranges rather than point estimates for probabilities of court outcomes.

Because the proportions should sum to 1 across all five outcomes and some combinations of values within ranges offered by participants did not sum to 1, where respondents offered a range of proportions, we restricted the respondent's range to a feasible range of the lowest to highest probabilities that, when combined with the probability ranges for other legal outcomes, allowed possible combinations that sum to 1 (equations (S8)–(S9) in the supporting information). Then, where the feasible values consisted of probability ranges, we converted ranges to single values using three alternative approaches. Also, where necessary, the five probabilities were adjusted so they summed to 1 (Figure S6). The main approach uses probabilities calculated with equation (2), which chooses values in the middle of the feasible range and ensures that the selected probabilities sum to 1.

$$\text{Main approach probability value}_j = \text{lower bound of feasible range}_j + \left(\frac{\text{upper bound of feasible range}_j - \text{lower bound of feasible range}_j}{\sum_{j=1}^{J}\left(\text{upper bound of feasible range}_j - \text{lower bound of feasible range}_j\right)}\right) * \left(1 - \sum_{j=1}^{J} \text{lower bound of feasible range}_j\right) \quad (2)$$

where j again represents the alternative legal outcomes

The two other approaches obtain a single-valued probability of each outcome using the boundaries of the feasible range in such a way as to maximize the probability of either low-conflict court outcomes or of high-conflict court outcomes. Together, they represent a form of bounds around the main estimate (equations (S8)–(S11)). Results for the main estimate are presented below, and the derivation of the low- and high-conflict probabilities and resulting regression models are in the supporting information. The ranges between low- and high-conflict outcome probabilities represent uncertainty about a transfer's legal outcome, as opposed to respondents' estimates of fees/completion times for simple versus complex cases, which represent uncertainty about the range of legal, hydrologic, or other complexity that can accompany transfers with a known legal outcome.

We modeled probabilities of the five outcomes as a function of the transfer characteristics using fractional multinomial logit (FMNL) estimation. FMNL is an extension of multinomial logit from the case where the observed outcomes are binary valued (0 if an outcome did not occur, 1 if it did) to the case where they are fractions (probabilities of occurrence) (Papke & Wooldridge, 1996; Sivakumar & Bhat, 2002). Let y_{ijk} denote the ith respondent's assessment of the probability of water court outcome j under water transfer scenario k, let $\boldsymbol{X}_{ik}$ denote a set of explanatory variables pertaining to respondent i and the characteristics of transfer k, and let $\boldsymbol{\beta}_j$ denote the set of coefficients associated with $\boldsymbol{X}_{\mathrm{ik}}$ in the case of court outcome j.

FMNL assumes the expected value of the y_{ijk} is given by

$$E\left(y_{ijk}|X_{ik}\right) = \frac{\exp\left(X_{ik}\beta_j\right)}{\sum_{j=1}^{J}\exp\left(X_{ik}\beta_j\right)} \quad j = 1...J \tag{3}$$

The coefficients $\boldsymbol{\beta}_j$ are estimated by maximizing the quasi-log-likelihood function formed as though the (y_{i1k}, … ,y_{ijk}) were a set of multinomial random variables (Ramalho et al., 2011):

$$L(\beta) = \sum_{i,j,k} y_{ijk} \ln E\left\{y_{ijk}|X_{ik}\right\} \tag{4}$$

The second component of the estimation provides hedonic cost functions for legal fees, hydrologist fees, and length of time to complete the transfer. In each case, for a given transfer scenario, we asked respondents to consider the fee/completion time for a simple and complex version of the transfer. A transfer's full complexity depends on the legal and hydrologic issues raised by third-party objectors and the intensity of their opposition. In more complex transfers, objectors may uncover major legal or hydrologic deficiencies in the proposed transfer, advance novel theories of opposition with limited precedent (e.g., for injury), or be uncompromising and less inclined to agree to legal settlements. The applicant may also add complexity by proposing, for example, transfers that raise novel issues, operationally complicated systems of exchanges or transfers of many direct flow and storage rights in the same court case, or transfers of water rights with poor records of historical use or historical use beyond legal limitations. More complexity can increase fees and completion times.

The simple and complex estimates produced a range of values, which we took as a bounded value. This format was chosen because we felt (and pretest respondents agreed) that it was more realistic and accommodating of variability among transfers in the real world than requesting a single estimate. We could have used the midpoint of the resulting range, taken it as a point estimate, and run a conventional ordinary least squares (OLS) regression estimation, such as the linear model

$$W_{ik} = X_{ik}\beta + \upsilon_k \tag{5}$$

or the log-linear model

$$\ln W_{ik} = X_{ik}\beta + \upsilon_k \tag{6}$$

In (5) and (6), W_{ik} is the dependent variable—for example, legal fees assessed by respondent i for transfer k. Explanatory variables are denoted by $\boldsymbol{X}_{ik}$ (identical to those in the FMNL model but also including legal outcome), their coefficient vector is $\boldsymbol{\beta}$, and υ_k are normally distributed error terms. Excluded categories for dummy variables are the same in equations (5) and (6) as (3), with the addition of legal outcome.

To accommodate bounded ranges of estimates for fees/completion times, however, the appropriate statistical technique is interval regression. If a respondent offers a range of values for W_{ik} between $100/acre-feet per year (AFY; 1 AF equals 1,233 m^3) and \$200/AFY, using the log-linear model, the probability of this response is given by

$$P(100 \leq W_{ik} \leq 200) = P\left(e^{X_{ik}\beta+\upsilon_k} \leq 200\right) - P\left(e^{X_{ik}\beta+\upsilon_k} \leq 100\right) \tag{7}$$

which is the term that enters the likelihood function with maximum likelihood estimation. Like equation (6), we use a parametric interval regression model that assumes normally distributed error terms for legal and hydrologist fees. In FMNL and interval regressions, we included interaction terms based on a variable selection process and identified functional form as described in the supporting information.

After separately developing these statistical models of probabilities of legal outcomes and fees/completion times, we calculated expected values using equation (1). We also estimated confidence intervals for these expected values using Monte Carlo simulations across the FMNL models of legal outcomes and each of the interval regression models (equations (S16) and (S17)).

5. Estimation Results

5.1. Water Court Outcomes for Transfers

As noted above, the outcomes, from least conflict to most conflict, are (i) referee ruling with no opposition, (ii) referee ruling with some opposition, (iii) settlement before trial, (iv) trial, and (v) appeal to the Colorado Supreme Court. Both (ii) and (iii) entail a settlement among the parties, whether before the water referee or the water judge. Potential determinants of the outcome (attributes in the choice experiments) are the volume of consumptive use transferred, seniority of the water right (junior/senior), and water division(s) in which the transfer occurs (Division 1, 2, 3, 5, or 4/6/7). We also added two explanatory variables describing the expert assessing the outcome probabilities: whether the respondent was a lawyer and the respondent's years of experience.

To our knowledge, no existing database systematically characterizes water court outcomes for water transfers in Colorado. WestWater Research maintains the most comprehensive modern database of prices and characteristics for past Colorado water rights transactions, used for Figure 2d, but it lacks data on legal proceedings prior to the transfer's completion. Because we have no such database, we first provide an overview of survey participants' assessments of outcomes across all transfer scenarios. The lowest-conflict outcome—referee ruling with no opposition—was judged to occur, on average, in 22.4% of the transfer scenarios in Divisions 4/6/7, in 16.0% of the scenarios in Division 5, 10.7% in Division 3, 5.95% in Division 2, and 2.64% in Division 1. The single most likely outcome was judged to be referee ruling with some opposition in Divisions 3, 5, and 4/6/7, and case settled on judge's docket awaiting trial in Divisions 1 and 2; as noted above, both outcomes involve the parties reaching a settlement. If there was no settlement, the outcome would be a trial, possibly followed by an appeal to the Colorado Supreme Court. The likelihood of a trial, with or without appeal to the Supreme Court, was assessed, on average, at 24.1% of transfer scenarios in Division 1, 16.8% for Division 2, 15.1% for Division 3, 13.7% for Division 5, and 8.17% for Divisions 4/6/7.

Water division, however, is not the only determinant: the volume traded potentially matters, and volume itself varies to some degree with the water division because our experimental design excluded very large transfers (10,000 or 40,000 AFY) outside of Divisions 1 and 2 (pretest respondents indicated that they had experience with transfers over 1,000 AFY in eastern Colorado but not western Colorado; Table S2). To disentangle the statistical relationship, we turn to estimation of the FMNL model (3). Because of the complexity of the FMNL estimation, the β_j coefficients lack a simple interpretation, so instead of showing the β_j coefficients, we show partial effects evaluated at the mean (Table 1). Partial effects at the mean of the $\boldsymbol{X}_{ik}$ variables, or $PE_{ik} \equiv \frac{\partial E\left(y_{ijk}|X_{ik}\right)}{\partial X_{ik}}$, have an interpretation similar to coefficients in standard linear regression (Table 1).

The most significant determinant of water court outcome is the volume of water transferred: a larger volume increases the probability of higher-conflict outcomes and reduces that of lower-conflict ones. Seniority of the water right transferred only shows a significant impact for one legal outcome, the water court trial, where senior rights increase the probability. As suggested previously, the FMNL model shows that probabilities of water court outcomes differ by water division, at least for two eastern Colorado

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Table 1

Fractional Multinomial Logistic (FMNL) Regression Results for Probabilities of Five Water Court Outcomes for Colorado Water Rights Transfers

Determinant	**Outcome 1**[a]**:** Referee ruling with no opposition	**Outcome 2**[a]**:** Referee ruling with some opposition	**Outcome 3**[a]**:** Case settled while on judge's docket awaiting trial	**Outcome 4**[a]**:** Water court trial	**Outcome 5**[a]**:** Colorado Supreme Court appeal
Volume traded: ln (consumptive use)[b]	−0.0244 (0.00890)**	−0.0482 (0.00137)***	0.0382 (0.00356)***	0.0243 (0.00816)**	0.0101 (0.00298)***
Seniority: Senior rights[c]	−0.00752 (0.0155)	−0.0229 (0.0264)	−0.0129 (0.0308)	0.0334 (0.0151)*	0.0100 (0.00610)
Location: Division 1 - South Platte[c]	−0.106 (0.0622)$^{\bullet}$	−0.260 (0.0397)***	0.217 (0.0476)***	0.123 (0.0307)***	0.0253 (0.0119)*
Location: Division 2 - Arkansas[c]	−0.0705 (0.0254)**	−0.126 (0.0386)**	0.102 (0.0552)$^{\bullet}$	0.0829 (0.0278)**	0.0117 (0.0113)
Location: Division 3 - Rio Grande[c]	−0.0465 (0.0404)	−0.125 (0.0483)**	0.0464 (0.0626)	0.0922 (0.0509)$^{\bullet}$	0.0330 (0.0197)$^{\bullet}$
Location: Division 5 - Colorado[c]	−0.0262 (0.0215)	−0.0443 (0.0357)	−0.0229 (0.0527)	0.0769 (0.0299)*	0.0164 (0.0122)
Respondent characteristic: lawyer[c]	−0.00752 (0.0155)	−0.0229 (0.0264)	−0.0129 (0.0308)	0.0334 (0.0151)*	0.0100 (0.00610)
Respondent characteristic: years of work experience[b]	0.000428 (0.000934)	−0.00417 (0.000879)***	0.000306 (0.00108)	0.00269 (0.000935)**	0.000749 (0.000384)$^{\bullet}$
Observations	**415 observations with five outcome probabilities each** (Of the 447 complete responses received, when the lower and upper bounds were summed across all five water court outcomes, 353 had lower bounds ≤100% and upper bounds ≥100%, plus we included and scaled to 100% an additional 62 responses with upper bounds ≥75% or lower bounds ≤125%. We eliminated as infeasible 32 responses with lower bounds >125%. See Figure S6.)				
Initial log likelihood			−566		
Model log likelihood			−504		
LR chi^2			125		
Prob > chi^2			0.00		

Note. Excluded categories are Seniority: junior rights; Location: Divisions 4/6/7—Gunnison, Yampa/White, or San Juan/Dolores; and Respondent characteristic: non-lawyer.
[a]Krinsky-Robb robust standard errors for partial effects against the mean provided in parentheses. We used the post-estimation procedure in the fmlogit package in R (Ji, 2016) that derived partial effects against the mean and standard errors for these partial effects from an underlying FMNL model with standard errors for the β_j coefficients clustered by respondent for odds ratios against the baseline choice; see equations (S6) and (S7) for bootstrapping procedure applied for clustering. [b]For continuous variables in $\boldsymbol{X}_{ik}$, the partial effects at the mean depicted in Table 1 represent the effect of a marginal change of one continuous variable X_{ik} on the choice variable y_{ijk} (i.e., the probability of a given legal outcome) at the mean of all $\boldsymbol{X}_{\mathrm{ik}}$ covariates (Ji, 2016). [c]For dummy variables in $\boldsymbol{X}_{ik}$, partial effects at the mean depicted in Table 1 are the effect of raising that dummy variable X_{ik} from 0 to 1 on the choice variable y_{ijk} (i.e., the probability of a given legal outcome) at the mean of all other $\boldsymbol{X}_{\mathrm{ik}}$ covariates (Ji, 2016). ***Significant at 0.1% **Significant at 1% *Significant at 5% $^{\bullet}$Significant at 10%

divisions: Divisions 1 and 2. In those regions—which, as noted, experience the most water transfer activity, expensive water rights, and water scarcity alongside complex water rights administration and operations—the outcome is significantly less likely to be a referee ruling and more likely to involve a trial; the single most likely outcome is the case settles awaiting trial. In other divisions, however, there is no general statistically significant pattern of outcomes. Also, fewer and less significant coefficients exist for the fifth legal outcome, a Colorado Supreme Court appeal, supporting some survey participants' claim that the probability of an appeal depends more on whether a case presents novel legal and hydrologic issues than more standardized determinants. Characteristics of the survey respondent exhibit some impact: respondents with more years of experience were more likely to assess the outcome as going to trial and less likely to assess the case being resolved before the referee with some opposition, while whether the respondent was a lawyer had almost no significant impact on outcomes, except for a slightly increased assessment of the probability of a trial.

5.2. Transaction Costs and Completion Times

As noted earlier, we treat respondents' estimates of legal fees, hydrologist fees, and completion times as interval estimates rather than point values. The ranges of these intervals are often quite large and frequently comparable to or larger than estimates themselves. For example, estimated legal fees range from an average of $56,598 for simple versions of the transfers to $143,121 for complex versions. For hydrologist fees, they range from $41,940 to $117,428. Completion times range from 22.5 to 41.9 months. As a percent of the midpoint of the range, the widest range of estimates for an individual transfer is 187% for legal fees, 196% for hydrologist fees, and 165% for completion times.

The largest estimate of total legal fees for a complex transfer was $2,000,000, for a transfer of 500 AFY of senior rights in Division 1 that was appealed to the Colorado Supreme Court, while the smallest estimate for a simple transfer was $1,000, for several different transfers in Divisions 4/6/7. The largest estimate of hydrologist fees for a complex transfer was also $2,000,000, for a transfer of 40,000 AFY of junior rights in Division 1 that was settled on the judge's docket awaiting trial; the smallest estimate for a simple transfer was $500, for 1 AFY of junior rights resolved before the referee with no opposition in Divisions 4/6/7. For total completion time, the largest estimate for a complex transfer was 180 months, for a 10,000 AFY transfer of senior rights in Division 1 appealed to the Colorado Supreme Court. The lowest estimate of completion time for a simple transfer was 3 months, for two transfers in Division 5 and one in Divisions 4/6/7 resolved before the referee with no opposition.

Table 2 shows the interval regression estimates, derived using (6).

With a larger volume of water transferred, transfers require significantly longer total completion times. Both unit legal fees and unit hydrologist fees are actually lower for larger volumes, showing important economies of scale. As we surmised, higher-conflict legal outcomes generate significantly greater legal fees, hydrologist fees, and completion times. The largest fees and completion times occur for a Colorado Supreme Court appeal, followed by a water court trial, case settled before the judge awaiting trial, referee's ruling with some opposition, and referee's ruling with no opposition. If the transfer occurs in Divisions 1, 2, or 5, this significantly raises legal and hydrologist fees compared to the other divisions, with the highest fees in Division 1, followed by Divisions 2 and 5. This ordering matches the WestWater data in Figure 2d, which show the highest water transfer prices in those divisions and in that order. This ordering is also largely consistent with data on water scarcity, water transfer activity, and operational complexity in Figures 2b, 2c, and 2e, which show Divisions 1 and 2 with the most water scarcity and water transfer activity and Divisions 1, 2, and 5 with the most operational complexity and water use structures. In particular, Division 1 has the highest legal and hydrologist fees, and Figures 2b–2e also show Division 1 with the greatest water scarcity, water transfer activity and prices, number of water use structures, and operational complexity. With completion time there is no significant difference between water divisions, suggesting that, unlike fees, completion times are more uniform statewide, possibly due to deadlines set by statewide water court rules. Similarly, while senior rights transfers entail higher legal and, especially, hydrologist fees, senior rights exhibit no significant impact on completion time. Finally, hydrologist fees are lower when assessed by a lawyer rather than a non-lawyer, suggesting that hydrologists have better information about their costs than lawyers, but no difference exists between legal fees or completion times for lawyers versus non-lawyers.

Table 2
Interval Regression Results for Unit Legal Fees, Unit Hydrologist Fees, and Total Completion Times Conditional on Water Court Outcome

Determinant	**Model 1[a]:** Natural log of unit (legal fees+1) ($/AFY consumptive use)	**Model 2[a]:** Natural log of unit (hydrologist fees+1) ($/AFY consumptive use)	**Model 3[a]:** Natural log of (total completion time+1) (months)
Volume traded: ln (consumptive use)	−0.820 (0.0178)***	−0.796 (0.0197)***	0.00934 (0.00299)**
Seniority: Senior rights	0.182 (0.0774)*	0.208 (0.0677)**	0.0140 (0.0111)
Location: Division 1 - South Platte	0.740 (0.162)***	0.858 (0.150)***	0.0170 (0.0244)
Location: Division 2 - Arkansas	0.697 (0.147)***	0.650 (0.122)***	0.0312 (0.0209)
Location: Division 3 - Rio Grande	0.344 (0.201)•	0.272 (0.159)•	−0.0233 (0.0245)
Location: Division 5 - Colorado	0.470 (0.140)***	0.370 (0.120)**	−0.00297 (0.0247)
Water court outcome 2: Referee ruling with some opposition	0.663 (0.151)***	0.595 (0.123)***	0.160 (0.0237)***
Water court outcome 3: Case settled while on judge's docket awaiting trial	1.04 (0.150)***	0.990 (0.127)***	0.233 (0.0279)***
Water court outcome 4: Water Court trial	1.34 (0.148)***	1.17 (0.122)***	0.259 (0.0275)***
Water court outcome 5: Colorado Supreme Court appeal	1.60 (0.133)***	1.28 (0.129)***	0.324 (0.0302)***
Respondent characteristic: lawyer	N/A	−0.312 (0.135)*	N/A
Constant	8.56 (0.174)***	8.07 (0.156)***	0.933 (0.0347)***
Observations	363	408	442
Initial log likelihood	−883	−954	−607
Model log likelihood	−491	−520	−489
LR chi^2	784	868	235
Prob > chi^2	0.00	0.00	0.00
Model standard error	0.723	0.691	0.115
Assumed distribution of dependent variable[b]	Normal	Normal	Lognormal

Note. Excluded categories are Seniority: junior rights; Location: Divisions 4/6/7—Gunnison, Yampa/White, or San Juan/Dolores; Water court outcome: Referee ruling with no opposition; and Respondent characteristic: non-lawyer. Coefficient values in these interval regressions can be interpreted similar to those in standard linear regression; the coefficient values represent how much the mean of the dependent variable changes given a one-unit change in the explanatory variable, holding other covariates constant. Standard error provided in parentheses (standard errors clustered by respondent).
[a]Box-Cox transformations for unit legal fee, unit hydrologist fee, and total completion time OLS regressions, using the midpoint of each interval-censored dependent variable, support the chosen log-linear functional form (Tables S6–S8). [b]Assumed distribution of dependent variable selected based on examination of AIC (Table S9). ***Significant at 0.1% **Significant at 1% *Significant at 5% •Significant at 10%

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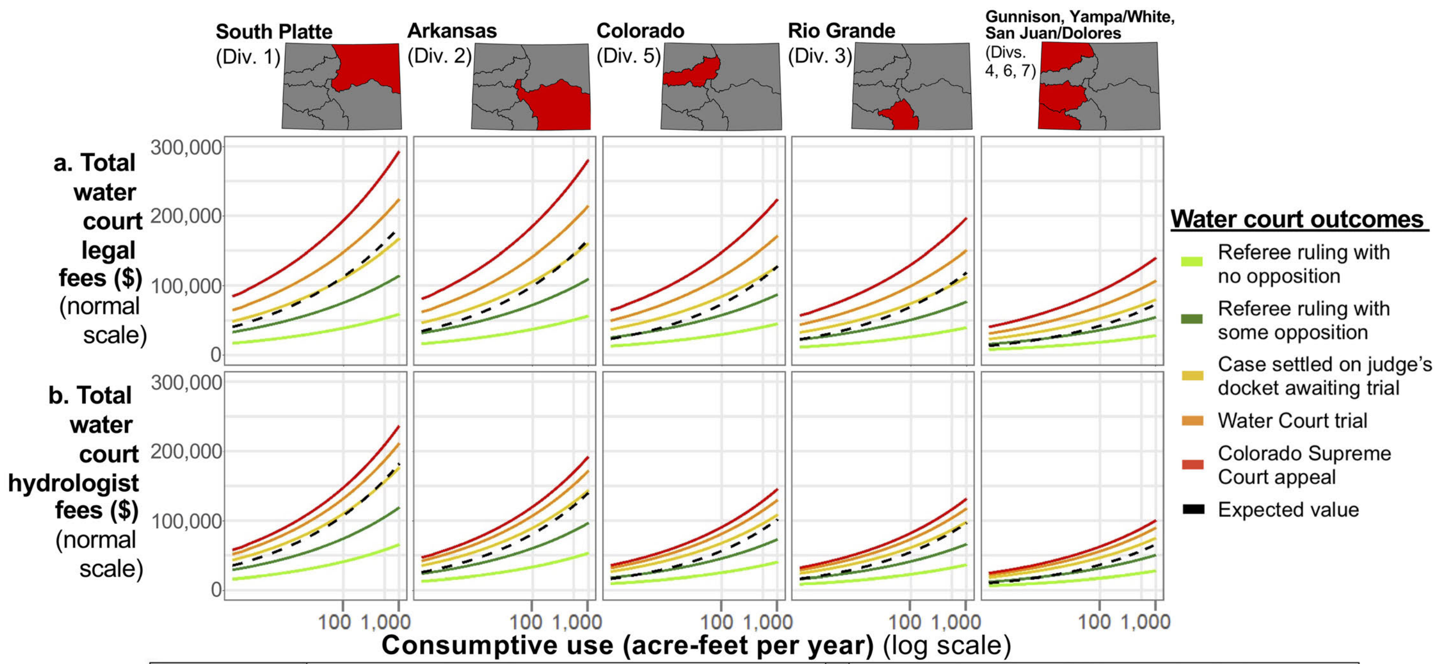

c. Total water court legal plus hydrologist fees for selected transfers of senior rights

	South Platte – Division 1 (*most expensive*)				Gunnison, Yampa/White, San Juan/Dolores – Divisions 4/6/7 (*least expensive*)			
Volume of consumptive use	***1***	***10***	***100***	***1,000***	***1***	***10***	***100***	***1,000***
Referee ruling with no opposition	**$33,091** ($33,091/AFY)	**$51,427** ($5,143/AFY)	**$79,985** ($800/AFY)	**$124,498** ($124/AFY)	**$14,935** ($14,935/AFY)	**$23,174** ($2,317/AFY)	**$35,985** ($360/AFY)	**$55,920** ($56/AFY)
Referee ruling with some opposition	**$62,153** ($62,153/AFY)	**$96,502** ($9,650/AFY)	**$149,949** ($1,499/AFY)	**$233,176** ($233/AFY)	**$28,109** ($28,109/AFY)	**$43,573** ($4,357/AFY)	**$67,597** ($676/AFY)	**$104,944** ($105/AFY)
Case settled on judge's docket awaiting trial	**$91,621** ($91,621/AFY)	**$142,282** ($14,228/AFY)	**$221,125** ($2,211/AFY)	**$343,921** ($344/AFY)	**$41,420** ($41,420/AFY)	**$64,219** ($6,422/AFY)	**$99,643** ($996/AFY)	**$154,725** ($155/AFY)
Water Court trial	**$116,506** ($116,506/AFY)	**$180,644** ($18,064/AFY)	**$280,306** ($2,803/AFY)	**$435,284** ($435/AFY)	**$52,843** ($52,843/AFY)	**$81,803** ($8,180/AFY)	**$126,729** ($1,267/AFY)	**$196,478** ($196/AFY)
Colorado Supreme Court appeal	**$142,620** ($142,620/AFY)	**$220,669** ($22,067/AFY)	**$341,685** ($3,417/AFY)	**$529,467** ($529/AFY)	**$64,974** ($64,974/AFY)	**$100,373** ($10,037/AFY)	**$155,174** ($1,552/AFY)	**$240,071** ($240/AFY)
Expected value	**$76,147** ($76,147/AFY)	**$131,044** ($13,104/AFY)	**$220,761** ($2,208/AFY)	**$366,015** ($366/AFY)	**$24,137** ($24,137/AFY)	**$43,711** ($4,371/AFY)	**$78,703** ($787/AFY)	**$139,192** ($139/AFY)

Figure 3. (a) Applicant's total legal fees and (b) total hydrologist fees for water court approval of transfers of senior water rights. (c) Total legal plus hydrologist fee values for selected transfers of senior water rights. Hydrologist fees in (b) are calculated with the dummy variable for lawyer respondents deactivated, and FMNL predictions of the probabilities of water court outcomes for (a) and (b) use a value of 0.5 for this variable. Both (a) and (b) use the average value for years of work experience (26.2 years) from our survey population. The values shown in Figure 3 do not depict statistical uncertainty (e.g., confidence intervals). Figure S9 plots identical information for junior rights.

6. Projected Transaction Costs and Comparison to Market Prices for Water Rights

Here we examine implications of the equations estimated above. We first focus on how projected transaction costs for water transfers in Colorado vary with water division, volume traded, and seniority, and we explore uncertainty in those estimates. Second, we compare our estimates of transaction costs to the prices paid for water rights in some market transactions that actually occurred in Colorado. Figures 3, 4, and the supporting information offer detailed descriptions of the inputs we used to arrive at the fee estimates we describe.

6.1. Projections of Transaction Costs

As noted above, the three most substantial determinants of fees are the division where the transfer occurs, the legal outcome, and the volume being transferred. The sensitivity of costs to these factors is shown in Figures 3a–3c. Figures 3a and 3b graph predicted legal and hydrologist fees for a senior rights transfer

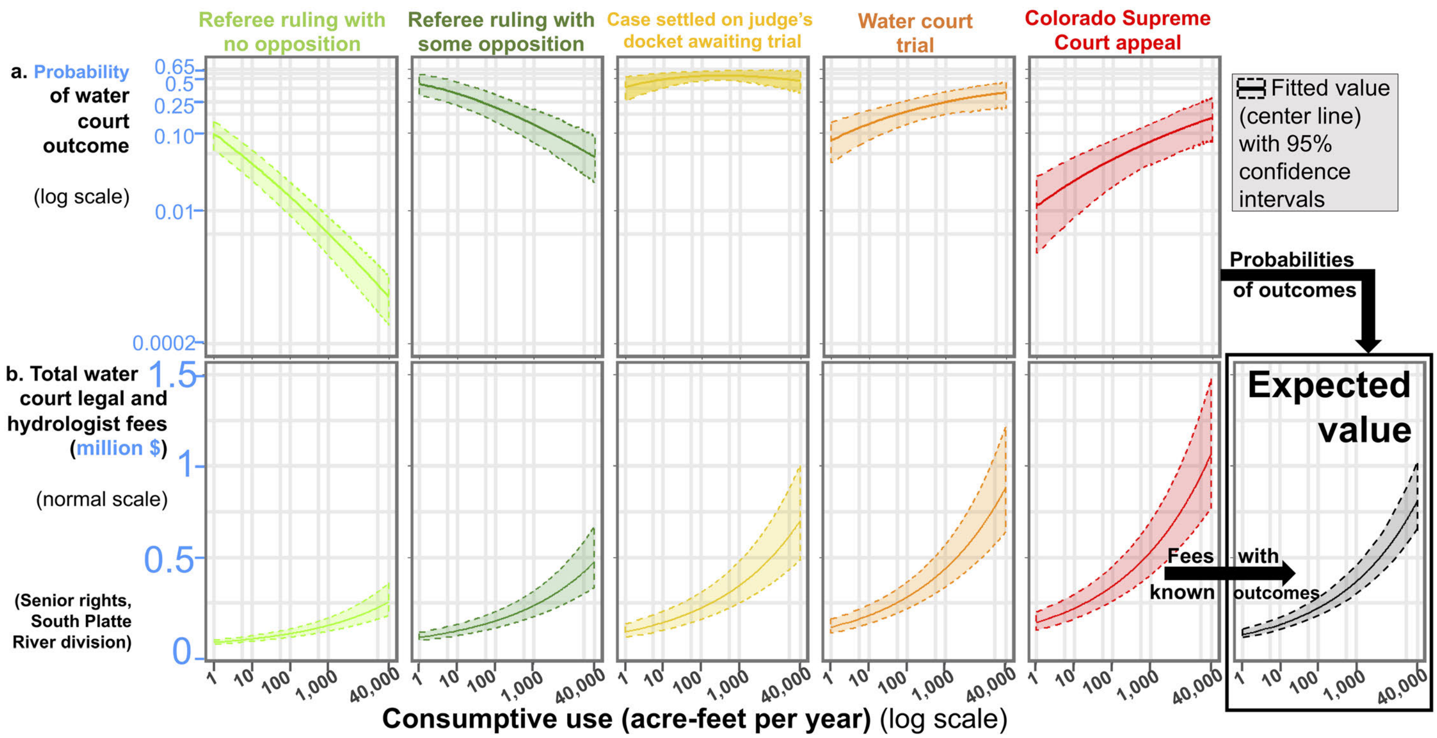

Figure 4. Uncertainty in probabilities of water court outcomes and transaction costs, depicted as 95% confidence intervals for transfers of senior water rights in Colorado's South Platte River Water Division (Division 1). In (a), low 95% confidence intervals come from the low-conflict version of the FMNL model, while high 95% confidence intervals come from the high-conflict FMNL model (Tables S4–S5). As in Figure 3, we deactivated the "lawyer" dummy variable for estimates of hydrologist fees and used a value of 0.5 for this dummy variable in the FMNL model predictions; we also used the average value for years of work experience (26.2 years) from our survey population. Figure S10 plots identical information for junior rights.

ranging from 1 to 1,000 AFY across all water divisions and all water court outcomes. Even for a transfer with the same volume of water and legal outcome, the fees differ substantially across water divisions. A transfer of 100 AFY of senior rights that is resolved with the lowest-conflict court outcome, a referee's ruling with no opposition, faces predicted legal plus hydrologist fees that range from $35,985 in Divisions 4, 6, and 7 to $79,985 in Division 1. The highest-conflict outcome, a Colorado Supreme Court appeal, has fees for this 100 AFY transfer of $155,174 for Divisions 4, 6, and 7 but $341,685 in Division 1. These differences in fees for the same outcomes in different regions may reflect cross-division differences in technical and legal complexity, numbers of objectors and intensity of opposition, the economic value of water, and billing rates, among other factors. Cross-division differences are also reflected in ex ante expected values of total legal and hydrologist fees before the legal outcome is known: this 100 AFY transfer has an expected value of $78,703 ($787/AFY) for Divisions 4, 6, and 7 but $220,761 ($2,208/AFY) in Division 1. Meanwhile, for a very large 40,000 AFY transfer of senior rights in Division 1, the expected value of total legal and hydrologist fees is $806,448 ($20/AFY), demonstrating significant scale economies.

Seniority also affects fees. Figures 3a–3c show fees for senior rights. By contrast, while expected fees for the 100 AFY transfer with senior rights in Division 1 total $220,761, the same value for junior rights is $177,015 (Figure S9). At least two reasons may explain higher fees associated with senior rights: (1) they are more valuable, meaning that applicants are willing to pay more to transfer them while objectors are willing to pay more to dispute transfers, and (2) because senior rights can curtail rights junior to their priority date, senior rights transfers may have more potential for third-party impacts.

6.2. Transaction Cost Uncertainty

Three main factors drive uncertainty in the transaction cost projections: (i) the difference between simple versus complex transfers with the same characteristics; (ii) the court outcome, which is uncertain ex ante; and (iii) the confidence intervals associated with coefficient estimates in the regressions in Tables 1 and 2. For the probabilities of alternative court outcomes, as noted above, three approaches are used to transform ranges of values elicited from respondents into point values. The main approach, used in the analysis so far, employs the middle value within the range calculated with equation (2). Two other approaches, described in equations (S10) and (S11), use boundaries of the range to maximize probabilities of low-conflict court outcomes or high-conflict outcomes. We developed two more FMNL regressions for these two additional sets of probabilities like the model in Table 1 (see Tables S4 and S5).

The three FMNL regressions—the main, low-conflict, and high-conflict versions—form the basis for the graphs in Figure 4a. These graphs, shown only for transfers of senior rights in the most expensive water division (Division 1), depict uncertainty in the probabilities of legal outcomes as a function of the volume of water transferred. In each graph, the middle (solid) line uses the FMNL regression in Table 1 to show how expected outcome probabilities vary with volume transferred. The dotted lines are 95% confidence intervals from the low- and high-conflict FMNL regressions computed via the Monte Carlo simulation described in section 4.3. The vertical distance between the dotted lines indicates uncertainty about the amount of conflict the transfer will encounter and statistical uncertainty in the FMNL regressions. The uncertainty is generally larger for higher-probability outcomes and smaller for lower-probability outcomes.

Given the legal outcome, the first five plots of Figure 4b depict uncertainty in the projection of legal plus hydrologist fees. The uncertainty band depicted is the 95% confidence interval associated with the cost functions in Table 2 using interval regression. The range of cost uncertainty increases for more expensive transfers—those with higher-conflict court outcomes, senior rights, larger transfer volumes, and in more expensive water divisions. However, as a percentage of expected total transaction cost with a known legal outcome, the range of cost uncertainty does not vary greatly. For the transfers in Figure 4b, this percentage ranges from 52.0% for a 210 AFY transfer resolved with a water court trial to 82.2% for a 1 AFY transfer settled on the judge's docket before trial.

The sixth plot of Figure 4b graphs ex ante uncertainty in transaction costs, combining (i) ex ante uncertainty in the legal outcome from Figure 4a with (ii) uncertainty in the interval regression cost estimations from the first five plots in Figure 4b. We combine (i) and (ii) using the Monte Carlo simulation. In the simulation, we treat the error terms from the two statistical models as independent, which is what the data suggest (Tables S10–S12). The resulting uncertainty range in the sixth plot of Figure 4b exceeds the uncertainty range for the two lower-conflict legal outcomes but does not exceed the uncertainty range for the three higher-conflict legal outcomes. This uncertainty range for expected values reflects lower cost uncertainty for some legal outcomes that have higher probabilities, as well as overlap between cost uncertainty ranges for different legal outcomes (the right tail of the cost distribution for a lower-conflict legal outcome can exceed the left tail of the cost distribution for a higher-conflict outcome).

6.3. Comparing Transaction Costs With Water Market Prices

To put the transaction cost projections in perspective and enable comparisons with prior research, we compared some of our transaction cost estimates with actual market prices for some transfers. For the actual market prices, we rely on prices from 2008 to 2018 in the WestWater dataset for transactions that involve types of water rights whose transfer could require water court approval. These data contain 523 transactions whose transfer could require water court approval, most (385) in Division 1, followed by Divisions 2 (87), 5 (28), 3 (12), and 4 (11). The volume transferred ranged from 0.4 AFY of consumptive use to 51,615 AFY; the median volume was 43 AFY. The lowest unit price was $198/AFY for a transfer of 4,282 AFY in Division 1 in 2009, and the highest unit price was $67,015/AFY for a transfer of 182 AFY in Division 1 in 2010; the median unit price was $8,470/AFY. Most of the transactions report a previous use in agriculture (373), and the new use for most (376) is municipal.

Of the 523 transactions, 452 involved shares in mutual ditch companies. Ditch company shares entitle a buyer to proportional ownership of the company's entire portfolio of water rights (Payne et al., 2014). Fifty transactions were for shares in one desirable ditch company, the Farmer's Reservoir and Irrigation Company, located in Division 1 upstream of Denver and surrounding cities. The mean unit price for shares in this ditch company was $40,216/AFY. Other types of water rights traded are summarized in the supporting information.

We compared our expected transaction cost estimates with actual market prices in two ways: (i) as a proportion of the market price and (ii) as a percentage of market price plus transaction costs. According to

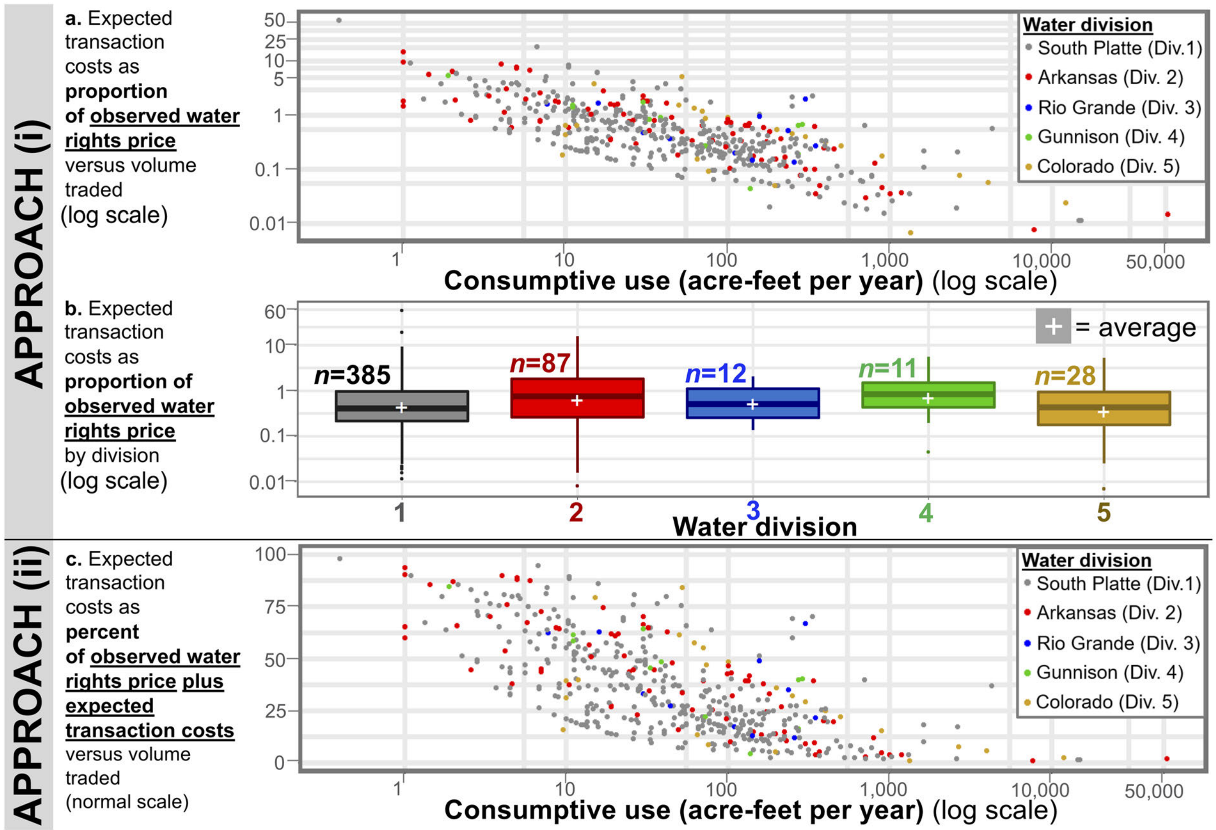

Figure 5. (a) Expected water court transaction costs (total legal plus hydrologist fees, assuming senior rights) as a proportion of observed water rights price versus volume traded for each water rights transaction that could require water court approval in the WestWater Research dataset for Colorado. (b) Expected water court transaction costs as a proportion of observed water rights price by water division for the transactions in (a). (c) Expected transaction costs as a percentage of observed water rights price plus expected transaction costs for the transactions in (a). The values shown in Figure 5 do not depict statistical uncertainty (e.g., confidence intervals). Figure S11 plots identical information but with expected transaction costs for junior rights.

WestWater, "market prices for water rights (that we track) do not include transaction costs and those costs are typically faced by the buyer after the transaction has closed" (Author email with Brett Bovee, Intermountain Regional Director, WestWater Research, LLC, 15 August 2019). Two water lawyers and a hydrologic expert whom we consulted also confirmed that transaction costs to change a water right are usually not included in the sales price. Accordingly, these transaction costs may exceed the value of water, so the proportion in (i) can exceed one. In instances where expected transaction costs exceed the market value of water, transactions may fail to consummate, though Nichols and Kenney (2003) also observed that, in Colorado, even "a routine unopposed change of water right" can incur water court "engineering and legal costs exceeding the value of the water involved by more than an order of magnitude."

The results using approach (i) are shown in Figures 5a and 5b for the transactions in the WestWater data, assuming senior rights. Across all 523 transactions, projected legal and hydrologist fees as a proportion of the water cost have a median of 0.473 and an average of 1.12. The lowest proportion is 0.00701 for a 1,337 AFY transfer in Division 5, and the highest is 57.3 for a 0.4 AFY transfer in Division 1. The proportion declines with volume transferred, reflecting economies of scale in the transaction costs. In around 5% of the transactions, legal and hydrologist fees amount to more than 4 times the water price, but the largest of these transfers has a volume of 52.5 AFY, while the median is 1 AFY. This result suggests that high ex ante expected unit transaction costs have probably discouraged more smaller-volume transfers from consummation. In larger-volume transfers, legal and hydrologist fees as a proportion of water prices are much smaller. In about 75% of the transactions, the water price exceeds legal and hydrologist fees, and in about 50% of the transactions, these fees are less than half of the water price. When the proportions are compared across

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Table 3
OLS Regression Results for Water Rights Prices

Determinant	**Natural log of unit water rights prices** (2017 $/AFY consumptive use)[a]
Volume traded: ln(consumptive use)	−0.0833 (0.0186)***
Buyer's location: Downstream Division 1 - South Platte (water districts 1, 49, 64, 65)[b]	−0.347 (0.113)**
Buyer's location: Upstream Division 2-Arkansas (water districts 10–16, 79)[b]	0.0259 (0.101)
Buyer's location: Downstream Division 2-Arkansas (water districts 17-19, 66, 67)[b]	−0.866 (0.124)***
Buyer's location: Division 3-Rio Grande[b]	−0.952 (0.199)***
Buyer's location: Division 4-Gunnison (no values from Yampa/White or San Juan/Dolores Basins)[b]	−1.12 (0.216)***
Buyer's location: Division 5-Colorado[b]	−0.184 (0.175)
Type of buyer: Municipal or Industrial buyer	0.321 (0.0756)***
Type of water right: Farmers Reservoir and Irrigation Co. shares (Div. 1 only)[c]	2.37 (0.206)***
Type of water right: Other mutual ditch company shares	1.13 (0.176)***
Type of water right: Certain Denver Basin groundwater (legally "not non-tributary groundwater"; Divisions 1 and 2 only)[c]	−0.709 (0.293)*
Type of water right: Other surface water rights; groundwater rights; and groundwater offset credits (legally "augmentation credits")	0.857 (0.194)***
Colorado Housing Price Index: lagged 21 months	0.00426 (0.00106)***
Constant	6.56 (0.433)***
Observations	523
R^2	0.589

Note. Excluded categories are Location: Upstream Division 1-South Platte (water districts 2–9, 23, 48, 76, and 80) and Type of Water Right: Other surface water storage and unspecified rights. Robust standard errors provided in parentheses.
***Significant at 0.1% **Significant at 1% *Significant at 5% •Significant at 10% [a]The supporting information describes statistical tests used to examine this model's determinants and functional form and tests for heteroskedasticity, endogeneity, and collinearity. [b]We use the buyer's location except where it was not reported; for those transactions, we use the seller's location.
[c]The OLS water rights pricing model includes several types of water rights, two of which do not exist in all water divisions: certain Denver Basin groundwater rights legally termed "not non-tributary groundwater" are found only in the South Platte and Arkansas River divisions, while sales of shares in a desirable mutual ditch company, the Farmers Reservoir and Irrigation Company, only exist in the South Platte River Division (Payne et al., 2014; Trout et al., 2011).

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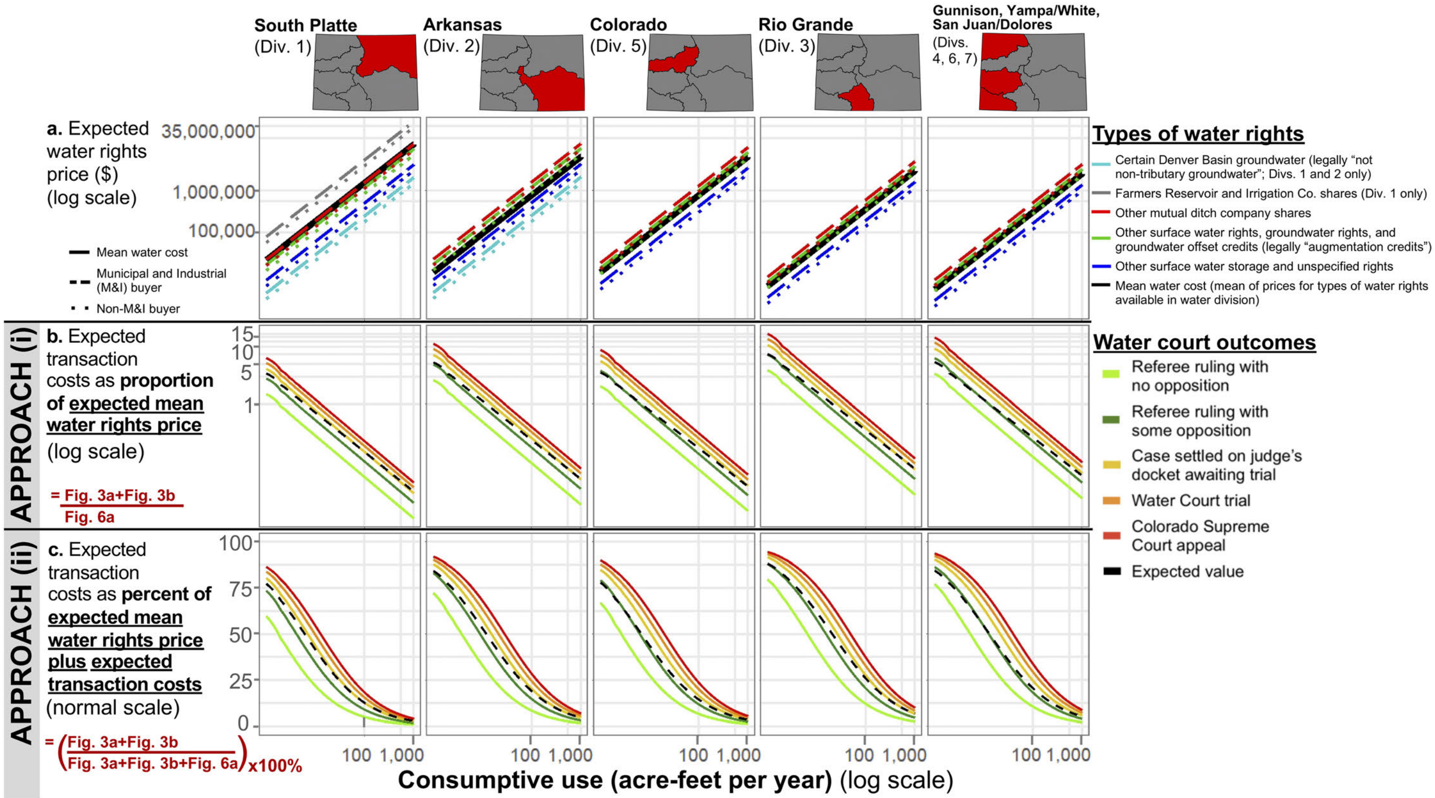

Figure 6. (a) Expected market prices for water rights projected using OLS regression in Table 3 based on WestWater data; prices for Divisions 1 and 2 in (a) are projected for the "Upper Division 1" and "Upper Division 2" regions identified in Table 3. Expected market prices are for 2017, so we use the Housing Price Index lagged from 21 months before 2017 (from 1 April 2015) as input for these projections. (b) Expected water court transaction costs, assuming senior rights, as a proportion of total expected mean water price in (a). (c) Expected water court transaction costs, assuming senior rights, as a percentage of total expected mean water price from (a) plus expected transaction costs. The values shown in Figure 6 do not depict statistical uncertainty (e.g., confidence intervals). Figure S12 plots identical information but with expected transaction costs for junior rights.

divisions in Figure 5b, Division 1, which has the most transactions, also exhibits the greatest range between its highest and lowest proportions, followed by Divisions 2, 5, 4, and 3. However, the interquartile ranges in this proportion across the divisions are similar, as are the median and average values.

The results using approach (ii) for the same transactions are shown in Figure 5c. The average transaction cost across all 523 transactions is 35.7% of the combined market price plus transaction cost—substantially greater than the average of 12% reported for Colorado by Colby (1990). The lowest percentage is 0.700%, while the highest is 98.3%.

In addition to using WestWater's data on actual prices of transfers that were consummated, we also compared the expected value of transaction costs over a continuum of volumes to expected prices using a regression model to project the expected value of the water rights price. This regression model—shown in Table 3—is similar to water market price equations in the existing literature (Bjornlund & McKay, 1998; Brown, 2006; Colby et al., 1993; Donoso et al., 2014; Hadjigeorgalis & Riquelme, 2002; Landry, 1995; Payne & Smith, 2012). Like the transaction costs regressions in Table 2, the water price regression exhibits economies of scale. Also, water rights prices differ across regions and across types of water rights and increase with the Colorado Housing Price Index.

We used the model in Table 3 to calculate a mean water rights price for each water division by averaging prices across the types of water rights traded in the division (Figure 6a). We then compared these mean water prices for each water division to legal and hydrologist fees projected using the models in Tables 1 and 2 and assuming a senior water right. The resulting fee proportions are plotted in Figure 6b. Scale economies in transaction costs outpace scale economies in water rights prices, so that the proportion of transaction costs to water prices declines when larger volumes are transferred, similar to Figure 5a. In the South Platte River

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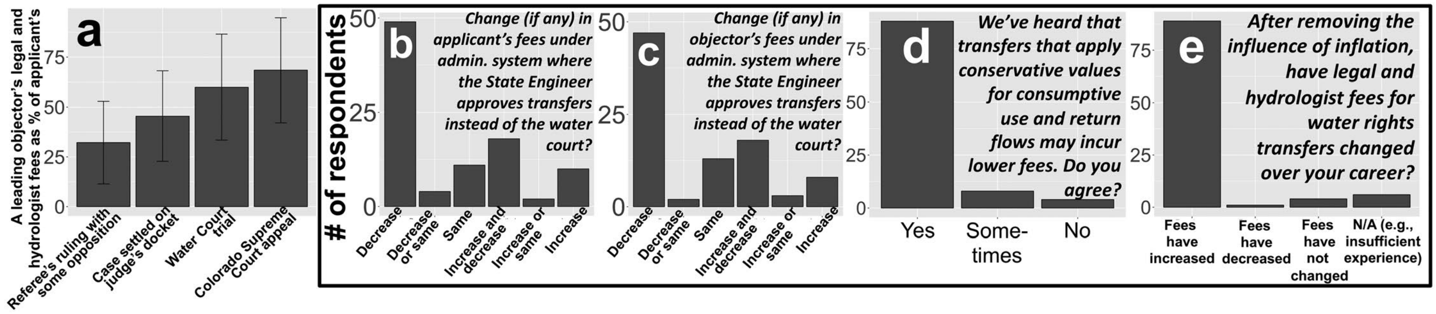

Figure 7. (a) Estimated legal and hydrologist fees for a leading objector to a water rights transfer as a percentage of fees for an applicant for different water court outcomes. (b) Survey responses regarding perceived impact on an applicant's transaction costs of an administrative, rather than a judicial, system for water rights transfers. (c) Survey responses regarding perceived impact on an objector's transaction costs of an administrative system for water rights transfers. (d) Survey responses regarding applicant strategy of reducing volume of water (consumptive use) sought in water rights transfer to lower transaction costs. (e) Survey responses regarding changes in transaction costs over time for transfers in Colorado's water courts.

division, expected legal plus hydrologist fees are 3.41 times the expected water price for transfers of 1 AFY but just 0.0291 times the expected water price for transfers of 1,000 AFY. A similar pattern exists in other divisions. The proportion is highest for a 1 AFY transfer in the Rio Grande Division (7.50), while it is 0.00183 for a 40,000 AFY transfer in the Arkansas River Division.

6.4. Transaction Costs for Objectors

Third-party objectors to water rights transfers also incur substantial transaction costs in water court to protect their water rights. Transfers commonly have more than one objector. While not the main focus of our survey, for the four legal outcomes that involve opposition, we asked survey participants to estimate objectors' fees as a percentage of an applicant's fees (Figure 7a). Respondents indicated that objectors generally incur lower transaction costs than an applicant for lower-conflict legal outcomes and incur transaction costs more comparable to an applicant's for higher-conflict outcomes.

7. Discussion of Qualitative Factors

In addition to quantitative data, our survey elicited qualitative opinions from respondents regarding (i) the relative merits of Colorado's specialized water courts and (ii) the trend in transaction costs in Colorado over time.

7.1. Specialized Water Courts

For over a century, water experts have debated whether courts or administrative agencies should adjudicate water rights matters, such as issuing water rights and processing water rights transfers. Colorado gave this authority to judicial courts in its 1879 Adjudication Act, which charged courts with decreeing water rights while administrative agency officials enforced those rights. At the time, Colorado's Legislature rejected draft legislation that gave agencies authority to adjudicate water rights because lawyers thought that the determination of property rights was inappropriate for executive branch officials, infringing upon separation of powers principles in the U.S. Constitution (Dunbar, 1983). Initially in Colorado, general state courts heard water disputes; in 1969, Colorado established specialized water courts (Hobbs, 1999). In 1889, by contrast, Wyoming pioneered an alternative system under which an agency determined water rights, a system that spread to the other western states (Dunbar, 1983).

Most survey participants thought that, on balance, transaction costs for water transfers in Colorado exceed those in other states because of the water court system (Figures 7b and 7c). This raises the question: does Colorado's judicial approach offer any benefits compared to administrative agencies? Survey respondents offered a variety of opinions, which are summarized in Table 4.

The most commonly identified benefit of Colorado's judicial approach was that, unlike an administrative agency accountable to a governor, water judges are insulated from political influence and provide more impartial and objective decision-making. “There tends to be a perception of the administrative agency being both the administer of water rights and also the judge and jury, so to speak, of cases, having worked in both

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Table 4
Identified Benefits of Colorado's Judicial System for Water Rights Transfers Compared to Administrative Agencies

Key phrase/concept[a]	Count (n=92)[b]
Objective, impartial decision-making	36
Increased opportunity for potentially affected third-party water rights holders to participate and protect their rights	36
More formalized procedures	17
Encourages cooperative, mutually satisfactory resolution of disputes	11
Strong embodiment of water as a property right	11
Promotes a more fluid market for water	8
Specialized courts provide substantive expertise	7
Allows adaptation through the evolution of law	6
In certain cases, courts are more efficient than an administrative system	4
Offers fairer outcomes because state agencies lack the time or resources to fully evaluate every case	2
Promotes statewide consistency of water law through direct appeals of water court decisions to the Colorado Supreme Court	1

[a]We asked survey participants to answer based on experience working in other states with administrative systems if they had any, or if they did not, to draw upon any experience they had working on temporary leases before the Colorado State Engineer's Office or groundwater transfers approved by the Colorado Ground Water Commission in designated basins in eastern Colorado. Water courts hear appeals from these two agencies (Trout et al., 2011). [b]The total number of interview transcripts was 92 (not 100) because this question was not asked in all pretest interviews and due to a voice recorder error.

New Mexico and Wyoming where they have administrative processes" (Author interview with hydrologist, 12 July 2017). Also, the court system offers a level playing field in which all interested parties have access, if they can afford requisite transaction costs, and stand as equals before the court. Several respondents noted that because courts apply strict formal rules of civil procedure and evidence while agencies do not, and because agencies may not develop legal precedent over time as courts do, the Colorado court system creates less potential for arbitrary or inconsistent decision-making. Moreover, respondents thought that Colorado's court system is protective of existing property rights in water because it provides more formalized procedures than an administrative agency.

Our econometric analysis identified a settlement among the parties, whether before the water referee or the judge, as the most likely legal outcome. In their comments, respondents noted that key parameters of water transfers—for example, the historical consumptive use that could be transferred or the return flow obligations required by court decrees to avoid injury—are frequently negotiated in settlement agreements among parties with diverging legal or hydrologic analyses rather than being set by the court. Given the tendency for negotiated settlements, nearly all respondents observed that applicants can reduce their transaction costs by accepting a conservative estimate for the consumptive use to be transferred instead of arguing for every last drop (Figure 7d). The decision to settle water rights litigation is frequently an economic trade-off: "a lot of more rational clients … will do a cost-benefit analysis and say … we'll take the haircut on the [consumptive use], because we're going to … save hundreds of thousands of dollars in legal and engineering fees by giving up a little bit of water" (Author interview with attorney, 26 June 2017). These settlements reduce static transaction costs by accepting less water for the transferred rights. However, to the extent that they forego possible opportunities to set legal precedent that clarifies standards for future transfers, they may increase dynamic transactions costs, generating more uncertainty for future transfers and shifting costs of setting precedent to future litigation.

Finally, it was noted that an administrative system can sometimes be more expensive than Colorado's court system in the case of especially contentious or complex transfers. "In the more difficult cases, in other states, you tend to have a two-part process. You go through the administrative process, and then there's an appeal. And then you're in court for years, and then you're back in the administrative process. … [T]he initial advantage of Colorado's judicial system is that, particularly for the more difficult cases, it's one-stop shopping" (Author interview with hydrologist, 10 August 2017).

Table 5
Reasons Identified for Increase Over Time in Water Court Transaction Costs to Complete Water Rights Transfers

Key phrase/concept	Count (n=92)[a]
Increasing competition for scarce water resources	27
Objectors demand more engineering, challenge it more frequently, and raise new issues	22
Modern transfers apply more sophisticated engineering methods (e.g., applicants must commonly develop hydrologic models; more and better data exist now)	20
Increased involvement in and opposition to transfers by the Colorado Attorney General's Office, representing the Colorado State and Division Engineers	15
Greater number of technical issues to address (e.g., consumptive irrigation requirement; maintain pre-transfer return flows, including timing, to avoid injury; surface water-groundwater interactions; longer representative study periods to calculate historical use; difficult to prevent injury to instream flow water rights, which are more common; downstream-to-upstream transfers increasingly consider complex water rights exchanges to avoid injury)	12
Cumulative experience has accumulated issues and complexity that are now expected in most modern transfers	11
Modern transfers include more participants (i.e., objectors)	9
Legal developments have opened new lines of opposition to transfers (e.g., implied limitations on size of water right) or added requirements (e.g., mutual ditch company boards must approve out-of-ditch transfers)	8
Stricter, more elaborate terms and conditions are now required	7
Modern transfers involve disputes over very small amounts of water, often well beyond the precision of applicable hydrologic analyses	7
Greater use of complex legal instruments like augmentation plans that offset surface water impacts of groundwater pumping and exchanges, which require more complicated engineering	3
More rigorous enforcement of limits on water rights	2
More formal legal procedure (e.g., disclosure requirements for expert reports)	1
Increased political sensitivity to permanent transfers that dry agricultural land	1

[a]The total number of interview transcripts was 92 (not 100) because this question was not asked in all pretest interviews and due to a voice recorder error.

7.2. Transaction Costs Over Time

Nearly all respondents felt that legal and hydrologist fees for water transfers have been increasing faster than the rate of inflation (Figure 7e). They generally attributed this to the increasingly complex legal and hydrologic standards applied in modern water transfers and increased scrutiny of transfer applications by objectors. Several specific factors were identified (Table 5).

Respondents most commonly cited growing competition for Colorado's water resources, which prompts more aggressive legal efforts. As one hydrologist remarked: “The resource is more scarce. … The parties on a river fight over every drop because it's important” (Author interview with hydrologist, 27 April 2017). An attorney remarked: “As the law gets more stringent, you could probably find water attorneys who've been doing this as long as I have who say, “Wow, if we took those old decrees and tried to apply modern standards to them, they'd never hold up.” It might have an old decree that was a page or two pages that would say, “You can use X amount of water for this purpose on 50 acres of irrigation.” And it didn't have all these limitations that now you wind up with these 50-page decrees that have all kinds of requirements” (Author interview with attorney, 26 July 2017). Indeed, increased involvement of objectors raises transaction costs in part because objectors often demand hydrologic analysis of issues that were not addressed in comparable prior cases.

While one might expect that scientific and computational advances in hydrologic modeling and data would lower transaction costs of water transfers, respondents reported the opposite: those advances have raised litigation costs by adding issues and increasing complexity. Newer tools allow better detection of injury, but sometimes they are “just looking … in really fine detail at something that just isn't that precise” (Author interview with hydrologist, 27 June 2017). Another hydrologist relayed that “computer models [are] being used to calculate things down to … many decimal places, based on data that … you have no idea what the accuracy is. It might be, you're basing it on data that might have a range of accuracy from 10 to 20 percent, yet you're calculating it to five decimal places … I think technology is being stretched in court” (Author interview with hydrologist, 14 June 2017).

Another source of the increase in transaction costs is increased complexity of managing water in the more complicated systems like Divisions 1 and 2, where legal instruments such as augmentation plans and upstream exchanges are more common (Figure 2e).

In addition, respondents noted that increased participation by Colorado administrative agencies, particularly the State Engineer's Office, had raised transaction costs. Respondents noted that this Office, which can object even when the state does not own potentially injured water rights, had recently objected more frequently to transfers due to policy concerns rather than concerns about water rights administration. Finally, some of the new issues raised in eastern Colorado have diffused to areas with less competition for water, like western Colorado.

8. Conclusions

We studied water market transaction costs in Colorado. Among western U.S. states, Colorado probably has the most clearly defined property rights to water and contains some of the region's most active water markets, with the highest share of permanent transfers. Colorado is also the only state where specialized water courts perform initial review of water transfers and third-party objections to transfers. We studied a key component of static transaction costs for water transfers in Colorado and in other western U.S. states: legal and hydrologist fees. Colby et al. (1989) reported that, in some Colorado transfers, these costs are essentially applicants' entire transaction costs.

Our study reveals systematic heterogeneity in transaction costs for water transfers depending on four features: the river basin (water division) where the transfer occurs, seniority of right(s) transferred, volume of water transferred, and legal outcome in litigation with opponents of the transfer. Two water divisions in eastern Colorado, the South Platte and Arkansas River Basins, have the highest transaction costs, with the South Platte Basin highest and the Arkansas second, followed by the Colorado River Basin in western Colorado. No water divisions had a significant impact on completion time for transfers, though we did find significantly greater probabilities of higher-conflict legal outcomes in the eastern Colorado divisions. Higher-conflict legal outcomes, in turn, raise legal and hydrologist fees and completion times. The ordering of divisions with the highest transaction costs—the South Platte River Basin first, followed by the Arkansas and Colorado River Basins—matches the order of divisions from most to least expensive market prices for water rights. The South Platte and Arkansas Basins also have the most water scarcity and water transfer activity, many third-party water users, and substantial complexity of water rights administration and operations. In particular, the South Platte River Basin has the highest transaction costs alongside by far the greatest water scarcity, water transfer activity, water market prices, third-party water users, and operational complexity of any division. While the Colorado River Basin has more abundant water supplies, operational and administrative complexity also exist there, in part because major transmountain diversions export water from that basin to eastern Colorado, leading eastern Colorado water users to regularly participate in Colorado River Division water court cases.

Senior water rights transfers exhibited higher transaction costs, though senior rights did not influence completion times. Because senior rights are more valuable (Payne et al., 2014), applicants would rationally spend more on transaction costs to complete a transfer and opposing parties would rationally spend more to protect their water rights from injury.

We also found substantial economies of scale in legal and hydrologist fees. Scale economies underscore why some survey respondents conveyed that a common strategy for applicants is to acquire multiple water rights and transfer them in a single water court case. Scale economies also probably explain why the past water market transactions we evaluated contain relatively few small-volume transfers, because the scale economies may disproportionately discourage small but nonetheless welfare-enhancing transfers and limit water markets' ability to adapt water use at the margin. To the extent water markets are promoted for other objectives that rely on smaller-volume transfers, like environmental water purchases, scale economies may discourage such activity. Scale economies in transaction costs may also exclude some smaller water users from markets. Accordingly, legal changes designed to lower transaction costs may be more effective by targeting lower-volume transfers.

An important difference exists among the water transfer features we considered. The applicant chooses the water division, seniority, and volume transferred. Our results also show that a transfer's legal outcome has a substantial and significant impact on legal and hydrologist fees and completion times, but the legal outcome depends on factors outside of the applicant's control. How many parties will object to the transfer? Will

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objectors agree to settle, or will they go to trial or appeal? Will unexpected disputes over the historical use of the water right or other implied limitations on the water right emerge after the transfer application is filed? These are initially unknown.

Our emphasis on cost uncertainty represents an important innovation in the transaction cost literature. We account for it through our analytical framework in equation (1), which, unlike previous literature, involves a hedonic transaction cost function estimated conditionally on the degree of legal conflict. From a policy perspective, transaction cost uncertainty highlights an understudied opportunity, namely, private financial schemes (e.g., insurance) to mitigate transaction cost uncertainty. These could lower transaction cost uncertainty while avoiding a politically contentious process of legislating new market-oriented laws that could be construed as eroding property rights.

Our quantitative results reveal that static transaction costs account for a much wider range of costs than in prior studies which relied on smaller datasets. The widest range in a prior study identified static transaction costs as 12–70% of total costs (Garrick & Aylward, 2012). Our analysis shows a range of 0.700–98.3%, where we calculated expected transaction costs for an applicant for past transactions as a percentage of those costs plus observed water acquisition prices. Because empirical studies of transaction costs have been constrained by limited data availability, this range demonstrates one advantage of our stated preference approach.

To what extent do our findings hold outside of Colorado? In the western United States, legal, economic, hydrologic, and infrastructure discrepancies between water markets abound, meaning that a statistical model of transaction costs like ours should not be lifted from any state or region and applied in another. Also, Colorado's specialized water court system is unique, and some of the transaction costs we assessed reflect particular frictions in Colorado's system. Therefore, the specific magnitude of transaction costs in other states probably differs from Colorado.

However, the determinants of transaction costs in Colorado probably apply elsewhere because many phenomena that generate transaction costs in Colorado also exist in other western U.S. states. All prior appropriation states apply some version of the no-injury rule, and like eastern Colorado, prior appropriation elsewhere exists against a backdrop of growing water scarcity and allocation of available water supplies: by 2030, new consumptive uses of water are projected to exceed legally available surface and groundwater supplies in 61% of watersheds in the 17 western U.S. states (Tidwell et al., 2014). Water rights administration to curtail junior and fulfill senior rights in times of scarcity occurs across the western states and has caused water conflict in other regions (e.g., Idaho's Snake River Basin), though whether and how water rights are administered can vary substantially within states depending on local conditions (Balleau & Silver, 2005; Elbakidze et al., 2012; Ghosh et al., 2014; Griggs, 2014; Kenney et al., 2008; Willardson, 2014). More complex water rights operations, like exchanges and plans to offset surface water impacts of groundwater pumping, also exist in many other states (MacDonnell, 1990; Nelson, 2015). Therefore, it is plausible that, like Colorado, other states in the western United States experience geographically variable transaction costs, with increased transaction costs in water-scarce systems with more third parties, greater conflict, and complexity. This suggestion is supported by Garrick (2015) and Garrick and Aylward's (2012) finding that water market transaction costs varied within and across states in the Columbia River Basin.

Transaction costs in other states also face legal uncertainty and probably exhibit scale economies. Other prior appropriation states require similar legal and hydrologic investigations to Colorado's to restrict the scope of transferred water rights (e.g., to historical use) and avoid injury. These requirements apply to all volumes of transfers. As suggested by Colby (1990), Brown et al. (1992), and MacDonnell et al. (1990), this likely yields scale economies in other states. Also, though other western U.S. states begin transfers before an agency instead of in water court, third parties can still legally object to transfers. The agency's decision regarding the transfer may then be appealed to court. Therefore, in other states, the degree of legal conflict also remains uncertain ex ante, varies from low (resolved with no hearing before the agency) to high (appealed to state Supreme Court), and may present transfer applicants with financial incentives to resolve transfers by legal settlement. While our statistical model should not be directly applied outside of Colorado, our two-stage modeling approach, first modeling the degree of legal conflict and then transaction costs conditional on legal conflict, could be used in future research to measure and model transaction costs and their uncertainty in other regions.

Colorado's experience with water courts also holds regional implications because water courts like Colorado's have been proposed for other states and court litigation over water rights is increasing across the western United States. We found that Colorado's water court system for dealing with these conflicts has some advantages, though most respondents also reported the perception that water courts increased transaction costs relative to agencies. Colorado's water courts provide a more level playing field for those who believe they face third-party impacts. The parties receive equal treatment before a neutral factfinder. This may engender procedural justice, something that parties to a dispute may value as much as the outcome itself (Lind & Tyler, 1988; Womble, 2017). This is not to say, however, that there is no room for improvement in Colorado's present system. In our survey of Colorado water practitioners, we also investigated some potential changes in Colorado's legal rules and procedures that might lower transaction costs and facilitate more water transfers; that is the subject of a separate investigation (Womble & Hanemann, 2020).

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