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Water demand responds asymmetrically to rising and falling prices

Abstract

This paper econometrically estimates residential water consumption in Germany between 2007 and 2013 based on a panel of almost 3000 supply areas. In particular, the analysis distinguishes periods of rising and falling water and sewage water prices. The short-run (long-run) price elasticity is estimated at around 4.2% (13%), but water demand appears to respond asymmetrically to rising and falling prices. When prices are rising, the short-run (long-run) price elasticity is around 6.5% (18%). When prices are falling, the short-run price elasticity is not statistically different from zero, and the long-run price elasticity is estimated at around 12%. Additional results illustrate that employing average prices instead of marginal prices results in substantially overestimating the price elasticity. These findings are particularly relevant for utilities and regulators planning to alter the tariff structure towards a higher fixed fee and a lower volumetric fee.

Keywords: water consumption; econometrics, rebound; tariff; price elasticity; panel data;

Highlights:

- The short-run (long-run) price elasticity of water demand is estimated at around 4% (13%).
- Water demand responds asymmetrically to rising and falling prices.
- When prices are rising, the short-run (long-run) price elasticity is around 6.5% (18%).
- When prices are falling, the short-run price elasticity is not statistically different from zero, while the long-run price elasticity is about 12%.
- Short-run and long-run price elasticities may be overestimated if average prices rather than marginal prices are used.

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1 Introduction

Long lifetimes and high fixed costs are defining characteristics of large technical systems such as the infrastructure networks for water, electricity or gas. Water networks often last for 50 years and more, and they typically account for about 70-80% of the total costs of supplying fresh water or disposing of sewage water. Specifically, on average, about 77% of the total costs of water supply in Germany are estimated to be fixed costs (VkU, 2017). Fixed costs mostly comprise depreciation (20%), interest (18%), labour costs (18%), and concession fees (10%), while variable costs are mainly made up of the costs for material and energy.

This cost structure poses challenges for tariff design. On the one hand, tariffs provide revenues for utilities so they can recoup total costs. Water tariffs typically comprise two parts: a usage price that is linked to actual consumption (volumetric fee), and a fixed fee. A higher fixed fee means greater security for utilities' revenues and investments. On the other hand, tariffs affect consumption levels. A higher volumetric fee normally decreases consumption. In the case of water use, lower consumption is typically socially desirable because this translates into lower resource use in water-scarce regions and lower local and global emissions from using energy and chemicals to heat, process and clean water.

This trade-off between investment security and social objectives has typically resulted in water tariff structures, where usage fees do not adequately reflect the underlying cost structure. For water or sewage water use, the usage fee is typically higher than the marginal costs of production, and the fixed fee is lower than the fixed costs of production. In Germany, for example, on average, 77% of water utilities' revenues stem from volumetric fees and 23% from fixed fees (VkU, 2017). The empirical findings by Garcia and Reynaud (2004) for France and Müller (2015) for Germany suggest that adjusting water tariffs to align better with economic efficiency, i.e. volumetric fees that reflect the variable costs and fixed fees that reflect the fixed costs, would lead to a slight increase in welfare.

In many countries (including Germany), technological progress and the diffusion of water- and energy-saving appliances has also resulted in lower water and energy use (e.g. Reynaud, 2016), hence lowering the revenues from energy and water sales. As a consequence, utilities habitually request changes to the structure of water tariffs, i.e. increases in the fixed cost component of the tariffs allowing them to recoup costs and decrease the usage price in return. Since these tariffs are usually set by public bodies (commissions, regulators, municipally-owned utilities, or city councils), adjusting the tariffs accordingly often proves politically infeasible. The public bodies are especially concerned about customer opposition to such a change in the tariff structure and negative environmental effects from increased water consumption.

The extent to which a lower marginal price results in higher water use depends on the responsiveness of demand, which is typically measured using price elasticity. To estimate price elasticity, empirical analyses usually employ a reduced-form water demand equation. These empirical studies have resulted in a wide range of estimates for price elasticity from around 0.1 to 1.0 (in absolute terms). Most studies find water demand responds to prices, but is price-inelastic. In their recent meta-analysis, Merzano et al. (2018) find a mean and median price elasticity of 0.4 and 0.34, respectively. These estimates are similar to those found in earlier surveys by Espey et al. (1997), Dalhuisen et al. (2003), Worthington and Hoffman (2008) and Sebri (2014). For Germany, several studies have estimated the price elasticity of water demand over the last decade. Relying on cross-sectional, municipality-level data, Schleich and Hillenbrand (2009) estimate the price elasticity at 0.24. Using district-level data, Müller (2015) estimates the price elasticity between 0.26 and 0.46, depending on the model. Employing district-level data for water use, but state-level data for water and sewage water prices, Reynaud (2015) finds a price elasticity of around 0.45 for the short run and 0.51 for the long run. In comparison, Frondel and Messner (2008) rely on household-level data for a municipality (the city of Leipzig) and estimate the price elasticity at 0.365.

There is an additional dispute in the empirical literature about whether households respond to marginal or to average prices. The empirical evidence here appears to be mixed (e.g. Ruijs et al., 2008; Taylor et al., 2004, Howe, 1998)[1]. Individuals are more likely to be aware of the marginal price, i.e. the volumetric fee, rather than the average price. For the latter, they would need to divide their total expenditure by their total consumption. In addition, as pointed out for electricity demand by Taylor (1975), Taylor et al. (2004) or Frondel and Kussel (2018), when tariffs include a fixed fee, using average prices to estimate price elasticities implies that the elasticity estimates are biased towards unity. This

1 Similarly, it is not clear whether household electricity demand responds to marginal or average prices (e.g. Frondel and Kussel 2018).

follows from an arithmetic artefact if the average price is defined ex post as the ratio of total expenditure to the quantity of water consumed, as is usually the case[2]. This bias towards unity will be larger, the higher the fixed fee share compared to the volumetric fee share. Indeed, the meta-analyses (e.g. Dalhuisen et al. 2003 or Marzano et al. 2018) report larger magnitudes for the elasticity point estimates when they are derived from average prices compared to marginal prices[3].

Several empirical studies allow for heterogeneity in the price elasticity[4]. Since most water uses cannot be easily substituted in the short term without exchanging water-using appliances, long-term elasticities tend to be somewhat larger (in absolute terms) than short-term price elasticities (e.g. Martínez-Espiñeira, 2007; Nauges and Thomas, 2003; Musolesi and Nosvelli, 2007). The price elasticity may also vary by the type of water use. Essential uses such as drinking and cooking may not be price responsive at all (Gaudin et al., 2001), while non-essential uses such as watering the garden may be particularly price sensitive. Socio-economic factors may also affect the magnitude of the price elasticity. In particular, lower income households have been found to exhibit a larger price elasticity than higher income households (Hajispyrou et al., 2002). Finally, Gaudin (2006) and also Frondel and Messner (2008) note that households' price responsiveness may depend on their knowledge about water prices. That is, the price elasticity should be larger for households who are better informed about water prices.

In this paper, we econometrically estimate the elasticity of residential water demand deploying a unique data set, which includes panel observations from almost 3000 utility supply areas in Germany. In contrast to the extant empirical literature, we allow households to respond asymmetrically to rising versus falling (marginal) prices. Notably, and in line with the finding from the literature on energy demand, technical rigidities may render demand less responsive when

2 To illustrate, suppose there is no volumetric fee at all, so the utility has to cover its total costs (= total revenues, assuming zero-profits) from the fixed fee only. Keeping profits at zero, a one percent increase in water consumption is then matched by a one percent decrease in the fixed fee and hence in average revenues.

3 Espey and Espey (2004) come to a similar conclusion for electricity demand.

4 See Reynaud and Romano (2018) for a recent overview.

prices are falling than when they are rising[5]. Among others, water-saving investments made during periods of rising water prices are unlikely to be reversed during times of falling prices. Thus, it may be necessary to allow for an asymmetric response of water demand in order to accurately assess the effects of a change in the tariff structure towards a higher fixed fee and a lower volumetric fee on utility revenues, water consumption and the ensuing environmental effects. In addition, if water demand responds asymmetrically, using price elasticities estimated during periods of rising prices would lead to an overestimation of the direct rebound effect associated with investments in water-saving technologies (e.g. water-saving appliances, grey water recycling systems), which lead to lower costs of water services. Data availability probably prevented previous studies testing for an asymmetric response of water demand. Studies relying on cross-sectional data cannot distinguish between periods of increasing and decreasing prices. Studies relying on time series and panel data tend to rely exclusively on periods where prices increased, typically owing to increasing water scarcity and environmental regulation such as the Urban Sewage Water Directive in the EU (EU 1991). In Germany, for example, water prices increased by more than 5% per year in the early 1990s (Hillenbrand et al 2013). Hence, data availability prevented modelling water demand as responding asymmetrically to rising and falling water prices. In contrast, our data include a substantial number of observations with falling volumetric water prices. First, about a decade ago, a large number of utilities started to modify the structure of their tariffs towards lower volumetric fees and higher fixed fees. Second, antitrust authorities at the state and federal levels forced many utilities to lower prices from 2012 on. For the data at hand, we also show that employing average prices instead of marginal prices results in substantially overestimating the price elasticity.

The remainder of the paper is organized as follows. Section 2 presents the methodology, including a description of the data, the variables and the econometric model. Section 3 presents and discusses the results. Section 4 concludes and draws policy implications.

5 Results from estimating residential energy demand provide mixed results. The findings from Gately and Huntington (2002), Haas and Schipper (1998) or Ryan et al. (1996) suggest that – in absolute terms – the price elasticity of the demand for oil and gas is larger when prices are rising than when they are falling. For electricity, however, Miller and Alberini (2016) find no evidence of such an asymmetric response.

2 Material and methods

Similar to the majority of the extant literature (e.g. Nauges and Thomas, 2000; 2003; Martínez-Espiñeira, 2002, 2003; Musolesi and Nosvelli, 2007; Schleich and Hillenbrand, 2009; Romano et al., 2016; Suárez-Varela and Martínez-Espiñeira, 2018), our empirical analysis relies on data at the level of a utility supply area. In Germany, a utility supply area typically coincides with a municipality. Currently, there are 5,845 water utilities (DESTATIS, 2018i) and more than 6,900 sewage companies (ATT et al., 2015) in Germany, most of which are rather small. Water utilities may be owned and managed by either private or public (i.e. municipalities) companies. In contrast, almost all sewage companies are publicly owned because German water regulation considers sewage treatment a sovereign task. By law, water and sewage prices must cover the total costs. In practice, utilities normally adjust water prices once a year when information becomes available about total consumption levels in the previous period[6].

The available data allowed us to include observations for the years 2007, 2010 and 2013 for more than 3300 supply areas located in the federal states of Hesse, North Rhine-Westphalia, Rhineland Palatinate, Saarland, Saxony-Anhalt and Thuringia.

Table 1 describes the variables used in the econometric analysis. Our choice of dependent and explanatory variables closely follows the literature in this field.

2.1 Dependent variable

Similar to the thrust of the empirical literature, we employ water use per capita per year (*water*) as the dependent variable. To calculate *water* in a particular year *t,* we divided the total amount of water sold by a water utility to private households and small businesses by the total number of persons connected to the system in *t*[7]. We subsequently use the term "water consumption" to relate to both the consumption of fresh water and sewage disposal. We collected the

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6 Under this price setting, endogeneity should not be a problem. Employing instrumental variable methods, Schleich and Hillenbrand (2009) found no evidence that water prices in Germany are endogenous.

7 German water statistics do not distinguish between private households and small businesses such as bakeries, butchers, or hair dressers. Thus, the data on water consumption also include the consumption of these small businesses. Our econometric analysis attempts to control for this.

data on water consumption from various reports and databases provided by the statistical offices of the German federal states ("Statistische Landesämter der Bundesländer"). These include data on water sold to single-family houses and apartment buildings in the years 2007, 2010 and 2013.

2.2 Explanatory variables

Our main focus is on price elasticity. Other variables are mainly included as control variables.

2.2.1 Water price

We expect households to respond to water prices and sewage prices; hence our price variable reflects the sum of both. The German law governing prices for water and sewage distinguishes between public and private companies. While prices set by public companies have to cover costs, the prices set by private companies are regulated by antitrust authorities at the state level. Official statistics (DESTATIS, 2018a, 2018b) report the average price for water as 1.69 € per m^3 (in 2013) and for sewage as between 2.30 and 2.60 € per m^3 (in 2016). Many water and sewage tariffs comprise a fixed fee (in € per year per customer) and a volumetric fee (in € per m^3). In our sample, the share of the fixed fee (for water and sewage water) ranges between 0 and 71%. On average, this share amounts to about 26%.

Data on water prices were obtained from different sources (water: DESTATIS, 2018c; sewage: Hessisches Statistisches Landesamt 2018, Statistisches Landesamt Rheinland-Pfalz 2018, Statistisches Landesamt Sachsen-Anhalt 2014; Bund der Steuerzahler Nordrhein-Westfalen 2018, Bund der Steuerzahler Thüringen 2018, Entsorgungsverband Saar 2018). All price variables are expressed in 2010 €. To adjust the figures for the years 2007 and 2013, we used the consumer price indices provided by the German federal statistical office.

2.2.2 Control variables

We include *income* as the average net income of private households, i.e. gross income minus income tax plus transfer payments. Since no data are available at the level of the supply areas, we took income data from DESTATIS (2018d) for the district where the supply area is located. We further note that a district may include more than one supply area, but that supply areas typically do not extend beyond district borders. Most, but not all, empirical studies find the expected positive relation between water consumption and income. Controlling for publication bias, among others, the recent meta-analysis by Havranek et al. (2018) estimates the income elasticity of water demand at 0.15 or even smaller. In our analysis, all income data are expressed in 2010 €.

The variable *size* measures the average number of household members and was calculated as the ratio of the population size and the number of housing units at the municipality level using data from DESTATIS (2018e, 2018f). In the literature, per capita water consumption has been found to vary with household size (e.g. Arbues et al., 2010; Schleich and Hillenbrand, 2009). Since some water uses like cooking, washing or watering the garden increase less than proportional to the number of household members, per capita water consumption is expected to decrease with *size*.

We further include the average *age* of the population in a supply area. The empirical evidence on the correlation of *age* and water consumption appears to be mixed. Nauges and Thomas (2000), Martínez-Espiñeira (2002) and Musolesi and Nosvelli (2007) find age and water consumption to be negatively related, while Schleich and Hillenbrand (2009) found a positive relation. Data on average age were retrieved from DESTATIS (2018g).

To capture heterogeneity in water use in rural versus urban regions, we included population *density*. For example, Reynaud (2016) found per capita water consumption to be positively related to population density in Germany. To construct density per water supply area (or municipality), we divided population by area size (DESTATIS, 2018j).

Finally, the set of covariates also includes information on commuters. In particular, the variable *commuter* is supposed to control for the fact that water consumption data do not distinguish between private households and small commercial businesses. *Commuter* is calculated as the number of net commuters into a water supply area (municipality) divided by area population size. Hence, a positive value means that more people are commuting into an area than commuting out of it. Previous studies, e.g. Schleich and Hillenbrand (2009), did not control for this effect. Data on *commuter* were assembled from DESTATIS (2018h).

Table 1: Description of variables and descriptive statistics (number of observations: 6,768; number of water supply areas: 2,829)

Variable name	Description	Mean	Std. Dev.	Min.	Max.
water	Consumption of fresh water per capita per day [litres]	96.27	25.05	40.1	289.1
price	Volumetric price of water and sewage water [€/1000 litres]	4.19	1.15	0.99	10.33
income	Average net income per capita per year [in €]	17745	2216	14795	29268
size	Average number of household members	2.16	0.24	1.5	3
age	Average age of population [years]	44.39	2.19	36.35	52.24
density	Population density [number of citizens/km^2]	227	339	6	3291
commuter	Net commuters as share of population	-0.10	0.18	-1.84	4.72

2.3 Econometric model

Following the thrust of the empirical literature, we estimated a reduced-form water demand function. Data availability allows us to estimate the following panel model:

$$water_{it} = constant + \beta_1 price_{it} + \beta_2 income_{it} + \beta_3 size_{it} + \beta_4 age_{it} + \beta_5 density_{it}$$
$$\beta_6 commuter_{it} + \beta_7 year2010 + \beta_8 year2013 + \sum_{j=1}^{5} \beta_{8+j} S_j + \varepsilon_{it} \quad (1)$$

where *i* indexes the cross-sectional units (water supply areas) and *t* = 2007, 2010, 2013. To account for year-specific effects, we include two dummies (*year2010 and year2013*) capturing time-specific effects compared to the base year 2007. State-level effects are assumed to be captured by the state dummies S_j. The random variable ε_{it} stands for the usual idiosyncratic error term. In addition, we also estimated a standard Koyck-lag model, which allows calculation of the long-run price elasticity:

$$water_{it} = constant + \delta_1 price_{it} + \delta_2 income_{it} + \delta_3 size_{it} + \delta_4 age_{it} + \delta_5 density_{it}$$
$$+ \delta_6 commuter_{it} + \delta_7 water_{it-3} + \delta_8 year2013 + \sum_{j=1}^{5} \delta_{8+j} S_j + \varepsilon_{it} \quad (2)$$

The long-run price elasticity may then be calculated as $\frac{\delta_1}{1-\delta_7}$.

When calculating equations (1) and (2), we follow the literature and transform *water*, *price*, and *income* into the natural logarithm. Thus, the coefficient of interest β_1 yields the price elasticity of per-capita water demand. Similar to Reynaud (2016), for example, we employ generalized least squares to estimate two types of models.

In the *symmetric response model*, we estimate equation (1) for the entire sample, assuming the price elasticity to be identical for rising and falling prices. In the *asymmetric response model*, we split the sample into two subsamples to allow for an asymmetric response in water demand to rising and falling volumetric prices. One sample includes only supply areas where the marginal price has increased in both periods, i.e. from 2007 to 2010 and also from 2010 to 2013. The other sample includes only observations where the marginal price has fallen in both periods.

3 Results and discussion

We first present and discuss the results for the symmetric response model. Then, we present and discuss the findings for the asymmetric response model.

3.1 Results for the symmetric response model

Table 2 displays the findings for the symmetric response model. Standard errors are clustered at the level of supply areas and reported in parentheses below the parameter estimates.

The point estimate for the coefficient on *price* suggests that the short-run marginal price elasticity is -4.18%, i.e. a one percent change in the volumetric fee leads to a 4.18% reduction in water demand. This value is at the lower end (in absolute terms) of the findings from previous empirical studies for Germany and most other countries[8]. Thus, an increase (decrease) in the volumetric water price is expected to lead to a small increase (decrease) in utility revenues. The coefficient of income is rather small and exhibits the expected sign, but – in contrast to most other studies – it is not statistically significant at conventional sig-

8 Except for the study by Müller (2015), all other analyses of German water demand relied on average prices to estimate the price elasticity.

nificance levels[9]. In line with Schleich and Hillenbrand (2009), a larger household size is associated with lower per-capita water consumption. Age, however, did not turn out to be statistically significant. Similar to Reynaud (2016), population density is positively related with per-capita water use. People living in urban areas tend to use more water than those living in rural areas, ceteris paribus. Finally, as expected, a positive commuting balance raises per capita water consumption, since water consumption data also includes water use by small businesses[10].

For the long-run model, we estimate the price elasticity at -0.13. A nonlinear Wald-type test finds the long-run elasticity to be statistically significant ($\chi^2(1) = 46.24, p < 0.01$). Thus, in line with the existing literature, the long-run price elasticity appears to be larger (in absolute terms) than the short-run elasticity.

To illustrate the effects of using the average price rather than the marginal price to calculate the price elasticity, Table 2 also reports the findings for the average price model. In this case, the short-run elasticity is estimated at -0.26 and the long-run elasticity at -.35 ($\chi^2(1) = 202.27, p < 0.01$). Thus, for both, the short-run and the long-run model, the point estimate of the price elasticity is substantially higher (in absolute terms) for the average price model than the marginal price model[11]. Our findings therefore empirically support the argument by Taylor (1975) and Taylor et al. (2004) that elasticity estimates are biased towards -1 if the average price is used. The findings for the other covariates in the average price model are qualitatively similar to those in the marginal price model.

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9 The recent meta-analysis by Havranek et al. (2018) suggests that, accounting for publication and endogeneity bias, the income elasticity is approximately 0.15 or less. Hence, finding low or even negative values in any particular sample should not be surprising. Also, richer households may be more likely to purchase water-saving devices and more water-efficient appliances, suggesting a negative relation between water consumption and income.

10 In alternative specifications, we also included rainfall and average temperature during summer months (April to September), and the number of wells. However, the coefficients associated with these variables were far from being statistically significant. Also, including these variables lowered the number of observations because of missing data. To save degrees of freedom, these variables were therefore not included in the final specification.

11 However, the samples are not identical, since data on the fixed fee was missing for a few supply areas for some years in the average price model. Using identical samples, we also find that short-run and long-run price elasticities are substantially larger for the average price model than for the marginal price model.

Table 2: Results for the symmetric response model

	marginal price		average price	
	short-run	**long-run**	**short-run**	**long-run**
price	-0.0418***	-0.0520***	-0.2596***	-0.1580***
	(0.0079)	(0.0075)	(0.0141)	(0.0129)
income	0.0159	-0.0074	-0.0410	-0.0387*
	(0.0357)	(0.0212)	(0.0343)	(0.0220)
size	-0.0422***	-0.0320***	-0.0433***	-0.0348***
	(0.0144)	(0.0119)	(0.0136)	(0.0115)
age	0.0027	0.0008	0.0047***	0.0022
	(0.0019)	(0.0014)	(0.0017)	(0.0013)
density	0.0641***	0.0140***	0.0356***	0.0029
	(0.0076)	(0.0050)	(0.0076)	(0.0053)
commuter	0.0655***	0.0337***	0.0452***	0.0200**
	(0.0148)	(0.0083)	(0.0130)	(0.0091)
water (t-3)		0.5993***		0.5547***
		(0.0234)		(0.0239)
year dummies	YES	YES	YES	YES
state dummies	YES	YES	YES	YES
constant	4.6748**	2.1138	5.5477***	2.7725***
	(0.3676)	(0.2549)	(0.3519)	(0.2660)
Observations	6,768	3,938	6,768	3,938
Number of supply areas	2,829	2,096	2,829	2,096

*** p<0.01, ** p<0.05, * p<0.1

3.2 Results for the asymmetric response model

The results for the asymmetric response model appear in Table 3. For the short-run model, we find that the price elasticity is statistically different from zero when prices are rising, but not when they are falling. When prices are rising, the price elasticity is estimated at -0.065. In comparison, both long-term elasticities are statistically significant, i.e. about -0.18 ($\chi^2(1) = 4.22;\ p < 0.05$) when prices are rising, and -0.12 ($\chi^2(1) = 20.63;\ p < 0.01$) when prices are falling. Thus, our findings for the short- and long-run models suggest that there is a stronger response of water demand when prices rise than when they fall.

Table 3: Results for the asymmetric response model

	marginal price (rising in both periods)		**marginal price (falling in both periods)**	
	short-run	long-run	short-run	long-run
price	-0.0651*	-0.0605**	0.0119	-0.0506***
	(0.0358)	(0.0259)	(0.0131)	(0.0105)
income	0.1949*	0.1472*	-0.0563	-0.0322
	(0.1067)	(0.0788)	(0.0653)	(0.0439)
size	0.0737	-0.0244	-0.0628***	-0.0189
	(0.0700)	(0.0521)	(0.0206)	(0.0153)
age	0.0037	-0.0017	-0.0014	0.0025
	(0.0107)	(0.0052)	(0.0027)	(0.0018)
density	0.0650***	0.0228*	0.0909***	0.0216**
	(0.0176)	(0.0129)	(0.0170)	(0.0108)
commuter	0.0929	0.0298	0.0151	0.0689**
	(0.0679)	(0.0390)	(0.0476)	(0.0288)
water (t-3)		0.6419***		0.5788***
		(0.0790)		(0.0294)
year dummies	YES	YES	YES	YES
state dummies	YES	YES	YES	YES
constant	2.6734*	0.4963	5.5122***	2.3503***
	(1.2721)	(0.9027)	(0.6582)	(0.4513)
Observations	405	264	3,349	2,194
Number of supply areas	139	137	1,149	1,126

*** p<0.01, ** p<0.05, * p<0.1

4 Conclusions

Relying on a fairly large panel of water supply areas in Germany, the short-run price elasticity of residential water demand is estimated at around 4.2% in absolute terms. We further find that the long-run price elasticity is around 13%. Both these point estimates are at the lower end of the range found in previous studies. Since a sizeable share of our sample contained observations for periods when water prices were falling, we were able to explore whether water demand responds asymmetrically to rising and falling prices. Indeed, our findings suggest that household water demand reacts more strongly to rising prices than to falling ones. These findings were derived using marginal prices, i.e. volumetric fees of water and sewage water consumption. Our results further show that employing average prices instead of marginal ones results in substantially overestimating the short- and long-run price elasticities.

These findings have important implications for policy making. When adjusting the tariff structure to better reflect the fixed and marginal costs of water supply, utilities and regulators need to recognize that lowering the volumetric fee leads to a demand increase in the long run, although the size effect is likely to be small. In the short run, demand may not react at all to falling volumetric fees. When quantifying the expected demand response to such a change in the tariff structure, decision-makers should rely on elasticities that were derived during periods of falling water prices. Estimates of the price elasticity based on data from periods with rising prices are likely to overstate the increase in water demand in response to falling prices. In this case, adjusting the fixed fee so that the expected revenues for the utility remain largely unchanged - as is often done in practice - would lead to a fixed fee, which is lower than the level needed to keep revenues unchanged. In any case, these assessments should be made using marginal rather than average prices to estimate the price elasticity. Finally, the generally low point estimates for the price elasticity suggest that any direct rebound effects from households implementing water-saving technologies are likely to be small.

Future empirical studies could explore to what extent households' actual knowledge about the level or changes in water and sewage water prices affects demand response. Similar to the finding by Frondel and Kussel (2018) for electricity demand, it may be the case for water that only households with sufficient knowledge respond to price changes.

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