Estimating the Gains from Water Trade: An Evaluation of Modeling Considerations*

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Abstract

The gains from water trade vary depending on local conditions and the specifics of market design. Models of water trading necessarily rely on assumptions that simplify the social, institutional, and environmental landscape within which a water market operates. A clear understanding of these assumptions is important for understanding the literature as a whole and its practical and policy relevance. We systematically evaluate peer-reviewed papers that estimate the gains from water trading to assess how models of water markets take local context into account. Our results demonstrate that whether and how models incorporate key considerations varies widely. We find that estimates of the economic impacts of water trading in the published literature are more likely to consider distributional effects and incorporate features of the legal and regulatory environment than to account for third-party impacts, transaction costs, the consequences of trading for the economy at large, or the administrative costs associated with setting up and operating a market. Researchers modeling the gains from trade could better support local decision makers by more explicitly articulating their models' capabilities and limitations.
JEL: Q25, Q28, Q52, Q15

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1 Introduction

Water managers and policymakers are increasingly interested in the potential for water markets to achieve water management goals in the face of increasing scarcity (King, 2004; Skurray and Pannell, 2012; Aladjem and Sunding, 2015; Wheeler et al., 2017; Green Nylen et al., 2017; Schwabe et al., 2020; Richter et al., 2020; Bruce et al., 2024; Bruno and Jessoe, 2024). A growing body of work from the engineering and economics literature has sought to quantify the economic impacts of actual or potential water trading, often described in terms of the "gains from trade." These estimates are important because they may influence decision makers who are contemplating whether and how to develop water markets. However, models of water trading necessarily rely on assumptions that abstract away from the local context that may be critical for understanding the impacts water markets will have in practice.

Understanding how the assumptions embedded in a modeling effort may affect a paper's results and interpretation have both scholarly and practical implications. For researchers seeking to better understand aspects of water markets, the structure and completeness of a model's considerations can affect its ability to accurately represent the benefits and costs of market implementation. For decision makers seeking to evaluate paths towards effective water management, it can be difficult to interpret or translate model results that do not address conditions relevant to their concerns. A study's management implications will depend on aspects of the research design, such as the research questions it addresses and the methods and abstractions it uses, as well as the similarities and differences between the studied area and the area of interest.

In this paper, we examine how and to what extent the literature on the gains from water trading incorporates key management and policy considerations that may affect both the accuracy of estimated gains and the utility of the literature to local decision makers. First, we synthesize the research methods used in this literature. In particular, we examine the goals of different research approaches and families of models, focusing on the trade-offs embedded in them and how these can affect the policy implications of a given paper's results. We articulate the strengths, weaknesses, and ideal applications of each major type of methodology, contributing a more holistic understanding of the methodological approaches in the literature. Second, we systematically assess whether and how academic papers that provide numeric estimates of the welfare impacts of water trading account for social, institutional, and environmental considerations that may affect the real-world gains from trade.[1]

To do so, we develop and apply a rubric to assess whether and how the modeling methodology for each study incorporates aspects of eight components: (1) transaction costs borne by market participants, (2) the distributional effects of trading across multiple participant categories, (3) third-party and environmental impacts, (4) dynamic efficiency, (5) spillover effects to other sectors of the economy, (6) the existing legal and regulatory context within which the market would operate, (7) potential institutional design scenarios that would require changes to the

[1]While water markets can reflect both formally documented trades and informal transfers or sharing arrangements, the papers we review focus primarily on formal trade, in large part due to the paucity of data on informal transfers (Young and Brozovic, 2019).

existing legal and regulatory context, and (8) administrative costs associated with market setup and operation. If the modeling methodology did not incorporate any aspect of a particular component, we evaluated whether and in what depth the paper mentioned or discussed it.

We found that the papers we analyzed varied in whether and how they addressed different aspects of the social, institutional, and environmental context for water trading. Some of this variation stems from basic differences between modeling approaches. For example, hydroeconomic models, which combine hydrophysical models of water resources with farm-profit or utility-optimization frameworks, can simulate and evaluate the gains from trade under finely parameterized scenarios, but often assume idealized (e.g., frictionless) mechanisms for transferring water among users and stylized representations of water supply and demand (Harou et al., 2009). In contrast, reduced-form empirical models rely on historical data for retrospective statistical analyses of water trading (e.g., Hagerty (2025)). These data implicitly embed market context and frictions, making estimates of the gains from trade more accurate for the studied example, but at the cost of the model's potential generalizability to other situations. These differences underscore the need to consider the literature as a whole when applying insights from these studies to a particular policy context or proposed intervention.

In three fundamental ways, our paper advances the body of knowledge that, collectively, describes and evaluates water markets, compares water to other environmental markets, and overviews hydroeconomic approaches.[2] First, we disentangle the tradeoffs that underpin different methodological approaches by examining the methods and assumptions underlying peer-reviewed articles that derive quantitative estimates of the gains from trade. Second, because a large proportion of these estimates are published in engineering or water science journals, we do not restrict our examination to the economics literature. Finally, we develop an original framework for evaluating whether and how different models of water markets account for relevant social, institutional, and environmental considerations in their estimates of the gains from trade. We offer this rubric as a tool for water market modelers to improve the practical relevance of their analyses, and for decision makers to better understand how such analyses can inform their work. Consequently, our results contribute a better understanding of the assumptions and abstractions embedded in models of water markets and their estimates of economic impacts.

The remainder of this paper is organized as follows. Section 2 provides background that informed rubric development. It outlines fundamental concepts related to the use of water markets as a policy instrument and how the implementation of markets in practice may deviate from basic theories. In Section 3, we classify different approaches researchers use to model water markets, highlight key distinctions between and within these model families, and articulate the strengths, weaknesses, and ideal applications of each. Section 4 describes how we identified the papers we included in our dataset and how we developed and applied our rubric. In Section 5, we summarize and discuss the results of our analysis. Section 6 concludes.

[2]Previous reviews of the water market literature include descriptive analyses by Rosegrant and Binswanger (1994), Chong and Sunding (2006), Wheeler (2022), Garrick et al. (2023), Wheeler et al. (2025), among others; comparisons with other types of environmental markets by Leonard et al. (2019) and Bruno and Jessoe (2024); overviews of hydroeconomic modeling approaches by Harou et al. (2009) and Ward (2024); and a systematic evaluation of water markets in practice by Grafton et al. (2011).

2 Water markets as a policy instrument

Water markets involve water trading—the voluntary, compensated transfer of water, water rights, or other water extraction/use entitlements—as well as the rules and institutions that govern trading.[3]

According to economic theory, a market can generate economic gains by facilitating higher-value use of limited resources, and the conclusion of many of the papers included in our study is that real-world markets generate positive economic gains. By enabling the voluntary reallocation of water, markets can reduce the cost to water users of capping use of the resource, which is why economic theory describes markets as representing a "least-cost" mechanism for achieving a given limit on total water use (Baumol and Oates, 1988; Goulder and Parry, 2008).[4] While this theory implies that water markets may be able to create larger economic surplus from scarce water than other water management policies, water trades may individually and cumulatively impact other water users, the environment, or regional economies in unintended ways (Chong and Sunding, 2006; Skurray and Pannell, 2012; Green Nylen et al., 2017; Bruno and Jessoe, 2024).

A first set of potential impacts relates to the physical consequences of trade: specifically, how trading changes the spatial and temporal distribution of water extraction and use. For example, trading a groundwater extraction allocation between two users could change local groundwater levels and flow gradients, affecting water access, pumping costs, or water quality for other groundwater users who were not involved in the trade (Skurray and Pannell, 2012; Brozović et al., 2010). Similarly, changes in where surface water is diverted and used could have consequences for river flow and the ecological services provided by a river system (Kuwayama and Brozović, 2013). These impacts can threaten the economic efficiency of market exchange if affected parties are not able to contract over the outcome at low cost (Coase, 1960; Dahlman, 1979).

Some existing water markets attempt to address third-party impacts and other challenges with rules that restrict when, where, or how water can be traded. For example, the groundwater market in the Mojave basin in Southern California imposes constraints on trade of water between different sub-basins (Ayres et al., 2022). Such trading rules—which form part of the institutional context for water trading—may reduce the number of market transactions, but they generally do so with a specific aim, such as protecting or compensating parties not involved in a transaction (Colby, 1990; Garrick and Aylward, 2012).

Another set of impacts relates to general equilibrium economic outcomes. Water trading can affect other sectors of the economy as a consequence of shifts in water use by different water users and sectors (Akhundjanov et al., 2023). For example, if water were priced under a market

[3]Without well-defined, limited individual entitlements, there would be little to no incentive for trade. Other institutional conditions that enable markets to function include measurement and accounting of water extraction and use, clear trading rules, and adequate enforcement (Green Nylen et al., 2017; Wheeler et al., 2017; Ayres et al., 2021a).

[4]A common way to manage water scarcity is to limit the total amount of water that can be extracted from a resource per unit of time (Colloff and Pittock, 2022; Miro and Famiglietti, 2019). We refer to this limit, whether declared by policy, defined by the natural capacity of the resource, or implied by the sum of individual allocations, as the aggregate *cap* on the resource.

regime, some regions could see dramatic shifts in their agricultural footprint or employment (Sum, 2025). These changes, referred to as pecuniary externalities, may have policy relevance because it can be costly for communities to adapt to large changes in prices or employment.

While many economists may view water markets primarily as a tool for allocating water efficiently, those contemplating water market adoption often have additional goals or constraints. It may be challenging for local decision makers to identify a model's implications for their real-world context when looking to estimates of the gains from trade to better understand how markets compare to other policy options. One reason is that models of water markets may overestimate the true gains from trade if they assume idealized trading mechanisms, ignore important physical or institutional constraints, or do not account for negative externalities (a question of internal research validity). Additionally, results from models that *do* account for important social, institutional, and environmental considerations in their study contexts may not directly translate to other contexts (reducing those studies' external validity). In either case, clearly articulating a model's assumptions and limitations can help.

3 Classifying approaches to modeling water markets

Researchers from different disciplines employ a variety of tools to estimate the gains from water trading. While acknowledging that there are not always clean delineations among categories, we classify different modeling approaches in this section and outline key distinctions among model types.

3.1 Hydroeconomic models

Hydroeconomic models bring together hydrophysical models of water resources and economic optimization frameworks to simulate water supply and demand under different scenarios (Ward, 2024). While the scope of the modeling exercise and the detail with which institutions, regulations, and spatial variation are modeled may vary, these models typically share a focus on scenario formulation and evaluation and use calibrated models of farmer or water–user choices as inputs to a simulation exercise (Harou et al., 2009). For example, a common component of hydroeconomic models is a fully parameterized "farmer optimization model," which specifies yields, production, water demand, and sometimes even crop choice as parameterized mathematical functions (Howitt et al., 2012).

Models in this family can incorporate rich detail about hydrologic and economic conditions, climate and agronomic suitability, and other parameters, and the researcher can manipulate them to simulate future hypothetical conditions such as drought, fewer restrictions on trade, or government buy-back programs—to name only a few. For example, Harou et al. (2010) estimate the benefits of water markets during a simulated severe, prolonged drought in California. The high level of detail their model incorporates through fully specified parameterization allows the researchers to study the effects of water markets along many dimensions (ecological, spatial, sectoral, etc.).

However, this detailed parameterization comes at the risk of misspecification. First, it can be difficult to evaluate the extent to which the mathematical representations of water demand or trade are realistic, or whether either would change in response to the simulated policy or environmental changes. In particular, many hydroeconomic models are unable to incorporate unobserved transaction costs, such as search and legal costs, or unobserved heterogeneity in water users' demand. Additionally, these models often implement idealized mechanisms for transferring water between users, which may be unrealistic and overstate the extent to which trade would occur in a real water market. As an example, some papers propose trading scenarios by stipulating that water be allocated to the highest value user, conditional only on some physical and infrastructure constraints (e.g., Jenkins et al. (2004)), an assumption that may not bear out in most real-world contexts (e.g., Bigelow et al. (2019) and Ayres and Bigelow (2022)).

3.2 Agent-based models (ABMs)

Agent-based models (ABMs) employ a "bottom-up" modeling framework focused on the behavior of agents who maximize profits subject to constraints and behavioral rules. Similar to hydroeconomic models, ABMs may couple this parameterized economic framework with a process-based hydrologic model. Unlike hydroeconomic models, ABMs may not assume that agents be rational, can include flexible behavioral rules among market participants, and do not always require the definition of traditional market equilibria. These model characteristics may lead to solutions that, in the aggregate, are suboptimal from the perspective of a hypothetical social planner, allowing ABM model outcomes to deviate from purely optimized allocations. For example, Aghaie et al. (2020a) model farmers' probability of violating their groundwater extraction limits or of reporting their neighbors for doing so, including boldness and vengefulness as motivations for their behavior. While ABMs' focus on modeling individual behavior allows for more flexible model specification—such as including behavioral biases or cooperative values—these models are subject to the same risk of misspecification as other hydroeconomic models.

3.3 Reduced-form empirical models

Reduced-form empirical models use statistical tools to retrospectively estimate the role that markets played in driving some observed outcomes. Because they are dependent on empirical data, they necessarily study markets that already exist. Thus, all results are implicitly situated within the institutional and policy context of the study setting, giving their estimates of the gains from trade the advantage of having built-in market limitations, costs, and rules. As a consequence, these estimates can achieve a high level of credibility but are a product of a specific setting and are thus context-dependent. Therefore, results from a given study may not generalize well to areas with significantly different social, institutional, or environmental contexts. Additionally, data availability constrains the contexts reduced-form empirical models can analyze and the outcomes they can observe.

A common method used in this literature is the hedonic regression, which uses prices to infer market value. Hedonic property regression models in particular are based on the idea that the price of a plot of land reflects all the positive and negative attributes of the parcel, including its access to water/water rights (Buck et al., 2014; Edwards et al., 2024). They hinge on foundational assumptions that (1) buyers and sellers have full knowledge of the attributes of the land when transacting and (2) land markets are competitive. With respect to water valuation, the long-term entitlement to water use typically embodied in land ownership means that the present value of expected (net) benefits of water use (and any subsequent changes) are assumed to be capitalized into land prices. If variation in a given characteristic can be isolated from other drivers of land value, then the difference in prices between parcels that vary on this characteristic will reflect the value of that attribute to buyers in equilibrium.[5] For example, Ayres et al. (2021b) use hedonic methods to estimate the gains from water markets in the Mojave groundwater basin. Their model leverages exogenous spatial variation in whether rights are tradable (related to an incomplete governance regime that applies to only a portion of the land over the groundwater aquifer) and uses land prices to infer the value of tradability to land owners.

Land price changes are treated as a sufficient measure of net economic gains because they are assumed to incorporate positive attributes such as appurtenant water rights, as well as negative effects to parcel owners, such as well interference or water level changes. However, these estimates will not include costs that buyers of land may not recognize or internalize, such as ecosystem degradation or other third-party impacts. That said, the fact that land price changes incorporate both the benefits and negative impacts of markets means that reduced-form empirical models are ex-ante agnostic about whether markets deliver non-negative net benefits. If markets result in negative externalities or other damaging third-party effects that exceed the value of water reallocation among market participants, then the estimated gains from trade can be negative. This is an advantage over more parameterized approaches, which often are constrained to estimating, at minimum, weakly positive impacts of trade due to the optimization of the system.

3.4 Structural models

Another type of modeling approach, referred to here as ”structural,” uses economic theory to construct a framework for defining and estimating the gains from trade. Although structural models employ a diverse set of methods, in general, they use optimization frameworks to construct model objects such as demand curves, crop choices, or transaction costs. Once these objects are calibrated or estimated with data, they can then be used to estimate the gains from trade achieved in a historical market or which might be achieved in a future market scenario.

Because these models use supply and demand curves to measure gains, they tend to focus only on market participants (as opposed to third-parties who do not participate in trade), who are assumed to trade voluntarily. Therefore, as with hydroeconomic models, the estimated gains from trade derived from structural models will be at least weakly positive, even though these models do not tend to assume that markets are efficient, perfect, frictionless, or costless.

[5] As researchers have increasingly adopted quasi-experimental approaches to isolate variation in these characteristics, the importance of associated assumptions about the comparability of land market equilibria over time has increased (see, e.g., Banzhaf (2021) and Kuminoff and Pope (2014) for a broad discussion). Nonetheless, hedonic property regression remains an important method in the evaluation of water market gains.

Structural studies vary in the degree to which they estimate key parameters using modern econometric tools, which is part of what differentiates modern structural models from hydroeconomic models. More recent papers tend to estimate key parameters, such as the elasticity of demand, using econometric tools and rich, disaggregated data. For example, Bruno and Sexton (2020) use economic theory to model an imperfectly competitive groundwater market and analyze how gains vary according to the competitive structure of the market.

3.5 Combined structural and reduced-form empirical models

Some papers combine empirical tools with structural frameworks to analyze existing markets and use these estimates to inform counterfactual policy scenarios. These papers tend to be divided into two parts. First, they use reduced-form empirical methods to estimate key parameters of a theoretical model from an existing water market. Then, they use these parameters to calibrate a structural model, and use this model to analyze the gains from trade and hypothetical policy scenarios—something a reduced-form empirical method, alone, would not be able to do. State-of-the-art structural models avoid parameterizing unobservables like transaction costs, and instead rely on theory to net out these costs non-parametrically, which significantly mitigates the risk of model misspecification while preserving the key advantage of structural modeling: the ability to analyze counterfactual scenarios. Hagerty (2025) exemplifies this approach. After using econometric tools to infer the value of the existing water market in California, inclusive of any and all existing transaction costs, the author then uses these estimates to simulate what the gains from trade would be if all non-physical transaction costs were removed. As with other parameterized models, the quality of the policy simulation depends on the credibility of the specification and estimation of the model, as well as the proposed policy scenario's plausibility.

3.6 Computable general equilibrium (CGE) models

Computable general equilibrium (CGE) models attempt to characterize how different sectors of the economy, beyond those directly engaged in water trading, interact. These models are sometimes called "micro-macro" models because they bring together *micro* modeling (of farms, irrigation districts, or other agents) with *macro* connections between different sectors of the economy. CGE models are particularly useful for examining how changes in water institutions or conditions affect the economy at large, including impacts on gross domestic product, employment, and wages and other prices. They can also model and analyze how other kinds of economic changes interact with water markets. For example, Roe et al. (2005) study how the gains from creating water markets would interact with simultaneous implementation of a trade liberalization policy in Morocco.

Similar to hydroeconomic or structural models, CGE models are able to achieve rich scenario development and economy-wide connections by parameterizing economic decisions such as crop choices, willingness-to-pay for water, and more. For example, these models tend to rely on input-output tables, which are data that characterize interlinkages among economic sectors, to parameterize how changes in one sector of the economy would affect another (e.g., Roe et al.

(2005); Peterson et al. (2005)). Thus they are also subject to cautions regarding internal validity, misspecification, and potential inability to identify negative gains from trade. In addition, the rich detail on broader economic connections can come at the cost of detailed modeling of water trading restrictions and costs. However, few other methodologies are positioned to capture general equilibrium impacts.

3.7 Complementary studies

Because our focus is solely on models that estimate the gains from trade, we do not consider papers that use either qualitative approaches for describing water markets or quantitative methods to ask other questions related to water markets. Since descriptive studies are not constrained to a particular quantitative exercise, they often contain rich descriptions of the behavior and outcomes of water markets along many dimensions, such as surface water flows, distributional impacts, farm bankruptcy, farmer distress and farm exit (Wheeler et al., 2014; Wheeler, 2022), climate adaptation (Quentin Grafton et al., 2016), institutions, environmental outcomes (Grafton et al., 2011), third-party effects (Chong and Sunding, 2006), legal and historical context (Donoso, 2013; Leonard et al., 2019; Young and Brozovic, 2019; Hanemann, 2022), and the interaction between trading and banking (Ayres, 2021), among others. Likewise, there is a large literature that quantitatively analyzes various aspects and impacts of water markets. Examples include providing estimates of the price elasticity of water demand (Bruno et al., 2024), analyzing trends in trading over time (Schwabe et al., 2020), and documenting the characteristics of market adopters (Wheeler et al., 2014). Wheeler and Xu (2021) offers a review that includes both qualitative water market papers and papers that use quantitative approaches to understand aspects of water markets but are not focused specifically on estimating the gains from trade. Although these studies represent an integral piece of our understanding of water markets, they fall outside the scope of our review.

4 Methods

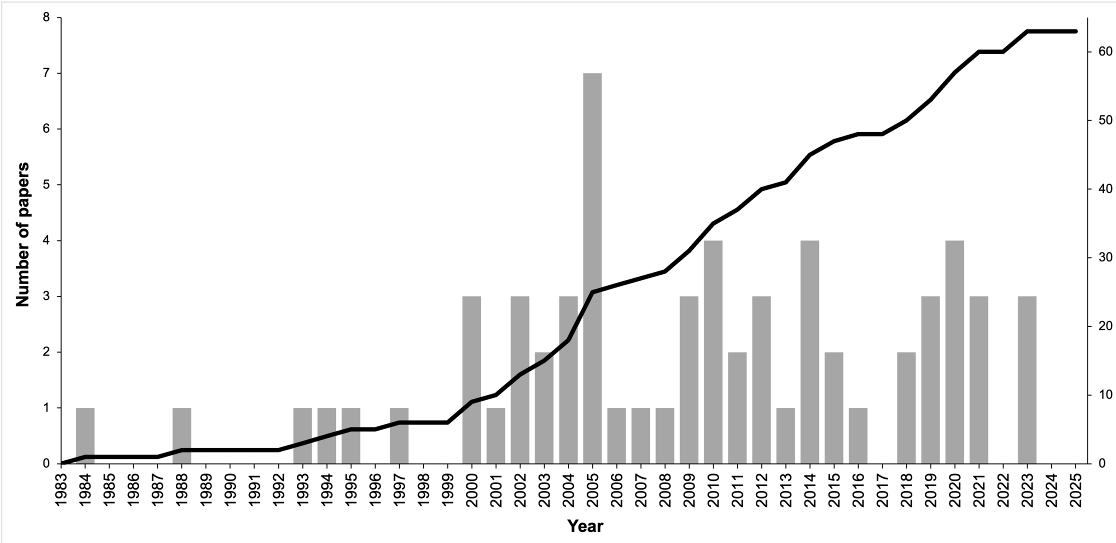
To assess how models of water trading address potentially important social, institutional, and environmental context, we (1) identified published papers that estimate the gains from trade, (2) developed and applied a rubric to the selected papers, and (3) analyzed the results in aggregate and by model family.

4.1 Paper selection

Our rubric analysis focused on original studies, published in peer-reviewed academic journals, that provided a numeric estimate of the gains from water trading.[6] We identified articles for

[6]Our dataset did not include technical reports, book chapters, working papers, or manuscripts presented at academic conferences that were not subsequently published in a journal.

Figure 1: Number of papers included in our analysis, by year of publication



potential inclusion in this study using a combination of expert elicitation, Google Scholar searches, and cited-reference searching in the bibliographies of already identified papers. We did not include papers that provided solely qualitative analyses or that involved quantitative analysis but did not estimate the gains from trade, such as papers that estimate the impacts (and costs) of water use absent markets. Although we did not include review or synthesis papers in our analysis, we used them to identify original research studies that fit our selection criteria. We ultimately analyzed a total of 63 studies published between 1984 and 2025, listed in Appendix A.

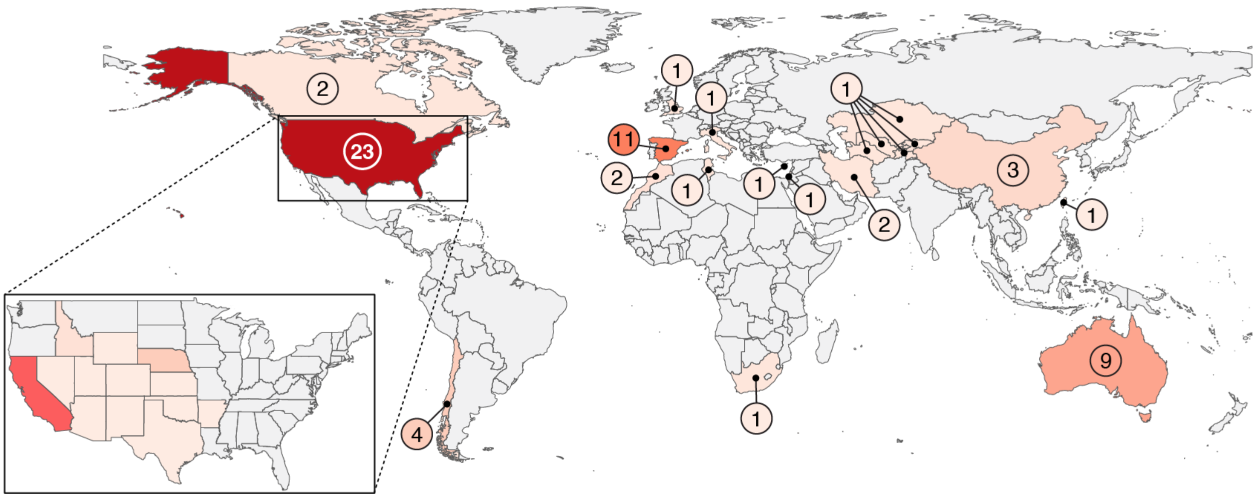
As Figure 1 illustrates, researchers have published papers estimating the gains from water trading since at least the 1980's, but the pace of these publications accelerated beginning in 2000. More than a third (22) of the papers we identified for analysis were published in the decade from 2014 to 2023.

Figure 2 maps the number of papers by geographic focus. Collectively, the studies we evaluated span all continents except Antarctica. Most of the papers focused on modeling actual or potential water trading in the United States, with a majority of these focused in California. Papers that focused on jurisdictions outside the United States (such as Spain, Chile, and Australia) commonly modeled water trading in areas where markets currently exist, or existed in the past. Panel (a) of Appendix Figure C1 plots the distribution of modeling approaches by whether a paper focuses on the U.S. or another country.

Figure 3 shows the breakdown of papers by model family. Almost half (30) fell under our "hydroeconomic" classification.

The papers also differed in the water source types they addressed and the market participants they considered, reflecting the real-world incidence of these types of markets. The majority (38) of the papers that met our criteria considered surface-water trading exclusively. Thirteen papers considered groundwater trading, nine papers considered both surface-water and groundwater trading, and three did not clearly identify the type of water source. Thirty-eight papers (60%)

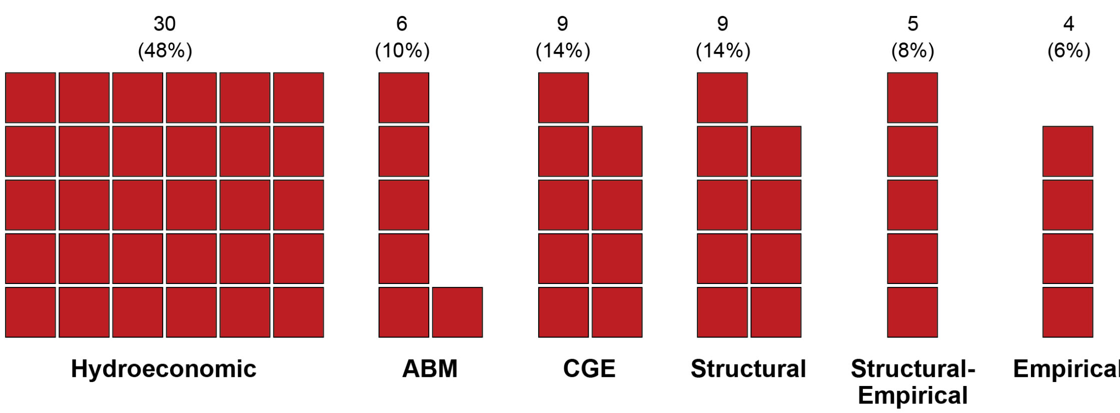
Figure 2: Geographic focus of the papers we analyzed



Notes: The map is color-coded according to the number of papers that addressed each jurisdiction, from dark red (indicating the most papers) to light pink (indicating the fewest papers).

focused exclusively on transfers among agricultural users of water, while twenty-five included other types of users (municipal, industrial, power generation, etc.), likely reflecting the fact that most water is consumed by agriculture in many areas (Ritchie and Roser, 2017). The majority of papers (45) considered only intrabasin trading. Panel (b) of Appendix Figure C1 shows that all the papers that considered interbasin trades used hydroeconomic, structural, or CGE models, reflecting the empirical challenge of studying interbasin transfers, which are less common worldwide.[7]

Figure 3: Selected papers by model family



NOTES: Each box represents one paper. Model families are abbreviated as follows: ABM = agent-based; CGE = computable general equilibrium; Empirical = reduced-form empirical.

[7]Interbasin trades are also challenging to study empirically because of the lack of a valid counterfactual for these trades.

4.2 Rubric development

We systematically evaluated each paper in our data set to determine whether and how it modeled—or otherwise addressed—aspects of the study area's social, institutional, and environmental context that may be relevant for water markets. We developed a rubric to guide our analysis, drawing from the considerations identified in Green Nylen et al. (2017). We included eight components in the rubric: (1) transaction costs borne by market participants, (2) distributional impacts among market participants, (3) third-party impacts, including environmental impacts, (4) dynamic efficiency, (5) general equilibrium effects to the broader economy, (6) the existing legal and regulatory context within which the market operates (or would operate), (7) potential institutional design scenarios that would require changes to the existing legal and regulatory context, and (8) administrative costs associated with market set-up and operation. Table 1 describes each component in more detail.

Many of the rubric components interact and intersect with one another in nuanced ways, but to ensure clarity in the evaluation process, we drew clear distinctions among them. First, we define transaction costs as trading costs that do not relate to the scarcity value of water (i.e., supply and demand). These costs include both physical or monetized costs—such as conveyance fees and losses and regulatory and legal fees—as well as non-monetized costs or frictions, such as search costs, information costs, and matching costs.

Second, we define third-party impacts as uncompensated impacts of trading on the environment or parties external to the transaction. Examples of negative impacts to water users include well interference, water quality degradation, decreased return flows as a result of increased consumptive use, and land subsidence that damages infrastructure (Roseta-Palma, 2002; Galloway and Burbey, 2011; Skurray et al., 2012). Impacts on the environment may include ecosystem and species impacts from changes in surface flows, surface-water/groundwater interactions, land subsidence, and changes in water quality, among others (Kuwayama and Brozović, 2013; Kahil et al., 2016; Skurray et al., 2012; Tisdell, 2001). While some parties may be able to contract over certain outcomes, we abstract from this for our analysis. We evaluate whether a study includes any treatment of these types of impacts. We exclude changes in employment and sectoral shifts in the local economy from this component. Instead, we capture these impacts under another component: general equilibrium effects. Similarly, we address impacts related to changes in the stock of water available in an aquifer or reservoir under the dynamic efficiency component.

Finally, we distinguish treatment of the existing legal and regulatory context from prospective modeling of potential institutional design scenarios, since some papers address only one or the other. Examples of institutional design scenarios that are market-specific include trading zones that restrict between-zone trading, spatial concentration limits, closure dates, and other rules that specifically govern the spatial or temporal distribution of water trades.

Table 1: Rubric components

Component	*Description*
Transaction costs	Costs associated with participating in water transactions (aside from those driven by supply and demand factors) borne by transaction participants.[1]
Distributional impacts	Differential benefits of trading for different categories of market participants (e.g., buyers versus sellers or participants from different water use sectors, such as municipal versus agricultural; different geographic subregions; or different wealth categories).
Third-party impacts	Uncompensated effects of water trading that accrue to parties beyond those directly involved in trading or to the environment—also known as externalities. Can be positive (benefits) or negative (costs).[2]
Dynamic efficiency	Costs and benefits that arise from changes in the stock of water available in an aquifer or reservoir.[3]
General equilibrium effects	Consequences of trading for the regional economy at large. May be direct (e.g., through changes in employment when water shifts from agricultural to municipal use) or indirect (e.g., through rising water prices).
Existing legal and regulatory context	Existing legal and regulatory requirements that may serve as constraints on or incentives for water trading (e.g., the scope and nature of water rights or other water-use entitlements, environmental flow requirements, rules that impose restrictions on the spatial or temporal distribution of water trades).
Potential institutional design scenarios	Potential institutional features that might be put in place if water trading is introduced or expanded, but would require changes to the existing legal and regulatory context.
Administrative costs	Costs associated with setting up and operating the market (e.g., updating trading rules, conducting monitoring and enforcement), commonly borne by government entities or local collective action organizations.

[1] Transaction costs do not include supply and demand factors that influence the market price, but rather costs related to carrying out a trade, such as those associated with finding appropriate trading partners, complying with applicable rules and regulations (including legal or administrative fees), agreeing on the characteristics of the asset and its price for trade, and accessing or establishing needed conveyance infrastructure (Allen, 1991).

[2] For example, groundwater trading often involves the transfer of an entitlement to extract and use groundwater, which results in decreased pumping in the seller's location and increased pumping in the buyer's location. Depending on pre-trade conditions in the two locations, a trade could increase—or reduce—well interference, land subsidence, water quality, harm to groundwater-dependent ecosystems, depletion of interconnected surface waters, etc.

[3] This component asks whether the gains from trade include the net benefits of establishing an aggregate cap, in addition to the benefits from reallocation conditional on that cap. For groundwater markets, this refers to the net benefits of constraining groundwater use (relative to open access) and relates to the optimal aggregate amount to pump in each time period. It carries implications for groundwater levels and the cost to pump for all groundwater users. For surface water markets, this refers to changes in the stock of water in reservoirs.

4.3 Rubric application

Our rubric asks whether each paper analyzes a given aspect of the rubric component and in what way. Appendix B provides more details about our process, summarized in Appendix Figure B1. We developed a set of standardized answers, shown in Appendix Table B1, to code our results and enable systematic evaluation and comparison across the papers.

The papers addressed rubric components in three general ways. First, some papers accounted for aspects of a rubric component in their models—whether implicitly (e.g., non-parametrically) via the use of historical data, through explicit data proxies, or through direct parameterization—or otherwise analyzed aspects of the component. Second, some papers mentioned aspects of a rubric component but did not quantify it in the modeling exercise. For these papers, we differentiated brief mentions from more in-depth discussions. Finally, some papers neither analyzed nor mentioned any aspect of a rubric component.

5 Results and discussion

Figure 4 summarizes the results of our analysis for each of the eight rubric components we described in Table 1, where components are ordered from most to least commonly addressed (in any way). Paper-by-paper results are summarized in Figure C2 in Appendix C.

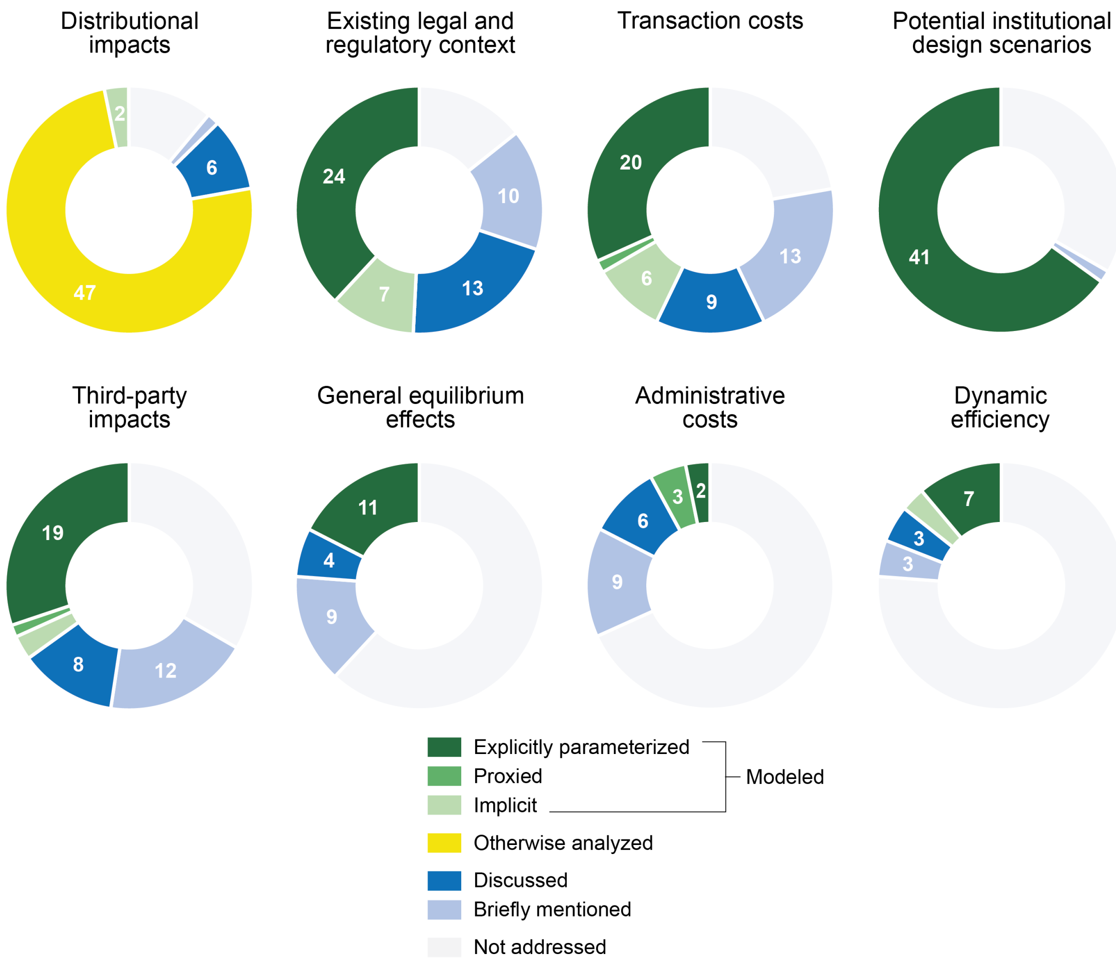
Some components were more commonly addressed than others overall. Five of the rubric components were addressed in some way by at least two-thirds of the papers: distributional impacts (89%), existing legal and regulatory context (86%), transaction costs (78%), potential institutional design scenarios (67%), and third-party impacts (67%). Fewer papers addressed general equilibrium effects (38%), administrative costs (32%), or dynamic efficiency (24%) in any way.

5.1 Distributional impacts

Understanding which market participants are most likely to benefit from trading is important context for those considering implementing a market in practice. One reason is that the perceived distributional impacts influence the political economy of market development. Actors often choose to support or oppose water market formation based on anticipated regional or sectoral impacts (Keenan et al., 1999; Tisdell and Ward, 2003; Giannoccaro et al., 2013; Simmons, 2016). If water trading is expected to have large, abrupt impacts on certain water-use sectors, decision makers might decide to take actions to mitigate those impacts (such as providing transitional assistance) or to implement an alternative policy instrument.

More than three-quarters (78%) of the papers in our dataset analyzed aspects of the heterogeneous impacts of water trading among market participants within their models (see Figure 4). Half of the remaining fourteen papers discussed or briefly mentioned some aspects of distributional impacts (11%), while half did not address them in any way.

Figure 4: Summary of rubric application results for each rubric component

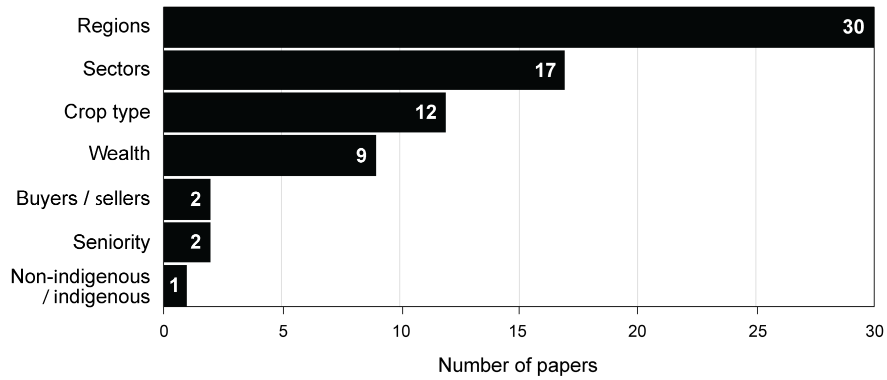


NOTES: Numbers indicate the count of papers that addressed some aspect of a rubric component in each way defined in Table B1. Light gray segments represent the fraction of papers that did not address *any* aspects of the rubric component (in any way).

Figure 5 shows that papers varied in which dimensions (categories) of distributional impacts they addressed. Categories that are easier to observe in data generally received more attention. Some papers addressed several categories. The most common form of distributional consideration, reflected in 30 papers, was by region (basin, sub-basin, or macro-region). Many of these papers disaggregated the gains from trade by region, although some simply mentioned the possibility of regional differences in trading impacts. Additionally, 17 papers addressed differences in impacts to market participants from different water-use sectors (e.g., agricultural v. urban, agricultural v. mining, or agricultural v. urban v. energy-related). Fewer papers addressed differential impacts based on wealth (9 papers), where wealth was generally described in terms of a market participant's farm size and/or productivity; crop type (12 papers); or other characteristics.

While studying distributional impacts by sector or region is helpful for understanding the general geography of impacts, aggregating to the regional level masks potentially large heterogeneity by crop type, farm productivity or size, location within a surface watershed or groundwater basin, or other characteristics. It also masks heterogeneity with respect to categories such as small farms or low-income groups which may be of particular interest to decision-makers.

Figure 5: Categories of distributional impacts



NOTES: Bar lengths reflect the number of papers that addressed distributional impacts among groups of market participants with different characteristics. Because papers that analyzed distributional impacts across multiple categories were counted for each category, bar lengths sum to greater than the total number of papers that addressed distributional impacts in some way.

5.2 Existing—and potential—legal and regulatory context

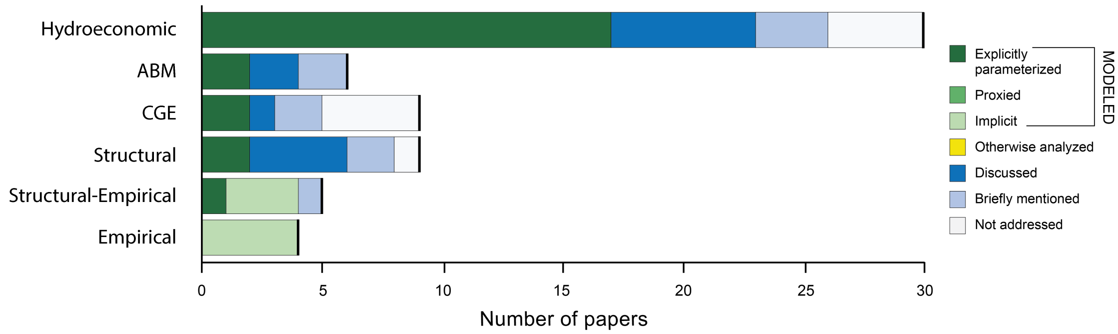
Figure 4 shows that almost half (49%) of the papers incorporated some aspects of the existing legal and regulatory context in their modeling methodologies. Figure 6 breaks this down by model type. Modeling the existing legal and regulatory context—or being very clear about omitting it in the text of a paper—is important because these modeling choices affect the accuracy and practical relevance of model output. One theoretical advantage of reduced-form empirical models is that their use of historical data implicitly embeds important aspects of the real-world regulatory environment that existed in the study location during the sample period. Models that capture the existing legal and regulatory context well are likely to produce results with greater internal validity.

Appendix Figure C3 summarizes the extent to which the literature we analyzed addresses *potential* institutional design scenarios that consider institutional features or rules that do not currently exist in the market being studied, such as trading rules that could be introduced with the goal of better managing potential externalities. Not surprisingly, we see that the papers that undertake this exercise predominantly use models that can explicitly parameterize scenarios.

5.3 Transaction costs

Consideration of the transaction costs that are borne by market participants is another important determinant of a model's ability to accurately estimate the gains from trade. These transaction costs may reduce the size of the gains from a given transaction, redirect trade to different parties, or even be sufficiently large to prevent otherwise beneficial trades from occurring in the first

Figure 6: Consideration of existing legal and regulatory context, by model family



NOTES: Bar lengths correspond to the number of papers of each model type that address aspects of the legal and regulatory context in a given way. Model families are abbreviated as follows: ABM = agent-based; CGE = computable general equilibrium; Empirical = reduced-form empirical.

place. Recent literature has found that, at least for some water markets, transaction costs may be substantial (Libecap, 2011; Regnacq et al., 2016; Hagerty, 2025; Leonard et al., 2019). Therefore, models that do not incorporate these costs carry a high risk of overstating the gains from trade.

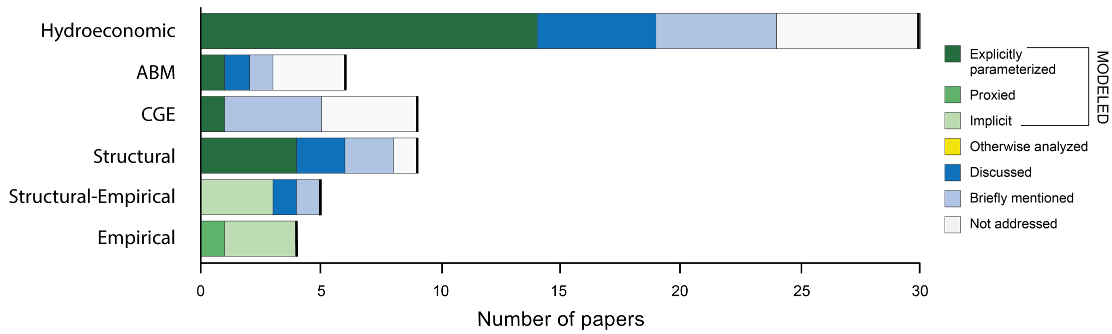
Some form of transaction costs were incorporated into the model in 43% of papers and discussed or briefly mentioned in another 35%. Twenty-two percent of papers did not address transactions costs in any way. Figure 7 summarizes how different model types addressed transaction costs. As they do for other rubric components, reduced-form empirical papers often include costs implicitly and non-parametrically, so that the estimated gains from trade flexibly net-out costs that accrue to market participants, but they generally do not disaggregate these costs by type. By contrast, 47% of hydroeconomic papers we examined explicitly parameterized transaction costs—for example, as variable and/or fixed costs to transact water or as conveyance costs that are functions of, e.g., electricity use or distance. Operation and transportation costs were most commonly included. Legal, information, and time costs were less frequently included (unless implicitly in empirical work). This is unsurprising given that these costs can be difficult, if not impossible, to observe in publicly available data and are therefore difficult to explicitly represent in models.

5.4 Third-party impacts

A comprehensive accounting of the gains from trade requires understanding the impacts of water trading on the environment and parties external to market transactions. Third-party impacts may also have direct relevance for those considering whether, or how, to implement a water market. The nature and scope of third-party impacts relative to the direct gains that accrue from transactions may vary significantly from locality to locality, as well as based on the details of market design and implementation (Green Nylen et al., 2017).

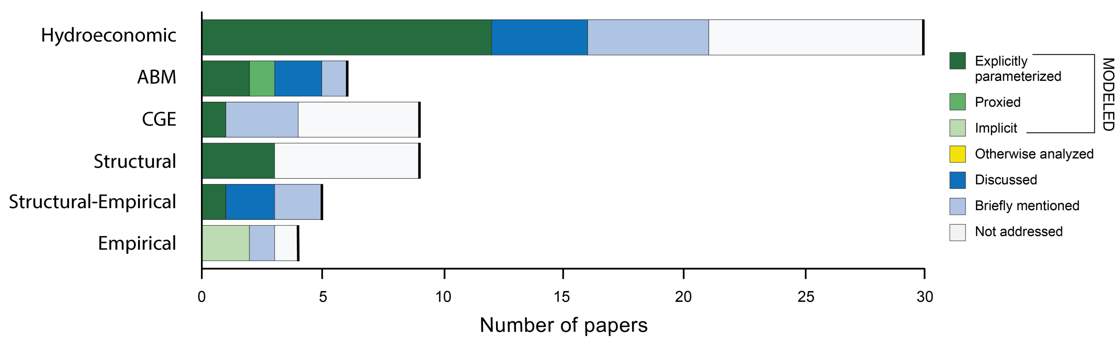
Thirty-five percent of the papers we examined modeled aspects of third-party impacts either explicitly, by proxy, or implicitly. Another 32% either discussed (8 papers) or briefly mentioned (12 papers) third-party impacts. The final third did not address third-party impacts in any way. Figure 8 summarizes these results by model type.

Figure 7: Consideration of aspects of transaction costs associated with market participation, by model family



NOTES: Bar lengths correspond to the number of papers of each model type that address aspects of transaction costs in a given way. Model families are abbreviated as follows: ABM = agent-based; CGE = computable general equilibrium; Empirical = reduced-form empirical.

Figure 8: Consideration of aspects of third-party impacts, by model family



NOTES: Bar lengths correspond to the number of papers of each model type that address aspects of third-party impacts in a given way. Model families are abbreviated as follows: ABM = agent-based; CGE = computable general equilibrium; Empirical = reduced-form empirical.

The papers in our dataset addressed a fairly limited range of third-party impacts. Most commonly, they focused on ecological impacts and/or costs to external users resulting from decreased groundwater levels (e.g., cones of depression affecting nearby wells) or reduced streamflow. Three papers mentioned or modeled the impact of changes in salinity on third parties. Well interference, subsidence, or other highly spatially disaggregated groundwater externalities were not explicitly studied in any hydroeconomic or structural papers, and were only studied implicitly in reduced-form empirical papers. Estimates of the gains from trade should be interpreted with this in mind, especially in contexts where, for example, water quality problems or sensitive species are known issues and contracting over these outcomes is difficult. A better understanding of the potential externalities associated with water trading, and the circumstances under which significant externalities are most likely to arise, is a promising area for future research.

5.5 General equilibrium effects, administrative costs, and dynamic efficiency

Finally, relatively few papers in our dataset addressed general equilibrium effects, the administrative costs of setting up and operating the market, or dynamic efficiency gains in some way. Eleven papers (17%) modeled the general equilibrium effects of large-scale change in water market institutions; most (8 papers) used CGE models.[8] Even fewer papers modeled administrative costs (5 papers) or dynamic efficiency (9 papers). These results reveal clear gaps in our understanding of how large-scale water reallocation could affect the many types of participants and sectors that are involved in or affected by water trade, suggesting an opportunity for future research to, for example, model water markets' heterogeneous impacts on labor, migrants, and the power and agriculture sectors. Quantifying these impacts is important not only for comprehensive accounting of the gains from trade, but also to address common policy concerns about how water trade may indirectly impact communities.

5.6 Intra-paper richness

Another way to look at our results is through the lens of paper-by-paper variation in *how many* rubric component are addressed and *how*. Figure 9 helps visualize these measures of intra-paper richness. Papers are grouped by model family. Within each model family, we order the papers based on the number of components they analyzed or otherwise addressed.

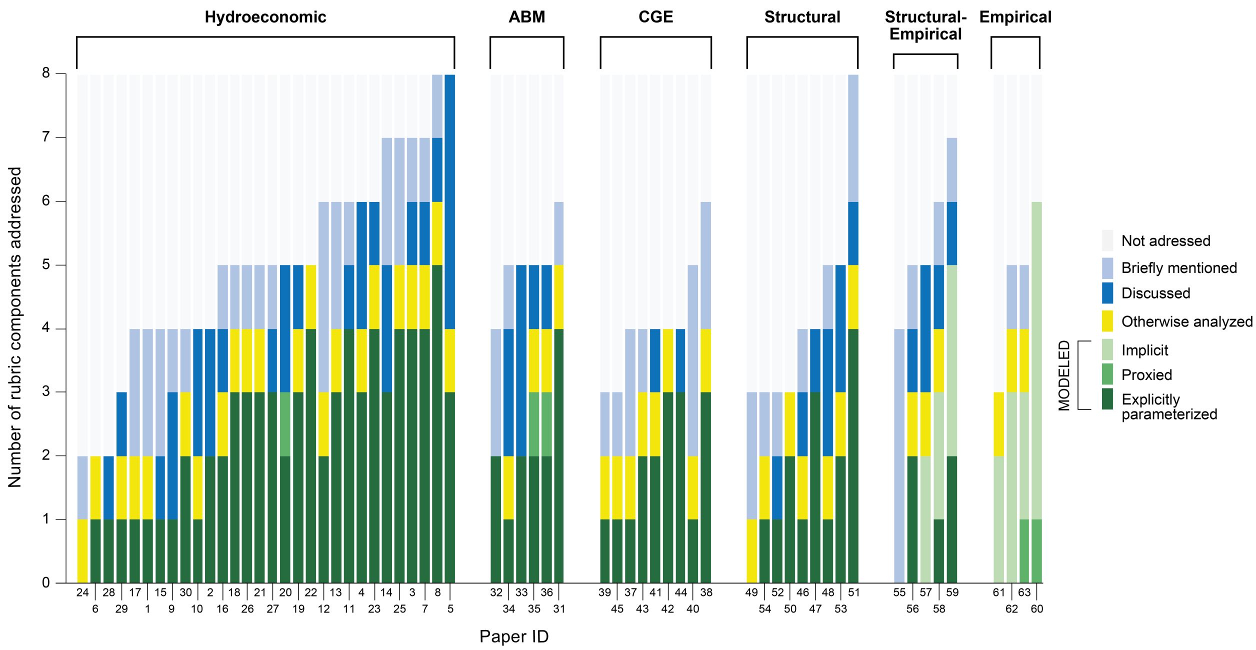
Three papers (5%) touched on all eight rubric components in some way, but no papers analyzed (as defined in Appendix Figure B1 and Appendix Table B1) aspects of every component. Instead, individual papers analyzed aspects of, at most, six rubric components. A substantial majority of papers (38, or 60%) analyzed aspects of three or fewer components, including 16 papers that analyzed aspects of just two components and 6 papers that analyzed aspects of only one component.

Notably, we see wide variation within each model family. The empirical distribution of component coverage suggests that no one modeling approach necessarily accounts for these factors more than others. We did not see any clear temporal trends within, or across, model families either.

Appendix Figure C4 shows that the components considered and the way they were addressed did not vary significantly based on the type of market participants studied (agricultural users only or multiple types of users). While agriculture is often the dominant use of water, the high value of municipal water use suggests that the gains from including these users in markets may be high. As shown in Appendix Figure C5, we found that reduced-form empirical papers were the most likely to include other types of users in addition to agricultural users, reflecting their ability to flexibly include all real-world market participants that are observed in the available historical data.

[8]We did not include Akhundjanov et al. (2023) in our dataset because the paper does not quantify the gains from trade. However, it studies the general equilibrium consequences, including employment impacts, of a large water transfer from rural Imperial County to urban Los Angeles.

Figure 9: Paper-by-paper summary of the number of rubric components addressed in different ways, organized by model family



NOTES: This figure plots the number of rubric components addressed by each paper, grouped by model family. Within each model family, papers are ordered by the number of components that are (a) analyzed in any way (i.e., explicitly parameterized, proxied, or implicitly addressed), (b) analyzed in any way or discussed, (c) explicitly parameterized or proxied, (d) explicitly parameterized, and, finally, (e) discussed. Papers that address more rubric components are not necessarily of higher quality; our rubric did not assess how well each component was captured. Additionally, rubric components are not necessarily of equal value, and their relative importance may vary significantly from context to context. Model families are abbreviated as follows: ABM = agent-based; CGE = computable general equilibrium; Empirical = reduced-form empirical.

5.7 Limitations of this study

Our systematic evaluation of papers that model the gains from water trading assessed only (1) whether each paper addressed *any* aspect of a rubric component and, if so, (2) in what way. In other words, we identified whether and how this literature accounts for aspects of the social, institutional, and environmental context for markets, but we did not assess *how well* each rubric component was captured. Furthermore, our evaluation did not allow us to determine whether more accurate or thorough accounting for a particular rubric component—or accounting for more components—would meaningfully change the papers' estimates of the gains from trade. Therefore, although analyzing more components more accurately might be helpful for local decision makers, readers should not assume that estimates of the gains from trade in papers that appear to rank higher in Figure 9 are necessarily better than those in papers that appear to rank lower. There may be tradeoffs between incorporating *more components* into a model and incorporating *fewer components well*. Additionally, the relative importance of each rubric component may vary significantly in different contexts.

6 Conclusion

In this paper, we assessed the literature on water markets and compared common methods for quantifying the gains from water trade. We developed a rubric of various factors relevant to understanding the impacts of water trading and applied it to 63 published papers. This work was motivated by the recognition that the degree to which models incorporate the full set of costs and benefits associated with trading affects the accuracy of estimated gains from trade and thus their policy implications. Furthermore, some considerations (e.g., distributional impacts among market participants) may not affect gross estimates of the gains from trade but may, nonetheless, create political economic frictions and be highly relevant for local decision making. Our results demonstrate that models vary widely in whether and how they address the local social, institutional, and environmental context within which markets operate.

The gains from trade are often estimated to be positive and large, but models may embed simplifying assumptions that could inflate these estimates. For example, negative externalities are not commonly modeled but likely quite important. Existing work also suggests that capturing transaction costs is crucial for accurately simulating water trade, but doing so can be challenging. In addition, the institutions that govern and regulate water are complex and vary from place to place, and capturing this complexity is difficult but fundamental. While these observations apply to the study of environmental markets generally, we emphasize that understanding the context-specific physical and institutional features of water resources, use, and management are important for market design, and incorporating these elements into research on water markets is crucial for credibly estimating the gains from trade.

Every modeling exercise, by its nature, involves abstractions from reality and a set of related tradeoffs—no study can be a "model of everything." However, as more data on water markets become available over time, we see opportunities for different model types to incorporate more of the benefits of alternative modeling approaches. For example, while early structural papers relied on stylized models of an entire region's demand for water, modern structural papers can use microdata on transactions and production to more realistically model user demand. Empirical modelers can also learn from hydroeconomic and CGE approaches to understand the many market participants and sectors that are likely to be affected in different ways from water trade. Increasingly rich reduced-form empirical work that studies new types of outcomes will become possible with more and better data, incorporating, for example, new remote-sensing products. Likewise, as more price and trading data become accessible, hydroeconomic papers can incorporate this information to benchmark trade volumes and market-clearing prices. More parameterized modeling approaches may want to consider ways of embedding reduced-form estimates that implicitly capture transaction costs, trading rules, and other institutional features.

Just as the gains from trade can be modeled in various ways, the sufficiency of a paper's contextual framework—social, institutional, and environmental—can be judged from several different perspectives. Two important considerations are the intended purposes of the research and its potential audiences. Many of the papers we examined were aimed at understanding specific aspects of water trading, as opposed to broadly assessing actual or potential water markets and their overall welfare implications. At the same time, local decision makers who are considering implementing water markets are a foreseeable audience for this research. Researchers can better inform policy and practice by clearly articulating the assumptions behind and limitations of their work, including whether and how it accounts for local context.

Our review offers a potential roadmap for both researchers and local decision makers to follow when evaluating the practical implications of academic research about water markets. First, researchers could use this rubric to clarify their modeling assumptions. They can produce more analytically rigorous and broadly representative pictures of existing and potential water markets by clearly articulating what components of the local social, institutional, and environmental context they are and are not considering. Justifying why certain components are being excluded from the model, and what might be lost by doing so, increases model transparency, credibility, and legitimacy. This, in turn, could help local decision makers, who are the ultimate applied consumers of many water-market modeling products. Those looking to this literature to improve their understanding of the value of markets can use our rubric as a key for identifying embedded assumptions and evaluating the strengths and weaknesses of different models and methods, acknowledging that any one paper will have limited scope.

Taken together, our rubric and results can inform both future modeling efforts and the interpretation and application of these models in policy and management, leading to models that better represent the impacts of water trading and more informed decisions about whether or how to implement water markets.

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Appendix A: Papers used in rubric analysis

Table A1: Papers used in rubric analysis

A. Hydroeconomic papers		
1	Alarcón and Juana (2016)	The water markets as effective tools of managing water shortages in an irrigation district
2	Arellano-Gonzalez et al. (2021)	The adaptive benefits of agricultural water markets in California
3	Bekchanov et al. (2015)	Potential gains from water rights trading in the Aral Sea Basin
4	Blanco-Gutiérrez et al. (2011)	Cost-effectiveness of groundwater conservation measures: A multi-level analysis with policy implications
5	Booker et al. (2005)	Economic impact of alternative policy responses to prolonged and severe drought in the Rio Grande Basin
6	Edwards and Null (2019)	The cost of addressing saline lake level decline and the potential for water conservation markets
7	Elbakidze et al. (2018)	Efficient groundwater allocation and binding hydrologic externalities
8	Erfani et al. (2014)	Simulating water markets with transaction costs
9	Harou et al. (2010)	Economic consequences of optimized water management for a prolonged, severe drought in California
10	He and Horbulyk (2010)	Market-based policy instruments, irrigation water demand, and crop diversification in the Bow River Basin of Southern Alberta
11	Howitt et al. (2012)	Calibrating disaggregate economic models of agricultural production and water management
12	Jenkins et al. (2004)	Optimization of California's water supply system: Results and insights
13	Kahil et al. (2015)	Modeling water scarcity and droughts for policy adaptation to climate change in arid and semiarid regions
14	Knapp et al. (2003)	Water transfers, agriculture, and groundwater management: A dynamic economic analysis

15 Levers et al. (2019)	Buying water for the environment: A hydro-economic analysis of Salton Sea inflows
16 Mahan et al. (2002)	Market mechanisms and the efficient allocation of surface water resources in southern Alberta
17 Marin and Smith (1988)	Water resources assessment: A spatial equilibrium approach
18 Newlin et al. (2002)	Southern California Water Markets: Potential and Limitations
19 Palazzo and Brozović (2014)	The role of groundwater trading in spatial water management
20 Pérez-Blanco et al. (2020)	A tale of two rivers: Integrated hydro-economic modeling for the evaluation of trading opportunities and return flow externalities in inter-basin agricultural water markets.
21 Pujol et al. (2006)	The potential impact of markets for irrigation water in Italy and Spain: a comparison of two study areas
22 Qureshi et al. (2007)	Economic assessment of acquiring water for environmental flows in the Murray Basin
23 Qureshi et al. (2009)	Removing barriers to facilitate efficient water markets in the Murray-Darling Basin of Australia
24 Qureshi et al. (2013)	A biophysical and economic model of agriculture and water in the Murray-Darling Basin, Australia
25 Rosegrant et al. (2000)	Integrated economic–hydrologic water modeling at the basin scale: the Maipo river basin
26 Sunding et al. (2002)	Measuring the costs of reallocating water from agriculture: A multi-model approach
27 Thompson et al. (2009)	Evidence Supporting Cap and Trade as a Groundwater Policy Option for Reducing Irrigation Consumptive Use
28 Tisdell (2001)	The environmental impact of water markets: An Australian case-study
29 Zekri and Easter (2005)	Estimating the potential gains from water markets: a case study from Tunisia
30 Zeng et al. (2016)	Modeling Water Trading under Uncertainty for Supporting Water Resources Management in an Arid Region
B. Agent-based Models (ABM)	

31	Aghaie et al. (2020a)	Agent-Based hydro-economic modelling for analysis of groundwater-based irrigation water market mechanisms
32	Aghaie et al. (2020b)	Emergence of social norms in the cap-and-trade policy: An agent-based groundwater market
33	Hung et al. (2014)	Water Trading: Locational Water Rights, Economic Efficiency, and Third-Party Effect
34	Khan and Brown (2019)	Effect of hydrogeologic and climatic variability on performance of a groundwater market
35	Smajgl et al. (2009)	Simulating impacts of water trading in an institutional perspective
36	Yang et al. (2012)	Decentralized Optimization Method for Water Allocation Management in the Yellow River Basin
C. Computable General Equilibrium (CGE) models		
37	Arriaza et al. (2002)	Local water markets for irrigation in southern Spain: A multicriteria approach
38	Diao et al. (2005)	Economy-wide gains from decentralized water allocation in a spatially heterogenous agricultural economy
39	Gomez et al. (2004)	Water exchanges versus water works: Insights from a computable general equilibrium model for the Balearic Islands
40	Goodman (2000)	More Reservoirs or Transfers? A Computable General Equilibrium Analysis of Projected Water Shortages in the Arkansas River Basin
41	Hassan and Thurlow (2011)	Macro–micro feedback links of water management in South Africa: CGE analyses of selected policy regimes
42	Hughes et al. (2023)	An economic model of spatial and temporal water trade in the Australian southern Murray-Darling basin
43	Peterson et al. (2005)	Water Trade in the Southern Murray–Darling Basin
44	Roe et al. (2005)	Feedback links between economy-wide and farm-level policies: With application to irrigation water management in Morocco

45	Tirado et al. (2010)	Economic Regional Impacts of Water Transfers: the Role of Factor Mobility in a Case Study of the Agricultural Sector in the Balearic Islands
D. Structural models		
46	Becker (1995)	Value of moving from central planning to a market system: lessons from the Israeli water sector
47	Booker and Young (1994)	Modeling intrastate and interstate markets for Colorado river water resources
48	Calatrava and Garrido (2005a)	Modelling water markets under uncertain water supply
49	Calatrava and Garrido (2005b)	Spot water markets and risk in water supply
50	Garrido (2000)	A mathematical programming model applied to the study of water markets within the Spanish agricultural sector
51	Kuwayama and Brozović (2013)	The regulation of a spatially heterogeneous externality: Tradable groundwater permits to protect streams
52	Rosen and Sexton (1993)	Irrigation Districts and Water Markets: An Application of Cooperative Decision-Making Theory
53	Vaux Jr and Howitt (1984)	Managing water scarcity: An evaluation of interregional transfers
54	Wang (2012)	A simulation of water markets with transaction costs
E. Empirical-structural models		
55	Bruno and Jessoe (2021)	Missing markets: Evidence on agricultural groundwater demand from volumetric pricing
56	Bruno and Sexton (2020)	The gains from agricultural groundwater trade and the potential for market power: Theory and application
57	Edwards et al. (2018)	An illiquid market in the desert: Estimating the cost of water trade restrictions in northern Chile.
58	Hadjigeorgalis and Lillywhite (2004)	The impact of institutional constraints on the Limarí River Valley water market
59	Rafey (2023)	Droughts, deluges, and (river) diversions: Valuing market-based water reallocation
F. Empirical models		

60	Ayres et al. (2021b)	Do environmental markets improve on open access? Evidence from California groundwater rights
61	Brooks and Harris (2008)	Efficiency gains from water markets: Empirical analysis of Watermove in Australia
62	Browne and Ji (2023)	The Economic Value of Clarifying Property Rights: Evidence from Water in Idaho's Snake River Basin
63	Hearne and Easter (1997)	The economic and financial gains from water markets in Chile

Appendix B: Rubric Application Details

Figure B1 outlines the process we used when applying the rubric, in which we characterized papers based on how they addressed each rubric component. We evaluated whether each paper accounted for or mentioned *any* aspect of a rubric component—not whether the paper addressed every aspect of the component that could affect the study's ability to evaluate policy trade-offs. For aspects that are analyzed, be it through explicit parameterization, proxies, implicitly, or otherwise, we characterize inclusion based on what a model does, not what the author recognizes in the text.

Figure B1: Rubric application process

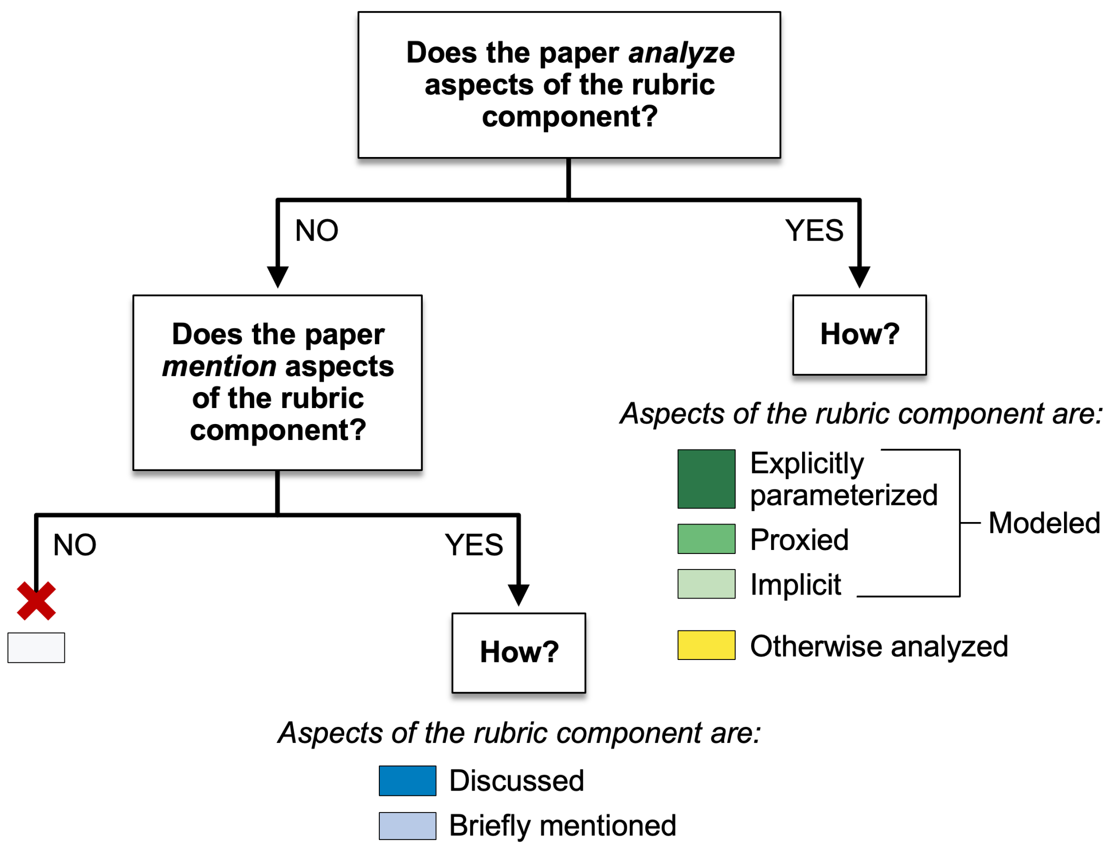


Table B1: Coding for standardized answers to the question "Does the paper analyze aspects of the component?" (used to code rubric application results)

Code	*Detailed code*	*Standardized answer*
Modeled	Explicitly parameterized	YES. The paper directly incorporates at least one aspect of the rubric component into the model estimating the gains from trade or it emerges as a consequence of modeling choices.[1]
	Proxied	YES. The paper uses a data proxy—thought to strongly correlate with at least one aspect of the rubric component—to substitute for it in the model, but no aspects of the component are directly incorporated.[2]
	Implicit	YES. The paper implicitly or non-parametrically incorporates at least one aspect of the rubric component into the model estimating the gains from trade (generally because the paper uses a reduced-form empirical model based on historical data).
Otherwise analyzed		YES. The paper does not incorporate the component into the model, but it analyzes an aspect of the component based on model results.[3]
Discussed		NO. The paper mentions and provides meaningful discussion of some aspect of the rubric component, but it does not model or otherwise analyze any aspect of the rubric component.[4]
Briefly mentioned		NO. The paper mentions but does not provide meaningful discussion of some aspect of the rubric component, and it does not model or otherwise analyze any aspect of the rubric component.[5]
Not addressed		NO. The paper does not address any aspect of the rubric component in any way.

[1] In some cases, aspects of the rubric component are used as rules or constraints in the model that define and/or limit possible behaviors or costs (e.g., a mathematical expression that defines water demand or transaction costs, a restriction against trading water out-of-basin, etc.).

[2] For example, a model might use an estimate of operating costs as a proxy for all administrative costs, or might proxy the numeric cost of environmental damage using some estimated figure.

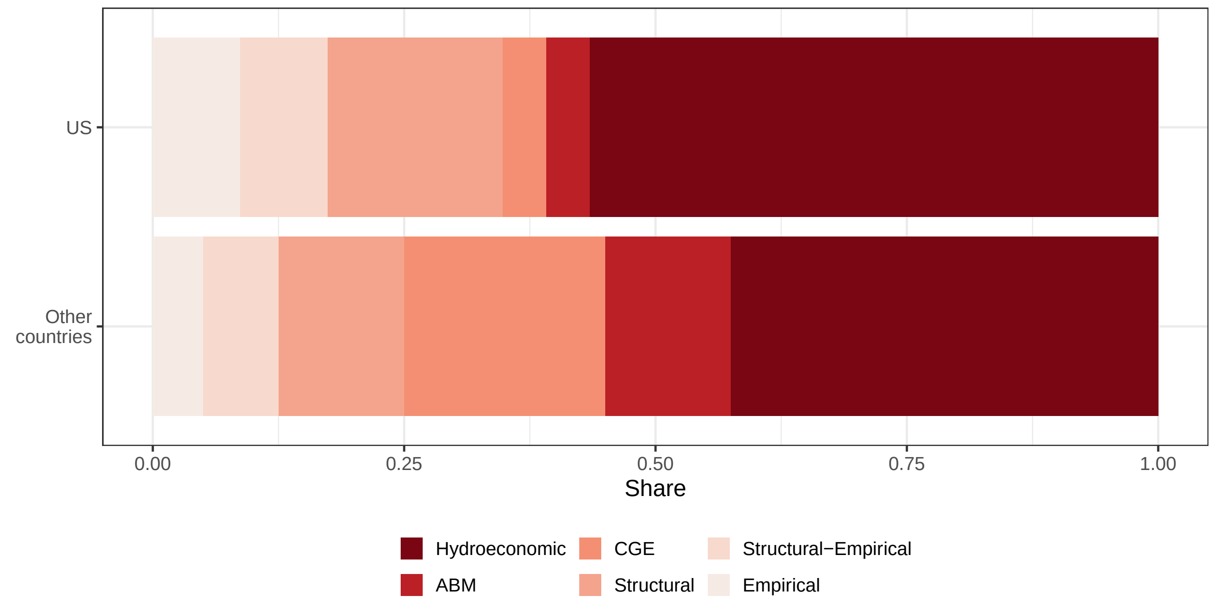
[3] We reserved this coding for instances when "explicitly parameterized," "proxied," or "implicit," were inappropriate, such as when a paper analyzed the distributional impacts of water trading based on model results.

[4] For example, a paper might discuss how simulated trading activity could affect stream flows and, thereby, other water users and the environment, or it might discuss the plausibility of freely trading water within a basin, given existing legal and regulatory constraints.

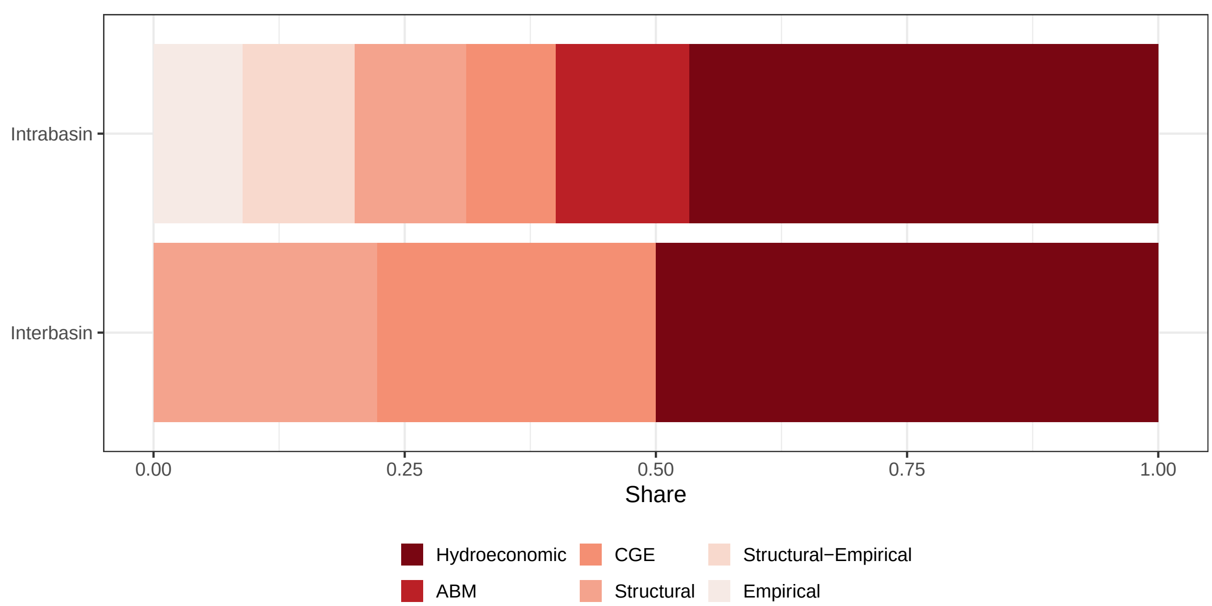
[5] For example, a paper that assumes no restrictions on trading might acknowledge that real-world markets operate in a complex environment without providing further discussion of how its assumptions compare to reality.

Appendix C: Additional figures

Figure C1: Model families by context studied and scope



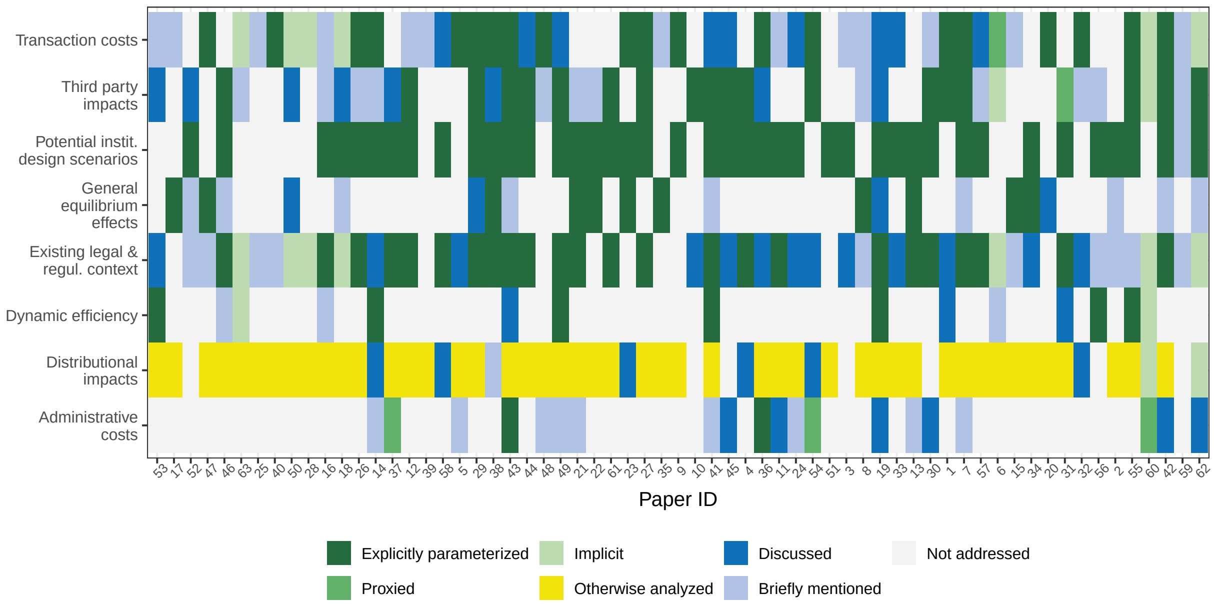
(a) Geographic context



(b) Scope of trading

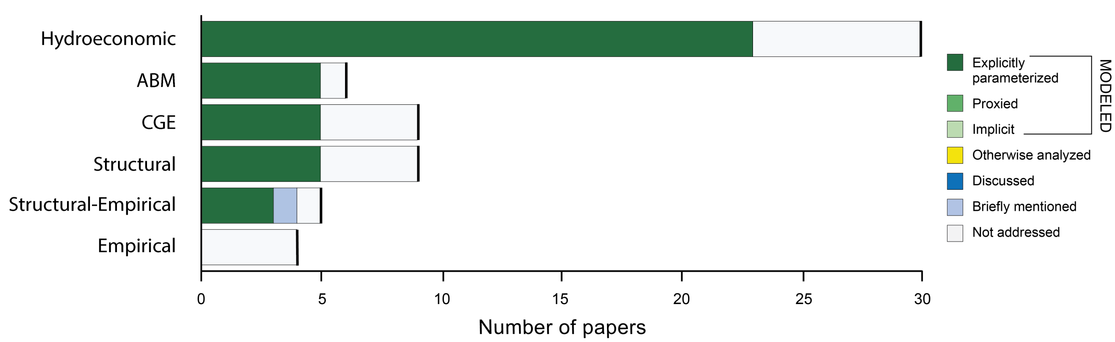
NOTE: Figure (a) reports the share of papers that model gains from trade for locations in the United States (n = 23) and in other countries (n = 40) that are classified in each model family. Figure (b) reports the share of papers that model gains from trade for within-basin trades (n = 45) and across-basin trades (n = 18) that are classified in each model family.

Figure C2: Paper-by-paper rubric results



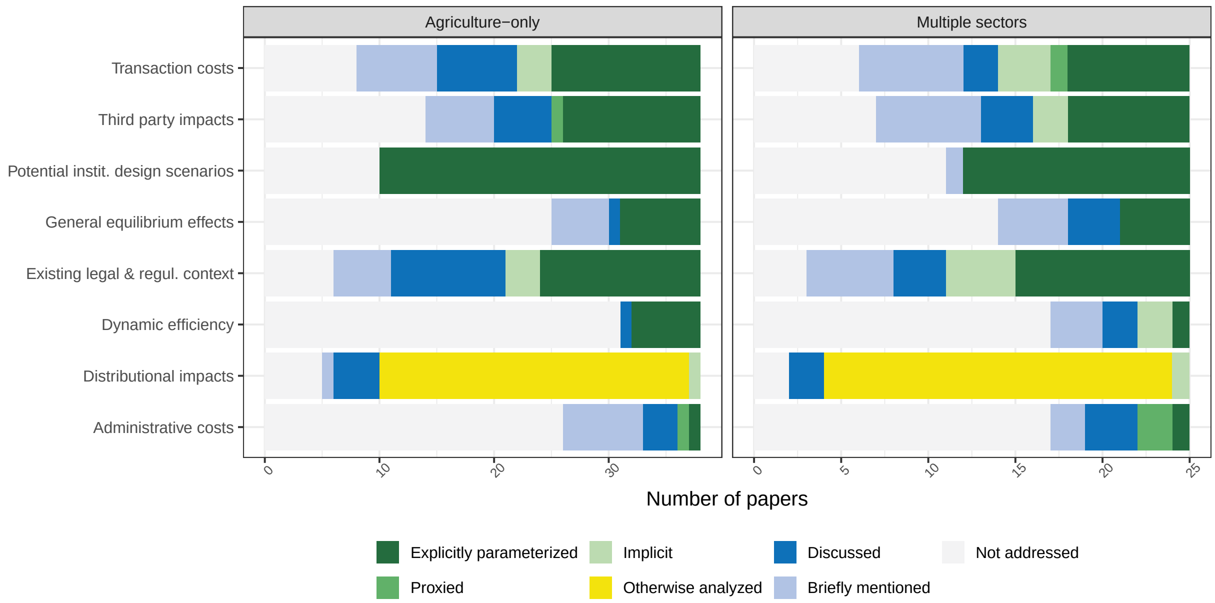
NOTE: Each grid cell is colored by the paper's rubric component categorization. Paper IDs refer to the IDs reported in Appendix Table A. Papers are ordered from left to right by year of publication then first author's last name.

Figure C3: Consideration of potential institutional design in scenarios, by model family



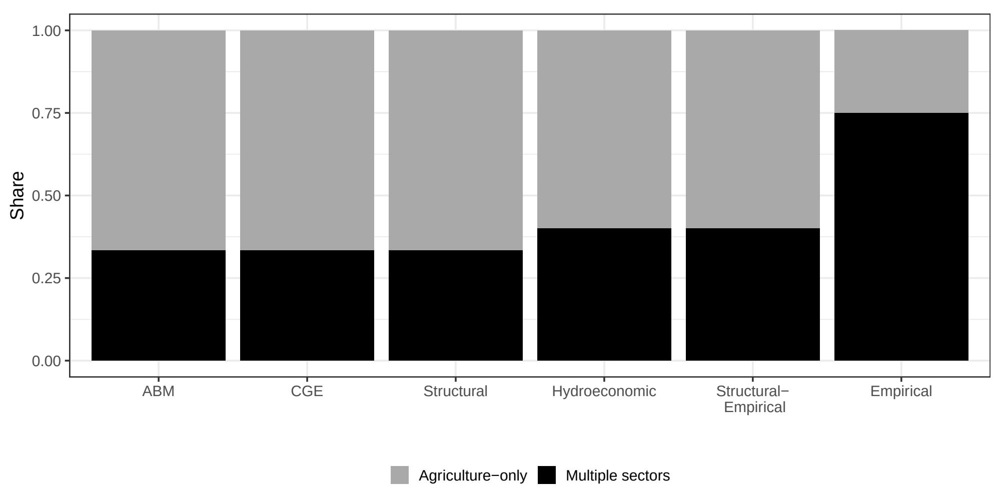
NOTE: This summarizes whether papers model potential institutional designs in the scenario analysis and does not apply to all included papers. Bar lengths correspond to the number of papers of each model type that address aspects of potential institutional design scenarios in a given way.

Figure C4: Method of addressing rubric components by market participant type



NOTE: The figure summarizes rubric application results for each rubric component split by the type of water market participant considered (agriculture only vs. multiple sectors). Each grid cell is colored by the paper's rubric component categorization. Papers are separated into those that only consider transfers that occur exclusively among agricultural users and papers that consider transfers between users of at least two different types (e.g., urban and agriculture).

Figure C5: Consideration of multiple types of market participants, by model type



NOTE: Each bar shows the share of papers in each family that model multiple types of market participants versus the share that limit transfers to agricultural users only.