Determinants of Residential Water Demand in Germany

Joachim Schleich[1,2,*] and Thomas Hillenbrand[1]

[1] Fraunhofer Institute for Systems and Innovation Research (Fraunhofer ISI), Breslauer Strasse 48, 76139 Karlsruhe, Germany

[2] Virginia Polytechnic Institute and State University, Blacksburg, Virginia, USA

**joachim.schleich@isi.fraunhofer.de;*

phone: + 49 721 6809 203; fax: +49 721 6809 272

Abstract:

We econometrically analyze the impact of several economic, environmental and social determinants for the per capita demand for water in about 600 water supply areas in Germany. Besides prices, income and household size, we consider the effects of population age, the share of wells and rainfall and temperature during the summer months on water demand. We also explore why per capita residential water consumption in the new federal states is about 30 % lower than in the old federal states. Our estimate of -0.229 for the price elasticity suggests that the response of residential water demand in Germany is quite inelastic, but no significant difference could be found between the two regions. In contrast, the income elasticity in the old states is found to be 0.241, but more than twice as high as this in the new states. Current differences in prices and income levels alone explain the largest part of the gap in residential water use between the two regions. Our results further suggest that household size and the share of wells have a negative impact on water demand. Remarkably, we find water use to increase with age. Finally, our results provide (weak) evidence for the impact of rainfall but not of temperature on residential water consumption.

Key words: residential water demand, water resources management, price elasticity, income elasticity, econometrics;

JEL: Q21; Q25; H31; C21;

1 Introduction

Economic, environmental and social factors affect the demand for residential fresh water and are expected to undergo substantial changes in the near future. Specifically, water prices may rise in response to increased scarcity or maintenance and reconstruction needs, sewage prices may increase because of environmental regulation to control harmful substances, or prices may change 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, an aging society, and lifestyle changes such as the trend towards smaller household sizes will also affect future water demand. Since fixed costs in the supply of fresh water and sewage typically account for about 80 % of total costs, a decrease in water demand would result in a higher than proportional increase in per unit production costs. Consequently, water prices would have to rise significantly to cover costs. 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, processing and cleaning water, and the positive impact on a region's water balance. Reduced water consumption may also 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 econometrically assess the impact of several economic, environmental and social determinants on residential water demand in Germany. The analysis is based on a unique cross-sectional dataset compiled for about 600 water supply areas, covering almost half of the population of Germany. 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 why water 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 cost 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 possible “endogeneity” or “simultaneity” problem, we apply single equation OLS-regressions and instrumental-variable techniques. Since a Wu-Hausman test does not indicate such an endogeneity problem, we may focus on the findings of the OLS model.

Our estimation result of -0.229 for the price elasticity suggests that residential water demand in Germany is rather inelastic. The income elasticity is found to be 0.241 for the old states, and more than double that of the new states. Differences in the price and income elasticities alone are able to explain more than half of the difference in per capita water consumption in the new states compared to the old ones. Not surprisingly, our findings suggest that an increase in household size or in the share of wells would decrease per capita water demand from the public system. Remarkably, an increase in population age was found to increase water consumption. As for the impact of climate variables, our results provide only weak evidence that rainfall affects water consumption, while temperature appears to have no impact at all.

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

2 German water sector

On the demand side, the typical German household uses about 39 % of total water use for personal hygiene (bathing, showering etc.), 30 % for flushing toilets, 13 % for laundry, 7 % for dishwashing, 7 % for room cleaning, washing cars and gardening and 4 % for cooking and drinking (UBA et al, 2007, p. 89). 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 consumption to over 200 litres per day, it actually decreased between 1991 and 2004 by about 13 % (Destatis, various years; see Figure 1). Residential water use in 2004 was 126 litres per capita per day, but water use in the new states was only 93 litres compared to 132 litres 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).

Remarkably, the per capita consumption levels in the old and new states were almost the same at the beginning of the 1990s. However, by 1995 these had 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, which was significantly higher in the new states.

Insert Figure 1 here

On the supply side, there are currently 6,383 water utilities and 9,994 sewage companies in Germany, 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 (ATT et al., 2005; Destatis, 2006;). In general, water utilities may be owned and managed by public (i.e. municipalities) or by private companies. 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 the costs involved (ATT et al., 2005).

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 Gaudin, 2006; Dalhuisen et al., 2003; or Höglund, 1999 and the overview provided therein). The drawback to this approach 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 education level or behavioral attitudes towards water saving (see Gilg and Barr, 2006) 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. For consistency, we only used data for utilities where the supply area coincides with a municipality. Together with the limited data availability for water and sewage prices, this restricts our sample to 599 supply areas. Due to a lack of data, it was also not possible to construct a panel.

Insert Table 1 here

“Dependent Variable”

The dependent variable *water* measures the average water consumption in litres per person per day from the utility in a particular supply area. It is calculated as the ratio of the total amount of water sold to the households by the water utility 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 disposal as “water consumption”. Water consumption data is taken from BGW (2005) and includes both the water sold to households in single-family houses and to households in apartment buildings in 2003. Also, our data on water use is for aggregate housing and does not permit single- and multi-family unit housing to be distinguished. Following the more recent literature (see, e.g. Arbués et al., 2002 or Dalhuisen et al., 2003), we use a log-linear specification, which also allows coefficients to be directly interpreted as elasticities.

“Explanatory 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, personal hygiene and gardening (see also Höglund, 1999). 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* as the total price for water and sewage. In cases where utilities also impose costs for metering, these are not included because they tend to be negligible. The principle of cost-covering implies that 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 can only react to the incentives provided by average costs. The empirical evidence for whether agents respond to marginal rather than average prices appears to be mixed (see for example Taylor et al., 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). Also, water prices are identical for all households in a supply area. To compile water and sewage prices, we used data on water and sewage prices for private households from several federal, regional and local sources, including BGW (2005), 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. Lagged prices could not be included as regressors due to the lack of data.

The variable *income* 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 Destatis (2003) for the county where the supply area is located. A county may include more than one supply area, but supply areas normally do not cross county borders.

Assuming the same responses to changes in explanatory variables – such as *price* and *income* – in the new and old states may be restrictive. In particular, average water prices and income levels differ considerably across the new and old states and elasticities may not be constant over the entire range. In addition, for cultural, historical or other reasons, households in the new and old states may not react to price or income changes in the same way. To allow for different responses to *price* and *income* in the new and the old states, we also estimated models where the associated parameters were allowed to differ across both regions. For other explanatory variables we did not conjecture differences in responses across both regions.

The variable *size* reflects the average number of household members in the supply area and captures differences in per capita water use if the average household size differs across supply areas. The data for *size* is for 2001 and was obtained from Destatis (2003) as the ratio of the population size and the number of housing units at community level.

We use the average age of the population to control for possible differences in water use due to age variation. So *age* may also capture the impact of an aging society in Germany. Data on average age in 2003 comes from Destatis (2005).

Since households can reduce water demand from the utility by using water from a well (primarily for gardening), we added *wells* – which stands for the share of households with a well - to the list of explanatory variables. Data on *wells* 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, *wells* are identical for all supply areas within the same county.

The variable *rain* measures the cumulated rainfall in mm during the months April to September in 2003. Similarly, *temp* captures the average temperature from April to September in 2003. Data on *rain* and *temp* were 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. The parameter estimates for *rain* and *temp* may hint at the future impact of global warming on residential water use in Germany.

Finally, regional dummies D were included for six old states and five new states to capture differences across regions not accounted for by the other explanatory variables in the regression equation. In total, observations from seven old states were used. To prevent the regressor matrix from becoming singular, a regional dummy was not included for one of the old states (Schleswig-Holstein) in equation (1) below. 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

$$water = const. + \beta_1 price + \beta_2 income + \beta_3 size + \beta_4 age + \beta_5 wells + \beta_6 rain + \beta_7 temp + \sum_{s=1}^{11} \delta_s D_s + \varepsilon \qquad (1)$$

where D_s reflects the dummy variables associated with the federal state s and ε is the error component. All variables enter equation (1) in logarithmic form. Thus, parameter estimates may be interpreted as elasticities.[1] 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[2]. In our example, the weight to address this

1 Note that for the rainfall and temperature variables the logarithmic specification allows 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).

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

type of heterogeneity is population in the supply area of the utility[3]. Estimating equation (1) by OLS yields Model 1.

Under the cost-pricing mechanism applied in the German water sector, reported prices do not balance supply and demand. Instead, prices are set to approximately cover costs. In this case, an increase in water demand results in lower prices because the fixed cost components are distributed among higher consumption levels. 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. *prices*) is correlated with the error component ε of the dependent variable. Estimating equation (1) may then result in biased estimates for the coefficients. To address the possible endogeneity problem, we also estimate equation (1) using Instrument Variable (IV) techniques (Model 2). In the first stage, instrument variables are used to predict water prices. The set of instruments contains the remaining explanatory variables in equation (1), and in addition population, population density 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 are 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

3 More specifically, weights of $(N_i)^{1/2}$ 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.

voters would translate into higher environmental standards and thus higher production costs. The parameter estimates for the instrument variables exhibit the expected signs with P-Values of 0.041 for population, 0.001 for population density, and 0.293 for the Green party vote share. 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. 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 contrast, 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, is distributed $\chi^2(20)$ and suggests that the assumption of exogeneity cannot be rejected. Thus, we have no evidence that results from the OLS and the IV models are fundamentally different. The most noticeable difference between Model 1 and Model 2 is the estimate for the price elasticity (β_1). While the price elasticity in Model 2 is almost three times as large as the price elasticity estimated in Model 1 these values are – depending on the level of significance used – 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. Since the standard errors in Model 1 are smaller, the interpretation of the estimation results focuses on the simple OLS model. Finally, 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.

4 Results

Table 2 displays the estimation results for the OLS and the IV model.[4] As indicated by the level of the (adjusted) R^2, both models explain 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 of 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. Since allowing for different price elasticities in new and old states did not hint at differences across both regions, Table 2 reports results for the model which assumes identical price elasticity in the new and old states. Our estimate for the price elasticity suggests that water demand is fairly inelastic. It is – in absolute terms – somewhat lower than that found by most studies for other countries. For example, the average price elasticity in the studies surveyed in the meta analysis by Dalhuisen et al. (2003, p. 295) 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

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

sewage) costs in total household expenditure, and are more likely to be associated with OECD countries. For example, Martinez-Espiñeira (2002, 2007) finds short-run price elasticities for regional residential water demand in Spain for different tariff systems and different specifications to lie around -0.15. 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. Using the Slutsky decomposition of price effects, and keeping in mind that we found no differences in the price elasticity between the new and the old states, the pure (i.e. Hicksian) substitution effect due to the price change must be higher in the new 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 relatively low level of per-capita water use in Germany compared to other OECD countries suggests that the elasticity may be lower (in absolute terms) because potentials to save water have already been exploited to a larger extent in Germany.

Insert Table 2 here

Our estimates for the income elasticities of 0.241 for the old federal German states and 0.685 (0.241 for *income* + 0.444 for *income_e*) 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, all of which increase indirect water demand. Further, 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. In particular, our result suggests that there are differences in income elasticities between average households in new and old states: Per-capita water demand in the new states appears to be more than twice as sensitive to income changes as in the old states.

Next, the parameter estimate associated with *size* is negative and highly significant. As the number of people per household increases, per capita water consumption goes down since several water uses such as washing, gardening or even cooking do not vary in relation to the number of household members. 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.[5]

Our results for age indicate that as people get older, they appear to use more water. For example, if the average age increases by one year (i.e. by 2.37 % compared to the average age of 42 years in our sample), water consumption

[5] For this and subsequent calculations we use the means from Table 1. Likewise, we implicitly assume that the parameter values remain constant over the relevant ranges.

per person increases by 1.5 litres per day. We are not aware of detailed comprehensive studies on the relationship between water consumption and age groups, but anecdotal evidence suggests a positive correlation. For example, retired people spend more time at home, children use less water for washing and hygiene than adults, or health reasons may force older people to use the bathroom more frequently. Using data from a recent survey of energy use patterns in more than 20,000 households in Germany (Schlomann et al., 2004), we find that older people take fewer showers and more baths, supporting the view that an aging society will be associated with higher per capita water use.[6] To corroborate 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.

The parameter estimate for wells is negative and highly significant. Its value suggests that doubling the share of households equipped with a well would result in a decrease in average water demand from the utility per person of 1.6 percent.

The level of rainfall in the summer months exhibits the expected negative sign. Since higher rainfall reduces the water demand for gardening (and indirectly also fills up water cisterns), a higher rainfall reduces water demand from utilities. However, *rainfall* is only statistically significant for Model 2. For Model 1, it

---

6 Differences are statistically significant at the 1 % level for both, showers and baths. We are thankful to Edelgard Gruber for conducting these additional analyses.

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).

Our parameter estimate for summer temperature is far from being statistically significant. It also exhibits the “wrong” sign, since higher temperatures would be expected to result in higher residential water demand for gardening, taking showers or drinking. A possible countervailing effect may be that people spend more time (and water) at pools and beaches, or lose excess liquids by sweating rather than by using the bathroom if temperatures are high.

The relatively small or insignificant elasticities for *rainfall* and *temp* may be rationalized by the small share of gardening in total residential water consumption in Germany. These effects would be larger in countries like the US or the UK, where gardening accounts for a much higher proportion of water use. To some extent, the results on rainfall and temperature may also reflect the effects of the unusually dry and hot summer of 2003 throughout Germany with little variation across supply areas (see Table 1). For the months of June, July and August in 2003 the average temperature was 3.4°C higher than usual (DWD, 2006). Similarly, the rainfall in 2003 was 23 % lower than usual (DWD, 2006). Arguably, data reflecting rainfall and temperature patterns on a weekly or daily basis or time series and panel data may be more appropriate to adequately capture impacts of climate change on water demand (see also Naugent and Thomas, 2000, or Mazzanti and Montini, 2006).[7]

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 between the new states and the old ones in our samples, 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.

Insert Table 3 here

Accordingly, the difference in price of about 11 % between old and new states in the sample explains 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. A substantial part of the difference in per capita water consumption between new and old states is also reflected by the state-specific dummies, which are all negative and statistically

7 In an alternative model specification we also used the De Martonne index for aridity (see Footnote 4). 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 %.

significant compared to a West German reference state. To some extent, these dummies reflect the impact of previous investment decisions on water-using technologies which together with current behavior determine actual residential water consumption levels. In the early 1990s, a large part of the residential building stock in the new states was modernized, including new and presumably more water-efficient appliances. In addition to this rather autonomous water-saving technological change, the hike in water prices is likely to have accelerated the diffusion of water-saving technologies, too. Arguably, in the early 1990s, the responsiveness of water demand was higher in the new states than it is today. Since water consumption per capita was then about 50 % higher, the expenditure share for water was also higher, implying a higher price elasticity (in absolute terms), ceteris paribus. Also, in the wake of the modernization of residential buildings in the new states after reunification, additional water meters were installed in particular at the level of individual dwellings (rather than buildings). This allowed water to be billed according to consumption, which increased both awareness of the water used as well as the financial incentives for water conservation. Further, the sharp increase in water prices may have permanently raised awareness of water consumption in the new states which translates into more pronounced water-saving behavior than in the old states. To substantiate these claims we refer to empirical findings for the diffusion of energy-efficient household appliances across old and new states. For example, using the data from Schlomann et al. (2004) again, we find that the share of dishwashers in the highest energy-efficiency class 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. Other explanations for the lower per capita residential water consumption in the new states which could not be examined in our analyses include job commuting from new to old states, or the higher share of children in day care facilities in the new states.

5 Conclusions

The findings for the determinants of residential water demand in Germany presented in the previous section may be used to cautiously assess the impact of changes in economic, environmental and social conditions on the future demand for water. Rather than summarizing and repeating the main findings, we conclude the paper with a tentative scenario for the development of water demand by 2020 based on the results of Model 1. To do so we assume that the parameter estimates are valid over the considered ranges of the variables given in Table 4 and also remain unchanged over time.

In the future, the costs for water services in Germany are expected to continue to rise because of environmental regulation and the need to refurbish and modernize existing infrastructure systems. For our tentative scenario we use a range of 1% to 3 % in real prices for the annual growth rate until 2020. At the same time, per capita income is expected to increase by 1% to 2%. Next, we conjecture that the trend towards single households will continue and will further lower average household size by about 5 % between 2003 and 2020 (BBR, 2006). 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 2004 (Destatis, 2006). We interpolated figures for 2020. Depending on the combination of impacts shown in Table 4, the projected aggregate effects from these four determinants range from being negligible to quite large.

Insert Table 4 here

Future challenges for water utilities, however, also depend on factors not explored in this study. Most importantly, the projected drop in the population of 10 % to 17 % by 2050 (Destatis, 2006) will reduce total residential water demand. Because of the high fixed cost component this will raise the costs and prices of water services per capita which will further decrease water consumption. Likewise, according to the concept of induced technological change (Hicks, 1932), higher water prices will spur the invention, adoption and diffusion of water-saving technological changes in appliances and sanitary technologies (EEA, 2001). Arguably, climate change may alter residential water demand via an increase in temperatures and changes in rainfall patterns. 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). Yet, the findings of our study suggest that, on average, the direct impact of climate change on residential water demand will be rather low. But climate change may also have an indirect effect on water demand from utilities: 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. Regional differences are not only to be expected for precipitation and temperature changes (EC, 2007) but also for other determinants such as migration patterns, demographic structures, water prices and income. These factors pose a particular challenge to the water utilities' planning of infrastructure systems. Given the uncertainty about the rate and possibly also the direction of these economic, environmental and social developments, more decentralized water infrastructure systems may exhibit greater flexibility and may be better suited to adaptation to these challenges for some water supply areas.

Acknowledgements

The authors would like to thank Manuel Frondel of the RWI Germany, 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. The paper also benefited from discussions at the 15th Annual Conference of the European Associations of Environmental and Resource Economists (EAERE) in 2007 in Thessaloniki, Greece. The usual disclaimer applies. The financial support by the Federal Ministry of Education and Research under the funding program "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.

References

Arbués, F., Garcia-Valinas, M.A., Martinez-Espiñeira, R., 2002. Estimation of residential water demand: A state of the art review. Journal of Socio-economics 32, 81–102.

ATT, BGW, DBVW, DVGW, DWA, VKU, 2005. Branchenbild der deutschen Wasserwirtschaft 2005. 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. BGW, Berlin.

Bund der Steuerzahler North-Rhine Westfalia (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., Nijkamp, P., 2003. Price and income elasticities of residential water demand: A meta analysis. Land Economics 79, 292–308.

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

Destatis (Statistisches Bundesamt) (Federal Statistical Office), 2006. Bevölkerung Deutschlands bis 2050 – 11. koordinierte Bevölkerungsvorausberechnung. Statistisches Bundesamt, Wiesbaden.

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

Destatis (Statistisches Bundesamt) (Federal Statistical Office) (various years): Umwelt – Öffentliche Wasserversorgung und Abwasserbeseitigung. Statistisches Bundesamt, Fachserie 19 Reihe 2.1. Statistisches Bundesamt, Wiesbaden.

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

EC (European Commission), 2007. Green paper from the Commission to the Council, the European Parliament, the European Economic and Social committee and the Committee of the Regions. Adapting to climate change in Europe – options for EU action. Brussels, COM(2007) 354 final, 29 June 2007.

EEA (European Environment Agency), 2001. Sustainable water use in Europe. Part 2: Demand management. Environment Issue Report No 19. European Environment Agency, Copenhagen.

Espey, M., Espey, J., Shaw, W.D., 1997. Price elasticity of residential demand for water: A meta analysis. Water Resources Research 33, 1369–1374.

EU (European Union), 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 (European Water Association), 2002. European Water Association Yearbook.

Gaudin, S., 2006. Effect of price Information on residential water demand. Applied Economics 38, 383–393.

Gilg, A., Barr, S., 2006. Behavioural attitudes towards water saving? Empirical evidence from a study of environmental actions. Ecological Economics 57, 400–414.

Herz, R., Marschke, L., 2005. Konsequenzen der Stadtschrumpfung für stadttechnische Infrastruktursysteme. Wissenschaftliche Zeitschrift der TU Dresden 54, 99–104.

Hicks, J., 1932. The Theory of Wages. London, Macmillan.

Howe, C.W., 1998. Forms and functions of water pricing: An overview. In: D.D. Baumann, J.J. Boland and W.M. Hanemann (Editors), Urban Water Demand Management and Planning. Mc Graw-Hill, Colorado, pp. 181–189.

Martinez-Espiñeira, R., 2007. An estimation of residential water demand using co-integration and error correction techniques. Journal of Applied Economics, forthcoming.

Martinez-Espiñeira, R., 2002. Residential water demand in the Northwest of Spain. Environmental and Resource Economics 21, 161–187.

Mazzanti, M., Montini, A., 2006. The determinants of residential water demand. Empirical evidence for a panel of Italian municipalities. Applied Economics Letters 13, 107–111.

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

Nauges, C., Thomas, A., 2000. Efficient estimation of residential water demand with panel data: The case of France. Land Economics 76, 66–85.

OECD (Organization for Economic Cooperation and Development), 1999. Towards More Sustainable Household Consumption Patterns: Indicators to Measure Progress. OECD Environment Directorate, Paris.

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

Schlomann, B., Gruber, E., Eichhammer, W., Diekmann, J., Ziesing, H.-J., Rieke, H., Wittke, F., Herzog, T., Barbosa, M., Lutz, S., Broeske, U., Merten, D., Falkenberg, D., Nill, M., Kaltschmitt, M., Geiger, B., Kleeberger, H., Eckl, R., 2004. Energieverbrauch der privaten Haushalte und des Sektors Gewerbe, Handel, Dienstleistungen. Bericht für das Bundesministerium für Wirtschaft und Arbeit. Karlsruhe, Berlin, Nürnberg, Leipzig, München.

Statistisches Landesamt, 2006. Regionalstatistik (regional statistics for various federal states).

Taylor, R.G., McKean, J.R., Young, R., 2004. Alternate price specifications for estimating residential water demand with fixed fees. Land Economics 80, 463–475.

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

UBA, BGR, Destatis (Umweltbundesamt, Bundesanstalt für Geowissenschaften und Rohstoffe, Statistisches Bundesamt) (Federal Environmental Agency, Federal Institute for Geosciences and Natural Resources, Federal Statistical Office), 2007. Environmental Data for Germany. Practicing Sustainability – Protecting Natural Resources and the Environment. Berlin, Hannover.

Tables

Table 1: Descriptive statistics for dependent and independent variables

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

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

	Model 1		Model 2	
	(OLS)		(IV)	
Variable				
price	-0.229	**	-0.593	**
	(0.032)		(0.161)	
income	0.241	**	0.314	**
	(0.071)		(0.084)	
income_e	0.444	*	0.501	*
	(0.235)		(0.261)	
size	-0.207	**	-0.120	
	(0.061)		(0.077)	
age	0.492	*	0.609	**
	(0.167)		(0.192)	
wells	-0.016	**	-0.012	**
	(0.003)		(0.004)	
rain	-0.052		-0.093	*
	(0.036)		(0.043)	
temp	-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

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

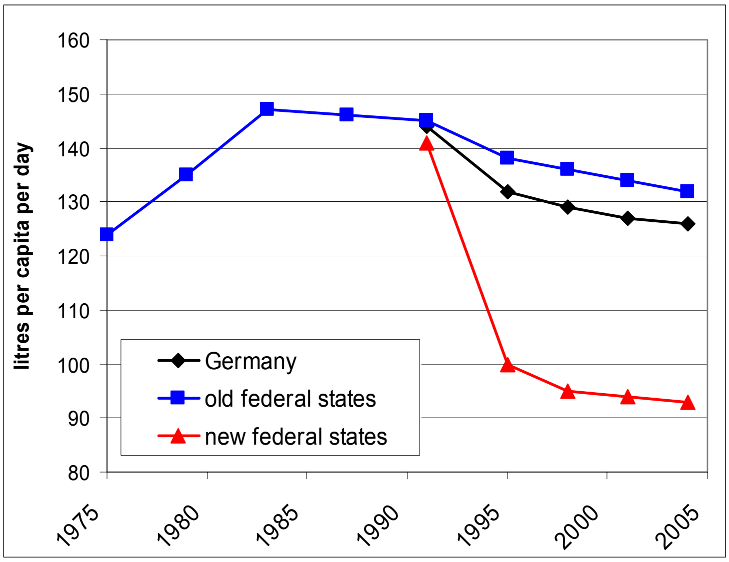
	Model 1	Model 2
	(OLS)	(IV)
Variable		
price	8.85%	22.90%
income	15.91%	20.71%
income_e	29.28%	33.04%
size	-10.91%	-6.33%
age	-5.58%	-6.91%
wells	1.92%	1.44%
rain	-5.41%	-9.65%
temp	-0.01%	-0.13%
Sum	34.06%	55.07%

Table 4: Projected changes in determinants and effects on per capita water consumption by 2020

	Change by 2020 compared to 2003		
	Range	%	litres
Price	18% to 65%	-4.2 to -15	-5.4 to -19
Income	18% to 40%	4.4 to 9.7	5.7 to 12.3
Size	-4% to -6%	0.8 to 1.2	1.1 to 1.6
Age	+2.2 to 3.6 years	2.5 to 4.2	3.3 to 5.4

Figures

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



Source: own calculations based on Destatis (various years)

Annex

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

	Model 1		Model 2	
	(OLS)		(IV)	
Variable				
price	-0.227	**	-0.497	**
	(0.032)		(0.129)	
income	0.248	**	0.324	**
	(0.069)		(0.081)	
income_e	0.436	*	0.457	*
	(0.235)		(0.249)	
size	-0.202	**	-0.125	
	(0.060)		(0.073)	
age	0.485	*	0.554	**
	(0.166)		(0.179)	
wells	-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). The logarithm of dM is used for the regression.