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Estimation of Price and Income Elasticity of Residential Water Demand in the Czech Republic over Three Decades

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Abstract:
Literature on residential water demand is rich, however, there are few estimates of price and income elasticities for Central and Eastern Europe and for countries undergoing economic or political transitions. To cover this gap, we estimate residential water demand in the Czech Republic – which has undergone deep structural, institutional and economic changes over the last three decades. Specifically, we analyse residential water demand from 1993-2016, when the price of water almost tripled, water consumption decreased by a third, and families became considerably richer. Controlling for price endogeneity, our estimates of price and income elasticity indicate low responsiveness of households. The estimate of income elasticity is about +0.16 and robust across all model specifications, and the effect of income is decreasing with household wealth. Price elasticity is low on average, about -0.22, which is on the low end of existing estimates of demand elasticity. While Czech households were more responsive to price changes during the 1990s period of economic transformation, in particular when household incomes were not increasing much, with the implied price elasticity of about -0.50, households became completely price irresponsive during the economic boom in the 2000s, even when the price of water was increasing considerably.

JEL: D12, C33, C36

Keywords: Residential demand, water consumption, 2SLS, price elasticity, income elasticity

1 Introduction

Literature on water demand analysis is huge, providing a large number of estimates of the key demand parameters, the price and income elasticities. Water is a limited resource but the water demand is globally rising (Wada et al., 2011) and therefore, we face the problem of water scarcity, decreasing water affordability, and drought. New pricing mechanisms and complicated water tariff structures are introduced to motivate customers for savings and still to provide affordable basic water consumption and it also induces the brought analyses of the price-quantity decisions. A typical pricing schedule that satisfies both these principles in the same time is an increasing block pricing (Wichman, 2014). Information on water demand elasticity is useful to assess the effect of proposed policies on water consumption and hence paid bills. Water charges is also a key revenue source of utilities that supply water to consumers. Naturally, water tariffs are not exogenous, and price endogeneity needs to be treated in water demand modelling.

Water tariffs are not adjusted by utilities as a response to changes in water consumption. They are affected by public regulation as a response to water scarcity and new requirements on water quality, such the one involved by the European Union (EU) environmental acquis. While demand-side management (including various pricing schemes and water use restrictions) is typically introduced to regulate end-users mainly in dry regions, supply-side water management has been introducing in areas with less developed or obsolete water supply infrastructure. The latter case has been typical for post-communist countries in Central and Eastern Europe that decided to improve water supply, increase water quality, reduce heavy leakages, and improve economic efficiency of water system overall. This was also the case of our case study, the Czech Republic, where a compliance to the EU water directives has been one of the most investment-intensive area. All of the requirements on water supply and water quality has led to continuously increasing price of water that almost tripled in real terms during 1993 to 2016.

The presented study contributes to the literature on water demand elasticity by making its focus on this specific case. Despite the large body of empirical literature on this subject, the estimates of water demand are still very rare as in this country as for the whole Central and Eastern region. This region was not exposed to a problem of water shortage as seriously as the others (comparing especially to countries such as California or Texas, Olmstead et al. (2007); Hanak et al. (2006)), however, recently, droughts mainly due to climate change have been considerably affecting water reservoirs, leading to serious water scarcity problem in some regions.[1] Moreover, our study on residential water demand covers a long period during 1993-2016 during that the Czech Republic faced crucial economic, political and institutional changes. Analysing the micro-level data for such long period allows us to analyse demand for a period when the Czech Republic started its transition from a centrally-planned system in the early 1990's, when it was implementing the EU environmental acquis and become a member of the European Union, and when it was transforming into a developed market economy.

The transformation of centrally-planned communistic regimes into a democratic and market-orientated system, which started in 1989 in the Soviet Block of countries brought dramatic changes in their water sectors. In the Czech Republic, all real costs related to drinking water supply and

[1]Thanks to decreasing water consumption, increasing share of households connected to water supply, and decreasing water leakages, vulnerability of water supply sector in the Czech Republic on water shortage is decreasing and hence the state is evaluated as favourable (CENIA, 2019). However, in the case of longterm droughts, water shortage in water reservoires has been considered the key problem, since droughts lead to reducing quality and availability of drinking water in reservoires (National Plan for Climate Change Adaptation of the Czech Republic, MoE (2015)).

wastewater treatment were financed through state budget until then, resulting in unrealistically very low, in some cases even zero, user charges. That situation induced over-consumption of drinking water by households and firms and heavily polluted rivers and water reservoirs. After 1990, economic instruments and rationale started to be implemented in the water sector. As a result, and together with a water quality improvement effort, the real price of drinking water supplied to the Czech households increased by almost 60 % between 1993 and 2000. Implementation of the European Union water quality regulation induced additional investment effort, and the real price of drinking water increased by another 30 % between 2000 and 2008 and continue to rise by another 30 % between 2009 and 2016. Economic and social conditions of the Czech households have also rapidly improved after 1989, especially since 1993 when household private consumption started to grow and increased in real terms by 18 % in 2000. Since that the consumption expenditures of households were increasing further and even faster and were 26 % higher in 2008 compared to its 2000 level. After the economic crisis (2009-2012), since 2015, expenditures have been increasing again by 3.5 % p.a.

This paper aims to provide one of the first sets of residential water demand estimates for a country from Central and Eastern Europe, using individual household-level data and covering a 24-year long period, encompassing some significant structural change and a significant increase in water price. This dataset is unique in the sense that the changes in residential water price are much larger than in any existing study, as far as we know, though this period covers a bit more than two decades.

Over the whole 24-years long period analysed in this study, the payment mechanism and price structure have not changed, keeping a one-part tariff linked to cubic meters. Although the tariff rate has increased considerably, the water budget share has been declining as disposable household income was increasing, especially in the last decade. This setting allows us to analyse sensitivity of household water demand on considerably large price increases accompanied by smaller or lager increases in incomes.

The paper is structured as follows. Next section provides a review of the literature. Section 3 presents the institutional context of socio-economic changes in the water sector in the Czech Republic. The data is described in Section 4, and the econometric model with the corresponding estimation results are presented in Section 5. Section 6 concludes.

2 Literature review

Water demand estimation using data from developed countries has been the focus of many empirical papers, starting with the work of Gottlieb (1963) and Howe and Linaweaver Jr (1967). Studies have been made in a large number of countries including Australia (Grafton and Ward, 2008), Canada (Kulshreshtha, 1996), Denmark (Hansen, 1996), France (Nauges and Thomas, 2000), Spain (Martínez-Espiñeira, 2002), Sweden (Höglund, 1999), Germany (Schleich and Hillenbrand, 2009), Italy (Romano et al., 2014; Musolesi and Nosvelli, 2007) and especially the US (Foster and Beattie, 1979; Agthe and Billings, 1980; Chicoine et al., 1986; Nieswiadomy and Molina, 1989; Hewitt and Hanemann, 1995; Pint, 1999; Renwick and Green, 2000). For comprehensive reviews of this literature, see Arbués et al. (2003), Dalhuisen et al. (2003), or Worthington and Hoffman (2008). Estimates of residential water demand from Central and Eastern European countries are still quite rare, except for Dalmas and Reynaud (2004, Slovak Republic), Bartczak et al. (2009, Poland), OECD (2011, Czech Republic), and Hortová and Krištoufek (2014, Czech Republic).

Most existing analyses have been based on data aggregated at the community or utility level. Household level data are better suited for analysing economic decisions (such as household consumption) taken at the household level. Such data also allows us for better control of household heterogeneity based on socio-demographic characteristics or/and characteristics of the household's place of living (size of the residence, number of water-using appliances). In particular, one can check whether the household's response to price changes depends on the household's characteristics such as income or family size (Arbués et al., 2010).

Most of these studies find that household water demand is both price and income inelastic. Espey et al. (1997)'s meta-review of 124 estimates reports an average own price elasticity of -0.51 for industrialized countries. Dalhuisen et al. (2003) explore 296 price elasticity estimates to provide an overall mean value of price elasticity at -0.41 (median is -0.35). Grafton et al. (2011) using household level data from ten OECD countries provides central value of the elasticity estimate for the average price at -0.43, while OECD (2011), using data from the same 2008 OECD survey, reports a price elasticity close to -0.6 specifically for the Czech Republic. Hortová and Krištoufek (2014) were inspired by Musolesi and Nosvelli (2007) and estimated short-run and long-run price elasticities on regional panel data for 2000-2011. Employing OLS estimation method on log-log model, they found out the water demand to be more elastic in the long-run (-0.54) than in the short-run (-0.20). The income elasticity was determined to be 0.10. They focused on household's size when estimating the water demand in Kladno (city in the central Bohemia region) and found out the short-run and long-run elasticities to be decreasing with increasing household size. Using data from a sample of 71 municipalities from Slovakia (data from 1999 to 2001), Dalmas and Reynaud (2004) find a price elasticity which varies between -0.5 and -0.3 depending on the specification of the water demand equation. Bartczak et al. (2009) examines the water demand in Poland. They determine price elasticity equal to -0.22 and income elasticity 0.12 on the sample of 50 000 inhabitants from large cities between 2001 and 2005. Schleich and Hillenbrand (2009) study the residential water demand in Germany. Employing several model specifications (log-log model and both semi-log variants) they determine similar results leading to price elasticity to be -0.24 and income elasticity 0.36.

Income elasticity has often been estimated in the range from +0.1 to +0.4 (see Arbués et al. (2003)). Very recent meta-analysis of Havránek et al. (2018) of 307 estimates of income elasticity from 62 studies reports the average value equal to 0.26. However, their analysis reveals that estimates accounting for endogeneity bias suffer from publication bias linked to the sign of the estimate and its significance. On the contrary, analyses that suffer from endogeneity bias are overestimated. Finally, they report the income elasticity corrected for publication bias to be equal to 0.15. Other households' characteristics (size and composition), housing characteristics (principal versus secondary residence, size of the garden (if any), stock of water-using appliances) and weather data (temperature, precipitations) are commonly acknowledged as determinants of water use (Worthington and Hoffman, 2008; Arbués et al., 2003).

In almost all studies with basis in industrialized countries, the demand for water is specified as a single equation linking (tap) water consumption q (the dependent variable) to water price p and a vector of demand shifters $\mathbf{x}$ (household socioeconomic characteristics, housing features, weather variables, etc.) to control for heterogeneity of preferences and outside variables affecting water demand:

$$q = f(p, \mathbf{x}) + u \tag{1}$$

The error term u is added to this relationship to account for unobservables and/or measurement errors in variables. In most cases, function f has been chosen to be linear in the parameters. A very popular functional form is the double-log, which yields direct estimates of elasticities but constrains the elasticity to be constant.[2]

Water as energy is usually sold using non-linear pricing schemes, mostly relying on increasing block tariffs. In such case, economic theory suggests the use of marginal price (the price of the last cubic meter) rather than the average price although the estimates have often been based on the latter. Authors who use average price argue that households are rarely well informed on the price structure and are thus more likely to react to average price than to marginal price. Households' sensitivity to marginal price or the average price remains an empirical question.[3] In a similar vein, Ito (2014) found that consumers in California were not bunching at the end of each electricity tariff block as they should if there were responding to the marginal price. This issue is however not relevant for our study, as a one-part linear water charge has been applying during the whole analysed period.

The correlation between the price of water and household's or community's characteristics has been less often discussed. Nauges and Thomas (2000) argue that "*endogeneity of water price may be caused either by instantaneous consumption entering average price, or correlation between price and unobserved heterogeneity, or both. [...] It may be the case that water utilities charge residential water prices depending on local communities' characteristics such as average revenue, municipal debt, or population density.*" Using panel data from 116 French communities, they find evidence that price is partly determined by some community-specific socio-demographic characteristics.

3 Institutional background

Before 1989, all costs related to river basin management, provision of drinking water and wastewater treatment were fully financed through state budget in the Czech Republic. As a consequence, the real price of drinking water that was charged to households was unrealistically low, in some cases drinking water was even supplied for free. It resulted in overuse of drinking water and overexploitation of water resources. Simultaneously, lack of resources and weak preference of communistic social planners for the quality of the environment led to over-pollution of surface and groundwater.

The social and economic transformation of centrally-planned communistic regimes in Central and Eastern European Countries into democratic and market-orientated systems, which started in 1989, also brought dramatic changes in the water sector. After 1989, the economic rationale started to be implemented. First, cross-subsidies between drinking water providers and sewage system utilities were abolished. Since then, each type of utility (water provider and sewage system operator), had to charge a price that covers operational and maintenance costs. These price

[2]There are few discussions on the choice of functional form, except for Griffin and Chang (1991) who advocated more flexible forms such as the generalized Cobb Douglas and Gaudin et al. (2001) who discuss the trade-off between simplicity and parsimony of parameters.

[3]The (only) theoretically consistent approach in the literature is the two-step approach describing the choice of the block (first step) and the choice of consumption inside the block (second step), see Burtless and Hausman (1978), Hewitt and Hanemann (1995) for an application to the water sector). This approach is appealing only if households are aware of the water pricing scheme. Whether or not households know the price of water is likely to depend on factors such as the share of water bill in overall expenditure, the complexity of the water pricing scheme, the frequency of billing, and the education level in the household.

policy changes have induced continuous increases in drinking water prices. Second, economic instruments started to be introduced and better enforced. Pollution charges for effluents discharged into water bodies were paid by sewage and wastewater utilities. This generated around 30 million EUR at the beginning of the 1990s (and since 1996 about 15 million EUR each year), which were paid to the Czech State Environmental Fund. Each water provider then has to pay a water extraction charge to the municipality (for groundwater), or to the river basin administration (for surface water). Third, although the price for drinking water, i.e. water user charges, has remained controlled by the Czech Ministry of Finance, the water price is set by each water utility. According to the Act No. 526/1990, the cost is calculated based on economically-justified costs including adequate profit. Despite the state intervention in price setting, utilities still have a large control on prices. Fourth, state-owned utilities were privatised in the so-called second wave of voucher privatisation that happened in 1994-1995 in the Czech Republic. Since then, new owners (mainly municipalities) and utility operators have started to price water according to operational and maintenance costs. Some years later, capital depreciation and reserves for future investment have been taken into account when setting the price, although how widely these cost items are considered in the price setting depends entirely on water utilities.

Since 2000, the environmental acquis communautaire has been more widely implemented in the Czech Republic before becoming an EU member (which happened in May 2004). This effort has induced huge investment particularly related to the Water Framework Directive that required building up wastewater treatment plants in municipalities with more than 2,000 population-equivalents.

As a consequence of bringing economic rationale into the water sector and the wide effort to improve water quality in the Czech Republic, either induced by the Czech authorities at the beginning of the 1990s or by the implementation of EU Directives since 2000, the situation in the water sector significantly improved. For instance, drinking water coverage increased from 82 % in 1993 to 94 % in 2016, the share of the population living in houses connected to sewage systems increased from 73 % to 85 %, and the number of connections to wastewater treatment plants increased from 52 % to 81 % (see Table 1). Moreover, water leakages, measured by the share of water produced, which is lost before reaching customers' tap, decreased from 29 % to 15 % between 1993 and 2016.

To better reflect costs in the pricing system the water price paid by the Czech households has been consisting of two components: a charge covering drinking water supply is set by each utility, and a charge for sewage and treatment is calculated following formulae given by law. Both price components are set as a one-part tariff, with a flat rate, implying that each household face a specific price per cubic meter of water delivered, collected and treated. Each utility calculates both price components taking into account its estimated operational and maintenance costs and residential water use at the beginning of each year. Bill adjustments are made at the end of each calendar year when the amount of water sold to the residential sector is known.

4 Description of the data

There are three different groups of residential consumers: consumers who are connected to both water supply and water sewage, consumers who use water from their own well and are either connected to sewage or use their own septic. In this paper, we analyse the former group of

Table 1: The water and wastewater network in the Czech Republic (1993-2008)

Year	Drinking water coverage [%]	Population living living in houses connected to sewerage systems [%]	Population living in houses connected to sewerage systems with WWTPs$^{(a)}$ [%]	Water losses [%]	Number of WWTPs$^{(a)}$ [%]
1993	82%	73%	52%	29%	677
1994	82%	73%	55%	29%	744
1995	81%	73%	56%	30%	783
1996	82%	73%	58%	31%	836
1997	83%	74%	59%	29%	870
1998	83%	74%	62%	27%	912
1999	84%	75%	62%	26%	959
2000	85%	75%	64%	25%	1,055
2001	85%	75%	65%	25%	1,122
2002	87%	77%	67%	24%	1,234
2003	88%	78%	69%	23%	1,410
2004	92%	78%	71%	21%	2,006
2005	92%	79%	73%	21%	1,994
2006	92%	80%	74%	21%	2,017
2007	92%	81%	75%	19%	2,065
2008	93%	81%	76%	19%	2,091
2009	93%	81%	76%	19%	2,158
2010	93%	82%	77%	20%	2,188
2011	93%	83%	78%	19%	2,251
2012	93%	83%	78%	19%	2,318
2013	94%	83%	79%	18%	2,382
2014	94%	84%	80%	17%	2,445
2015	94%	84%	81%	17%	2,495
2016	94%	85%	81%	15%	2,554

(a) wastewater treatment plants

households, which represent 92 % of families recorded in the FBS.[4]

To analyse household behaviour, we rely on a rich household-level dataset based on the Family Budget Surveys (FBS) conducted yearly since 1993 by the Czech Statistical Office.[5] This household-level database includes variables on income, expenditures, household and house characteristics, along with expenditure for drinking water supplied at home. This dataset does not contain any information on the quantity of water used by each household. Therefore, water use is computed by dividing the household's expenditure by the region-specific price. The FBS also includes infor-

[4]We decided not to include households who are not connected to the sewage system (about 8 % of our initial sample) since these households face only the user charge for supplied water. We believe that this decision will not induce any selection bias for the main reason that the payment for wastewater is related to the type of housing (92 % of the households who pay for the water service only live in detached houses and another 3 % in row houses). We also remove from the sample households who are not connected to any water supply system (21 observations overall).

[5]Households are selected using the non-probability quota sampling technique. The database contains a weight variable indicating how many households each household included in the FBS survey represents. The dataset is a rotating unbalanced panel, i.e. each household remains in the survey for several years (four at the maximum). The finest geographical identification for each household is the district code (our sample covers more than 90 districts).

mation on the number and year of purchase of washing-machines (automatic or non-automatic) and dishwashers. We present some descriptive statistics for households' socio-demographic characteristics, characteristics of the place of residence, and ownership of water devices in Table 2.

Table 2: Main characteristics of households and residence places

Variable name	Variable description	Mean	Std Dev	Min	Max
Socio-demographics					
size	number of family members	2.5	1.19	1	8
children	number of children in a family	0.74	0.93	0	6
children_5	number of children younger than 5 years	0.17	0.44	0	3
childless	dummy; family without children	0.55	0.5	0	1
single	dummy; single-person household	0.23	0.42	0	1
single_male	dummy; if single is male	0.05	0.22	0	1
female	dummy; female present in the household	0.27	0.44	0	1
retired	number of retired persons in a family	0.36	0.64	0	3
less_prom	dummy; highest education in the family less than graduate school	0.3	0.46	0	1
more_prom	dummy; highest education in the family more than graduate school	0.18	0. 38	0	1
hhownbus	dummy; self-employed head of a family	0.14	0.35	0	1
income	net household monthly income in CZK in 2005 prices	22,461	12,407	148	340,805
monthnot12	dummy; family less than 12 months in the survey	0.08	0.27	0	1
Flat and house characteristics					
village1	dummy; less than 1,000 inhabit.	0.09	0.29	0	1
village2	dummy; less than 5,000 inhabit.	0.16	0.36	0	1
rental	dummy; family rents their flat	0.28	0.45	0	1
cooperative	dummy; family lives in a cooperative flat	0.22	0.42	0	1
own	dummy; family owns their flat or house	0.47	0.5	0	1
singlefamhse	dummy; family living in a single-family house (detached) house	0.23	0.42	0	1
rowhouse	dummy; family living in a row house or mirror image houses sharing side walls	0.04	0.19	0	1
paidhotwater	dummy; hot water included in water bill	0.54	0.5	0	1
Devices					
dishwashers	number of dishwashers	0.17	0.38	0	2
washmachines	number of automatic washing-machines	1.07	0.39	0	4

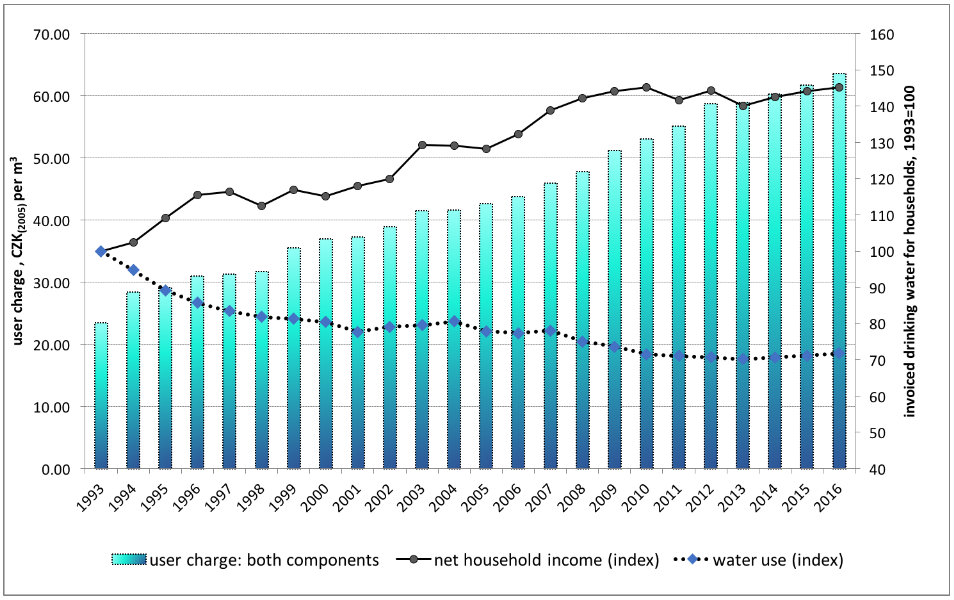
N=58,297

Our dataset covers the period 1993-2016 and includes 69,416 observations overall and there are 64,039 families qualifying our selection criteria (to be connected to both systems). We also remove from the sample households with zero or negative water expenditures (11% of the initial sample), resulting in 58,297 observations used in the analysis.[6]

Over the years 1993-2016, the Czech households analysed in this paper spent on both water supply and wastewater services on average 3,245 CZK (in 2005 prices). Water expenditures represented on average 1.4 % of total household net income. At the beginning of the analysed period it amounted to 1.1 %, and since then it has been continuously increasing to 1.6 % at the end of

[6]In order to check for the robustness of our water demand estimates, we estimated a Tobit model using a sample which includes those non-positive observations. Our results were found to be similar to the ones discussed later.

Figure 1: Index of household water consumption (base 100 in 1993), user charge for water and wastewater, and index of net household income (base 100 in 1993)



Note: The value-added tax rate on water services has changed several times during the given period: it was 5 % 1993-2007, 9 % 2008-2009, 10 % 2010-2011, 14 % 2012, and 15 % 2013-2016

the period. This low share is common to observe in developed countries, especially with cold or mild climate. One may, therefore, expect low price elasticity, in particular when the price was relatively flat.

Since the FBS does not record quantity, nor specific charge each family was facing to, for the purpose of our empirical modelling, we collect region-specific data on the water supply charge and the wastewater charge from the Czech Statistical Office, and we add up the year-specific value-added tax to get final price. All prices (as well as all monetary values in our database) have been transformed in 2005 real prices using the Consumer Price Index. Although water price may vary within each region, we consider the average regional price as a good proxy for the price that is charged by all water utilities in each region.

Figure 1 displays the national average price of water and wastewater combined ("user charge: both components") between 1993 and 2016. The combined water and wastewater charge has increased from 23.4 CZK per cubic meter (or equivalently 0.8 EUR[7]) in 1993 to 63.6 CZK per cubic meter (2.1 EUR) in 2016, which corresponds to an average rate of increase of 4 % per year. The increase in the price of drinking water led to a decrease in the volume of water billed: the average water consumption per capita (index = 100 in 1993, Figure 1) has decreased by 28 % from 1993 to 2016, concretely from 43 m^3 per year in 1993 to 31 m^3 in 2016.

As discussed in the previous section, huge investment in water infrastructure over the years 1993-2016 led to a significant increase in the number of water connections (from 1 215 767 to 2 102 999), a significant increase in connections to sewage systems and in the volume of treated wastewater (see Table 1). The expansion of the water supply and wastewater networks in turn changed the cost structure of water utilities and impacted prices. We gather region-specific in-

[7]To convert Czech crowns (CZK) into Euros (EUR), we use the exchange rate as of the year 2005: 29.78 CZK for 1 EUR. For comparison, the exchange rate with the USD was 23.95 CZK per USD.

formation on the water and wastewater utilities from the Czech Statistical Office, including the length of water supply system [$lngth\_supp$], length of sewerage system [$lngth\_sew$], share of treated wastewater in water discharged into sewerage systems [$treated$], quantity of invoiced water in m^3 [$invoiced$], share of losses in pipeline networks in produced drinking water [$leakage$], and number of wastewater treatment plants [$wwtp$]. This information has been gathered for 8 regions over the years 1993-1999 and for 14 regions since 2000, making a total of 294 region- and year-specific observations for each variable[8]. Table 3 reports some descriptive statistics.

Table 3: Regional variables on population and characteristics of the water and wastewater network

Variable name	Variable description	Mean	Std Dev	Min	Max
lngth_supp	Length of water supply system per capita [m/person]	6.59	1.96	2.51	11.41
lngth_sew	Length of sewerage system per capita [m/person]	3.29	1.2	1.29	6.46
treated	Share of treated wastewater in water discharged in the sewerage system [%]	93.63	7.14	45.6	100
invoiced	Invoiced water per capita [m^3/person]	5.11	1.12	3.69	9.8
leakage	Share of losses in pipeline networks in produced drinking water [%]	21.16	5.9	10.25	48.01
wwtp	Number of wastewater treatment plants per capita [n/100 000 persons]	18.53	10.86	1.15	52.95
wwtpPrague	Number of wastewater treatment plants per capita [n/100 000 persons] in Prague	0.14	0.5	0	2.2

N=294

For the analysis, we combine the region-specific data on water prices and water utilities with comprehensive household-level dataset formed from the Family Budget Survey described above.

5 Estimation of the residential water equation

5.1 Description of the model

The residential water demand function is specified as follows:

$$log(Q_{ijt}) = \beta_0 + \alpha_{P_{-1}} log(\hat{P}_{j(t-1)}) + \alpha_{P_0} log(\hat{P}_{jt}) + \alpha_I log(I_{it}) + \mathbf{X_{it}}\beta + \lambda_\mathbf{t} + \mathbf{v_{ijt}} \quad (2)$$

where Q_{ijt} is monthly water consumption by household i (belonging to region j) in year t, P_{jt} is the average (regional) price of water charged to household living in region j in year t, I_{it} is monthly income of household i in year t, X_{it} is a vector gathering socio-demographic characteristics of the household as well as characteristics of the place of living, λ_t are time-specific effects, and v_{ijt} is the idiosyncratic error term, assumed of mean 0. Alpha coefficients are equal to own-price and income elasticity, respectively.

As water quantity consumed is not directly observed and is determined as expenditures for water divided by the regional price that is thus on both sides of the equation, we control for possible spurious correlation using instrumental variables. We proceed in two stages. First, we estimate the relationship between the price for water and wastewater and a set of technical characteristics of the water and wastewater operators. Second, we estimate the residential water demand model using the instrumented price instead of the observed price.

[8] The list of regions is provided in Table A1 in Appendix.

5.2 Estimation result

Price equation

The dependent variable is the average regional price (including the charge for the water supply service, the charge for the wastewater and treatment service, and the value-added tax) charged to residential users. All prices are transformed to 2005 real prices. On the other side of the equation, there are technical characteristics of the water supply system and wastewater sewerage system. All variables are region-specific and increasing in time. We include in the equation region-specific fixed effects as the level of price is different in each region and then increasing in time. There are 14 regions after 1999 that can be associated in previous 8 regions with small nuances. To avoid the spurious correlation between price and independent variables (all increasing), we add a time variable to the equation. Beside the technical variables and time variable, we include the rate of tax imposed on the water and wastewater price, which increased during the analysed period from 5 to 15 %. The results are give in Table 4.

Table 4: Price model: Ordinary Least Square estimation results

Variable name	Variable description	Parameter estimate	Standard error	Pr>t
	Intercept	41.924	21.444	0.051
lngth_supp	Length of water supply system per capita [m/ person]	-5.783	1.515	0
lngth_supp_sq	Square of lngth_supp	0.37	0.089	0
lngth_sew	Length of sewerage system per capita [m/person]	3.999	1.499	0.008
lngth_sew_sq	Square of lngth_sew	-0.96	0.178	0
invoiced	Invoiced water per capita [m^3/person]	-0.078	0.042	0.064
leakage	Share of losses in pipeline networks in produced drinking water[%]	0.171	0.088	0.051
treated	Share of treated wastewater in water discharged in sewerage system [%]	-0.846	0.428	0.048
treated_sq	Square of treated	0.006	0.002	0.015
wwtp	Number of wastewater treatment plants per capita [n/100 000 persons]	0.135	0.072	0.062
wwtpPrague	Number of wastewater treatment plants per capita [n/100 000 persons] in Prague	7.009	2.536	0.006
tax	Rate of value added tax imposed on water [%]	0.644	0.151	0
time	level variable for different years	1.555	0.103	0
R_prague	Reference region – Prague	-	-	-
R_central	dummy; region Central Bohemia	21.11	5.012	0
R_south	dummy; region South Bohemia	26.214	4.777	0
R_west	dummy; region West Bohemia – Pilsen, Carlsbad	19.13	5.072	0
R_north	dummy; region North Bohemia – Ústí n. Labem, Liberec	25.555	4.689	0
R_east	dummy; region East Bohemia – Hradec Králové, Pardubice	21.256	4.981	0
R_smoravia	dummy; region South Moravia – Vysočina, Zlín, South Moravia	21.798	5.225	0
R_nmoravia	dummy; region North Moravia – Olomouc, Moravia-Silesia	15.616	5.047	0.002
	Number of observations	294		
	Adjusted R-square	0.9478		
	F (19, 274)	281.19		

The total number of observations is 294, covering years from 1993 to 2016. The price equation is estimated by Ordinary Least Squares (OLS), and the standard errors are determined using the bootstrap method as the estimate has characteristics of panel data. The adjusted R-square is 0.95, and all variables are significant at the 5 % or 10 % level of significance. Several specifications have been tested, and we present here the one with the highest adjusted R-square.

Firstly, we include the length of the water supply system and sewerage system per capita. The supply system has been developing rapidly between 1993 and 2004 (see Table 1) and then the development stopped. For the sewerage system, the situation was the opposite. It developed slowly at the beginning of the analysed period and then faster after 2004. The investments in water systems spilt over from the supply system into the sewerage system. Hence, we add squared terms of both variables and expect opposite signs. Negative sign at level term and positive sign at squared term for water supply system and opposite behaviour for the sewerage system. The estimate fulfils our expectation, and the price is increasing with the rapidly increasing length of supply and sewerage system.

The coefficient for invoiced water per capita is negative, thus on average, with a larger quantity of produced water invoiced to inhabitants, the fixed costs (for maintenance, operation and development of water systems) are better dissolved between the customers, and the price can be smaller. Next, with a higher share of water losses in the pipeline network, the price is higher as well, all other things equal. We find a non-linear effect of the share of treated wastewater in water discharged into sewerage systems. In our sample, the marginal effect of the share of treated wastewater on price is negative. We include the total number of wastewater treatment plants (WWTP) per capita in different regions that is increasing over the time, and this construction of new plants increases the water price. The special case is the number of plants in Prague region, which was increasing very slowly during the period in comparison with other regions (e.g., the number of plants in Prague increased from 15 to 26 and in Central Bohemia from 98 to 495). We filter the effect of the number of WWTP in Prague by additional variable $wwtpPrague$ that increases the price as well. Finally, the price is increasing in time and with increasing tax rate. All region-specific dummy variables are positive with respect to the reference Prague region.

Residential water demand equation

Several specification tests have been performed on the residential water demand equation. The models that are presented here provide the best fit to our data (Table 5 and 6, time dummies are presented in the Appendix). The dependent variable is the logarithm of household annual water use. Price and income are measured in logarithms, so the coefficients of the price and income variables correspond to price and income elasticities, respectively. The standard errors are estimated by the bootstrap method as we estimate the 2SLS model in two separate steps. Outlier analysis showed that there are households with extremely low and extremely high water consumption in our dataset. We decided to conduct our estimates omitting 2 % of observations with the lowest consumption (approximatively less than 10 litres per person per day) and 2 % with the highest consumption (more than 277 litres per person per day). Hence, our dataset reduced to 55,965 observations. The generally reported average consumption is 70-75 litres per person per day.[9]

[9]Considering the average consumption of water, it can be distinguished according to usage purpose as human consumption (drinking, cooking), washing and maintenance (dishwashers, washing machines) or gardening. Our dataset only offers a possibility to account for purchase of bottled non-alcoholic beverages that could influence the water consumption for drinking. We have verified the usability of such variable and found out to be negligible as

To assess the effect of price endogeneity and delay of price effect in the demand equation, we compare the outcome of four models: model 1 - residential water demand equation with current price and no instrumented price; model 2 - water demand equation with current instrumented price; model 3 - water demand equation with current and lag instrumented price; model 4 – water demand equation with lag instrumented price.

Table 5: Estimation results – model 1 and 2

Variable name	Variable description	No IV price **Model 1**		IV price **Model 2**	
		Coef.	P-value	Coef.	P-value
	Intercept	0.946***	0.000	0.462***	0.000
l(price)	Log of the water price	-0.390***	0.000	-0.238***	0.000
l(income)	Log of income	0.155***	0.000	0.155***	0.000
size	Number of family members	0.180***	0.000	0.181***	0.000
children_5	Number of children younger than 5 years	-0.059***	0.000	-0.059***	0.000
retired	Number of retired persons	-0.031***	0.000	-0.031***	0.000
female	dummy; female present in the household	0.061***	0.000	0.061***	0.000
single	dummy; single-person household	-0.352***	0.000	-0.351***	0.000
rental	dummy; family rents their flat	0.318***	0.000	0.317***	0.000
cooperative	dummy; family lives in a cooperative flat	0.147***	0.000	0.146***	0.000
own	dummy; family owns their flat or house	0.123***	0.000	0.120***	0.000
paidhotwater	dummy; hot water included in water bill	0.039***	0.000	0.038***	0.000
village1	dummy; less than 1,000 inhabit.	-0.484***	0.000	-0.486***	0.000
village2	dummy; less than 5,000 inhabit.	-0.247***	0.000	-0.247***	0.000
less_prom	dummy; highest education in the family less than graduate school	-0.013*	0.025	-0.012*	0.034
more_prom	dummy; highest education in the family more than graduate school	-0.018**	0.005	-0.018**	0.003
hhownbus	dummy; self-employed head of family	0.071***	0.000	0.070***	0.000
singlefamhse	dummy; family living in detached house	0.064***	0.000	0.067***	0.000
rowhouse	dummy; family living in terraced house	0.114***	0.000	0.115***	0.000
washmachines	number of automatic washing-machines	-0.027***	0.000	-0.027***	0.000
dishwashers	number of dishwashers	0.025***	0.000	0.024***	0.001
monthnot12	dummy; family less than 12 months in the survey	0.036***	0.000	0.036***	0.000
	Number of observations	55,965		55,965	
	Adjusted R-square	0.367		0.365	

* p<0.05, ** p<0.01, *** p<0.001

Firstly, comparing Model 1 and Model 2, we can see that due to the spurious correlation the price elasticity is overestimated by more than 60 % (the elasticity is estimated to be -0.390 compared to -0.238). Hence, we use in all other specifications the instrumented price. The second specification task arising with the price definition is the employment of current prices or past prices. We hypothesize that consumers react to the prices of the previous year as they are not usually informed about the current prices. They receive an invoice for water use once a year where the total price is adjusted to the real consumption. Hence, they are informed about the price for past year. To get know the current price they would have to ask the providing distribu-

average consumption of bottled water per household per month is about 23.5 l in our dataset comparing to 6,555 l of water use per household and month

Table 6: Estimation results – model 3 and 4

Variable name	Variable description	No IV price **Model 3**		IV price **Model 4**	
		Coef.	P-value	Coef.	P-value
	Intercept	0.946***	0.000	0.462***	0.000
l(price)	Log of the water price	-0.028	0.711	-	-
l(price$_{t_1}$)	Log of the lag water price	-0.191**	0.010	-0.216***	0.000
l(income)	Log of income	0.155***	0.000	0.155***	0.000
size	Number of family members	0.180***	0.000	0.180***	0.000
children_5	Number of children younger than 5 years	-0.062***	0.000	-0.062***	0.000
retired	Number of retired persons	-0.032***	0.000	-0.032***	0.000
female	dummy; female present in the household	0.061***	0.000	0.061***	0.000
single	dummy; single-person household	-0.350***	0.000	-0.350***	0.000
rental	dummy; family rents their flat	0.306***	0.000	0.306***	0.000
cooperative	dummy; family lives in a cooperative flat	0.133***	0.000	0.133***	0.000
own	dummy; family owns their flat or house	0.120***	0.000	0.120***	0.000
paidhotwater	dummy; hot water included in water bill	0.055***	0.000	0.055***	0.000
village1	dummy; less than 1,000 inhabit.	-0.487***	0.000	-0.487***	0.000
village2	dummy; less than 5,000 inhabit.	-0.244***	0.000	-0.244***	0.000
less_prom	dummy; highest education in the family less than graduate school	-0.012	0.052	-0.012*	0.037
more_prom	dummy; highest education in the family more than graduate school	-0.017**	0.006	-0.017**	0.007
hhownbus	dummy; self-employed head of family	0.070***	0.000	0.070***	0.000
singlefamhse	dummy; family living in detached house	0.049***	0.000	0.049***	0.000
rowhouse	dummy; family living in terraced house	0.098***	0.000	0.098***	0.000
washmachines	number of automatic washing-machines	-0.028***	0.000	-0.028***	0.000
dishwashers	number of dishwashers	0.024***	0.000	0.024***	0.000
monthnot12	dummy; family less than 12 months in the survey	0.033***	0.000	0.033***	0.000
	Number of observations	53,292		53,292	
	Adjusted R-square	0.364		0.364	

* p<0.05, ** p<0.01, *** p<0.001

tor. We have also tried to include second lag of price but we decided to continue the model with one lag as such model had better performance and we consider it to be closer to the reality. Model 3 shows that including both current and lag price, the lag price is significant. Model 4 includes the lag price only, and we can see that the total price elasticity remains the same, -0.219 in Model 3 and -0.216 in Model 4. Model 2 includes the current price only, and the elasticity is slightly higher as the prices are higher than the prices of the previous year.

Income elasticity is estimated at +0.16 in all four models. Next, we find that the number of household members and the presence of a woman has a positive effect on water use, increasing water use. On the other hand, the number of children younger than 5 years and the number of retired persons resulted in lower water consumption. The single households have lower water consumption as well. Ownership status induces lower water consumption comparing to the rental or cooperative housing. Owners usually get direct incentives to save water since they pay for their water consumption (which is usually not the case for renters). Owners can also benefit from the adoption of water saving devices, while renters need not have such strong incentive to invest in devices with long lifetime (see Millock and Nauges (2010)). Households living in smaller cities and better educated households are found to consume less, on average. Better educated households are usually known to be more sensitive to environmental issues and could thus pay greater attention to their water use. Living in smaller cities may be related to more possibilities to capture rain water and hence to reduce water consumption supplied by a utility or lower water use may just reflect different habit or lifestyle when living in a village. Higher water demand of families living in a single-family house and in particular in a row house may be associated with higher needs for gardening or maintenance, even when there are more opportunities to capture rain water than in a multi-family apartment buildings. Our dataset does not allow for controlling for the water usage for gardening, thus we controlled in a demand model for outdoor temperature, this effect was not significant as, for instance, in Romano et al. (2014) or Schleich and Hillenbrand (2009). Consumption is increased when the family head operates its own business, which could be explained by free-lance or some small-business activities taking place at home in most cases.

Households with a greater number of washing-machines consume less, on average, which can be due to the fact that households would have more washing machines in a transitional period and thus the new machines are more economical. Households with a greater number of dishwashers consume more, on average. Households who are charged for their hot water consumption in their water bill and not through their energy bill (the variable $paidhotwater$ is equal to 1) have a higher consumption all other things equal, which is as expected.

Testing for heterogeneity in price and income response

Using model 4 as a basis, we tested the heterogeneity of price response across time and households by interacting the instrumented lag price (in the log) with time dummies and household's characteristics (see Table 7, time dummies are presented in the Appendix). We find evidence that

i) price elasticity is changing over the period. Specification tests indicate that four sub-periods should be considered: 1994-97 (price elasticity estimated at -0.431), 1998-2001 (-0.556), 2002-2010 (-0.055 not significant), and 2011-2016 (0.271). During the first period, after the Velvet revolution, consumers started to learn about the water price for the first time, and the price elasticity was expected to be high. In the following period, they were changing their habits towards water consumption and realised the ways to save the water. Before the financial crisis in 2008, the income of households was rapidly increasing, and at the same time, it is not possible to continuously decrease the consumption. Hence, the zero price elasticity is not surprising. The same holds for the last period during which the households become richer and the consumption slightly increased. Moreover, the change in prices is very small between years, and thus the positive price elasticity is not unexpected (see Model 5, Table 6);

ii) a single-person household is less responsive to price changes, all other things equal (the coefficient of the cross-term for singles is equal to 0.096; see Model 6). This might indicate that a single person has better control over water-saving behaviour than a family with several members;

iii) a household with a greater number of children is more responsive to price changes comparing to the childless household, all other things equal (cross-term coefficient estimated at -0.009). The number of retired persons does not influence the responsiveness to price changes (see Model 6);

Table 7: Testing for heterogeneity in price response, IV model

Variable name	Variable description	Model 5		Model 6		Model 7	
		Coef.	P-value	Coef.	P-value	Coef.	P-value
	Intercept	1.133***	0.000	0.503***	0.000	0.677**	0.002
l(price$_{t-1}$)	Log of the lag water price	-	-	-0.226***	0.000	-	-
lp_i(9497)	l(price$_{t-1}$) x i_9497$^{(a)}$	-0.431***	0.000	-	-	-0.429***	0.000
lp_i(9801)	l(price$_{t-1}$) x i_9801	-0.556***	0.000	-	-	-0.556***	0.000
lp_i(0210)	l(price$_{t-1}$) x i_0210	-0.055	0.201	-	-	-0.056	0.207
lp_i(1116)	l(price$_{t-1}$) x i_1116	0.271***	0.000	-	-	0.272***	0.000
linc_i(9497)	l(income) x i_9497	-	-	-	-	0.198***	0.000
linc_i(9801)	l(income) x i_9801	-	-	-	-	0.169***	0.000
linc_i(0210)	l(income) x i_0210	-	-	-	-	0.131***	0.000
linc_i(1116)	l(income) x i_1116	-	-	-	-	0.148***	0.000
lp_retired	l(price$_{t-1}$) x retired	-	-	-0.017	0.200	-	-
lp_single	l(price$_{t-1}$) x single	-	-	0.096***	0.000	-	-
lp_singlemale	l(price$_{t-1}$) x singlemale	-	-	0.004	0.366	-	-
lp_children	l(price$_{t-1}$) x children	-	-	-0.009***	0.000	-	-
l(income)	Log of income	0.151***	0	0.144***	0.000	-	-
size	Number of family members	0.181***	0.000	0.212***	0.000	0.180***	0.000
children_5	Number of children younger than 5	-0.063***	0.000	-0.060***	0.000	-0.062***	0.000
retired	Number of retired people	-0.033***	0.000	0.027	0.582	-0.031***	0.000
female	dummy; female present in the hhold	0.059***	0.000	0.081***	0.000	0.059***	0.000
single	dummy; single-person hhold	-0.351***	0.000	-0.706***	0.000	-0.350***	0.000
rental	dummy; family rents their flat	0.306***	0.000	0.310***	0.000	0.308***	0.000
cooperative	dummy; family lives in a cooperative flat	0.136***	0.000	0.136***	0.000	0.137***	0.000
own	dummy; family owns their flat or house	0.123***	0.000	0.122***	0.000	0.124***	0.000
paidhotwater	dummy; hot water included in water bill	0.057***	0.000	0.055***	0.000	0.057***	0.000
village1	dummy; less than 1,000 inhabit.	-0.484***	0.000	-0.487***	0.000	-0.484***	0.000
village2	dummy; less than 5,000 inhabit.	-0.241***	0.000	-0.245***	0.000	-0.241***	0.000
less_prom	dummy; highest education in the family less than graduate	-0.013*	0.035	-0.013*	0.029	-0.012*	0.042
more_prom	dummy; highest education in the family more than graduate	-0.017*	0.012	-0.015*	0.033	-0.017**	0.010
hhownbus	dummy; self-employed head of family	0.069***	0.000	0.068***	0.000	0.067***	0.000
singlefamhse	dummy; family living in a single family house	0.050***	0.000	0.051***	0.000	0.051***	0.000
rowhouse	dummy; family living in a row house	0.103***	0.000	0.100***	0.000	0.104***	0.000
washmachines	number of washing-machines	-0.028***	0.000	-0.032***	0.000	-0.031***	0.000
dishwashers	number of dishwashers	0.023***	0.001	0.029***	0.000	0.028***	0.000
monthnot12	dummy; family less than 12 months in the survey	0.035***	0.000	0.032***	0.001	0.034***	0.000
	Number of observations	53292		53292		53292	
	Adjusted R-square	0.366		0.365		0.367	

(a) i_9394 is a dummy variable equal to 1 if the year of observation is 1993 or 1994.

* p<0.05, ** p<0.01, *** p<0.001

iv) the income elasticity is decreasing over the analysed period. This goes in link with the rapidly increasing income of the households during the same period except for the last period between 2011-2016. The income recognizes a small decline and the income elasticity is slightly higher in this period comparing to the previous one between 2002-2010 (Model 7).

These findings indicate that response to price changes differs over time and across the population, depending on the household's characteristics.

6 Conclusion

This article contributes to the rather small literature on residential water demand in Central and Eastern Europe. One nice feature of our data is that it encompasses a period when significant structural and institutional changes occurred both at the country level and in the water and wastewater industry. The social and economic transformation which started in 1989 induced dramatic changes in this sector, such as major improvements in water and wastewater coverage and significant increases in water prices. Using household-data combined with regional data on the water and wastewater providers, we estimate the main drivers of household water use over a 24-year period (1993-2016). Over this period, the price of water has more than doubled (in real terms), household consumption has decreased by 28 %, and income has increased significantly. The purpose of our article was to disentangle the influence of income and price on consumption while controlling for household's socio-demographic characteristics and characteristics of the place of residence. Our preferred model indicates that the price elasticity is -0.22 on average over the period, which is on the low end of existing estimates of demand price elasticity estimated for the most industrialized countries[10], but very similar to estimates obtained by studies in the same geographical region such as Dalmas and Reynaud (2004, Slovak Republic), Bartczak et al. (2009, Poland), and Schleich and Hillenbrand (2009, Germany). However, our findings indicate that households were more responsive at the beginning of the period (1994-97) and in particular during 1998–2001 than at the end of the analysed period (2011-16), resulting in the own price elasticity of -0.43, -0.56, and 0.27, respectively. Our estimate of the income elasticity is +0.16 and it is robust across various models. This estimate is also in line with the estimate found in the meta-analysis by Havránek et al. (2018). Finally, our findings confirm that response to price changes differ over time and also across households depending on households' characteristics.

[10]For instance, Brent and Ward (2018) use the elasticity of -0.13 in their welfare analysis that is considered by them to be on the low end of existing price elasticity estimates.

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References

Agthe, D. E. and R. B. Billings (1980). Dynamic models of residential water demand. *Water Resources Research 16*(3), 476–480.

Arbués, F., M. Á. Garcıa-Valiñas, and R. Martınez-Espiñeira (2003). Estimation of residential water demand: a state-of-the-art review. *The Journal of Socio-Economics 32*(1), 81–102.

Arbués, F., I. Villanua, and R. Barberán (2010). Household size and residential water demand: an empirical approach. *Australian Journal of Agricultural and Resource Economics 54*(1), 61–80.

Bartczak, A., A. Kopanska, and J. Raczka (2009). Residential water demand in a transition economy: evidence from poland. *Water Science and Technology: Water Supply 9*(5), 509–516.

Brent, D. and M. Ward (2018). Price perceptions in water demand. Technical report, Department of Agricultural Economics, Sociology, and Education, Pensylvania State University. Department of Economics, Monash University.

Burtless, G. and J. A. Hausman (1978). The effect of taxation on labor supply: Evaluating the gary negative income tax experiment. *Journal of political Economy 86*(6), 1103–1130.

CENIA (2019). Hodnocení zranitelnosti české republiky ve vztahu ke změně klimatu k roku 2017. Technical report, Processed by Havránek, M., and T. Ponocná, CENIA, česká informační agentura životního prostředí.

Chicoine, D. L., S. C. Deller, and G. Ramamurthy (1986). Water demand estimation under block rate pricing: a simultaneous equation approach. *Water Resources Research 22*(6), 859–863.

Dalhuisen, J. M., R. J. Florax, H. L. De Groot, and P. Nijkamp (2003). Price and income elasticities of residential water demand: a meta-analysis. *Land economics 79*(2), 292–308.

Dalmas, L. and A. Reynaud (2004). Residential water demand in the slovak republic. In P. Koundouri (Ed.), *Econometrics Informing Natural Resource Management: Selected Case Studies.* Edward-Elgar Publishing.

Espey, M., J. Espey, and W. D. Shaw (1997). Price elasticity of residential demand for water: A meta-analysis. *Water resources research 33*(6), 1369–1374.

Foster, H. S. and B. R. Beattie (1979). Urban residential demand for water in the united states. *Land Economics 55*(1), 43–58.

Gaudin, S., R. C. Griffin, and R. C. Sickles (2001). Demand specification for municipal water management: evaluation of the stone-geary form. *Land Economics 77*(3), 399–422.

Gottlieb, M. (1963). Urban domestic demand of water in the united states. *Land Economics 39*(2), 204–210.

Grafton, R. Q. and M. B. Ward (2008). Prices versus rationing: Marshallian surplus and mandatory water restrictions. *Economic Record 84*, S57–S65.

Grafton, R. Q., M. B. Ward, H. To, and T. Kompas (2011). Determinants of residential water consumption: Evidence and analysis from a 10-country household survey. *Water Resources Research 47*(8).

Griffin, R. C. and C. Chang (1991). Seasonality in community water demand. *Western Journal of Agricultural Economics*, 207–217.

Hanak, E., M. Davis, et al. (2006). Lawns and water demand in california. *PPIC Research Reports*.

Hansen, L. G. (1996). Water and energy price impacts on residential water demand in copenhagen. *Land Economics*, 66–79.

Havránek, T., Z. Irsova, and T. Vlach (2018). Measuring the income elasticity of water demand: the importance of publication and endogeneity biases. *Land Economics 94*(2), 259–283.

Hewitt, J. A. and W. M. Hanemann (1995). A discrete/continuous choice approach to residential water demand under block rate pricing. *Land Economics*, 173–192.

Höglund, L. (1999). Household demand for water in sweden with implications of a potential tax on water use. *Water Resources Research 35*(12), 3853–3863.

Hortová, J. and L. Krištoufek (2014). Price elasticity of household water demand in the czech republic. In *IES Working Paper*, Volume 38/2014. IES FSV. Charles University.

Howe, C. W. and F. P. Linaweaver Jr (1967). The impact of price on residential water demand and its relation to system design and price structure. *Water Resources Research 3*(1), 13–32.

Ito, K. (2014). Do consumers respond to marginal or average price? evidence from nonlinear electricity pricing. *American Economic Review 104*(2), 537–63.

Kulshreshtha, S. N. (1996). Residential water demand in saskatchewan communities: role played by block pricing system in water conservation. *Canadian Water Resources Journal 21*(2), 139–155.

Martínez-Espiñeira, R. (2002). Residential water demand in the northwest of spain. *Environmental and resource economics 21*(2), 161–187.

Millock, K. and C. Nauges (2010). Household adoption of water-efficient equipment: the role of socio-economic factors, environmental attitudes and policy. *Environmental and Resource Economics 46*(4), 539–565.

MoE (2015). Národní akční plan adaptace na změnu klimatu. Technical report, Ministry of the Environment of the Czech Republic.

Musolesi, A. and M. Nosvelli (2007). Dynamics of residential water consumption in a panel of italian municipalities. *Applied Economics Letters 14*(6), 441–444.

Nauges, C. and A. Thomas (2000). Privately operated water utilities, municipal price negotiation, and estimation of residential water demand: the case of france. *Land Economics*, 68–85.

Nieswiadomy, M. L. and D. J. Molina (1989). Comparing residential water demand estimates under decreasing and increasing block rates using household data. *Land Economics 65*(3), 280–289.

OECD (2011). Greening household behaviour: The role of public policy. Technical report, OECD Publishing.

Olmstead, S. M., W. M. Hanemann, and R. N. Stavins (2007). Water demand under alternative price structures. *Journal of Environmental Economics and Management 54*(2), 181–198.

Pint, E. M. (1999). Household responses to increased water rates during the california drought. *Land economics*, 246–266.

Renwick, M. E. and R. D. Green (2000). Do residential water demand side management policies measure up? an analysis of eight california water agencies. *Journal of environmental economics and management 40*(1), 37–55.

Romano, G., N. Salvati, and A. Guerrini (2014). Estimating the determinants of residential water demand in italy. *Water 6*(10), 2929–2945.

Schleich, J. and T. Hillenbrand (2009). Determinants of residential water demand in germany. *Ecological economics 68*(6), 1756–1769.

Wada, Y., L. Van Beek, and M. F. Bierkens (2011). Modelling global water stress of the recent past: on the relative importance of trends in water demand and climate variability. *Hydrology and Earth System Sciences 15*(12), 3785–3805.

Wichman, C. J. (2014). Perceived price in residential water demand: Evidence from a natural experiment. *Journal of Economic Behavior & Organization 107*, 308–323.

Worthington, A. C. and M. Hoffman (2008). An empirical survey of residential water demand modelling. *Journal of Economic Surveys 22*(5), 842–871.

Appendix

Table A.1: List of regions

Region	No. of obs.	Percentage
14 regions (2000-2016)		
Praha	6,249	10.7
Středočeský	4,023	6.9
Jihočeský	2,826	4.8
Plzeňský	2,030	3.5
Karlovarský	1,557	2.7
Ústecký	3,636	6.2
Liberecký	1,517	2.6
Královéhradecký	2,015	3.5
Pardubický	1,684	2.9
Vysočina	2,254	3.9
Jihomoravský	4,363	7.5
Olomoucký	2,596	4.5
Zlínský	2,242	3.8
Moravskoslezský	4,865	8.3
8 regions (1993-1999)		
Praha	2,640	4.5
Středočeský	1,573	2.7
Jihočeský kraj	1,358	2.3
Západočeský	1,376	2.4
Severočeský	2,105	3.6
Východočeský	1,694	2.9
Jihomoravský	2,953	5.1
Severomoravský	2,741	4.7
Total	58,297	100

Table A.2: Estimation results – model 1 and 2

Variable name	Variable description	No IV price Model 1		IV price Model 2	
		Coef.	P-value	Coef.	P-value
	Intercept	0.946***	0.000	0.462***	0.000
l(price)	Log of the water price	-0.390***	0.000	-0.238***	0.000
l(income)	Log of income	0.155***	0.000	0.155***	0.000
size	Number of family members	0.180***	0.000	0.181***	0.000
children_5	Number of children younger than 5	-0.059***	0.000	-0.059***	0.000
retired	Number of retired persons	-0.031***	0.000	-0.031***	0.000
female	dummy; female present in the household	0.061***	0.000	0.061***	0.000
single	dummy; single-person household	-0.352***	0.000	-0.351***	0.000
rental	dummy; family rents their flat	0.318***	0.000	0.317***	0.000
cooperative	dummy; family lives in a cooperative flat	0.147***	0.000	0.146***	0.000
own	dummy; family owns their flat or house	0.123***	0.000	0.120***	0.000
paidhotwater	dummy; hot water included in water bill	0.039***	0.000	0.038***	0.000
village1	dummy; less than 1,000 inhabit.	-0.484***	0.000	-0.486***	0.000
village2	dummy; less than 5,000 inhabit.	-0.247***	0.000	-0.247***	0.000
less_prom	dummy; highest education in the family less than graduate school	-0.013*	0.025	-0.012*	0.034
more_prom	dummy; highest education in the family more than graduate school	-0.018**	0.005	-0.018**	0.003
hhownbus	dummy; self-employed head of family	0.071***	0.000	0.070***	0.000
singlefamhse	dummy; family living in detached house	0.064***	0.000	0.067***	0.000
rowhouse	dummy; family living in terraced house	0.114***	0.000	0.115***	0.000
washmachines	number of automatic washing-machines	-0.027***	0.000	-0.027***	0.000
dishwashers	number of dishwashers	0.025***	0.000	0.024***	0.001
monthnot12	dummy; family less than 12 months in the survey	0.036***	0.000	0.036***	0.000
Y1993	dummy; year 1993 (reference)	-	-	-	-
Y1994	dummy; year 1994	0.086***	0.000	0.033*	0.042
Y1995	dummy; year 1995	0.069***	0.000	0.032	0.059
Y1996	dummy; year 1996	0.049**	0.004	0.004	0.814
Y1997	dummy; year 1997	0.061***	0.000	0.020	0.303
Y1998	dummy; year 1998	0.112***	0.000	0.075***	0.000
Y1999	dummy; year 1999	0.084***	0.000	0.017	0.379
Y2000	dummy; year 2000	0.133***	0.000	0.062**	0.002
Y2001	dummy; year 2001	0.142***	0.000	0.080***	0.000
Y2002	dummy; year 2002	0.161***	0.000	0.086***	0.000
Y2003	dummy; year 2003	0.195***	0.000	0.104***	0.000
Y2004	dummy; year 2004	0.191***	0.000	0.101***	0.000
Y2005	dummy; year 2005	0.199***	0.000	0.104***	0.000
Y2006	dummy; year 2006	0.218***	0.000	0.123***	0.000
Y2007	dummy; year 2007	0.190***	0.000	0.084***	0.000
Y2008	dummy; year 2008	0.181***	0.000	0.078**	0.002
Y2009	dummy; year 2009	0.161***	0.000	0.039	0.124
Y2010	dummy; year 2010	0.184***	0.000	0.059*	0.029
Y2011	dummy; year 2011	0.213***	0.000	0.078**	0.004
Y2012	dummy; year 2012	0.171***	0.000	0.03	0.296
Y2013	dummy; year 2013	0.211***	0.000	0.077**	0.009

* p<0.05, ** p<0.01, *** p<0.001

Variable name	Variable description	No IV price Model 1		IV price Model 2	
		Coef.	P-value	Coef.	P-value
Y2014	dummy; year 2014	0.227***	0.000	0.085**	0.004
Y2015	dummy; year 2015	0.220***	0.000	0.076*	0.012
Y2016	dummy; year 2016	0.213***	0.000	0.061	0.051
	Number of observations	55,965		55,965	
	Adjusted R-square	0.367		0.365	

* p<0.05, ** p<0.01, *** p<0.001

Table A.3: Estimation results – model 3 and 4

Variable name	Variable description	No IV price Model 1		IV price Model 2	
		Coef.	P-value	Coef.	P-value
	Intercept	0.946***	0.000	0.462***	0.000
l(price)	Log of the water price	-0.028	0.711	-	-
l($price_{t\_1}$)	Log of the lag water price	-0.191**	0.010	-0.216***	0.000
l(income)	Log of income	0.155***	0.000	0.155***	0.000
size	Number of family members	0.180***	0.000	0.180***	0.000
children_5	Number of children younger than 5 years	-0.062***	0.000	-0.062***	0.000
retired	Number of retired persons	-0.032***	0.000	-0.032***	0.000
female	dummy; female present in the household	0.061***	0.000	0.061***	0.000
single	dummy; single-person household	-0.350***	0.000	-0.350***	0.000
rental	dummy; family rents their flat	0.306***	0.000	0.306***	0.000
cooperative	dummy; family lives in a cooperative flat	0.133***	0.000	0.133***	0.000
own	dummy; family owns their flat or house	0.120***	0.000	0.120***	0.000
paidhotwater	dummy; hot water included in water bill	0.055***	0.000	0.055***	0.000
village1	dummy; less than 1,000 inhabit.	-0.487***	0.000	-0.487***	0.000
village2	dummy; less than 5,000 inhabit.	-0.244***	0.000	-0.244***	0.000
less_prom	dummy; highest education in the family less than graduate school	-0.012	0.052	-0.012*	0.037
more_prom	dummy; highest education in the family more than graduate school	-0.017**	0.006	-0.017**	0.007
hhownbus	dummy; self-employed head of family	0.070***	0.000	0.070***	0.000
singlefamhse	dummy; family living in detached house	0.049***	0.000	0.049***	0.000
rowhouse	dummy; family living in terraced house	0.098***	0.000	0.098***	0.000
washmachines	number of automatic washing-machines	-0.028***	0.000	-0.028***	0.000
dishwashers	number of dishwashers	0.024***	0.000	0.024***	0.000
Y1994	dummy; year 1994 (reference)	-	-	-	-
Y1995	dummy; year 1995	-0.012	0.477	-0.014	0.403
Y1996	dummy; year 1996	-0.03	0.075	-0.031	0.079
Y1997	dummy; year 1997	-0.011	0.551	-0.011	0.579
Y1998	dummy; year 1998	0.044*	0.013	0.044*	0.012
Y1999	dummy; year 1999	-0.016	0.377	-0.017	0.371
Y2000	dummy; year 2000	0.033	0.064	0.032	0.097
Y2001	dummy; year 2001	0.047*	0.014	0.046*	0.019
Y2002	dummy; year 2002	0.062**	0.002	0.063**	0.002

* p<0.05, ** p<0.01, *** p<0.001

Variable name	Variable description	No IV price **Model 1**		IV price **Model 2**	
		Coef.	P-value	Coef.	P-value
Y2003	dummy; year 2003	0.072***	0.001	0.072***	0.001
Y2004	dummy; year 2004	0.076***	0.001	0.076***	0.001
Y2005	dummy; year 2005	0.074***	0.001	0.074***	0.001
Y2006	dummy; year 2006	0.089***	0.000	0.088***	0.000
Y2007	dummy; year 2007	0.052*	0.037	0.051*	0.030
Y2008	dummy; year 2008	0.033	0.182	0.031	0.203
Y2009	dummy; year 2009	0.004	0.868	0.004	0.882
Y2010	dummy; year 2010	0.019	0.473	0.018	0.515
Y2011	dummy; year 2011	0.042	0.127	0.041	0.131
Y2012	dummy; year 2012	-0.018	0.507	-0.021	0.464
Y2013	dummy; year 2013	0.036	0.208	0.035	0.227
Y2014	dummy; year 2014	0.049	0.114	0.049	0.109
Y2015	dummy; year 2015	0.036	0.227	0.036	0.25
Y2016	dummy; year 2016	0.023	0.487	0.022	0.506
	Number of observations	53,292		53,292	
	Adjusted R-square	0.364		0.364	

* $p<0.05$, ** $p<0.01$, *** $p<0.001$

Table A.4: Testing for heterogeneity in price response, IV model

Variable name	Variable description	Model 5		Model 6		Model 7	
		Coef.	P-value	Coef.	P-value	Coef.	P-value
	Intercept	1.133***	0.000	0.503***	0.000	0.677**	0.002
l(price$_{t-1}$)	Log of the lag water price	-	-	-0.226***	0.000	-	-
lp_i(9497)	l(price$_{t-1}$) x i_9497$^{(a)}$	-0.431***	0.000	-	-	-0.429***	0.000
lp_i(9801)	l(price$_{t-1}$) x i_9801	-0.556***	0.000	-	-	-0.556***	0.000
lp_i(0210)	l(price$_{t-1}$) x i_0210	-0.055	0.201	-	-	-0.056	0.207
lp_i(1116)	l(price$_{t-1}$) x i_1116	0.271***	0.000	-	-	0.272***	0.000
linc_i(9497)	l(income) x i_9497	-	-	-	-	0.198***	0.000
linc_i(9801)	l(income) x i_9801	-	-	-	-	0.169***	0.000
linc_i(0210)	l(income) x i_0210	-	-	-	-	0.131***	0.000
linc_i(1116)	l(income) x i_1116	-	-	-	-	0.148***	0.000
lp_retired	l(price$_{t-1}$) x retired	-	-	-0.017	0.200	-	-
lp_single	l(price$_{t-1}$) x single	-	-	0.096***	0.000	-	-
lp_singlemale	l(price$_{t-1}$) x singlemale	-	-	0.004	0.366	-	-
lp_children	l(price$_{t-1}$) x children	-	-	-0.009***	0.000	-	-
l(income)	Log of income	0.151***	0	0.144***	0.000	-	-
size	Number of family members	0.181***	0.000	0.212***	0.000	0.180***	0.000
children_5	Number of children younger than 5	-0.063***	0.000	-0.060***	0.000	-0.062***	0.000
retired	Number of retired people	-0.033***	0.000	0.027	0.582	-0.031***	0.000
female	dummy; female present in the hhold	0.059***	0.000	0.081***	0.000	0.059***	0.000
single	dummy; single-person hhold	-0.351***	0.000	-0.706***	0.000	-0.350***	0.000
rental	dummy; family rents their flat	0.306***	0.000	0.310***	0.000	0.308***	0.000
cooperative	dummy; family lives in a cooperative flat	0.136***	0.000	0.136***	0.000	0.137***	0.000
own	dummy; family owns their flat or house	0.123***	0.000	0.122***	0.000	0.124***	0.000
paidhotwater	dummy; hot water included in water bill	0.057***	0.000	0.055***	0.000	0.057***	0.000
village1	dummy; less than 1,000 inhabit.	-0.484***	0.000	-0.487***	0.000	-0.484***	0.000
village2	dummy; less than 5,000 inhabit.	-0.241***	0.000	-0.245***	0.000	-0.241***	0.000
less_prom	dummy; highest education in the family less than graduate	-0.013*	0.035	-0.013*	0.029	-0.012*	0.042
more_prom	dummy; highest education in the family more than graduate	-0.017*	0.012	-0.015*	0.033	-0.017**	0.010
hhownbus	dummy; self-employed head of family	0.069***	0.000	0.068***	0.000	0.067***	0.000
singlefamhse	dummy; family living in a single family house	0.050***	0.000	0.051***	0.000	0.051***	0.000
rowhouse	dummy; family living in a row house	0.103***	0.000	0.100***	0.000	0.104***	0.000
washmachines	number of washing-machines	-0.028***	0.000	-0.032***	0.000	-0.031***	0.000
dishwashers	number of dishwashers	0.023***	0.001	0.029***	0.000	0.028***	0.000
monthnot12	dummy; family less than 12 months in the survey	0.035***	0.000	0.032***	0.001	0.034***	0.000
Y1994	dummy; year 1994 (reference)	-	-	-	-	-	-

(a) i_9394 is a dummy variable equal to 1 if the year of observation is 1993 or 1994.
* p<0.05, ** p<0.01, *** p<0.001

Variable name	Variable description	Model 5		Model 6		Model 7	
		Coef.	P-value	Coef.	P-value	Coef.	P-value
Y1995	dummy; year 1995	0.003	0.882	-0.014	0.408	0.000	0.955
Y1996	dummy; year 1996	0.013	0.526	-0.029	0.088	0.006	0.764
Y1997	dummy; year 1997	0.046*	0.048	-0.008	0.634	0.039	0.075
Y1998	dummy; year 1998	0.542*	0.029	0.047*	0.010	0.827**	0.003
Y1999	dummy; year 1999	0.493*	0.047	-0.015	0.410	0.776**	0.006
Y2000	dummy; year 2000	0.563*	0.024	0.035	0.064	0.847**	0.003
Y2001	dummy; year 2001	0.591*	0.019	0.049*	0.010	0.874**	0.002
Y2002	dummy; year 2002	-1.211***	0.000	0.066**	0.001	-0.555*	0.043
Y2003	dummy; year 2003	-1.204***	0.000	0.075***	0.000	-0.546*	0.047
Y2004	dummy; year 2004	-1.206***	0.000	0.080***	0.000	-0.548*	0.046
Y2005	dummy; year 2005	-1.208***	0.000	0.078***	0.000	-0.551*	0.046
Y2006	dummy; year 2006	-1.198***	0.000	0.092***	0.000	-0.541	0.050
Y2007	dummy; year 2007	-1.241***	0.000	0.055*	0.015	-0.583*	0.036
Y2008	dummy; year 2008	-1.267***	0.000	0.035	0.136	-0.608*	0.029
Y2009	dummy; year 2009	-1.307***	0.000	0.007	0.774	-0.648*	0.021
Y2010	dummy; year 2010	-1.297***	0.000	0.021	0.428	-0.638*	0.023
Y2011	dummy; year 2011	-2.576***	0.000	0.045	0.090	-2.091***	0.000
Y2012	dummy; year 2012	-2.649***	0.000	-0.018	0.524	-2.163***	0.000
Y2013	dummy; year 2013	-2.629***	0.000	0.038	0.193	-2.144***	0.000
Y2014	dummy; year 2014	-2.631***	0.000	0.051	0.095	-2.146***	0.000
Y2015	dummy; year 2015	-2.648***	0.000	0.038	0.224	-2.162***	0.000
Y2016	dummy; year 2016	-2.669***	0.000	0.024	0.451	-2.184***	0.000
	Number of observations	53292		53292		53292	
	Adjusted R-square	0.366		0.365		0.367	

* p<0.05, ** p<0.01, *** p<0.001

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