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Tariff familiarity sustains household water conservation

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Due to rapid urbanization and income growth, residential water consumption worldwide is increasing much faster than in other sectors. This exponential growth in demand threatens freshwater resources, and policymakers across the globe are attempting to curb usage by redesigning tariff structures and implementing price hikes. Using a unique seven-year dataset of daily household water usage from multiple counties in China, we show that tariff reforms that simultaneously change both structure and price yield only short-lived conservation effects, as usage rebounds within months. Instead, our empirical results confirm that staggered tariff reforms—introducing price hikes only after households have adapted to a new structure—can reduce water consumption. Policy simulations suggest that a staggered reform approach could achieve an additional 4-percentage-point reduction in water usage. These findings provide new evidence on how tariff design shapes consumption behaviour and offer actionable, evidence-based insights for policymakers seeking to design effective, equitable, and sustainable water management strategies.

It has been highlighted recently in a global report that the hydrological cycle is out of balance for the first time in human history, and one of the main causes is overconsumption[1]. The largest water users globally are high-income countries, and low- and middle-income countries (LMICs) with large population (Fig. 1). More importantly, due to urbanization and economic expansion, municipal water consumption has grown at more than twice the rate of any other sector over the past decade[2] (Fig. 1), although agriculture continues to account for the majority of global freshwater withdrawals (Fig. S1). In contexts marked by rapid urban growth, limited supply, and weak governance, unmanaged household water demand can considerably contribute to local water scarcity.

While increased residential water use may reflect expanded access in some regions, such aggregate trends often obscure persistent inequalities in water distribution. Recent studies show that water consumption is frequently concentrated among high-income households[3], even as large segments of the low-income urban residents remain unconnected to safe piped water[4]. This trend is likely to continue, and even accelerate in LMICs, posing a serious challenge to achieving Sustainable Development Goal (SDG) 6 - ensuring universal and equitable access to clean water[2,5]. Effectively curbing household water usage is therefore essential to closing the demand-supply gap and realizing this global target.

China exemplifies this challenge, where rapid economic growth has been closely linked to increasing water scarcity. Currently, over 700 million Chinese experience water shortages for at least one month each year[6]. This crisis is projected to intensify for two key reasons. First, for every 1% increase in China's urbanization rate, household water consumption rises by 1.67 billion cubic meters[7]. Second, climate change is projected to drive household water demand up by 3.1–10.4% by 2030–2049 and by 7.2–43.8% by 2080–2099[8]. Taken together, residential water consumption in China is projected to increase by 15.4 billion cubic meters (a 25.6% rise from 2023 levels) by 2030 under the Shared Socioeconomic Pathway 245 scenario. By then, household water demand is projected to surpass industrial usage, further straining water resources and exacerbating the country's water scarcity crisis[7].

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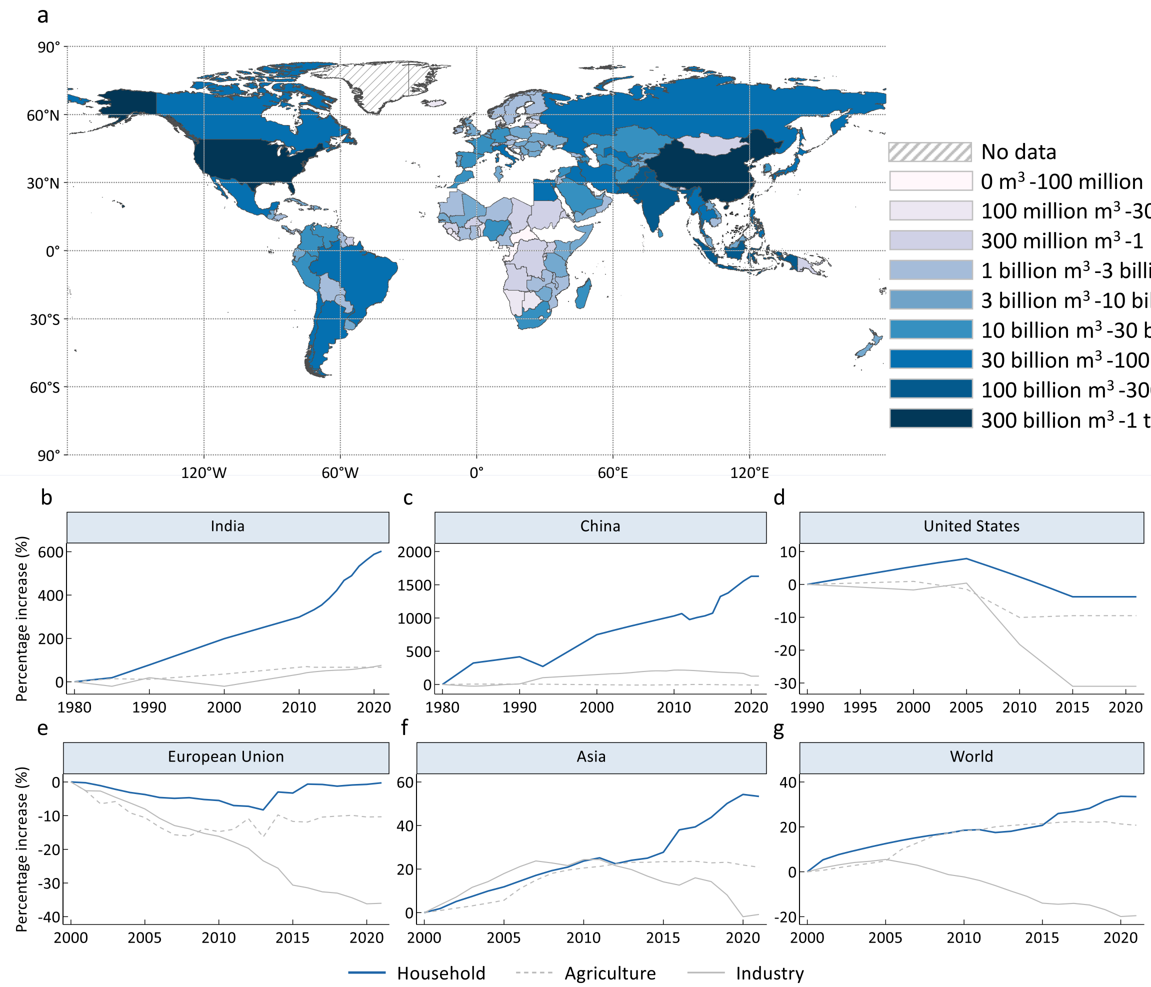

Fig. 1 | Global annual freshwater withdrawals. a The annual freshwater withdrawals by country in 2022. **b**–**g** The percentage increase relative to reference year in freshwater usage by household (blue solid), agriculture (gray solid) and industry (gray short dash) sector. Data from (Food and Agriculture Organization of the United Nations – AQUASTAT, https://data.apps.fao.org/aquastat/?lang=en).

To address this impending crisis, the Chinese government has mostly focused on supply-side policies (e.g., desalination, regional water transfers) to meet the ever-growing water demand. However, these measures alone are insufficient as a comprehensive solution requires demand-side management as well, particularly through water pricing reform and urban water conservation initiatives[5]. Toward this end, a new report issued by the OECD emphasized using water tariff reforms to better manage usage[9].

From a sustainable development perspective, water pricing reform is a powerful tool for balancing efficiency and equity[5]. By adjusting both the price levels and tariff structures, such as rising marginal prices and subsidized lifeline blocks, policymakers can incentivize conservation while ensuring equitable access to water. Moreover, artificially low water tariffs not only encourage discretionary use but also constrain the financial capacity of utilities, diverting resources away from investments needed to expand access equitably[4]. In this light, tariff reform plays a critical role in achieving SDG 6—not only by curbing inefficient or excessive residential water consumption, but also by enhancing the financial sustainability of water utilities and enabling service expansion to marginalized households.

However, implementing water pricing reform is challenging. In practice, while simultaneous adjustment of water prices and tariff design appear to yield the best of both worlds (e.g., efficiency and equity), consumers frequently respond in irrational or unanticipated ways when confronted with complex pricing schemes. One explanation is that limited attention arises because water expenses typically constitute only a small share of total household expenditures, causing consumers to invest insufficient effort in fully understanding their bills[10]. Information asymmetry also contributes to misunderstandings of tariff structures. Many residential water tariffs employ increasing block tariffs (IBTs), characterized by tiered thresholds and progressively higher marginal prices. Consumers typically are unaware of the marginal price they face and frequently overestimate it[11], which undermines their ability to make informed consumption decisions.

These cognitive biases lead households to rely on heuristic decision-making rather than fully optimized choices when making water usage decision. A recent study showed that residential water customers with heuristic decision rules make water consumption decision based on easily-accessible bill information rather than detailed tariff structures[12].

If households anchor their perceptions on inflated prior bills, they may initially overreact to a transition from flat rates to IBTs, perceiving water as more expensive than it actually is. Conversely, upon discovering that water is cheaper-than-expected, consumers may paradoxically increase their usage over time. Thus, an "effective" water tariff reform should meet three key criteria: it should be easily understood by the general public, clearly communicates water scarcity, and encourages sustained behavioral changes aligned with long-term conservation goals (e.g., exceeding two years[13]).

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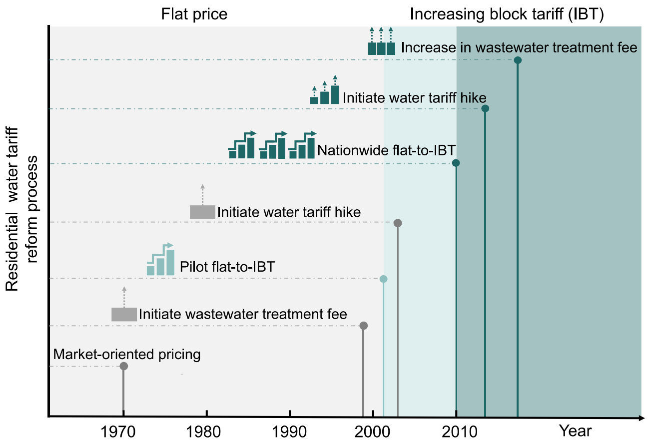

Fig. 2 | Timeline of China's water tariff policy reforms. Grey shade indicates flat water tariff across China, light green indicates pilot implementation of IBT, and dark green indicates full adoption of IBT.

Table 1 | Baseline results

	(1) Flat to increasing block tariff (IBT)	(2) Within-IBT reform
Tariff reform	−0.0151	−0.0555
	(p = 0.07)	(p < 0.01)
Observations	6,431, 463	6,555,452
Adjusted-R^2	0.30	0.31

Both models estimated the impact of water tariff reform on log-transformed daily household water usage. The regression models are estimated with daily weather controls (temperature, total precipitation, relative humidity, wind speed, hours of sunlight, and atmospheric pressure), calendar date fixed-effects, and households fixed-effects. Standard errors are clustered two-way at the county, and year-by-month level. p-values are shown in parentheses.

In this regard, a key knowledge gap in "pricing water right" is whether we should reform the tariff design and price levels concurrently or separately. Even though there is a voluminous literature examining how households react toward water pricing[14–17], few if any, have attempted a simultaneous examination of various types of tariff reforms. Moreover, evidence is especially scarce in LMICs, where institutional capacity, billing transparency, and public comprehension vary widely. China, with its diverse reform history, offers a natural laboratory for testing these questions.

Water pricing reform in China began in the late 1970s under a "cost-reflected tariff" scheme that considered only supply costs (e.g., raw water extraction) while excluding investment profits, wastewater fees, and resource charges. Tariffs during this period averaged less than 0.05 CNY m^{-3}, resulting in extremely low prices and poor efficiency (see Table S1 for a list of policy documents on China's water pricing policies, and Fig. 2 for overview of policy reforms timeline). Reforms in the 1990s and early 2000s progressively incorporated wastewater treatment fees and water resource charges, laying the foundation for two major innovations: increases in base water prices to reflect production and environmental costs, and the nationwide promotion of IBTs to replace flat-rate structures. Under the 2002 directive, pilot cities were required to adopt three-tier tariff systems covering 80% of average use in the first block and maintaining at least a 1:1.5:3 price ratio across tiers. Localities facing severe scarcity were encouraged to adopt steeper ratios to enhance conservation. Implementation, however, proceeded unevenly. While early adopters such as Shenzhen transitioned in the 1990s, many counties delayed adoption until after 2010 because of technical constraints (e.g., inadequate metering) and inter-agency negotiations. Subsequent regulations in 2015 further clarified wastewater fee structures, mandating minimum rates across urban and rural jurisdictions. As a result, by the 2010s most counties had implemented multi-tier tariffs, but substantial heterogeneity remained in timing, structure, and communication strategies. This diversity in reform experiences—spanning both shifts from flat to tiered tariffs and price adjustments within existing tiers—creates a unique quasi-experimental setting for identifying the causal effects of tariff reform on household demand.

In this work, we combine a seven-year panel of household-level daily water-usage data from 25 counties across seven provinces (2012–2019) with detailed administrative records on tariff reforms to estimate how different reform types influence residential consumption (see section 4.2 on Dataset). We make three key contributions to the literature. First, we provide one of the earliest causal estimates of household water-demand responses using high-frequency administrative data, exploiting quasi-experimental variation in the timing and nature of tariff changes across counties[17–22]. Second, we address a previously unexplored policy dilemma—whether tariff design and price levels should be reformed concurrently or sequentially—by systematically contrasting their short- and long-term effects[18,23,24]. Third, we extend the empirical evidence base to one of the most water-stressed and policy-active settings in the Global South[25,26], offering generalizable insights for LMICs seeking to balance efficiency, equity, and fiscal sustainability in water governance[1,27–30].

We show that when tariff reforms simultaneously modify both structure and rates, households initially reduce usage by about 6% but gradually rebound, maintaining only a 1.5% long-term reduction. In contrast, when only rates change under familiar tariff structures, usage declines by 5–6.5% and remains persistently lower even after two years. Through a series of robustness tests—including variations in communication strategy, tariff complexity, and survey-based assessments of billing comprehension—we demonstrate that tariff familiarity enhances the durability of conservation by allowing consumers to correctly internalize price signals. Simulations indicate that applying this insight could reduce household water use by 5.4%, compared with only 1.4% under current mixed reform practices. Our findings reveal that sequencing and clarity in tariff design are as crucial as price magnitude for sustaining conservation, offering actionable guidance for designing effective and equitable water-pricing reforms.

Results

Baseline results

We begin analysis by examining the overall impacts of water tariffs on household water usage for the two types of tariff reforms. The results in Table 1 show that within-tier ("within-IBT") changes have the largest impact on household water usage at an average 6% (P < 0.001, 95% CI [−0.07, −0.03]) decrease. The change from flat to increasing block tariffs ("flat-to-IBT") also causes a statistically significant decrease but its effects are much smaller at 1.5% (P = 0.099, 95% CI [−0.03, 0.00]).

While the initial set of results provides us an overall view of the relative effectiveness of each type of tariff change on water usage, we can further exploit the granularity of our dataset to observe the evolution of households' responses over time. To do that, we restricted the initial sample to one month after tariff reforms, and gradually expanded the dataset to include more months.

We begin with "flat-to-IBT" reforms in Fig. 3a. Compared to households located in counties with flat tariffs, water usage decreased by about 6% (P = 0.012, 95% CI [−0.10, −0.01]) immediately (i.e., one month) after the policy change. However, this behavioral change is not fully sustained as there is a gradual rebound in household usage over time. Eventually, households' water usage decreased by only 1.5% in the long-term as shown earlier. This dichotomy in impacts over time also reflects the mixed evidence observed from earlier studies[31,32]. For instance, one study found that "flat-to-IBT" reform reduced annual residential usage by 3–4% in the short-run and 5% in the longer run[31].

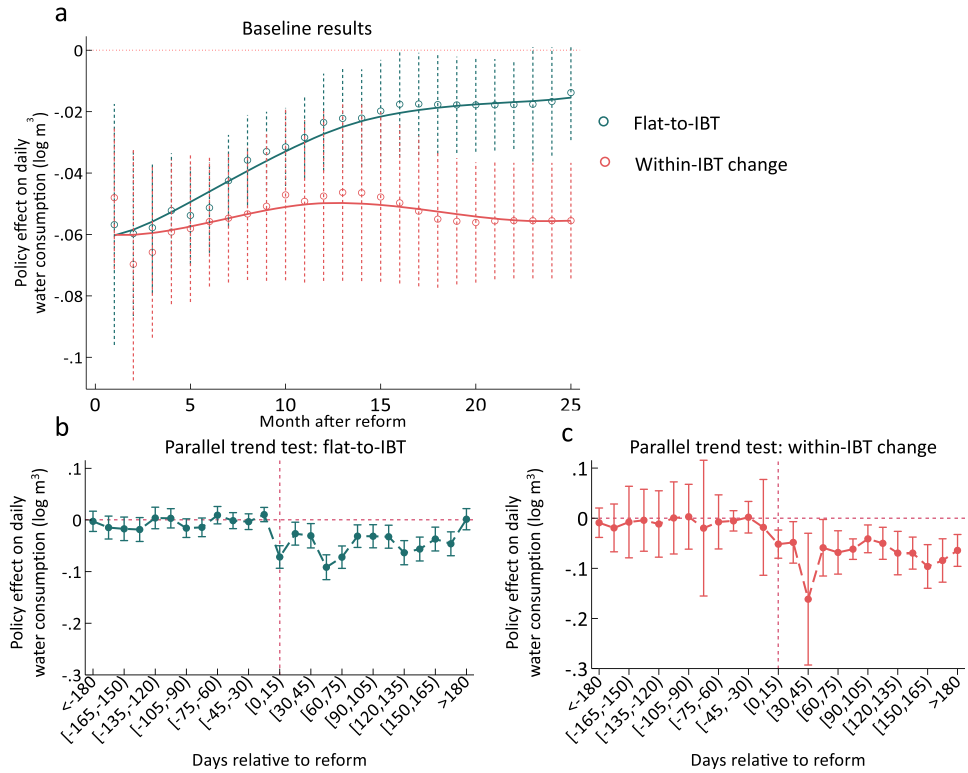

Fig. 3 | Baseline impact of tariff reforms. a The baseline impact of tariff reforms on log-transformed daily household water usage of households. In each regression, we begin by using data up until one month after reform, and gradually add observations from latter time periods. **b**, **c** The parallel trend tests, which is implemented by including an interaction term for each time period (i.e., days relative to reform) with the treatment or reform variable. In each graph, the dots indicate coefficient size, and the bars represent 95% confidence intervals. The regression models are estimated with daily weather controls (temperature, total precipitation, relative humidity, wind speed, hours of sunlight, and atmospheric pressure), calendar date fixed-effects, and households fixed-effects. Standard errors are clustered two-way at the county, and year-by-month level.

However, another study found that the same reform did not reduce usage[31]. These two contrasting findings imply that households may respond differently to the "flat-to-IBT" reform in the short and long term.

The second reform we examine is "within-IBT" change. In this scenario, households were already under an IBT structure, and the price change they experienced is a direct change to volumetric rates within each usage block. Figure 3a shows water usage decreased by around 5% ($P = 0.002$, 95% CI [−0.07, −0.02]) one month after rates changed. Unlike the "flat-to-IBT" scenario, the reduced usage is largely sustained over time. Specifically, household water consumption decreased by around 7.0% ($P = 0.004$, 95% CI [−0.112, 0.028]) two months later, and stabilized at approximately 6% in the longer term.

A central assumption of the two-way fixed-effects model is that treatment and comparison groups share common trends before policy implementation, known as the parallel trends assumption. We test this by interacting treatment status with time dummies for each day relative to the benchmark, 15 days prior to the reform dates (See SI Section 1 for details on the methods). Figure 3b, c show no significant pre-treatment trends for both of the reforms.

One plausible explanation for the results obtained so far is that the magnitudes of price changes may vary substantially, and more importantly, be correlated with the different types of tariff changes. For instance, if "flat-to-IBT" reform price changes are on average smaller than "within-IBT" changes, then it is possible that the relatively smaller long-term effects in the former are due to price change magnitude rather than differences in how consumers perceive tariff structures.

As changes to water tariffs are relatively infrequent across most countries and local jurisdictions, most studies can only examine the impact of one-time changes. By contrast, this study enables us to map out different magnitudes of changes as our dataset includes multiple counties that experienced water tariff reforms at different points in time, each with their own unique price levels.

To rule out price magnitude effects, we need to first compute marginal water prices of each tariff type. To do so, we categorize each household into their respective tariff rate blocks. For the "flat-to-IBT" reform, we use pre-reform average monthly water consumption of each household (denoted by C_0) in the treatment group to assign them their post-reform tiered tariff blocks. For instance, if a household averaged 25 m^3 monthly water consumption before "flat-to-IBT" reform and the county where the household is located will have three tariff blocks of 0 to 20 m^3, 20 to 30 m^3, and more than 30m^3, we assign this household to the middle block.

Based on C_0, we can then derive pre-reform marginal price $MP_{i,0}$. For the "flat-to-IBT" sample, the marginal price is equal to the corresponding unit price; for the "within-tier" reform, the marginal price is the unit price for an additional unit of quantity. We then calculate the marginal price after the reform (denoted by $MP_{i,1}$), using C_0, and the new tariff scheme. Finally, we compute the proportional change in marginal water price (Price_change_i) for each household.

A direct way to assess price magnitude effects is by replacing the binary treatment variable with a log-transformed marginal price change variable. In this manner, we can interpret the treatment coefficient as the elasticity of tariff on water usage (i.e., the percentage change in water demand for a one percentage change in price).

However, as prices are potentially endogenous to the household, we use marginal price change computed at each household's pre-reform average consumption[33], which is predetermined and thus plausibly exogenous to post-reform behavior. Another approach is by

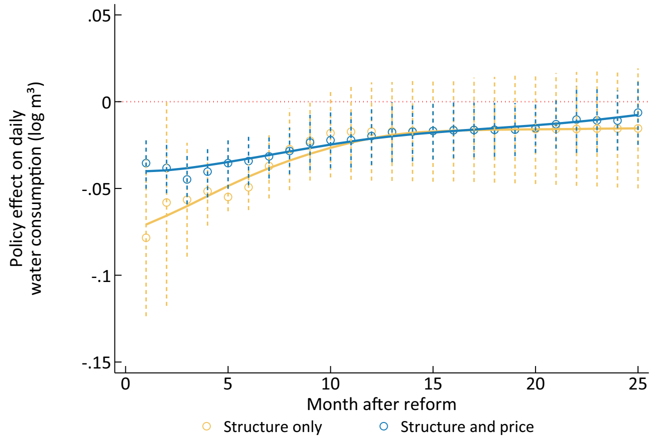

Fig. 4 | Heterogeneity analysis by price change in flat to IBT reform. This figure shows the impact of flat-to-IBT reform on water usage, with counties separated by whether they also experienced price changes. Structure only households are those with average monthly consumption within the first tier of the IBT and located in counties that transitioned from a flat-rate to an IBT structure while keeping first-tier rates unchanged. Structure and price households refer to those in counties where both the tariff structure and price levels were adjusted. In each regression, we begin by using data up until one month after reform, and gradually add observations from latter time periods. The dots indicate coefficient size, and the bars represent 95% confidence intervals. The regression models are estimated with daily weather controls (temperature, total precipitation, relative humidity, wind speed, hours of sunlight, and atmospheric pressure), calendar date fixed-effects, and households fixed-effects. Standard errors are clustered two-way at the county, and year-by-month level.

using changes in the marginal price schedule at each block as the instrumental variable[21,34]. This two-stage least-squares (2SLS) approach leverages on the fact that the full structure of the block-rate schedule is correlated with the price changes households face but is exogenous to their contemporaneous demand shocks.

Figure S2 reports both OLS (Panel a) and 2SLS (Panel b) estimates. Standard diagnostic tests—including the Cragg-Donald F-statistic and Kleibergen-Paap LM statistic—confirm strength of the instrumental variable. The close alignment between OLS and 2SLS estimates further reinforces the robustness and internal validity of our findings. Similar trends persist even after controlling for price magnitude. Households experiencing "flat-to-IBT" change continue to have a reduce-and-rebound effect. In contrast, the "within-IBT" change delivers relatively consistent reduction in water usage over time.

An indirect way to assess price magnitude effects is to combine counties that experienced similar magnitudes of price changes and conduct sub-group analyses. According to Fig. S3, we observe results consistent with the baseline's, regardless of whether the percentage price change was below 10%, or between 10% and 15%.

Heterogeneity analyses

The results so far are in part consistent with evidence that households reduce water usage in response to price hikes. However, we also show that, not only do different modalities of tariff reforms have varied impacts on water usage but households take different amount of time to process price effects. In this sub-section, we conduct heterogeneity analyses by prior water usage to examine if households' sensitivity to price changes is in accordance to the amount of water they use prior to policy changes.

To do so, we follow the same procedure outlined in Section 2.1 to assign their water usage blocks.

Panels a and b of Fig. S4 show that for the "flat-to-IBT" reform, households in Block 1 (the low-usage group) reduced water consumption by 5% ($P = 0.033$, 95% CI [−0.10, −0.01]) at the beginning. By contrast, their high-usage counterparts (i.e., Block 2) decreased usage by 14% ($P < 0.001$, 95% CI [−0.180, −0.101]) in the same period. This disparity is not surprising as "flat-to-IBT" reform is designed to disproportionately restrain high-usage groups. However, a trend common across both groups is that water usage rebounded in later periods and, in this case, the low-usage group fully rebounded in its water consumption by some 18 months after the policy change, while the high-usage group rebounded to an average 8% ($P < 0.001$, 95% CI [−0.109, −0.050]) decrease over time.

We next examine "within-IBT." Panels a and b of Fig. S4 show similar patterns from earlier where the low-usage group (Block 1) reduce usage by a smaller amount (3%, $P = 0.020$, 95% CI [−0.06, −0.01]) compared to the high-usage (Block 2) group's 9% ($P = 0.006$, 95% CI [−0.15, −0.03]). However, a key difference here is that the decrease in water usage is consistent over time for both groups.

The result that high-usage households exhibit greater responsiveness to price changes also suggests that well-designed IBTs may have progressive features by encouraging conservation among higher-consuming households, who are often relatively wealthier[3]. A more steeply tiered IBT structure—with a lower-priced first-tier and a higher-priced second-tier—could enhance both equity and efficiency by promoting cross-subsidization and targeting discretionary water use.

As the vast majority of households (around 90–95%) belonged to the low-usage group, we further examine whether the previous results are replicable within Block 1. We further split low-usage (i.e., Block 1) households into two equal-sized groups based on usage. The results in Fig. S5 are consistent from earlier. For the "flat-to-IBT" change, the higher-users within Block 1 are more sensitive toward tariff changes. However, policy impacts continue to decay over time. For the "within-IBT" changes, decrease in water usage is steady over time.

In all, this set of results is consistent with our baseline findings as they show that households can better process "within-IBT" tariff changes.

To validate the baseline results, we perform additional analyses (SI Section 2). We first investigate the impact of annual household water budgets[17] by excluding counties with such policies from the baseline model. We then conduct a placebo test by randomly assigning treatment groups and treatment timing to ensure the baseline findings are not driven by other factors (Fig. S6). Further robustness checks—including using alternative clustered standard errors, nonlinear effects of weather variables and excluding abnormal water consumption observations—show that the baseline results remain robust (Fig. S7). We also rule out the possibility that other confounding policies that impact water use (such as, water conservation campaigns, water efficiency subsidies, watering restrictions) could coincide with the water tariff (Fig. S8 and Table S2). Lastly, recent studies suggest that the usual two-way fixed-effects (TWFE) model may not accurately estimate policy effects in scenarios of staggered treatment adoption[35,36]. We reinforce the robustness of our baseline results using estimators proposed by Gardner[37] and Callaway and Sant'Anna[35], demonstrating that our TWFE model provides reliable estimates of reform effects (Table S3).

Possible mechanisms

The results so far suggest that households are less reactive when confronted with a change in tariff structure compared to changes in volumetric rate. Here, we explore several reasons for such behavioral patterns.

First, "flat-to-IBT" involves changes to both the tariff structure and the volumetric rate (at least at the higher tiers). We can further isolate these two separate effects as there are some counties that switch from "flat-to-IBT" while keeping rates at the first tier intact. In such cases, since there are no changes to the water bills for households in the first usage tier, they should not exhibit any behavioral changes. Figure 4 separates the "flat-to-IBT" counties into these two categories, and

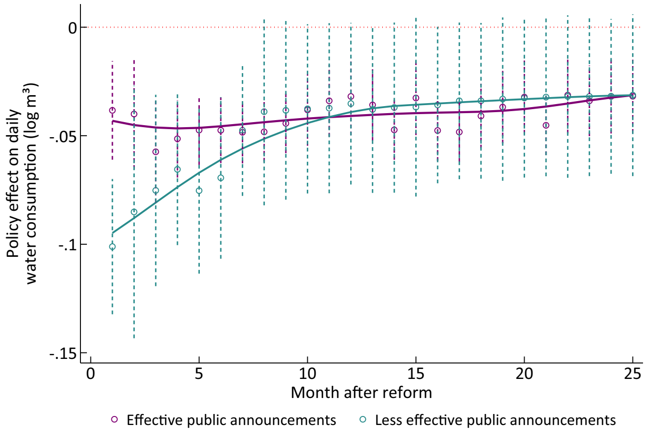

Fig. 5 | Heterogeneity analysis by flat-to-IBT policy announcements effectiveness. This figure shows the impact of flat-to-IBT water tariff reform on log-transformed daily household water usage, with counties separated by whether their public announcements included useful or pertinent information. We begin by using data up until one month after reform, and gradually add observations from latter time periods. The dots indicate coefficient size, and the bars represent 95% confidence intervals. The regression models are estimated with daily weather controls (temperature, total precipitation, relative humidity, wind speed, hours of sunlight, and atmospheric pressure), calendar date fixed-effects, and households fixed-effects. Standard errors are clustered two-way at the county, and year-by-month level.

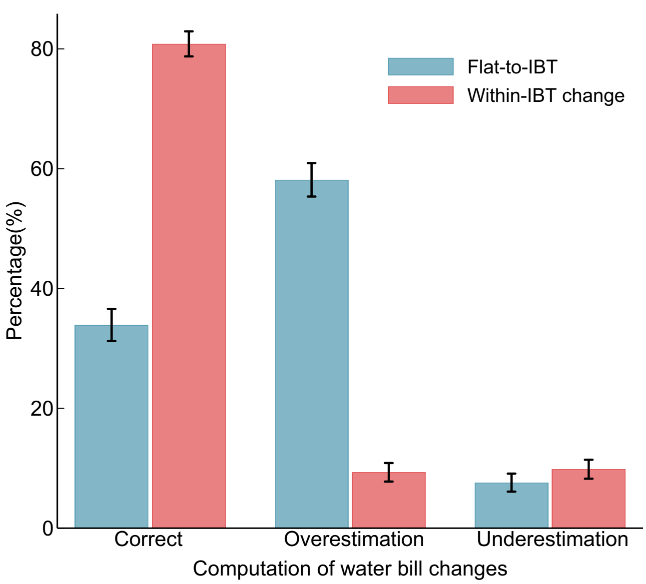

Fig. 6 | Computation of water bill changes. This figure shows the proportion of survey respondents that answered correctly to how different types of tariff reforms will affect water bills. The bars denote average percentage and the lines refer to the 95% confidence interval of the mean percentage. Number of survey observations: 853. Data is obtained from an online survey sampled across China. Descriptive statistics are collected in Table S5.

includes only households in first usage tier. While water usage of households in the "structure-only" group rebound much faster than the "structure and price" group, both sets of households have the same reduce-and-rebound usage pattern. From here, we conclude that households inadvertently react to changes in tariff structure even if the underlying tariff did not change for them. We also note that although the corresponding coefficients across these two groups are not statistically different, the larger magnitude observed in the "structure-only" group may be partially explained by their exposure to more substantial second-tier price increases during the "flat-to-IBT" reform. However, this finding merits future research.

Second, one plausible reason why households undergoing "flat-to-IBT" reforms exhibited reduce-and-rebound effects is that they could not fully comprehend the implications of the tariff change. We test this hypothesis using public announcements of tariff changes, and survey responses. County governments communicated the change in tariff structure to their citizens through public announcements. However, since there is no fixed template, there is substantial variation in how these announcements are phrased. We exploit these heterogeneities by categorizing them into two groups according to their inclusion of useful or pertinent information. Specifically, we classify announcements as effective if they included at least five of the following six elements: concise length (under 800 words), policy start date, old and new tariff rates, tier-specific usage thresholds, and estimated bill changes. For details and coding examples, see SI Section 3, and Table S4. Figure 5 shows that households from "flat-to-IBT" counties that effectively communicated the tariff change reduced water usage in a consistent manner, and did not rebound. On the other hand, households from counties with less effective communication have the same reduce-and-rebound effect we saw earlier. The second method we investigate is via an individual-level survey implemented on 853 respondents located across the country (Fig. 6). We asked them to compute total changes to a water bill under two scenarios: i) "flat-to-IBT" and ii) "within-IBT". Findings from our survey mirror our empirical findings as only 33.9% of respondents correctly answered how "flat-to-IBT" change will affect water bills. Moreover, the vast majority of responses (59%) overestimated the changes in water bills. On the other hand, 80.8% answered correctly when they were quizzed on the implications of within-IBT changes, and the wrong responses were evenly split between over- and underestimation (9.3% and 9.8%, respectively). As we required respondents to compute hypothetical bill changes, the error rates may be due to questions' complexity instead of the true misunderstanding of water tariff. In SI section 4 and Table S6, we provide evidence that the mistakes mainly reflect true misunderstanding about the water tariff.

Third, the results so far confirm that households can better comprehend the implications of "within-IBT" reform. We can further test this hypothesis by examining the effects of another straightforward volumetric rate increase based on wastewater treatment fees (WWTF). Water bills in China consist of two components: i) water tariffs and ii) WWTF. While the latter is itemized as a separate bill item for transparency and audit reasons, it is identical to the former in its contribution to the final water bill. In this regard, households should react similarly to an increase in WWTF as they would with "within-IBT" since both are volumetric rates. However, Fig. 7 shows that water usage does not respond to WWTF reforms whether in the short- or long-term. One plausible explanation is that Chinese households mostly do not know that WWTF are part of their water bills, and so did not react to this change. In the same survey (Fig. 8), we find that only 21.1% of respondents were aware their water tariff included a WWTF component even though this tariff structure is ubiquitous nationally. Even when informed that China's water tariffs were designed with a WWTF component, less than half the respondents (42%) were aware that all residential water usage is subjected to this fee. Instead, most of them (72%) had the wrong impression that only "dirty" water collected from toilets or kitchen were charged under this tariff.

In all, this series of examinations confirm that households will only behave predictably when water tariff is reformed under familiar circumstances.

Policy simulations

Our findings so far confirm that household water usage is most sensitive toward price increase when they are already familiar with the tariff structure or fees components. As such, we conduct two policy simulations using these insights.

The first aims to assess the impact on household water usage if Chinese local governments adopted a staggered approach when transitioning from "flat-to-IBT". In this scenario, the tariff structure would be changed in the first year while retaining the same volumetric rate in the first tier. In the second year, the tiered rates would then be increased to the originally intended levels (see SI Section 5 for full exposition of policy simulation). Compared to the existing scenario where both structure and tariff changed simultaneously, our proposed staggered tariff reform will reduce household water usage by 5.4% compared to 1.4% under current policies – a difference of four percentage points.

Similarly, the second simulation aims to assess the impact on household water usage when the increase in wastewater treatment fees is reframed as a volumetric tariff increase. In this scenario, our simulation shows that household water usage reduces by around 5% compared to the current no-effect outcome. This is because households are much more likely to adopt behavioral changes if the tariff increase is expressed in familiar terms.

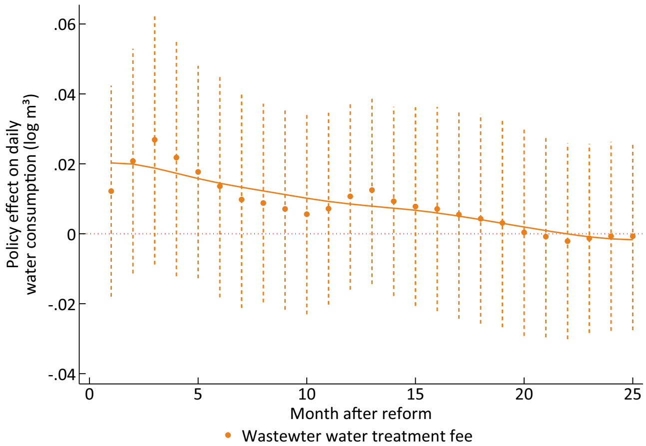

Fig. 7 | Impacts of change to WWTF on household water usage. This figure plots the impact of change to wastewater treatment fee (WWTF) reform on log-transformed daily household water usage. We begin by using data up until one month after reform, and gradually add observations from latter time periods. The dots indicate coefficient size, and the bars represent 95% confidence intervals. The regression models are estimated with daily weather controls (temperature, total precipitation, relative humidity, wind speed, hours of sunlight, and atmospheric pressure), calendar date fixed-effects, and households fixed-effects. Standard errors are clustered two-way at the county, and year-by-month level.

Discussion

SDG 6, which aims to ensure clean water for all, is increasingly under threat due to ever-rising demand, and diminishing supply caused by climate change. Among the various demand drivers, household is the fastest-growing sector due to urbanization and rapid income growth in LMICs[2,3,38]. China exemplifies this trend, with residential water usage projected to surpass industrial consumption by 2030, making it the second-largest water-consuming sector[7]. This shift underscores the urgent need for demand management policies. One of the key recommendations by the Global Commission on the Economics of Water is to eliminate water underpricing to better reflect scarcity and incentivize conservation[1]. While extensive research has explored the effects of water tariffs on consumption, critical knowledge gaps remain on understanding how households react toward tariff reforms. Addressing these gaps is crucial for designing effective policies to balance water demand and ensure long-term sustainability.

In particular, a central question emerges for policy makers and utility managers: should reform focus on tariff design, prices, or a combination of both to effectively reduce water usage. Here, we pair a unique dataset of household-day water usage across multiple counties over a seven-year period, spanning the widely-varying policy landscape of China's water tariff structures to conduct natural experiments on

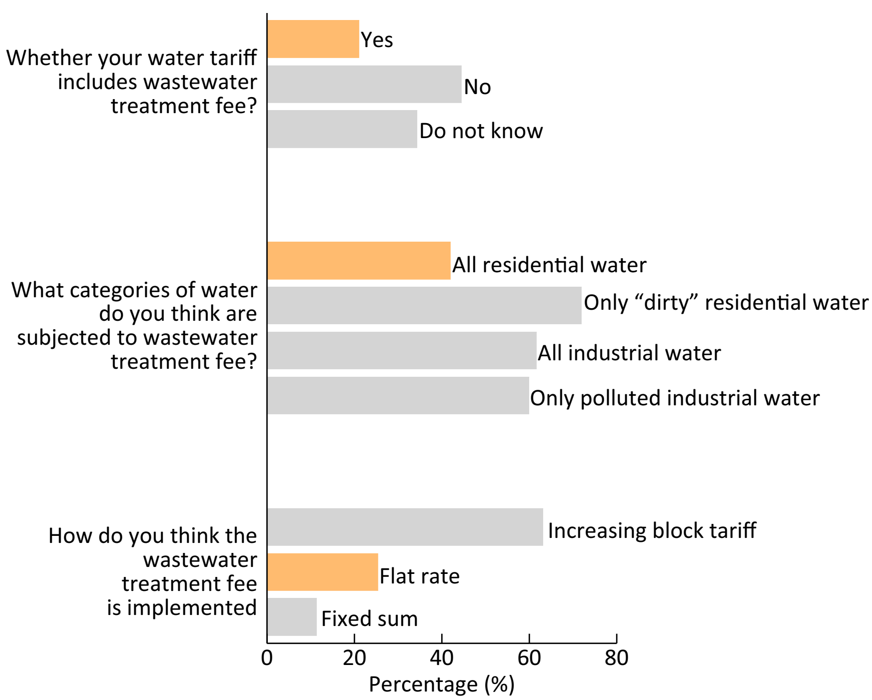

Fig. 8 | Consumers' knowledge about WWTF. This figure shows the extent to which survey respondents are aware of wastewater treatment fee (WWTF) policies. Objectively correct answers are highlighted in yellow. Number of survey observations: 853. Data is obtained from an online survey sampled across China. Descriptive statistics are collected in Table S5.

how residents alter their water usage in response to two main types of tariff changes.

When the reform involves both structure and price, i.e. flat rate to increasing block tariffs ("flat-to-IBT"), households exhibit a reduce-and-rebound behavioral change as they reduce usage by a large amount (6% decrease) in its immediate aftermath. However, usage rebounds steadily over time to a 1.5% usage decrease in the long-run. This pattern likely reflects learning lags: initially, households may overreact due to anchoring on inflated pre-reform bills and prices. As they gain experience and realize that bills and marginal prices are lower than expected, their consumption adjusts upward.

When the change is "within-IBT," policy impacts are much more consistent as households decrease water usage by around 5–6.5% across short- to long-term.

We also exploit other types of tariff changes, heterogeneity in information dissemination by local governments, and survey responses to further explore how households react toward reform in tariff rates vis-à-vis tariff structure. In all, our body of evidence conclude that households are best assessing impact of changes in tariff rates made under a familiar design. In contrast, changes to tariff structure are often confusing for households, and results in muted responses to water usage.

This study yields the following policy implications that are generalizable to any locations looking to reform water tariffs.

First, decouple tariff structure from price adjustments. There are still 1.8 billion people worldwide without access to safe drinking water[39]. It is projected that urbanization, and climate change will greatly worsen water scarcity across the world, bringing us further away from SDG 6[2,3,40]. One way to correct the imbalance between supply and demand is to not only "price water right," but also implement new tariff designs that can ensure higher overall prices without jeopardizing basic affordability. Utility managers often package these two changes together, and our findings show that such policies fail to reduce water usage. On this note, a key insight from our study is for policymakers to decouple reforms to tariff structure from price increase. As much as possible, they should first allow households to familiarize with the new tariff structure before introducing additional rate changes. It is likely that the "structure versus price" dilemma identified here is not unique to the Chinese context, but represents a broader challenge in many LMICs. Nearly 44% of urban water utilities in LMICs still employ flat tariffs[41], suggesting many are candidates for flat-to-IBT or other reforms. Moreover, empirical evidence from diverse contexts—including South Africa, Mexico, and Spain—consistently indicates the complexity of IBTs and their poor comprehension by consumers[10,42,43].

Second and related, if it is only feasible to package tariff structure and rate changes together, the next best solution is to ensure that communications on these reforms are simplified and concise. There is evidence that attempts to improve price salience through increased billing frequency or non-price interventions like social norm comparisons lead to modest and often short-lived, or counterintuitive outcomes—such as increased water usage[11,44–48]. We find that households residing in counties that communicated effectively on the "flat-to-IBT" changes exhibit consistent behavioral shifts compared to those in counties that failed to do so. These evidence may have clear implications for water rate design. Enhancing price salience—e.g., through simplified billing formats or clearer communication, not just social comparison or increasing water bill frequency—could help ensure that price signals are both understood and sustained over time[49]. One plausible strategy to ensure effective communications is to conduct multiple focus group discussions to ensure that ordinary residents can readily understand these changes[50,51].

Third, reframe obscure charges using more intuitive or familiar language. From the perspective of price transparency, it is good that water bills are itemized into distinctive components. However, this also creates a new problem where households may not readily associate with some obscure components, and thus fail to curb water usage. According to mental accounting framework[52], households may categorize WWTF as a separate charge distinct from the water tariff, because it is itemized differently and often framed in unfamiliar terminology. To improve the behavioral effectiveness of such rate components, utilities might consider reframing them in ways that emphasize their impact on the overall bill. For instance, instead of announcing an increase in WWTF alone, it may be more effective to present the change as an increase in total water bills.

In summary, households' water usage is projected to rise exponentially across much of the LMICs in the near future[40,53]. An inevitable policy solution is to increase water tariffs to curb the rising demand. While China has mostly wasted this opportunity in maximizing the effectiveness of using tariff reforms to reduce water usage, lessons from them are valuable to the rest of the LMICs embarking on similar reforms. Policy simulations conducted using our findings show that by simply staggering tariff reforms, and reframing tariff components in terms familiar to consumers can bring about additional reduction in water usage of 4 to 5 percentage points.

Methods

Estimating equation

The water tariff reform examined in this study constitutes a quasi-natural experiment with different counties implementing reforms at varying times. Consequently, we employ a two-way fixed effects (TWFE) model to estimate the effect of the water tariff reform on household water usage. This method is particularly well-suited for evaluating staggered policy rollouts and has been widely used in related empirical work on environmental and public policy evaluation[54–56] (see SI Section 6 for more discussion on policy evaluation methods). All analyses were performed using STATA/MP 16, and the effect of each water tariff reform on household water usage is estimated using the following TWFE model:

$$\ln(\text{usage}_{\text{ict}}) = \beta_0 + \beta \times \text{reform}_{\text{ct}} + \mathbf{W}_{\text{ct}} + \lambda_{\text{t}} + \gamma_{\text{i}} + \varepsilon_{\text{it}} \quad (1)$$

where $\ln(\text{usage}_{\text{ict}})$ represents log-transformed water usage of the household i at date t in county c.

$\text{reform}_{\text{ct}}$ indicates whether county c where household i is located has already implemented water tariff reform at date t. Here we primarily consider two types of reforms: i) flat-to-tiered tariffs, ii) changes in volumetric water price within tiered tariffs.

$\mathbf{W}_{ct}$ is a vector of weather control variables which include temperature, total precipitation, relative humidity, wind speed, hours of sunlight, and atmospheric pressure.

The granularity of our dataset also allows us to include high-dimensional fixed effects to λ_{t} and γ_{i}, to respectively control for any household-invariant and time-varying factors. Lastly, ε_{it} is an idiosyncratic error term clustered two-way at the county and year-by-month level.

Dataset

The dataset used in this analysis is compiled from two sources. First, household water usage is an unbalanced seven-year (from 1st January 2012 through 20th May 2019) panel of daily water usage from urban households located in 25 counties across seven provinces in China. The dataset contains 18,593,559 observations for 13,575 unique accounts. These seven provinces are mostly located in the heavily populated and economically active southern part of China, and the households are all located in apartment buildings (as opposed to standalone houses). The geographic distribution of observations is shown in Fig. S9. Installation of the meters was not a choice by the households. Rather, in most counties, developers are required to install 'smart' meters for newly-constructed buildings. Older buildings undergoing major renovations or retrofitting are also required to do the same. The dataset was obtained from a major company that specializes in installation of smart meters (Zhiheng Technology, http://www.gszh.cn), and represents all water meters installed by them as of May 2019.

According to the company, once installed, these meters transmit daily water usage data to the installation company, using a combination of radio waves and cellular networks. Each daily observation contains the dwelling's water meter ID, water usage, and location specified up to the neighborhood level (neighborhoods are the urban administrative equivalent of villages in rural areas). To improve data quality, we drop the entire year of observations for a household if: (1) there is no water usage for more than 60 days; (2) average daily water usage is less than 0.2 m^3 or more than 0.8 m^3 (at the 5th and 95th percentile of usage). Unlike household utilities such as electricity, it is more likely that observations of "no water usage" indicate that an apartment is unoccupied on that day.

Following data cleaning, we collected water tariff reform information from a variety of online sources including government, water supply company, and news media websites. The advantages of a multi-county dataset are that it allows us to study different types of water tariff changes, and use treatment and comparison groups to identify policy impacts. A county is placed into the "treatment" group if they experienced the specific tariff reform that we are analyzing. Similarly, a county is included in the "control" group if they had already implemented the targeted tariff structure, and did not experience any price changes.

Specifically, for the "flat-to-IBT" reform, the treatment group consists of households from eight counties that experienced a transition from flat water rates to IBT where unit price of water increases as usage increase. The control group consists of households in nine counties that maintained the same flat-rate tariff.

For "within-tier" tariff reform, the treatment group includes households from four counties that experienced an increase in water price while remaining under the IBT structure while the control group consists of households from nine counties that maintained the same IBT structure.

To fully maximize our sample, and exploit variation in policy implementation dates across the counties, there are several counties that were used respectively, as treatment and control groups in analyses of different tariff reforms (see Table S7 for full list). For instance, Wuyishan county is used as a treatment group in "flat-to-IBT" reform and as a control group in "within-tier". In its first inclusion as a treatment county, we use data from 1st January 2012 through 20th May 2019, in which its water tariff changed from flat to IBT on 1st July 2016. In its second inclusion as a control county, we use data from 1 July 2016 through 20th May 2019, in which their IBT tariffs did not change.

Similarly, there are some counties that experienced more than one tariff change. For example, Fuqing experienced a within-IBT change on 1st Apr 2015 and wastewater treatment fee increase on 1st Jan 2017. For the first inclusion, we used data from Fuqing for the period of 1st Jan 2012 – 31st Dec 2016, and for the second inclusion data from 1st Apr 2015 – 20th May 2019. By splitting the observation windows in this manner, we ensure that post-reform effects from one analysis do not contaminate the identification strategy of another. This approach maintains the internal validity of each reform evaluation while enabling efficient use of the dataset.

As a first check of comparability between these treatment and comparison groups, we plot the distribution of households according to their water usage for each type of tariff change. We can see from Fig. S10 that the treatment and comparison groups show highly similar distributions across all both types of reforms. Balance tests for each type of tariff reform also show that the treatment and control counties are statistically identical on many socioeconomic characteristics (Table S8).

The second source of data is daily weather information obtained from the 337 ground weather stations of the China Meteorological Data Service Center where we used inverse distance weighting to attribute weather for each county in the dataset[57,58].

As the water usage dataset is a non-random collection of counties located in southern provinces, we compared the socioeconomic characteristics of these counties with those of the larger provinces in which they are located. Table S9 presents the results of *t*-tests for mean values. Apart from urban residents' per capita disposable income (which is statistically significant at the 10% level), there are no other statistically significant differences between the sample counties and their corresponding provinces, in gender and age structure, household size, economic development status, and rural residents' disposable income. Therefore, we conclude that the sample in this paper is generally representative of southern China.

Household survey on water tariffs

To complement the administrative dataset, we conducted household survey in China to assess residents' understanding of water pricing systems and their behavioral responses to tariff reforms. The survey was administered via an online platform and collected 853 valid responses nationwide. Respondents were screened to include only individuals responsible for paying their household water bills, and participation was voluntary and anonymous. The questionnaire covered household water use, billing practices, and perceptions of tariff fairness, followed by randomized scenarios describing either a shift from flat-to-IBT tariffs or within-IBT uniform price increases. Respondents calculated expected changes in their monthly bills under each scenario, allowing us to measure comprehension of tariff structures. The survey concluded with demographic questions on age, gender, location, education, occupation, and income. Responses were pretested for clarity, and the final sample reflects a broad cross-section of urban and peri-urban households across China. The survey protocol was reviewed by the Institutional Review Board of Renmin University of China (L20250107), and determined to be exempt from full review under the category of minimal-risk, anonymous human-subjects research. No personally identifiable information was collected, and all participants provided informed consent prior to participation.

Reporting summary

Further information on research design is available in the Nature Portfolio Reporting Summary linked to this article.

Data availability

The data that support the findings of this study are available in Zenodo with the identifier: https://doi.org/10.5281/zenodo.17180292[59].

Code availability

All data are processed and analyzed in Stata (16MP) and the code is available in Zenodo with the identifier: https://doi.org/10.5281/zenodo.17180292[59].

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Author contributions
J.S.T.S. conceived the study, and coordinated the overall research. J.S.T.S., P.Q., and J.L. designed the research. J.L. performed the analysis with support from J.S.T.S., and P.Q. P.Q. provided data. J.S.T.S., and P.Q. designed the survey, and J.L., and Y.Q. implemented the survey. J.S.T.S. wrote all versions of the manuscript. P.Q., J.L., and Y.Q. provided comments on the manuscript.

Competing interests
The authors declare no competing interests.

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