Working Paper Sustainability and Innovation
No. S 3/2007

Joachim Schleich
Thomas Hillenbrand

Determinants of Residential Water Demand in Germany

Fraunhofer Institute
Systems and
Innovation Research

Abstract:

In this paper we econometrically analyze the impact of several economic, environmental and social determinants for the average per capita demand for water and sewage in about 600 water supply areas in Germany. Besides prices, income and household size, we also consider the effects of population age, the share of wells, and rainfall and temperature during the summer months on water demand. We also attempt to explain regional differences in per capita residential water consumption, which is currently about 30 % lower in the new federal states than in the old states. Our estimate for the price elasticity of -0.229 suggests that the response of residential water demand in Germany is rather inelastic, but no significant difference could be found between both regions. In contrast, the income elasticity in the new states is found to be 0.685 which is more than double that of the old states. Differences in prices and income alone explain the largest part of the current gap in residential water use between the two regions. Our results further suggest that household size, the share of wells and summer rainfall have a negative impact on water demand. In contrast, higher age appears to be associated with higher water use. We also find (weak) evidence for an impact of rainfall but not of temperature on residential water use. Our findings imply that future research should include analyses of household-level data to further explore the effects of socio-economic determinants, and analyses of panel data to adequately study the effects of climate change on residential water use.

Table of Contents

Figures

Tables

1 Introduction

Economic, environmental and social factors which are shaping the demand for residential fresh water and sewage are expected to undergo substantial changes in the near future. More specifically, economic growth will lead to higher income levels, water prices may rise in response to increased scarcity, sewage prices may increase because of environmental regulation to control harmful substances, or prices may fall if water markets are deregulated. Likewise, climate change will alter temperatures and rainfall patterns within and across years. Finally, demographic changes such as a shrinking population and an aging society, or lifestyle changes such as the trend towards smaller household sizes will also affect future water demand.

Changes in water demand have economic, ecological and technical ramifications. For example, since fixed costs in the supply of fresh water and sewage typically account for about 80 % of total costs, a decrease in water demand results in a higher than proportional increase in per unit production costs. Since, in many countries, the regulations concerning water and sewage prices require that prices are set to cover costs, water prices would have to rise significantly. For example, in the European Union, the Water Framework Directive (EU 2000, Article 9) requires that, as of 2010, water prices cover the costs of water services, including environmental and resource costs. From an ecological perspective, a drop in water consumption would be beneficial, especially in regions where water supply is scarce, but also in other regions because of the ensuing savings in energy and chemical use for heating and processing water, and the positive impact on a region’s water balance. Finally, reduced water consumption may pose technical and possibly sanitary challenges for the management of infrastructure systems. In particular, a decreased flow rate could exacerbate sedimentation of sludge in the sewers and re-formation of germ layers in fresh water pipes (e.g. Herz and Marschke 2005). Since water infrastructure systems are large technical systems with a useful life of often more than 50 years, the costs for adapting the systems could be high if water demand does not evolve as predicted.

In this paper we estimate an econometric model to analyze the impact of several economic, environmental and social determinants on the per capita, residential demand of fresh water and sewage in Germany based on a unique cross-sectional dataset compiled for about 600 water supply areas, covering 38.9 million people (47 % of the German population). Besides prices, income and household size, which are typically included in residential water demand analyses, we also consider population age, the share of wells, rainfall during the summer months and average annual temperature in the supply areas as explanatory variables. We also explore the extent to which these variables can explain geographic differences in average per capita residential water demand – in our sample, demand in the new federal states of East Germany is about 30 % lower than in the old federal states of West Germany.

Since German regulations require that water and sewage prices are set to cover total costs, consumers face average cost prices rather than marginal prices. Thus, the price-setting mechanism induced by regulation may lead to an endogeneity problem in the econometric estimation of the water demand functions: because of the fixed costs, a decrease in water demand results in higher water prices under average cost pricing. To address this “endogeneity” or “simultaneity” problem, we apply single equation OLS-regressions and instrumental-variable techniques and then conduct a Wu-Hausman test for specification.

Since the results of this test do not indicate an "endogeneity" problem when estimating residential water demand in Germany, we may limit the discussion to the results of the OLS model. Accordingly, our estimate of -0.229 for the price elasticity suggests that residential water demand in Germany is rather inelastic. The price elasticity appears to be the same for average households in both the new and the old federal states, but our estimates for income elasticities differ substantially across these regions. Income elasticity for the new states is found to be 0.685 which is more than double that of the old states. A decrease in the average household size by 25 % from the current level of around 2 persons would increase per-capita water consumption by 7 litres per day (from 128 litres)[1]. We also find that average daily water use per capita in our sample increases by 1.5 litres as the average age of the population increases by one year. Further, a one per cent increase in the share of households with wells results in a decrease in the average water demand per person of about one per cent (from the public water supply system). As for the impact of climate variables, our cross section analyses suggest that rainfall matters more than temperature, but the statistical evidence is rather weak. Clearly, time series or panel data analyses would be more appropriate to explore the effect of climate-related factors on water use. Finally, differences in the estimated price and income elasticities alone are able to explain more than 50 % of the difference in per capita water consumption in the new federal states compared to the old ones.

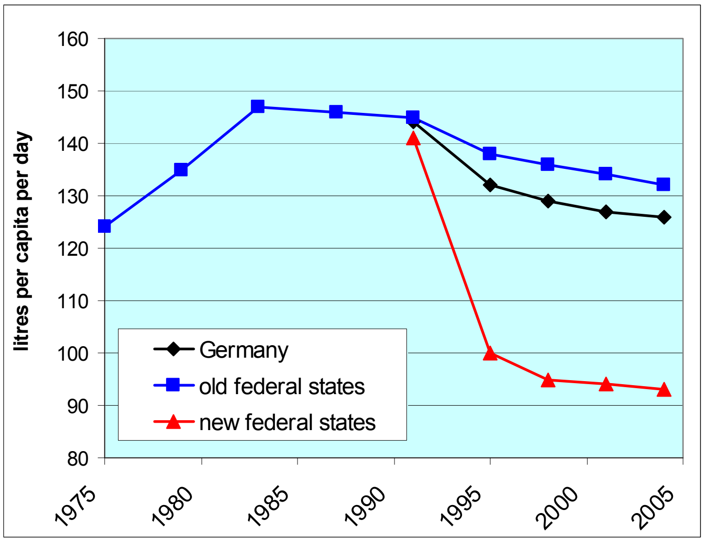
1 Assuming the elasticity remains constant over this range.

The remainder of the paper is organized as follows. Section 2 provides a brief overview of the water market in Germany. In Section 3 we present the econometric models including a description of the variables and data used. Results are presented and discussed in Section 4. In the final section, we discuss the implications of our results in the context of future economic, environmental, social and technological developments.

2 German water market

The typical German household uses about 32 % of total water use for toilet flushing, 30 % for bathing and showering, 14 % for laundry, 6 % for personal hygiene, 6 % for dishwashing, 4 % for gardening, 3 % for cleaning, 3 % for cooking and drinking and 2 % for car washing (Umweltbundesamt 2001, p. 34). Over the last two decades residential water consumption in Germany has changed substantially. While forecasts made in the 1970s had predicted an increase in per capita water to over 200 litre per day, per capita water consumption between 1991 and 2004 actually decreased by about 13 % (Statistisches Bundesamt, various years; see Figure 1). Current average daily per capita residential water use in 2004 in Germany is 126 l, but water use in the new states is only 93 l compared to 132 l in the old states. Both figures are well below the average daily per capita consumption levels in most OECD countries. For example, average daily per-capita water use in EU-15 countries ranges from 115 l in Belgium to 265 l in Spain (EWA 2002); depending on the region, consumption levels for North America are even higher (OECD, 1999; IWSA, 1999). Interestingly, the per capita consumption levels in the old and new states were almost the same at the beginning of the 1990s. However, until 1991 these dropped dramatically by about 34 percent in the new states, but decreased by only 9 % in the old states. At least to some extent, the decline in specific water consumption may be rationalized by a substantial increase in water and sewage prices in the early 1990s (Figure 2), which was significantly higher in the new states. But more detailed analyses are lacking.

Figure 1: Water consumption in Germany (in litres per capita per day)

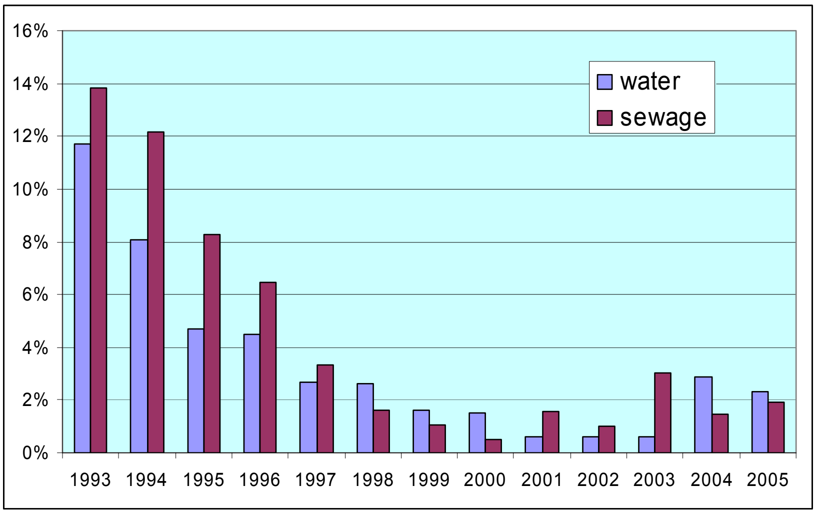


Source: own calculations based on Statistisches Bundesamt (various years)

In Germany, there are currently 6,383 water utilities and 9,994 sewage companies, most of which are fairly small. The largest 100 water utilities and the largest 900 sewage companies serve half the population in a total of about 12,500 communities (Statistisches Bundesamt, 2006; ATT et al., 2005). Water utilities may be either privately or publicly owned, with a tendency towards more private companies in recent years. In contrast, almost all sewage companies are public, since the German water law considers the treatment of waste water to be a sovereign task. After an intense debate about the deregulation and further liberalization of the water markets, the German parliament decided against this in 2002. Instead it passed a national modernization strategy to make the water and sewage services more efficient, consumer-oriented, competitive and sustainable. As a key instrument to achieve these goals, utilities are to be benchmarked against each other in terms of prices and services.

The German water law on setting prices for water and sewage distinguishes between public and private companies. Accordingly, public companies' prices have to cover costs, while private companies' prices are controlled by state antitrust agencies. In 2005, the average prices for water were 1.81 € per m³ and 2.14 € per m³ for sewage. On average, these prices approximately cover costs (ATT et al. 2005)

Figure 2: Change of prices for water and sewage in Germany (in %)[2]



Source: BGW (2006), Statistisches Landesamt Baden-Württemberg (2006)

2 Prices shown are nominal prices. Also, since sewage prices are not available for Germany, data for a "representative" federal state, Baden-Württemberg, are used. Also, the development of water prices is only available at the level of Germany, but not separately for the former East and West Germany.

3 Estimation of residential water demand

We use cross-sectional data at the level of utility supply areas to estimate a standard aggregate water demand model. Since sufficient data at the level of individual households are typically not available, it is quite common to use aggregate data (see Höglund 1999 and the overview provided therein, or Dalhuisen et al. 2003, or Gaudin 2006). The drawback to this approach, however, is that variations across households are eliminated. Also, variables which may only be available on an ordinal scale cannot be used since they cannot be aggregated in a meaningful way. Thus, for example, the impact of the education level etc. on water use cannot be explored.

3.1 Variables and data

The descriptive statistics of the (population-weighted) variables used in the econometric analyses are displayed in Table 1 along with data on the size of the supply area in terms of population.

Table 1: Descriptive statistics for dependent and independent variables

Variable	Description	Units	Mean	Std. Dev.	Min.	Max.
Q	average water use per capita per day	litres	128.23	27.26	65.70	334.20
P	price for fresh water and sewage	€ / 1000 litres	3.80	0.72	1.99	7.10
Y	average net income per capita	Euros	16509	2037	12735	21893
S	average number of household members	number of persons	2.03	0.26	1.25	3.66
A	average age of population	years	42.11	1.89	30.40	47.90
W	share of households with wells	%	1.03	2.23	0.01	20.07
R	summer rainfall	mm	305.58	71.12	166.70	629.20
T	summer temperature	Celsius	16.70	1.04	13.10	19.80

“Dependent Variable”

The dependent variable Q measures the average household water consumption in litres per person per day in a particular supply area. It is calculated as the ratio of the total amount of water sold to the household by the water utility and sewage works and the total number of persons connected to the system. For simplicity, for the remainder of the paper we refer to the consumption of fresh water and sewage as 'water consumption'. Water consumption data is taken from BGW (2005) and includes both water sold to households in single-family houses and to households in apartment buildings in 2003. Because of limited data availability for water and sewage prices, the sample used in our analysis is restricted to 599 supply areas. Following the more recent literature (see, e.g. Dalhuisen et al. 2003), we use a log-linear specification. The log-linear functional form allows coefficients to be directly interpreted as elasticities. Thus in the actual specification of the model, we use the logarithm of water use as the “dependent” (or exogenous) variable rather than the level.

“Independent Variables”

From an economic perspective, the household demand for water is a composite demand, consisting of the direct demand for drinking purposes and the indirect demand for water as a complement to different household activities such as cooking, cleaning, washing, body hygiene and gardening. The extent to which water demand responds to changes in prices depends on whether water is used for necessities (e.g. to cook) or non-necessities (e.g. to wash cars). If water use is for necessities, a price increase is expected to result in only a small decrease in use (low price elasticity). If there are substitutes available, a price change will lead to large changes in water use (high price elasticity). However, data on water use does not distinguish between the two types. Thus, the estimated parameters relate to the sum of water used for necessities and non-necessities.

Since water demand is expected to not only depend on water prices, but also on sewage prices, we use the sum of both types. We refer to the water price P as the total price for water and sewage. The principle of cost pricing (see above) implies that if prices cover costs, then prices reflect the average costs of producing and distributing water, and of collecting and treating sewage. Thus, households in Germany only receive information on the average price of water (not on variable and fixed cost components separately) and they may only react to incentives provided by average costs[3]. Also, water prices are identical for all households in a supply area. To compile data on water and sewage prices, we used data from Statistisches Landesamt Baden-Württemberg (2004), Bund der Steuerzahler NRW (2004), Bund der Steuerzahler Thüringen (2004) and MDR (2003). In several cases we also contacted utilities or used information available on the internet to gather missing price data. Most price data are for the year 2003, but for several supply areas, the lack of data made it necessary to use data for 2002 or 2004 instead.

The income variable Y is the average net income of private households in 2002, i.e. average gross income minus income tax plus transfer payments. Since data at the level of the supply areas is not available, we used income data from Statistik regional (2004) for the county where the supply area is located.[4] If the composite demand for water behaves as a normal good, higher income levels should lead to increased water demand. To allow for different responses to income changes in the new and the old German states, we included the average net household income Ye for supply areas in the new German states. For supply areas in the old German states Ye is zero.

S reflects the average number of household members in the supply area; thus S captures differences in per capita water use if the average household size differs across supply areas. Since several water uses such as washing, gardening or even cooking do not vary (in proportion to the number of household members), larger households are expected to use less water per capita than smaller households. The data for S is for 2001 and was obtained from the Statistisches Bundesamt (2003) as the ratio of the population size and the number of apartments at community level.

We use the average age of the population (A) to control for possible differences in water use due to age variation. We are not aware of detailed studies on the relationship of water consumption and age groups, but anecdotal evidence suggests a positive correlation. For example, children use less water for washing and hygiene than adults; retired people spend more time at home using toilets

---

3 The empirical evidence for whether agents respond to marginal rather than average prices appears to be mixed (see for example Taylor 2004 and Howe 1998), while estimates for price elasticities tend to be larger for average cost pricing than for marginal cost pricing (e.g. Dalhuisen et al. 2003).

4 A county may include more than one supply area, but supply areas do not cross county borders.

etc. Thus, variable A should capture the impact of an aging society in Germany. Data on average age in 2003 comes from the Statistisches Bundesamt (2005).

Since households can reduce water consumption (primarily for gardening) by using water from a well, we added W to the list of independent variables. W stands for the share of households with a well and is expected to have a negative impact on water demand from utilities. Data on the number of wells per supply area was taken from Statistische Landesämter (2006) and calculated as the ratio of the number of private wells or springs and the number of residential buildings. Since data was only available at county level, W is identical for all supply areas within the same county.

The variable R measures the cumulated rainfall in mm during the months April to September in 2003. Data was available from DWD (2006). Table 1 indicates that 2003 was a very dry summer. On average, the rainfall in 2003 was 23 % lower than usual (DWD 2006). Since higher rainfall reduces the water demand for gardening (and also fills up water cisterns), a higher R is expected to reduce water demand.

The variable T measures the average temperature from April to September in 2003 and was taken from DWD (2006). If available, we used temperature data for the supply area and otherwise for the meteorological station closest to the supply area. Higher temperatures are expected to result, in particular, in a higher water demand for gardening, and to a lesser extent possibly also for taking showers or drinking. The data also reflects the effects of the unusually hot and dry summer of 2003. For the entire year 2003, the average temperature was 1.1°C higher than usual (9.4°C instead of 8.3°C) (DWD 2006), for the months of June, July and August the average temperature was even 3.4°C higher than usual (DWD 2006). The parameter estimate for T may also be used to assess the future impact of global warming on water use in Germany.

Finally, regional dummies D were included to capture differences across regions not accounted for by the other explanatory variables in the regression equation. Data was available for 12 of the 16 federal states[5]: Baden-Württemberg, Bavaria, Berlin, Brandenburg (*), Bremen, Hamburg, Hesse, Mecklenburg-Western Pomerania (*), Lower-Saxony, North Rhine-Westphalia, Rhineland-Palatinate, Saarland, Saxony (*), Saxony-Anhalt (*), Schleswig-Holstein and Thuringia (*). To prevent the regressor matrix from becoming sin-

5 An "(*)" behind the name of the state means that this state is a former East German state.

gular, no dummy variable was included for Schleswig-Holstein. Of the 599 supply areas included in the subsequent analyses 477 are in the old and 122 in the new federal states.

3.2 Econometric models

First we use Ordinary Least Squares to estimate the following log-linear model

$$(1)\quad Q_i = const. + \beta_1 P_i + \beta_2 Y_i + \beta_3 Ye_i + \beta_4 S_i + \beta_5 A_i + \beta_6 W_i + \beta_7 R_i + \beta_8 T_i + \sum_{s=1}^{11} \delta_s D_s + \varepsilon_i$$

where i is the index for the supply areas (i = 1 to 599), D_s reflects the dummy variables associated with the federal state s and ε_i is the error component. All variables enter equation (1) in logarithmic form. Thus, parameter estimates may be interpreted as elasticities.[6] As pointed out earlier, to allow the income effects to differ between the new and old federal states, we included Ye_i which is the (log) of income in the new states. Thus β_3 reflects the differences in the income elasticity between average households in the new and the old states. Since the variables used are themselves observed averages rather than observations for individual households in the supply area, the appropriate method of estimation is analytically weighted least squares[7]. In our example, the weight to address this type of heterogeneity is population in the supply area of the utility[8]. Results for this model specification (Model 1) appear in the second column of Table 2.

Under the cost-pricing mechanism applied in the German water sector, reported prices do not equilibrate supply and demand. Instead, prices are set to approximately cover costs. In this case, an increase (decrease) in water demand results in lower (higher) prices because the fixed cost components are distributed among higher (lower) consumption levels (see for example Renzetti 2002).

6 Note that for the rainfall and temperature variables the logarithmic specification implies for a more general form of the aridity index P developed originally by De Martonne (1925), $P = \frac{R}{(T+10)}$, where R and T refer to annual data on rainfall (in mm) and temperature (in °C).

7 See STATA Release 9 Reference R-Z (pp. 50).

8 More specifically, weights of $\sqrt{N_i}$ are used where N_i is the population in supply area i. In our sample, population per supply area varies considerably and ranges from about 1,000 to 3,340,000 inhabitants with a mean of 63,908 and a standard deviation of 186,673 inhabitants.

Thus, water prices may have to be treated as endogenous in equation (1), violating the orthogonality condition because one of the explanatory variables (i.e. water prices) is correlated with the error component ε_i of the dependent variable. Estimating equation (1) would then result in biased estimates for the coefficients. To address the possible endogeneity problem, we also estimate equation (1) using Instrument Variable (IV) techniques[9] (Model 2). In the first stage, instrument variables are used to estimate predicted values for water prices. The set of instruments includes the remaining exogenous variables in equation (1), and in addition population, population density (both in logarithmic terms) and the share of voters for the Green party at the elections to the German parliament in 2002 in the respective county of the supply area. The more people connected to the water system and the higher the density, the lower the per unit production costs should be. The share of Green Party voters is included as a proxy for the stringency of environmental standards in water supply and sewage, assuming that a higher share of Green voters would translate into higher environmental standards and thus higher production costs.[10] In the second stage, equation (1) is estimated using (weighted) OLS, but now the predicted prices from the first stage are used in place of *price*. Results for this second stage are reported in the third column of Table 2. The most noticeable difference between Model 1 and Model 2 is the estimate for the price elasticity (β_1). To test the exogeneity of prices in equation (1), we conducted a standard Wu-Hausman Test to the Null hypothesis (H_0) of exogeneity, i.e. the difference in coefficients is not systematic. In the usual terms of the Wu-Hausman Test, Model 1 yields efficient and unbiased parameter estimates under H_0, but biased and inconsistent estimates if H_0 does not hold. By comparison, Model 2 yields consistent estimates independent of whether H_0 holds or not. Since both Models yield consistent estimates under H_0 any difference between them should vanish asymptotically. The test statistic, calculated at 5.36, suggests that the assumption of exogeneity cannot be rejected. Also, comparing the standard errors for β_1 between both models indicates that the standard errors for the IV estimates in Model 2 are relatively high. While these high standard errors are primarily the result of potentially imperfect choice of instruments, it is challenging to find more suitable instruments for which data is also available. Furthermore, even if Model 2 were the "correct" model – keeping in mind that the empirical evidence for this based on the Wu-Hausman Test is extremely weak– the

9 This estimation procedure is also referred to as two-stage least squares (2SLS).

10 The adjusted R^2 for this first stage regression is 0.2714.

consistent estimator is unlikely to be unbiased in finite samples (see for example, Johnston and DiNardo, p. 316f). As a consequence, the interpretation of the estimation results for the price elasticity and the other parameters focuses primarily on the first model. It should be noted, though, that parameter estimates and P-values are generally quite similar in both models.[11] Results from several tests for model specification including those for heteroscedasticity (Breusch-Pagan / Cook-Weisberg) and collinearity (variance inflation factors) did not indicate specification errors.

11 Even though the price elasticity in Model 2 is almost three times as large as the price elasticity estimated in Model 1, depending on the level of significance chosen, these values may be indistinguishable from a statistical point of view. For example, the value from Model 1 would lie just inside the 99 % interval for the price elasticity in Model 2 which ranges from -1.005 to -0.226. The relatively wide confidence interval is a direct consequence of the larger standard errors in Model 2.

4 Results

The estimation results displayed in Table 2 for both models are generally in line with theoretical expectations as far as signs are concerned, and most parameters turn out to be significant from a statistical perspective.[12] As indicated by the level of the (adjusted) R^2, the model explains quite a large share of the variation in water demand across supply areas. We first discuss the results for the determinants of residential water use and then analyze to which extent these determinants contribute to explaining the differences in water use between the new and the old federal states in Germany.

4.1 Determinants or residential water use

The parameter estimate of -0.229 for the price elasticity means that an increase in water price of one percent results in a decrease in water demand of 0.229 percent. Thus water demand is fairly inelastic. Our estimate for the price elasticity is – in absolute terms – somewhat lower than that found by most other studies for other countries. For example, the average price elasticity in the studies surveyed in the meta analysis by Dalhuisen et al. (2003, p. 95) is -0.41 and the median is -0.35 for a standard deviation of 0.86. The average price elasticity in a similar, earlier survey by Espey et al (1997, p. 1370) is -0.51. Low estimates for water price elasticities may be rationalized by a relatively low share of water (and sewage) costs in total household expenditure, and are more likely to be associated with OECD countries.[13] Also, our data on water use is for aggregate housing and does not allow single- and multi-family unit housing to be distinguished. More disaggregated data might have been able to capture that multi-family units tend to exhibit lower price elasticities - at least in the US. In particular, if the expenditure share is low, the real income effect of a price change is low, too. For our sample, the average share of water costs in net income is 1.05 % for Germany, 1.01 % for the new states and – because of higher specific consumption levels – 1.07 % in the old states. However, specification tests for differences in price elasticities between the old and the new states suggest that they are identical (from a statistical point of view) for both regions. Thus, the pure substitution effect due to the price change must be higher in the new

12 To save space, results for the state-specific dummies are not reported in Table 2. They are available from the authors upon request.

13 For example, Martinez-Espiñeira (2002) finds short-run price elasticities for regional residential water demand in Spain for different tariff systems to lie between -0.12 and -0.17.

states than in the old states. Additionally, most types of water uses are not easily substituted in the short term, estimates for long-term price elasticities are expected to be higher (in absolute terms). Finally, the price elasticity may be lower in Germany compared to other OECD countries because – as suggested by the relatively low level of per-capita water use – potentials to save water have already been exploited to a larger extent in Germany.

Table 2 Estimation results for water demand (standard errors are in parentheses)

	Model 1		**Model 2**	
	(OLS)		(IV)	
P	-0.229	**	-0.593	**
	(0.032)		(0.161)	
Y	0.241	**	0.314	**
	(0.071)		(0.084)	
Ye	0.444	*	0.501	*
	(0.235)		(0.261)	
S	-0.207	**	-0.120	
	(0.061)		(0.077)	
A	0.492	*	0.609	**
	(0.167)		(0.192)	
W	-0.016	**	-0.012	**
	(0.003)		(0.004)	
R	-0.052		-0.093	*
	(0.036)		(0.043)	
T	-0.010		-0.197	
	(0.115)		(0.151)	
constant	1.396		1.461	
	(0.975)		(1.077)	
adjusted R^2	0.6519		0.5789	
sample size	599		599	
F-value	59.95		48.30	

* individually statistically significant at least at 10 % level

** individually statistically significant at least at 1 % level

First, our estimates for the income elasticities of 0.241 for the old federal German states and 0.685 (0.241+0.444) for the new states confirm that water is a normal good, i.e. consumption increases with income. Households with a higher income are expected to consume more of the complementary commodities associated with water through having gardens, dishwashers, saunas, or pools, which increase indirect water demand. Second, as income increases, water consumption increases disproportionately, i.e. the expenditure share for water decreases. Previous studies have also provided strong empirical evidence that water demand is rather inelastic in terms of income changes. Our estimates for the income elasticity lie well in the range of the values found in the literature. For example, the mean and median for the income elasticities surveyed by Dalhuisen et al. (2003, p. 95) are 0.43 and 0.24, respectively, with a standard deviation of 0.79. Our result also suggest that there are statistically and economically significant differences in income elasticities between average households in new and old federal German states. Interestingly, per-capita water demand in the new states appears to be more than twice as sensitive to income changes as in the old states.

As expected, the parameter estimate associated with S is negative and highly significant. As the number of people per household increases, per capita water consumption goes down. For example, if the average number of household members decreased by 25 % from 2.0 to 1.5, a parameter value of -0.207 suggests that the average water use per person would increase by about 5.2 % or nearly 7 litres per day (using the means from Table 1).[14]

Our results for age indicate that as people get older, they appear to use more water. For example, if the average age of society increases by one year (i.e. by 2.37 % compared to the average age of 42 years in our sample), water consumption per person increases by 1.5 litres per day. There are several possible explanations, e. g. children are likely to use less water for showers or baths, younger people do more sports and tend to take showers at gyms rather than at home. Similarly, retired people spend more time at home than younger, working people, and thus use more water at home. Finally, for health reasons older people tend to use the bathroom more frequently.

The parameter estimate for wells is negative and highly significant. Its value suggests that a one percent increase in the share of households equipped with

14 For this and subsequent calculations we implicitly assume that the elasticity remains constant over the relevant range.

a well would result in a decrease in average water demand per person of about one percent.

The level of rainfall in the summer months exhibits the expected negative sign but is found to be statistically significant only in Model 2. For Model 1, summer rainfall would be statistically significant at the 14 % level. A ten percent decrease in summer rainfall would result in an increase in daily water consumption per person by about 0.7 litres according to Model 1 and by 1.2 litres according to Model 2 (using the means from Table 1). The relatively small elasticity value in both models may – at least to some extent - be rationalized by the small share of gardening in total residential water consumption of only 4 %. However, the change in rainfall patterns may also have an additional indirect effect on water demand from water utilities: reduced rainfall decreases the water supply from cisterns, resulting in a higher demand for water from utilities.

Our parameter estimate for summer temperature is far from being statistically significant and even exhibits the “wrong” sign. A possible explanation may be the relatively low variation in temperature across supply areas in the cross section (see Table 1). Likewise econometric analyses based on time series, or panel data would be more appropriate to explore variations in temperature and other climate-related factors over time.[15]

Finally, regional dummies (not reported here to save space) for all the new federal states turn out to be statistically significant compared to a reference state from West Germany (Schleswig-Holstein).

4.2 Differences between new and old federal states

To examine the extent to which the non-dummy variables in our estimated regression equations contribute to explaining differences in the average per capita daily water consumption in our sample between the new federal German states (104 litres) and the old ones (139 litres), we multiplied the differences of the respective means of the (logs of the) explanatory variables for all new and for all old states with our slope parameter estimates. Results for the relative contribution of the various variables are displayed for both models in Table 3.

15 In an alternative model specification we also used the De Martonne index for aridity (see Footnote 6). Results are given in the Annex and indicate that the parameter for the aridity index is – as expected – negative. The associated P-Value for the OLS model is 14.4 % and for the IV model 13 %, and not far from being statistically significant for conventional significance levels.

Table 3: Contribution of estimated slope parameters to regional differences in water demand

	Model 1 (OLS)	**Model 2** (IV)
P	8.85%	22.90%
Y	15.91%	20.71%
Ye	29.28%	33.04%
S	-10.91%	-6.33%
A	-5.58%	-6.91%
W	1.92%	1.44%
R	-5.41%	-9.65%
T	-0.01%	-0.13%
Sum	34.06%	55.07%

Accordingly, the differences in prices of about 11 % between old and new states in the sample explain about 9 % of the difference in per capita water consumption in Model 1 and 23 % in Model 2. Taken by themselves, the higher prices and lower income (by about 20 %) in the new compared to the old states would explain 54 % of the lower per capita water consumption in the new states using Model 1 and 76 % using Model 2 while differences in most other factors alone would imply lower water consumption in the old states. In total, the slope parameters from Model 1 and Model 2 help explain about 34 % and 55 % of the difference, respectively. Thus, a substantial part of the difference in per capita water consumption between new and old states is also reflected by the state-specific dummies. For example, the negative dummies for new states may capture the effect of a higher awareness regarding water costs in this region and the purchase and installation of water-efficient appliances and technologies in the past. First, the sharp increase in water costs in East Germany following reunification in 1990 is likely to have raised awareness of water consumption and water costs in this region. Also, it seems reasonable to assume that in the early 1990s when specific water use in the new states was about 50 % higher than today, the expenditure share for water was also higher. So the responsiveness to price changes may have been higher, too. Both effects are likely to have translated into behavioural changes towards a more efficient use of water as a reaction to the price hike. Second, after reunification, households in the new states were able to "catch up" with their Western counterparts with regard to household appliances and a large part of the residential building stock was modernized at this time. Arguably, the increased awareness of water consumption and the high price responsiveness resulted in the purchase and installation of water-saving appliances and technologies. Thus, as was the case for energy-efficient appliances (Schlomann et al. 2004), the rate of diffusion of water-efficient technologies was higher for households in the new federal states than in the old states. For example, using the data from Schlomann et al. (2004) on energy use from more than 20,000 households in Germany, we find that the share of dishwashers in the highest energy-efficiency categories (A and B labels) is 63.2 % in the new states compared to 44.7 % in the old states. For washing machines, these shares are 29.3 % and 25.8 %, respectively.[16] This argument is reinforced by the fact that energy-efficient dishwashers and washing machines are also more water-efficient. Moreover, since the bulk of residential buildings in the new states were modernized after reunification, additional water meters were installed, in particular at the level of apartments (rather than buildings). This allowed water to be billed according to consumption, which increased both awareness of the water used as well as financial incentives for water conservation. These mechanisms – together with differences in income levels – would help explain the widening and persistence of the gap in residential water consumption between the old and new federal states since the beginning of the 1990s (see Figure 1).

16 We are thankful to Edelgard Gruber for conducting these additional analyses.

5 Conclusions

The findings for the determinants of residential water demand in Germany presented in the previous section may be used to tentatively assess the impact of changes in economic, environmental and social conditions on the future demand for water. Thus, they may help build scenarios for the development of future water demand, and also serve as a starting point for planning investments in water infrastructure.

In the future, the costs (and thus the prices) for water services are expected to continue to rise because of environmental regulation and the need to refurbish and modernize existing infrastructure systems. For example, assuming an annual growth rate of 2 % in prices until 2020, the results from Model 1 suggest that per-capita water demand would decline by about 10 % (or about 13 litres per day), provided that the parameter estimates are valid over this range of prices and remain unchanged over this time horizon. At the same time, per capita income is expected to increase. Again, using the estimation results for Model 1, an annual real growth rate of 1 % in per capita income would lead to an increase in per-capita water use of 5 % (or about 6.5 litres per day) until 2020. Also, demographical change including a continued trend towards single households is expected to further lower average household size by about 5 % between 2003 and 2020 (BBR 2006). Taken by itself, such a decrease in household size would translate into an increase in per capita water demand of about 1 % based on the estimates from Model 1. Similarly, because of an increased life expectancy, the average population age in Germany is expected to rise by between six and ten years until 2050 compared to 2002/2004 (Statistisches Bundesamt 2006). According to our findings, these figures would lead to an increase in per capita water consumption of about eight to 13 litres per day. However, to substantiate these findings it would be necessary to conduct further research based on data for individual rather than average households in order to obtain greater insights into the relationship between water consumption patterns and age. These economic and social factors are expected to affect utilities symmetrically across regions, and forecast data is often available. In contrast, forecasts for changes in temperature and rainfall in response to climate change are less coherent, and effects are likely to vary across regions (IPCC, 2001). Existing analyses on the impact of climate change suggest that the direction of expected changes in precipitation vary across summer and winter periods (Lahmer 2004, Küchler 2004, Stock 2004). In some regions, summer rainfall is projected to decline by 30 %. At a general level, recent studies predict a temperature increase of 1.8°C to 2.3°C for Germany by the end of this century, extended drought periods during the summer and higher precipitation in the winter (UBA 2007). Since the water use for gardening only accounts for a small share of water consumption in Germany, the impact of changing rainfall patterns on residential water demand may be limited. This effect would be larger in countries like the US or the UK, where gardening accounts for a much higher share of water use. However, since changes in rainfall patterns would lower the groundwater level in several regions, many wells would then cease to operate, especially in the summer months when water supply is smaller anyway due to lower precipitation. Time series or panel data analyses would be better suited to exploring and projecting the effects of climate change on residential water use than the cross-sectional data available for this study.

To sum up, it is difficult to assess the future impact of the determinants of per capita water consumption considered in this paper because they work in opposing directions, so that the net effect is ambiguous. Future challenges for water utilities also depend on factors not explored in this study. Most importantly, the projected drop in the population of 10 % to 17 % by 2050 (Statistisches Bundesamt 2006) will lower total residential water demand and – because of the high fixed cost component - raise the costs of water services per capita. Since there are regional differences in migration patterns and demographic structures, these challenges may differ substantially across utilities. In the past, particularly utilities in the new states have had to cope with the negative effects of migration on water demand. Finally, water demand in the future also depends on the rate of technological change in appliances and sanitary technologies. Higher expected prices in particular, may speed the development and diffusion of water-efficient technologies (EEA 2001). For example, results from patent analyses suggest that, in recent years, research and development in the domain of more water-efficient washing machines and dishwashers has been increasing substantially (Hillenbrand and Hiessl 2007).

To sum up, the general socio-economic and environmental conditions affecting residential water demand from utilities are projected to change substantially in the next decades. But the overall extent and even the direction of change is difficult to estimate, in particular at the regional and local levels. This uncertainty poses a particular challenge to the water utilities’ planning of infrastructure systems, which typically exhibit a technical life of more than 50 years. Thus, future water supply systems may have to be more decentralized in nature and exhibit greater flexibility in order to be able to adapt to these challenges.

Acknowledgements

The authors would like to thank Bradford Mills of Virginia Polytechnic Institute and State University and Jeffrey Mullen of the University of Georgia for their thoughtful comments on earlier draft versions of the paper. The usual disclaimer applies. The financial support by the Federal Ministry of Education and Research under the funding programme “Global Change Impacts on the Water Cycle in the Elbe River Basin - Risks and Options (GLOWA-Elbe II)” is gratefully acknowledged. Part of this study was conducted while Joachim Schleich was a visiting professor at the Université Louis Pasteur, Strasbourg, France.

Literature

ATT, BGW, DBVW, DVGW, DWA, VKU(2005): Branchenbild der deutschen Wasserwirtschaft 2005. wvgw Wirtschafts- und Verlagsgesellschaft Gas und Wasser mbH, Bonn.

BGW (Bundesverband der deutschen Gas- und Wasserwirtschaft) (2006): Preisentwicklung beim Trinkwasser. http://www.bgw.de/pdf/0.1_resource_2005_4_13_7.pdf

BGW (Bundesverband der deutschen Gas- und Wasserwirtschaft (2005): Wasserstatistik Bundesrepublik Deutschland. Berlin.

Bund der Steuerzahler NRW (2004): Gebührenumfrage. http://www.steuerzahler-nrw.de/download/abwasser2003.pdf

Bund der Steuerzahler Thüringen (2004): Gebühren-/Entgeltsätze für Wasser, Abwasser und Niederschlagswasser ausgewählter Städte in Thüringen. http://www.steuerzahler-thueringen.de/webcom/show_article.php/_c-161/_nr-79/i.html

BBR (Bundesamt für Bauordnung und Raumwesen) (2006): Raumordnungsprognose 2020/2050 – Bevölkerung, private Haushalte, Erwerbspersonen, Wohnungsmarkt. BBR, Bonn.

Dalhuisen, J. M, Florax, R. J. G. M., de Groot, H. and Nijkamp, P. (2003): Price and Income Elasticities of Residential Water Demand: A Meta-Analysis. Land Economics 79 (2), 292–308.

De Martonne, E. (1925): Traité de géographie physique, Vol. I: Notions generales, climat, hydrographie. Geographical Review 15 (2), 336–337.

Deutscher Wetter Dienst (DWD) (German Weather Service) (2006): Special data-analyses. Offenbach.

Espey, M., Espey, J. and Shaw, W.D. (1997): Price Elasticity of Residential Demand for Water: A Meta Analysis. Water Resources Research 33 (6), 1369–1374.

EEA (2001): Sustainable water use in Europe. Part 2: Demand management. Environment issue report No 19, European Environment Agency, Kopenhagen.

European Union (EU) (2000): Directive 2000/60/EC of the European Parliament and of the council of 23 October 2000 establishing a framework for Community action in the field of water policy, Official Journal of the European Communities, 22 December 2000, L327/1–L327/72.

EWA (2002): European Water Association Yearbook.

Gaudin, S. (2006): Effect of Price Information on Residential Water Demand. Applied Economics 38 (4), 383-393.

Herz, R. and Marschke, L. (2005): Konsequenzen der Stadtschrumpfung für stadttechnische Infrastruktursysteme. Wissenschaftliche Zeitschrift der TU Dresden 54 (3-4), 99-104.

Hillenbrand, T. and Hiessl, H. (2007): Sich ändernde Planungsgrundlagen für Wasserinfrastruktursysteme. Teil 2: Technologischer Fortschritt und sonstige Veränderungen. KA - Abwasser, Abfall 54 (1), 47–53

Howe, C.W. (1998): Forms and Functions of Water Pricing: an Overview. In: Urban Water Demand Management and Planning. D.D. Baumann, J.J Boland and W.M. Hanemann (eds.), Mc Graw-Hill Colorado, 181-189.

IPPC (2001): Climate Change 2001, Third Assessment Report of IPCC, Working Group I: The Scientific Basis; WG II: Impacts, Adaptation, and Vulnerability. Cambridge University Press, Cambridge..

Johnston, J. and DiNardo, J. (1997): Econometric Methods. 4th edition, McGraw-Hill, New York.

Küchler (2004): Projektion des Klimawandels in Sachsen für die Dekade 2041–2050. Wasser und Abfall 11, 10–14.

Lahmer (2004): Hydrologische Auswirkungen sich ändernder Klimabedingungen im Land Brandenburg. GWF Wasser-Abwasser 145, Nr. 6, Oldenbourg Industrieverlag München, 400–412.

Martinez-Espiñeira, R. (2002): Residential Water Demand in the Northwest of Spain. Environmental and Resource Economics 21, 161–187, 2002.

MDR (2003): MDR-Umschau: Abwasserpreise in Sachsen. http://www.mdr.de/DL/592073.pdf

Renzetti, S. (2002): The Economics of Water Demands. Kluwer Academic Press, Norwell.

Schlomann, B. u. a. (2004): Energieverbrauch der privaten Haushalte und des Sektors Gewerbe, Handel, Dienstleistungen (GHD). Bericht für das Bundesministerium für Wirtschaft und Arbeit. Karlsruhe, Berlin, Nürnberg, Leipzig, München.

Statistisches Bundesamt (various years): Umwelt - Öffentliche Wasserversorgung und Abwasserbeseitigung. Statistisches Bundesamt, Fachserie 19 Reihe 2.1, Wiesbaden.

Statistisches Bundesamt (2006): Bevölkerung Deutschlands bis 2050 – 11. koordinierte Bevölkerungsvorausberechnung, Wiesbaden.

Statistisches Bundesamt (2003): Statistik lokal: Daten für die Kreise, kreisfreien Städte und Gemeinden Deutschlands, DVD, Statistisches Bundesamt, Wiesbaden

Statistisches Bundesamt (2005): Statistik lokal: Daten für die Kreise, kreisfreien Städte und Gemeinden Deutschlands, DVD, Statistisches Bundesamt, Wiesbaden.

Statistisches Landesamt Baden-Württemberg (2006): Trink- und Abwasserpreise 2006. Statistisches Monatsheft Baden-Württemberg 9/2006; http://www.statistik.baden-wuerttemberg.de/ Veroeffentl/Monatshefte/PDF/ Beitrag06_09_10.pdf

Statistisches Landesamt Baden-Württemberg (2004): Wasserwirtschaft in Baden-Württemberg. Stuttgart.

Statistische Landesämter (2006): Regional Statistics – Data and information from the statistical offices of the Länder and the federation - 2006 edition.

Stock, M. (2004): Klimafolgenforschung – Mögliche Auswirkungen von Klimaänderungen auf die Gesellschaft. Beitrag 2: Fallstudien, UWSF – Z Umweltchem Ökotox 16 (2), 115-124.

Taylor, R.G., McKean, John R., Young, Robert A (2004): Alternate Price Specifications for Estimating Residential Water Demand with Fixed Fees, Land Economics 80 (3), 463-475.

UBA (Umweltbundesamt 2007): Hintergrundpapier Neue Ergebnisse zu regionalen Klimaänderungen, Umweltbundesamt (Environmental Protection Agency), Dessau.

Annex

Figure A-1: Estimation results for water demand (standard errors are in parentheses)

	Model 3		Model 4	
	(OLS)		(IV)	
P	-0.227	**	-0.497	**
	(0.032)		(0.129)	
Y	0.248	**	0.324	**
	(0.069)		(0.081)	
Ye	0.436	*	0.457	*
	(0.235)		(0.249)	
S	-0.202	**	-0.125	
	(0.060)		(0.073)	
A	0.485	*	0.554	**
	(0.166)		(0.179)	
W	-0.016	**	-0.013	**
	0.003		(0.004)	
dM	-0.043		-0.047	
	(0.029)		(0.031)	
constant	1.145		0.495	
	(0.816)		(0.916)	
adjusted R^2	0.6554		0.6125	
sample size	599		599	
F-value	64.17		55.39	

* individually statistically significant at least at 10 % level

** individually statistically significant at least at 1 % level

Note: The variable dM is the de Martonne Index for aridity defined as $P = \frac{R}{(T+10)}$ Here R and T refer to summer rainfall (in mm) and summer temperature (in °C). For the regression the logarithm of dM is used.

Contact:

Fraunhofer Institute for Systems
and Innovation Research (Fraunhofer ISI)
Breslauer Strasse 48
D-76139 Karlsruhe
Telephone: +49 / 721 / 6809-150
Telefax: +49 / 721 / 6809-272
e-mail: brigitte.kallfass@isi.fraunhofer.de
URL: www.isi.fraunhofer.de

Karlsruhe 2007