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Modelling Household Water Demand in Europe

Insights from a Cross-Country Econometric Analysis of EU-28 countries

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Abstract

This document provides an update of the knowledge on household water use in Europe. We first review the existing scientific literature on household water demand modelling in Europe. Second, we have assembled a new dataset with a NUTS 3 resolution and an EU-28 coverage with data on household water consumption and on household water prices. The typical source of data includes national statistical offices, regulators of water and wastewater services, national associations of water and wastewater services and national associations of municipalities. Having access to this reliable and disaggregated data on water use is a prerequisite for designing any efficient water management policy. Third, we provide some new estimates of household water demand functions for all EU-28 countries using consistent data and econometric methods. Primary data on household water consumption, household water prices and household characteristics that are supposed to have an impact on water consumption have been collected, assembled and checked for each one of the EU-28 countries. A household water demand function has then been estimated for each country using aggregate and recent data (typically municipality, water service or NUTS 3 levels covering the period 2005-2012). The econometric estimates allow us to identify the determinants of the household water demand for each country. We also provide a new set of price and income elasticities.

This work is a part of the Euro Freshwaters project developed by the JRC and led by Ad de Roo and Alberto Pistocchi. Lead author is Arnaud Reynaud. Contributing authors are Denis Lanzanova and Vassileos Markantonis.

Executive summary

This report provides an update on the knowledge on household water demand (with a specific focus on economic modelling) in the European Union. The report is largely based on existing public data sources at the national and sometimes regional level, consolidated into a coherent way.

Context Water demand modelling has taken on new importance with the need to better understand market and non-market water use values for evaluation of reallocation and investment benefits and policies. In Europe, Article 9 of the Water Framework Directive requires the implementation of pricing policies that provide an incentive to use water efficiently. Among the possible tools which can be used by public authorities, it has been stressed by European Commission (2012) that pricing is a powerful awareness-raising tool for consumers which combines environmental and economic benefits while stimulating innovation. However, any change in water prices will induce some modifications in household behaviour and will also impact on issues such as water affordability for the poorest. Economic modelling tools are then required to understand ex-ante how household water consumption may react to changes in price schemes. Economists have developed a great variety of models to predict water demand for domestic users. Although estimations of a domestic water demand function have been undertaken for a substantial number of countries all over the world, the level of knowledge in Europe is still limited or incomplete. In Europe, household water demand functions are available for several countries, but the recent report from the European Environmental Agency (EEA, 2013) has pointed out that most available reference studies date back 10 or 20 years.

Methodology We first review the existing scientific literature on household water demand modelling in Europe. By doing so, we have not been able to find any estimate of the household water demand function for 10 of the EU-28 countries (Austria, Bulgaria, Croatia, Estonia, Finland, Hungary, Ireland, Latvia, Lithuania and Slovenia). For the 18 remaining countries, it should be pointed out that existing estimates of the household water demand function rely on data posterior to 2010 for six of them only (Cyprus, Czech Republic, Germany, Luxembourg, Romania and the United Kingdom). For Denmark and Sweden, the more recent studies date back to 1990 and 1992, respectively. Despite these limitations, this literature provides some indications on the empirical determinants of household water use in Europe.

Second, we have assembled a new dataset with a NUTS3 resolution and an EU-28 coverage with data on household water consumption and household water price. The typical source of data includes national offices of statistics, regulators of water and wastewater services, national associations of water and wastewater services and national associations of municipalities. Having access to this reliable and disaggregated data on water use is a prerequisite for designing any efficient water management policy. Our dataset aims at solving one of the main limitations faced by policymakers, namely the lack of detailed and up-to-date water use statistics.

Third, we provide some new estimates of household water demand functions for all EU-28 countries using consistent data and econometric methods. Primary data on household water consumption, household water prices and household characteristics supposed to have an impact on water consumption have been collected, assembled and checked for each one of the EU-28 countries. Then, a household water demand function has been estimated for each country using the most possible disaggregated data (typically municipality-, water service- or NUTS3- levels) and the most recent data (typically 2005-2012). The econometric estimates allow us to identify the determinants of the household water demand for each country. We also provide a new set of price and income elasticities.

Main insights For most of the countries, the estimated price elasticity of the household water demand is found to be negative. Facing a price increase, EU households will react by reducing their water consumption. It is then demonstrated that water price may play a role in signalling water scarcity or water cost to households. In addition, we have found that household water demand functions are typically price-inelastic for most of the EU-28 countries. This means that the household water consumption decreases by less than 1 % for every 1 % increase in price. The price elasticities typically vary between -0.5 and -0.1 across countries. Facing a price increase by 10 %, it is then expected that the household water consumption will be reduced by 1 to 5 %. To achieve more significant reductions of household water consumption, public authorities should complement their price policies with non-price policies such as education or awareness campaigns.

Household water consumption may be, at least somehow, persistent over time due to household habits or to the time needed to adjust durable equipment (showers, for instance). It is then expected that households may react to a change in the water price in the long term rather than in the short term. Using the panel-data structure for some countries, we have shown that long-term price elasticity is in general greater (in absolute value) than short-term price elasticity. From a policy perspective, it means that even if households do not immediately react to a change in the water price, public authorities may expect them to modify their behaviour in the long term. So the benefits (in terms of reducing the water consumption) from a water price increase may be visible only a few years after having implemented the price change. It should be noted that the higher responsiveness of household water consumption in the long term to change in water price is in line with the existing literature (Nauges and Thomas 2000, Musolesi and Nosvelli 2007, Hortová and Kristoufek 2014).

Our range of value for income elasticities is much wider. For Austria, Croatia, France, Germany, Greece and Spain the income elasticity is very low (between 0.00 and 0.25). We do not expect any strong impact of change of household income on household water consumption per capita for these countries. The income elasticity is found to be much higher in Bulgaria, Cyprus, Estonia, Finland, Latvia, Lithuania, Portugal and Slovakia (greater than 0.50). This group of countries includes some Eastern European countries where both household income and water pricing have significantly changed over the last 10 years. For these countries, the expected trend in water consumption is a priori difficult to assess since it will be the result of two opposite effects. First, since household income is expected to increase in these countries (income convergence process), one may expect an increase in the water consumption per capita (income effect). On the other hand, we may anticipate some price increases for these countries, in particular due to the implementation of the full cost-recovery principle for water and wastewater services. This price effect should result in a decreasing impact on water consumption per capita. The combined impact of the income and price effects on water consumption is then a priori undetermined. Case-by-case analyses have then to be conducted.

Structure of the report The remainder of this document is organised as follows. In the first chapter we summarise the existing knowledge and gaps in household water demands in the EU-28. We also present our new dataset and the main results of the cross-country econometric analysis of household water demand for the EU-28. In particular we provide in this chapter an updated set of price and income elasticities of the household water demand function for all Member States. This report also includes a chapter for each country where in more detail we present the source of data used for the econometric analysis and the estimation of the household water demand function.

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Naturally all errors, omissions and mistakes in this report are only under the responsibility of the author of this report.

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Chapter 1

Updating the knowledge on household water demand in the EU

1.1 Introduction

This report focuses on household water consumption defined as the quantity of water used to cover household and related utility needs of the population through the water supply industry and self-supply, calculated as a total and per capita. Household water consumption provides a measure of the pressure on the environment in terms of water abstraction from different water sources through household use. This type of indicator is important for defining the level of development of water economy services and the degree of water accessibility to cover all household needs of the population. The indicator may also help to identify trends in household water use in a particular country.

There are several reasons that call for a good understanding of household water use. First, most national allocation regimes define domestic and human needs as the highest priority use (OECD, 2015).[1] Second, most large-scale water assessment models predict some very significant changes in household water use (or more generally in urban water use) for the next 50 years (Hejazi, 2013). Third, water is an essential good for households in the sense that water has no good substitute for most indoor water uses (personal hygiene, cleaning, etc.).

Economists have been working on household water use for a long time. However, water demand modelling has taken on new importance with the need to better understand the role economic instruments (i.e. water pricing) might have to induce change in water user behaviours (i.e reduction of water abstraction or polluted discharges). To this end, economists have developed a great variety of models allowing to predict water demands for industrial, agricultural and domestic users. For domestic users, the level of knowledge is quite advanced. Estimations of domestic water demand functions have been undertaken for a substantial number of countries all over the world, and the existing literature has already been summarised and reviewed by several authors (Arbues 2003; Worthington, 2008; Tanverakul, 2012) .

In Europe, household water demand functions are available for some countries. However, the recent report from the European Environmental Agency (EEA, 2013) points out that most available reference studies in Europe date back 10 or 20 years and that 'new case studies with primary data are required to provide fresh and relevant evidence that accounts for the socio-economic, management and technological changes that have taken place in the last 20 years'. This is the main objective of this report.

This document therefore provides an update on the knowledge on household water use in Europe.

We first review the existing scientific literature on household water demand modelling in Europe. By reviewing the existing literature, we have not been able to find any estimate of the household water demand function for 10 of the EU-28 countries (Austria, Bulgaria, Croatia, Estonia, Finland, Hungary, Ireland, Latvia, Lithuania and Slovenia). For the 18 remaining countries, it should be pointed out that existing estimates of the household water demand function rely on data posterior to 2010 for 6 of them only (Cyprus, the Czech Republic, Germany, Luxembourg, Romania and the United Kingdom). For Denmark and Sweden, the more recent studies date back to 1990 and 1992, respectively. Despite these limitations, this literature provides some indications on the empirical determinants of household water use in Europe.

Second, we have assembled a new dataset with a NUTS 3 resolution and an EU-28 coverage with data on household water consumption and on household water prices. The typical source of data includes national statistical offices, regulators of water and wastewater services, national associations of water and wastewater services and national associations of municipalities. Having access to this reliable and disaggregated data on water use is a prerequisite for designing any efficient water management policy. Our dataset aims at solving one of the main limitations faced by policymakers: the lack of detailed and up-to-date water use statistics.

Third, we provide some new estimates of household water demand functions for all EU-28 countries using

[1] Some exceptions include the Netherlands, a small number of Canadian provinces, water uses in Israel, and Peru.

consistent data and econometric methods. Primary data on household water consumption, household water prices and household characteristics that are supposed to have an impact on water consumption have been collected, assembled and checked for each one of the EU-28 countries. A household water demand function has then been estimated for each country using the most possible disaggregated data (typically municipality, water service or NUTS 3 levels) and the most recent data (typically 2005-2012). The econometric estimates allow us to identify the determinants of the household water demand for each country. We also provide a new set of price and income elasticities.

The remaining of this document is organised as follows. In Section 1.2 we briefly present the water demand function approach. In Section 1.3 we summarise the existing knowledge and gaps in household water demands in the EU-28. Section 1.4 is devoted to presenting our new dataset that allows to conduct a cross-country analysis of household water demand for the EU-28. In Section 1.5, we present the cross-country econometric analysis of household water demand in EU-28. In particular, we first provide a new price and income elasticities list of the household water demand function before presenting country-specific chapters where more detailed information on data and estimation methods is provided for each country.

1.2 The household water demand approach

Economic water demand modelling began in 1926, when Leonard Metcalf presented a hand-drawn regression on a double-logarithmic scale of price against water demand (Metcalf, 1926). A few decades later, several articles were published estimating proper water demand functions (Howe, 1967 etc.). Since these initial studies, the literature on water demand modelling has produced an abundance of published and unpublished research papers, primarily focusing on household demand (Gardner, 2010). In this section, we provide some basic methodological foundations of the household water demand function approach.

The water demand function approach The water demand function approach relies on standard neoclassical economic assumptions. In particular, it is assumed that for each consumer there exists a continuous utility function that is of the consumed commodity bundle and where the functional form is determined by underlying consumer preferences. The utility of each consumer is then maximised under a budget constraint and given the prices of the commodities. Thus the demand for a commodity is assumed to depend on the income of consumers, on the price of the commodity and on the availability and prices of all other commodities that are substitutes or complements to the commodity in question, as well as on consumer preferences.

Most scholars have made the assumption of weak separability of water with respect to other goods. Under this assumption, household water consumption will not depend on the price of other goods consumed. As discussed in Arbués, Barberán, and Villanúa (2004), there is no logical difficulty in imposing separability of water with respect to other goods. First, most indoor water uses (personal hygiene, cleaning, etc.) have no good substitutes. Second, household habits may be considered constant, at least in the short run. Third, complementary goods related to domestic water consumption are typically durable equipment (washing machines, sanitary equipment, etc.) that is unlikely to be changed in the short term in reaction to a water price change. Under this separability assumption, the Marshallian demand in water can be written as:

$$y = y^*(p, I, Z) \tag{1.1}$$

where y is the water consumption either per capita or per household, p and I denote the unit water price (representing both water supply and the sewage treatment services) and the representative household income, respectively. Z is a vector of exogenous variables assumed to influence water consumption (climate conditions, household and housing characteristics, etc.).

In this report, we are especially interested in providing empirical evidence on the relationship between water price and household water consumption, as well as the relationship between household income and household water consumption. A simple way to measure these relationships is to compute the *price elasticity* of the water demand and the *income elasticity* of the water demand. The price elasticity of the water demand measures the responsiveness (or elasticity) of the water use to a change in water price, all other things being equal. To be more precise, it gives the percentage change in household water use in response to a 1 % change in price (all other things being equal, i.e. holding all the other determinants of demand, such as income, constant). The price elasticity of the water demand may be written as:

$$\epsilon_p = \frac{\partial y^*(.)}{\partial p} \times \frac{p}{y^*}. \tag{1.2}$$

Similarly, the income elasticity of the water demand measures the responsiveness (or elasticity) of the water use to a change in household income, all other things being equal. To be more accurate, it gives the percentage change in household water use in response to a 1 % change in household income. The income elasticity of the water demand may be written as:

$$\epsilon_I = \frac{\partial y^*(.)}{\partial I} \times \frac{I}{y^*}. \tag{1.3}$$

Water demand functions can be used for computing the implications of alternative water pricing policies on consumer behaviours. In addition, they provide some tools for developing welfare analysis. For instance, the welfare effects of an alternative pricing policy on households can be measured (approximated, in fact) using the household water demand function (consumer surplus).

Discussion One implicit assumption we have made when writing Equation (1.1) is that water is a homogenous good. In reality, however, water that is used by households is a composite good. It consists of the direct use of water for drinking water (which in general represents a small share of the total water consumption) and the indirect use for water as a complement to different household activities (washing, cooking, hygiene, gardening, etc.). Water is therefore a necessity in households in a number of its uses and, as such, has no substitute, while it is not a necessity in many other of its uses. In the latter case, the demand for water is likely to be more affected by price changes. Since it is not usually possible to separate the different types of demand, the estimated elasticities are usually based on an aggregated household demand for water as depicted in Equation (1.1). However, alternative specifications, such as a Stone-Geary utility function, which allows to identify a volume of water covering basic needs, have also been explored (Gaudin, Griffin, and Sickles 2001).

One should also stress that the price and income elasticities of the water demand function presented in Equation (1.2)-(1.3) provide only a local measure of the responsiveness of the water demand to changes in water price and household income. For any given household, it is likely that the price elasticity may vary depending on the level of the water price.

As discussed in Gardner (2011), the existing literature has debated on a large number of methodological and empirical issues. Methodological issues include the appropriated level and structure of data for estimation (micro data versus aggregated data), the appropriate price specification (marginal water price versus average water price) and the appropriate functional form to be used for estimating Equation (1.1). Empirical issues include the magnitude and variation of estimated price and income elasticities (Espey, Espey, and Shaw 1997, Dalhuisen, Florax, de Groot, and Nijkamp 2003, Worthington and Hoffman 2008), the existence of seasonal differences, the long and short-run differences in water consumption, and geographic or income group differences in water consumption. The literature offers vast coverage. Estimations have been undertaken in several countries (Gardner 2011). The literature has already been summarised and reviewed by several authors (Arbués, García-Valiñas, and Martińez-Espiñeira 2003, Worthington and Hoffman 2008, Tanverakul and Lee 2012). In addition, four meta-analyses have been conducted, more specifically on the price and income elasticities of the household water demand (Espey, Espey, and Shaw 1997, Dalhuisen, Florax, de Groot, and Nijkamp 2003, Gardner 2011, Sebri 2014). The interested reader should also refer to Kelly Gardner's PhD dissertation Gardner (2011) for a more extensive discussion on methodological and empirical aspects of household water use modelling.

1.3 Existing knowledge and gaps on household water demands in EU-28

In this section we summarise the literature on household water demand modelling that has focused on the Member States of the European Union. In what follows, we present the main insights from studies having estimated a household water demand function in a Member State. A few general and quite robust conclusions may be drawn from this literature.

1.3.1 Existing studies on household water demands

The scientific references have been selected through systematic searches of the keywords 'household water demand', 'residential water demand', 'household water use', 'residential water use' and 'urban water' on various search engines and on the web sites of major publishers of academic journals (Scopus, Science Direct, Wiley, Web of knowledge, RepEc, AgEconSearch, etc.). Lastly, the 'grey literature' was searched using various search engines, including Google Scholar. We have also used the references provided by the previous meta-analysis on residential water use. The list of reviewed studies having estimated a household water demand is provided in Table 1.1. The selection procedure led us to retain 45 studies; a vast majority of them are peer-reviewed articles

Although the spatial coverage is vast, we have not been able to find any household water demand function for 10 Member States, namely Austria, Bulgaria, Croatia, Estonia, Finland, Hungary, Ireland, Latvia, Lithuania and Slovenia. For the 18 remaining states, it should be pointed out that the estimates of the household water demand functions rely on data posterior to 2010 for six of them only (Cyprus, the Czech Republic, Germany, Luxembourg, Romania and the United Kingdom). For Denmark and Sweden, the more recent studies date back to 1990 and 1992, respectively. Not surprisingly, the three countries for which the highest number of studies on household water demand function is available are Spain, Italy and France. Since these three countries regularly face problems of water scarcity, identifying and understanding the drivers of household water use might be of primary interest for public authorities. In addition, the fact that water services are organised at the municipality level may facilitate data collection.

One may argue that the results obtained for the 18 countries may be 'transferred' to the other 10 countries. Value transfer, however, raises some methodological issues, but we will not discuss that here. In addition, in his recent meta-analysis of household water demand functions, Sebri (2014) has shown that estimates strongly vary across the geographic location, so decision-makers in a given country should not *directly* rely on the findings of studies conducted in other countries when formulating their own policies.

Concerning the type of data, a vast majority of published studies have used aggregated data at the municipality level. In other words, these studies have estimated a household water demand function for a representative household using a set of municipalities. A few studies have relied on household-level data, but they are usually limited in terms of spatial coverage to a specific municipality or a specific region. [2] It is then

[2] One recent example is Vanhille (2012) who has used household-level data to estimate the residential water demand function in the Flanders region in Belgium. One reason explaining the scarcity of household-level studies is that household-level data are typically obtained from water company records. It is then often difficult to match these household-level records with household characteristics, such as income or age.

Table 1.1: Household water demand studies in the EU-28

Country	Study	Data*	Spatial coverage	Time coverage
Austria	n.a.	n.a.	n.a.	n.a.
Belgium	Vanhille (2012)	H	1 Region	2009
Bulgaria	n.a.	n.a.	n.a.	n.a.
Croatia	n.a.	n.a.	n.a.	n.a.
Cyprus	Polycarpou and Zachariadis (2013)	M	3 Muni	2008-2009
	Hajispyrou et al. (2002)	H	Country	1997-1998
Czech Republic	Grafton et al. (2009)	H	Country	2008
	Slavíková et al. (2013)	M	2 Muni	2004-2009
	Hortová and Kristoufek (2014)	R	14 Regions	2000-2011
Denmark	Hansen (1996)	H	1 Muni	1981-1990
Estonia	n.a.	n.a.	n.a.	n.a.
Finland	n.a.	n.a.	n.a.	n.a.
France	Nauges and Reynaud (2001)	M	225 Muni	1989-1995
	Nauges and Thomas (2003)	M	116 Muni	1988-1993
	Garcia and Reynaud (2004)	M	50 Muni	1995-1998
	Grafton et al. (2009)	H	Country	2008
	Rinaudo et al. (2013)	M	137 Muni	2005
Germany	Frondel and Messner (2008)	H	1 Muni	1998-2001
	Schleich and Hillenbrand (2009)	M	Country	2001-2005
	Muller (2012)	R	Country	2007, 2010
Greece	Athanasiadis et al. (2005)	H	17 Muni	1994-2000
	Bithas and Chrysostomos (2003)	M	1 Muni	1981-1999
	Vagiona and Mylopoulos (2009)	H	1 Muni	1997-2005
Hungary	n.a.	n.a.	n.a.	n.a.
Ireland	n.a.	n.a.	n.a.	n.a.
Italy	Mazzanti and Montini (2006)	M	1 Region	1998-2001
	Statzu and Stazzera (2007)	M	1 Region	2000-2005
	Musolesi and Nosvelli (2007)	M	Muni	1998-2001
	Grafton et al. (2009)	H	Country	2008
	Di Cosmo (2011)	H	Country	1999-2005
Latvia	n.a.	n.a.	n.a.	n.a.
Lithuania	n.a.	n.a.	n.a.	n.a.
Luxembourg	MECE (2012)	M	Country	2010
Malta	Delia (2004)	M	Country (av)	1989-1999
Netherlands	Kooreman (1993)	M	60 Muni	1988-1989
	Linderhof (2001)	H	Country	1978-1994
	Grafton et al. (2009)	H	Country	2008
Poland	Bartczak et al. (2009)	M	Country	2001-2005
Portugal	Martins and Fortunato (2007)	M	5 Muni	1998-2003
	Monteiro and Roseta-Palma (2011)	M	Country	1998-2005
	Monteiro et al. (2014)	H	10 Muni	1998-2005
Romania	Ciomos et al. (2012)	M	1 Muni	2002-2010
Slovakia	Dalmas and Reynaud (2005)	M	Country	1999-2005
Slovenia	n.a.	n.a.	n.a.	n.a.
Spain	Martinez-Espineira (2002)	M	132 Muni	1993-1999
	Martinez-Espineira (2003)			1995-2003
	Arbues (2004)	H	1 Muni	1996-1998
	Martinez-Espineira and Nauges (2004)	M	1 Muni	1991-1999
	García-Valinas (2005)	H	1 Muni	1991-2000
	Martinez-Espineira (2007)	M	1 Muni	1991-1999
	Martinez-Espineira and García-Valinas (2010)	M	301 Muni	2005
	March and Sauri (2010)	M	160 Muni	2003
	Arbues et al. (2012)	H	1 Muni	1996-1998
	March et al. (2012)		1 Muni	2003-2007
Sweden	Hanke-de Maré (1982)	H	1 Miuni	1971-1978
	Hoglund (1999)	M	Country	1980-1992
	Grafton et al. (2009)	H	Country	2008
United Kingdom	Gardner (2010)	H	1 WU	2007-2010

*: H, M, R for household-, municipal- and regional-level data respectively.

difficult to extrapolate such local results at the scale of a country. More generally speaking, even when a large number of spatial units was used (either municipalities or regions) for estimating the household water demand function, the national territory was not fully covered.[3]

1.3.2 Knowledge and gaps on household water demands

In Table 1.2, we summarise the main findings in terms of significant drivers of the household water demand function in the EU-28. As a word of caution, it should be pointed out that the cross-country comparison is made difficult by the fact that variables introduced as determinants of the household water demands are not consistently defined across studies. In addition, the dependent variable may also differ between studies, some of them using water consumption per capita while others may refer to water consumption per household. However, certain general and persistent trends do emerge. In order to organise the discussion, we will analyse different groups of determinants, including water price and tariffs, household income, population characteristics, housing characteristics and climate conditions.

Water price and water tariffs Most economists working on domestic water use generally recognise that domestic water consumption reacts to changes in water prices. It is however usually found that the household water demand function is price inelastic which means that water consumption decreases by less than 1 % for every 1 % increase in price, the price-elasticity typically varying between -0.1 and -1.0.[4]

Among all the studies we have reviewed for the EU-28, only two of them have found a price-elastic household water demand, Mazzanti and Montini (2006) in Italy and Arbues et al. (2012) in Spain. As explained by the former, the high tariffs characterising Emilia Romagna, with respect to other regions in Italy, may explain their results. In Arbues et al. (2012), the highest price elasticity (in absolute value) is found for a single-person household. For a typical household made up of four persons, the price elasticity is equal to -0.27.

Most published studies provide single price elasticity for the household water demand function. However, some authors have investigated the heterogeneity of price elasticity.

- Price elasticity varies depending on the type of water use. Essential uses such as water for human consumption or for cooking are found to be very price inelastic, whereas water-related leisure activities (watering the garden or making use of swimming pools) are usually much more price reactive.
- Price elasticity also varies over time. Demand studies using summer data that appear to exhibit higher price elasticity in absolute value (Arbués, García-Valiñas, and Martińez-Espiñeira 2003).
- Price elasticity is found to vary depending upon some characteristics of households. It is for instance documented that elasticity varies with household size (Arbués, Villanúa, and Barberán 2010, Vanhille 2012). In developed countries, it is also usually found that price elasticity varies with household income, lower income groups being more price-responsive than higher income groups. For Cyprus, Hajispyrou, Koundouri, and Pashardes (2002) reports price elasticity equal to -0.79 for the lowest income group compared to -0.39 for the highest income group. In Belgium, the price elasticity for the lowest income quintile is estimated to be -0.76 compared to -0.25 for the highest income quintile (Vanhille 2012). Since

[3] There are a few exceptions. For instance Grafton, Ward, To, and Kompas (2011) has estimated residential water demand functions for 10 countries using household-level data. They use a representative sample stratified with respect to income, age, gender and region within each country (approximately 1 000 households per country).

[4] In his recent meta-analysis, (Sebri 2014) reports a mean and a median price elasticities equal to -0.365 and -0.291, respectively.

Table 1.2: Price, income and other determinants of household water demand in the EU-28

Country	Study	Price elasticity	Income elasticity	Other determinants
Austria	n.a.	n.a.	n.a.	n.a.
Belgium	Vanhille (2012)	-0.62	0.62	Population density (+) Size(+) Age (+)
Bulgaria	n.a.	n.a.	n.a.	n.a.
Croatia	n.a.	n.a.	n.a.	n.a.
Cyprus	Polycarpou and Zachariadis (2013)	-0.45 ; -0.25	0.53 ; 0.75	Temp (+) Rainfall (+) Rationing (-)
	Hajispyrou et al. (2002)	-0.79 ; -0.39	0.22 ; 0.48	-
Czech Republic	Grafton et al. (2009)	-0.42	0.01	Dual-flush toilets (-) Age(+) Size(+) Housing size(+)
	Slavíková et al. (2013)	-	-	-
	Hortová and Kristoufek (2014)	-0.20 ;-0.54	0.10	LagCons (+) Rainfall (-)
Denmark	Hansen (1996)	-0.10	-	PriceElectricity (-)
Estonia	n.a.	n.a.	n.a.	n.a.
Finland	n.a.	n.a.	n.a.	n.a.
France	Nauges and Reynaud (2001)	-0.22 ; -0.08	0.01	Housing recent (-)
	Nauges and Thomas (2003)	-0.40 ; 0.40	0.50	-
	Garcia and Reynaud (2004)	-0.25	0.03	Size (+) Recent Housing (+)
	Grafton et al. (2009)	-0.41	0.01	Dual-flush toilets (-) Age(+) Size(+) Housing size(+)
	Rinaudo et al. (2013)	-0.18	0.42	Temp (+) Dry days (+) Secondary homes (+)
Germany	Frondel and Messner (2008)	-0.49	0.13 ; 0.30	Size (+) House(+) Dishwater (+)
	Schleich and Hillenbrand (2009)	-0.24	0.35	Size (-) Age(+) Rain (-) Well (-)
	Muller (2012)	-0.46 ; 0.26	-0.01 ; 0.04	Size (+)
Greece	Athanasiadis et al. (2005)	-0.34	0.35	Temp (+) Rainfall (-) Information (-)
	Bithas and Chrysostomos (2003)	-0.10	0.72	Time trend (+)
	Vagiona and Mylopoulos (2009)	-0.95	-	Temp (+) Rainfall (+)
Hungary	n.a.	n.a.	n.a.	n.a.
Ireland	n.a.	n.a.	n.a.	n.a.
Italy	Mazzanti and Montini (2006)	-1.33 ; -0.99	0.40 ; 0.71	Altitude (-)
	Statzu and Stazzera (2007)	-0.25	0.43	Size (+) Aridity index (+) Tourist (+) Rationing (-)
	Musolesi and Nosvelli (2007)	-0.47 ; 0.27	0.18 ; 0.31	Age (+)
	Grafton et al. (2009)	-0.59	0.01	Dual-flush toilets (-) Age(+) Size(+) Housing size(+)
	Di Cosmo (2011)	-0.36 ; -0.14	0.40 ; 0.46	-
Latvia	n.a.	n.a.	n.a.	n.a.
Lithuania	n.a.	n.a.	n.a.	n.a.
Luxembourg	MECE (2012)	-0.33	0.60	-
Malta	Delia (2004)	-0.37 ; -0.28	0.24	-
Netherlands	Kooreman (1993)	-0.19 ; -0.09	-	-
	Linderhof (2001)	-0.07	0.11	Size (+) Age(-) Dishwasher(+) No washing machine(-)
	Grafton et al. (2009)	-0.40	0.01	Dual-flush toilets (-) Age(+) Size(+) Housing size(+)
Poland	Bartczak et al. (2009)	-0.20	0.12	Size (-)
Portugal	Martins and Fortunato (2007)	-0.56	0	Size (+) Temp (+) Age (-)
	Monteiro and Roseta-Palma (2011)	-0.13 ; -0.05	0.04 ; 0.09	Temp (+) Age(-) No bath (-) Non-permanent (-)
	Monteiro et al. (2014)	-0.48	0.25	Size (+) House(+) Secondary homes (-)
Romania	Ciomos et al. (2012)	-0.70	-	-
Slovakia	Dalmas and Reynaud (2005)	-0.50 ; -0.35	0.26 ; 0.32	Size (-)
Slovenia	n.a.	n.a.	n.a.	n.a.
Spain	Martinez-Espineira (2002)	-0.16 ; -0.12	0.30 ; 0.68	Temp (+) Rainfall(-) Size (-)
	Martinez-Espineira (2003)	-0.67 ; -0.37	n.a.	
	Arbues (2004)	-0.06 ; -0.03	0.07 ; 0.21	n.a.
	Martinez-Espineira and Nauges (2004)	-0.10	0.1	
	García-Valinas (2005)	-0.55 ; -0.46	0.58	
	Martinez-Espineira (2007)	-0.50 ; -0.10	0.00	Temp (+)
	Martinez-Espineira and García-Valinas (2010)	-0.06	0.06	Size (+) Age (-) Rainfall (-) Tourist (+)
	March and Sauri (2010)	n.a.	0.70	Size (+) Age (-) Density (-)
	Arbues et al. (2012)	-1.31 ; -0.26	0.00	Temp (+) Age (-)
	March et al. (2012)			
Sweden	Hanke-de Maré (1982)	-0.15	0.11	
	Hoglund (1999)	-0.20; -0.10	0.09 ; 0.12	Size (-)
	Grafton et al. (2009)	-0.41	0.01	Dual-flush toilets (-) Age(+) Size(+) Housing size(+)
United Kingdom	Gardner (2010)	-0.29	0.01	Size (+) Temp (+) rain (-) Summer (+)

households will react in a very different way to water pricing depending on their level of income, any change in the water price policy will have to address some social and equity issues.

- Price elasticities differ in the short and in the long run. Short-run elasticities are usually found to be smaller than their long-run counterparts, suggesting that consumers might need time to adjust water-using capital stocks and to learn about the effects of use on their bills. For Spain, Martínez-Espiñeira (2007) finds that the price elasticity of demand is around -0.1 in the short run and -0.5 in the long run. For France the short- and long-run price elasticities reported by Nauges and Thomas (2003) are respectively -0.26 and -0.40. Using a panel of 101 Italian municipalities, Musolesi and Nosvelli (2007) find a short-term and long-term elasticity for the Italian household water demand equal to be -0.27 and -0.47, respectively. For the Czech Republic, the water demand is shown by Hortová and Kristoufek (2014) to be more elastic in the long run than in the short run, as the price elasticity in the short run is estimated to be -0.20, while the price elasticity in the long run is -0.54.

- Spatial variations in price elasticities have also been documented. Dalhuisen, Florax, de Groot, and Nijkamp (2003) reports that price elasticities tend to be smaller in Europe compared to the United States, and price elasticities within the United States are greater in absolute value in the arid West. These spatial patterns have also been recently reported in (Sebri 2014).

Household income It is widely accepted and has been empirically demonstrated that domestic water consumption is positively correlated with income. The explanation is quite simple. A high level of income is associated with high living standards, which could imply a higher quantity of water-consuming appliances and a higher probability of the presence of high-water demanding outdoor uses such as lawn gardens and swimming pools.

Population characteristics The age distribution within the household also affects residential water use even if the impact of age on water use still needs to be explored. It is usually found that older people, all else being equal, consume less water than younger people. Nauges and Thomas (2000) supports this finding and observes that communities with more seniors have lower water consumption, and similar results have been found by (Martínez-Espiñeira 2002, Martins and Adelino 2007, Musolesi and Nosvelli 2007). By contrast, Schleich and Hillenbrand (2009) finds the converse, namely that as people get older they consume more water per person, and proposes three types of explanations. Water use may increase with age because retired people spend more time at home and gardening, because children use less water for washing and hygiene than adults, or because health reasons may force older people to use the bathroom more frequently. A variable that has a positive effect on household water consumption is the number of people in a residence (Hanke and Maré 1982).

Housing characteristics Residential characteristics associated with houses and properties have, in some studies, been shown to affect household water consumption. Some authors find a statistically significant effect between household water consumption increases and house size, and also lawn size. Using French data from 116 communities, Nauges (2000) finds that, all else being equal, the older the house the more water is consumed.

Climate conditions Climate is one of the most studied drivers of domestic water demand. Indeed, it is considered that household water consumption varies depending on variables, such as temperature and rainfall, which may influence the amount and/or frequency of activities that involve water-consumption activities, such as garden watering, swimming pool use and personal hygiene (Romano, Salvati, and Guerrini 2014).

The climatic indicators usually considered include rainfalls (annual or in the summer, number of rainy days), evapotranspiration, temperature (maximal or average) and solar radiation in particular.

With respect to weather conditions, Martínez-Espiñeira (2002) (Northwest Spain) has found that water use was highest in summer. In addition, Martínez-Espiñeira (2002) and Schleich and Hillenbrand (2009) (for Germany) have found that water consumption decreases as the number of rainy days increases. In contrast, Arbués and Villanúa (2006) has reported an association between high temperatures and low water consumption in the city of Zaragoza in Spain, which they suggested was due to consumption levels tapering off in the summer because of the outflow of residents to holiday destinations. Focusing also on Spain, García-Valiñas (2005) has observed higher price elasticity in peak periods (summer) than in off-peak periods (all other seasons). In Portugal, Martins and Adelino (2007) has demonstrated that high temperatures tend to result in an increase of the demand for water, although rainfall has no significant association with it.

Non-price policies Non-price policies correspond to all non-market-based programmes designed to increase the efficiency of water use or water conservation. Although non-price policies are by nature very heterogeneous, they may be classified into three categories: public education, technological improvements and water restrictions.

A number of papers have considered the impact of non-price policies on residential water use. Public education programmes have been shown to have a limited impact on residential water use, especially in the short term. Literature suggests that a certain critical mass of educational programmes is necessary to generate significant benefits Michelsen, McGuckin, and Stumpf (1999).

Somewhat more attention has been paid to understanding the effectiveness of technological changes, especially indoor retrofitting of water-using devices such as toilets, showerheads and washing machines. Studies with this focus are frequently based on engineering assumptions of expected reductions (Michelsen, McGuckin, and Stumpf 1999). One notable exception is provided by Millock and Nauges (2010). Using survey data on 10 OECD countries, the authors of this paper show that the adoption of water-efficient equipment is strongly affected by housing ownership status, by being water-metered and charged with a volumetric price on water consumption and by behavioural factors. Environmental attitudes are shown to be strong predictors of the adoption of water-efficient equipment, with a marginal effect that exceeds ownership status in some cases. Gilg and Barr (2006) has also focused on attitudinal factors that determine water consumption behaviour (in particular on environmental preferences, intrinsic motivations and social norms). This study reveals that it is possible to classify households into relatively homogenous groups based on their water consumption behaviour. These attitudinal differences should then be taken into account when designing non-price policies.

Lastly, some authors have specifically focused their attention on the efficiency of restrictions in water use. For Spain, Garcia-Valinas (2006) measures the impact on consumers of rationing policies implemented during water shortages. The author demonstrates that the restrictions implemented during the drought in Seville have had an important impact on water demands. Some papers, whose articles generally focus on the comparison of voluntary programmes versus mandatory programmes, have analysed the effectiveness of outdoor watering restrictions and. consistently show significant savings from mandatory restrictions (sometimes 30 % or more). Findings regarding voluntary restrictions are much more variable.

Attitudinal and behavioral drivers Grafton, Ward, To, and Kompas (2011) finds that attitudinal characteristics and environmental concerns increase the likelihood for households of undertaking certain specific and self-reported water-saving behaviour. Some attitudinal characteristics and environmental concerns also increase the rate of adoption of a low volume/dual-flush toilet that reduces household water consumption. The Spanish study by Domene and Saurí (2006) is one of the very few to examine the influence of attitudinal variables on household water consumption, and it finds a significant association.

1.4 A new dataset for analyzing household water demand in the EU-28

We present in this section our new dataset which will be our main material for estimating the household water demand functions in each EU-28 country. Primary data on household water consumption, on household water prices and on household characteristics supposed to have an impact on water consumption have been collected, assembled and checked for each one of the EU-28 countries. The typical source of data includes national statistical offices, regulators of water and wastewater services, national associations of water and wastewater services and national associations of municipalities.

1.4.1 Data sources

Estimating a household water demand for a single country can sometimes be difficult due to the lack of appropriate data. Conducting a cross-country analysis on 28 different countries represents a challenge in terms of data collection. We describe here the main source of data we have relied on. Our data collection strategy has been to use official statistics published by each country as much as possible.

We present in Table 1.3 the main source of data for each EU-28 country. We limit our presentation to the main source of data, noting that data may have been complemented by other sources of information. More detailed information on data sources is provided in each country-specific chapter of this report.

Table 1.3: Main data sources used for estimating household water demand in the EU-28

Country	Main sources of data
Austria	Statistics Austria, Austrian Association for Gas and Water
Belgium	National or regional statistical office (be.STAT, WalStat), Association of Water and Wastewater Utilities (Aquawal)
Bulgaria	National Office of Bulgaria, State Energy and Water Regulatory Commission of Bulgaria
Croatia	Croatian Bureau of Statistics, IBNET
Cyprus	Cyprus Statistical Service
Czech Republic	Statistical Office of the Czech Republic
Denmark	Statistics Denmark, Danish Association of Water and Wastewater Utilities (DANVA)
Estonia	Statistics Estonia, Estonian Association of Waterworks (EVEL)
Finland	Finland Statistics, Finnish Water Utilities Association (FIWA), Finnish Institute of Environment (SYKE)
France	National Institute of Statistics and Economic Studies (INSEE), French observatory on public water and sanitation services (SISPEA)
Germany	Federal and State Statistical Offices of Germany
Greece	National Statistical Office of Greece, National river basin management plans
Hungary	Hungarian Central Statistical Office, IBNET
Ireland	Environmental protection Agency, Central Statistical Office of Ireland, Irish Business and Employers Confederation
Italy	Italian National Institute of Statistics, Federconsumatori
Latvia	Public Utility Commission of Latvia, Latvian Environment Geology and Meteorology Center, Latvian Central Statistical Bureau
Lithuania	Statistics Lithuania
Luxembourg	Statistical Office of Luxembourg (STATEC)
Malta	National Statistics Office of Malta, Central Bank of Malta
Netherlands	Statistics Netherlands, Association of Dutch Water Companies (VEVIN)
Poland	Central Statistical Office of Poland
Portugal	Statistics Portugal, Water and Waste Services Regulation Authority (ERSAR)
Romania	National Institute of Statistics of Romania, IBNET
Slovakia	Statistical Office of the Slovak Republic, Slovak Ministry of Agriculture, Water and Soil Management
Slovenia	Statistics Slovenia, LM Veritas
Spain	National Statistics Institute (INE)
Sweden	Statistics Sweden, Swedish Water & Wastewater Association (SWWA)
United Kingdom (England & Wales)	Office for National Statistics, Water Services Regulation Authority (OFWAT)

IBNET: International Benchmarking Network for Water and Sanitation Utilities

When collecting data, we have tried to rely on published official statistics (and regularly undated) either provided directly by national statistical offices or by governmental agencies such as ministries, environmental agencies or regulators of the water sector.

For all countries, our major source of data (especially for household and housing characteristics) has been the national statistical offices. Depending on the country, data related to water pricing and to water consumption of households may come from water service regulators (Bulgaria, Latvia, Portugal and the United Kingdom), from national environmental agencies (Ireland), from associations of water and wastewater services (Austria, Denmark, Estonia, Finland and Sweden) or from other sources including central banks or non-governmental organisations (Greece, Ireland, Italy, Malta and Slovenia).

Most of the data collected are publicly available (either from the web or from published reports). For some countries, data have been obtained through personal communication and are not publicly available.

1.4.2 Data description

In Table 1.4, we give a brief overview of the type of data collected. In particular we describe in this table both the spatial and the temporal resolution/coverage.

Table 1.4: Description of data collected for estimating household water demands in the EU-28

Country	Spatial resolution	Number spatial units	Type of data	Time coverage
Austria	Mun	72	Panel	2007-2009
Belgium	Mun	249 / 308	Panel	2004, 2008, 2011 / 2012-2013
Bulgaria	NUTS 3	28	CS	2010
Croatia	WS	21	Panel	2000-2004
Cyprus	NUTS 3	1	TS	1998-2012
Czech Republic	NUTS 3	14	Panel	2006-2011
Denmark	WS	56	Panel	2010-2012
Estonia	NUTS 3	15	Panel	2006-2012
Finland	Mun	140	CS	2011
France	Mun	9 000-13 000	Panel	2008-2011
Germany	NUTS 3	370	Panel	2004, 2007, 2010
Greece	Other	114	CS	2010
Hungary	NUTS 3	20	Panel	2000-2007
Ireland	Other	34	CS	2011
Italy	Mun	113	Panel	2001-2011
Latvia	Mun	77	CS	2013
Lithuania	NUTS 3	10	Panel	2001-2012
Luxembourg	Mun	14	CS	2010
Malta	Country	1	TS	2000-2010
Netherlands	NUTS 3	40	Panel	2009-2011
Poland	NUTS 3	66	Panel	2003-2012
Portugal	Mun	232	Panel	2007, 2009
Romania	NUTS 3	18	Panel	2000-2010
Slovakia	NUTS 3	8	Panel	2001-2011
Slovenia	NUTS 3	12	Panel	2001-2011
Spain	NUTS 2	17	Panel	2004-2011
Sweden	NUTS 3	21	CS	2011
United Kingdom (England & Wales)	WS	16	Panel	2002-2009

Spatial resolution: Mun for municipality, WS for water service. Municipal unit in Greece. Water Service Authority in Ireland.
Type of data: CS for cross-section, TS for time-series.
For Belgium separated data are available for Flanders and for the Walloon Region (including Brussels-Capital region).

We have collected aggregated data with various levels of resolution. For the spatial resolution, our strategy has been to collect and compile recent data available at the most disaggregated level.[5] There is of course a trade-off between having access to highly spatially disaggregated data but with a specific and limited area and using more aggregated data but covering a large area. Since our objective is to estimate a household water demand function for each EU-28 country, the latter option has always been preferred.

Most of the datasets we have collected have a spatial resolution at least corresponding to NUTS 3. For 12 countries (Bulgaria, the Czech Republic, Estonia, Germany, Hungary, Lithuania, Netherlands, Romania, Slovakia, Slovenia and Sweden), our resolution matches NUTS 3 exactly.[6] We have municipal-level data for seven countries (Austria, Finland, France, Italy, Luxembourg, Latvia and Portugal) and data at the water service level for three countries (Croatia, Denmark and the United Kingdom). Greece has the highest spatial resolution (municipal unit which corresponds to a sub-division of municipalities) but with a relatively low spatial coverage (see the specific chapter on Greece). For Spain, due to data availability we will work at NUTS 2 level (autonomous communities and cities).

The number of spatial units in each country varies from one (Cyprus and Malta) to a few thousands, such as the case of France. In most cases, our data cover a substantial area in each country.

We have collected panel data for 18 countries (Austria, Croatia, the Czech Republic, Denmark, Estonia, France, Germany, Hungary, Italy, Lithuania, Netherlands, Poland, Portugal, Romania, Slovakia, Slovenia, Spain and the United Kingdom). The remaining countries are split across cross-section data (Bulgaria, Finland, Greece, Ireland, Latvia and Sweden) and time-series data (Cyprus and Malta). A vast majority of datasets collected refers to the period 2000-2010. The oldest data corresponds to Croatia (2000-2004). For 13 countries we have data after 2010 (Cyprus, Denmark, Estonia, France, Ireland, Italy, Latvia, Lithuania, Netherlands, Poland, Slovakia, Slovenia and Sweden).

1.4.3 Measuring household water use and water price

Since household water use patterns and household water prices differ very significantly across water services, municipalities or regions in any given country, comparing national averages should be done with caution. Moreover, when comparing water prices across countries one should take into account differences in purchasing power parity.

Household water use In this report our focus is on understanding and modelling the drivers of *household water use*. By reference to the United Nations Economic Commission for Europe, we will define household water use as the quantity of water used to cover the household and related utility needs of the population through the water supply industry and self-supply, calculated as a total and per capita. In our report our focus will be on household water use per capita. We will then propose empirical models to predict the water consumption per capita in each of the EU-28 countries. Although this definition may appear simple at first, it raises substantial issues when considering a cross-country analysis since the definition used in each country might differ from the proposed one.

First, household water use may be mixed with water use for some other types of consumers (typically small industrial or commercial establishments). In our work we have tried to identify the water that is really used

[5] Ideally we would have needed household-level micro data. This type of data is not, however, available in a standardised way for a vast majority of EU-28 countries. The bias of using aggregated data (compared to using household data) is not clear since the vast majority of studies has relied on aggregated level.

[6] For any given country in this case, the number of spatial units included in our analysis might not be equal to the number of NUTS 3 in the considered country due to data availability. For Cyprus and Malta, the NUTS 3 level corresponds to the country-level.

by households.[7] Second, some countries may not report the water actually used by households but a volume including distribution network losses. In such cases, the distribution losses have been excluded when computing household water use. Third, in some countries self-supply is included in the household water use. Finally, for computing household water use per capita, some countries use the total population whereas others rely on the population connected to the water network. This issue is not important if almost all households are connected to the water network, but it may really matter otherwise. Our approach has been to try to get reliable information on the share of households connected to the water network. We have then focused on household water use per capita connected to the network.

When compiling data from the EU-28 countries, we have tried as much as possible to comply with our definition of household water use per capita. As a result, figures presented in Table 1.5 should be viewed as being *relatively* homogenous across countries in terms of definition of household water use per capita. Columns 2-5 in this table give the national average for household water use per capita for 2008 through to 2011.

Table 1.5: Household water use and price in the EU-28

Country	Service	Household water use (m3/capita/year)				Household water price (€/m3)				Household water price (PPP) (PPP€/m3)			
		2008	2009	2010	2011	2008	2009	2010	2011	2008	2009	2010	2011
Austria	w	53.7	53			1.4	1.4			1.3	1.3		
Belgium	w	31.9			31.7	3.2			4.2	2.9			3.8
Bulgaria	w	36.3	36.4	35.9				0.7				1.4	
Croatia	w,w												
Cyprus	w	79.5	87	99	94.7	0.6	0.7	0.8	0.8	0.7	0.8	0.9	0.9
Czech Republic	w,w	34.1	33.6	32.6	32.2	2.0	2.2	2.3	2.5	2.6	3.0	3.1	3.4
Denmark	w			44.6	47.6			2.8	2.9			2.0	2.1
Estonia	w,w	40.5	34.3	33.8	40.1	1.6	2.0	2.2	2.3	2.1	2.6	2.9	3.0
Finland	w				66.5				3.7				3.0
France	w	63.1	54.3	49.5	49.1	2.1	2.2	2.0	2.1	1.9	2.0	1.8	1.9
Germany	w,w			43.7				3.9				3.8	
Greece	w,w			81.9				1.3				1.4	
Hungary	w	37.8	37.7	35.8	35.9								
Ireland	w,w				49.3				2.2				1.8
Italy	w,w	69.2	68.3	66.8	64.0		1.3	1.4	1.5		1.2	1.4	1.5
Latvia	w,w				58.6				1.4				1.9
Lithuania	w	25.4	24.3	24.1	25.0	0.7	0.7	0.7	0.7	1.1	1.0	1.1	1.1
Luxembourg	w,w			51.2				5.7				4.7	
Malta	w	27.2	27.3	25.9		1.1	1.8	1.8		1.4	2.3	2.3	
Netherlands	w		48.0	48.0	47.5		1.4	1.4	1.4		1.3	1.3	1.3
Poland	w	35.3	34.8	34.5	34.7	0.5	0.6	0.6	0.7	0.7	1.0	1.0	1.2
Portugal	w,w	59.7	63.5				1.2				1.3		
Romania	w	61.0	57.3	55.8	54.4	1.3	1.0	0.8		2.1	1.7	1.4	
Slovakia	w,w	33.4	30.9	30.1	29.6	1.6	1.7	1.8	1.8	2.3	2.3	2.6	2.5
Slovenia	w,w	47.9	45.9	44.8	44.5	1.6	1.8	2.0	2.0	1.9	2.0	2.3	2.3
Spain	w,w	56.2	54.4	52.4	51.6	1.3	1.4	1.5		1.4	1.4	1.6	
Sweden	w			61.1				3.2				2.7	
United Kingdom	w	53.6	53.7			1.9	1.9			1.8	1.8		

Source: Author's calculations based on the data sources presented above. Please refer to country-specific chapters for more details.
Column 'Service' gives services considered for computing the price. 'w' for water supply only and 'w,w' for water supply and wastewater.
For Latvia, data refer to 2013. Belgium restricted to Wallonia. United Kingdom restricted to England and Wales.

[7] For some countries, the definition of a household water consumer is based on a maximum volume of water per year (250 m3 per year in the case of Belgium for instance).

Household water price Since pricing has been shown in most of the existing studies as an important determinant of household water use, we also present in Table 1.5 some basic statistics on the water price paid by households for the water service. An inherent difficulty when comparing water prices across countries is related to the fact that pricing schemes might be very different from one country to another, for instance since price levels and pricing structures can be decided at different levels (local, regional or national level). In some countries the water and wastewater services are jointly charged to household, which can make difficult the identification of the specific part related to the water service. In some countries, the water bill is not related to the water consumption, which makes difficult the computation of an average water price. The price data presented in Table 1.5 refer to the average water price (in EUR per cubic meter) paid by a representative household either for the water supply service only or for the water supply and wastewater services (the 'Service' column gives the services considered for computing the price for each country). It follows that the water prices are not directly comparable across countries.

Discussion A first message from Table 1.5 is that there are major differences in household water use per capita across countries. A first group of countries emerges with a high level of household water use per capita (more than 60 m3 per inhabitant per year). This group includes Cyprus, Greece, Italy, Portugal and Sweden (Southern European countries mainly). Contrarily, a low level of household water use per capita (less than 40 m3 per inhabitant per year) is found in Bulgaria, the Czech Republic, Estonia, Hungary, Lithuania, Poland and Slovakia. This group then includes mainly Eastern European countries.

There are also major differences across countries in terms of average water price paid by household users. A first group of countries with a 'high' water price includes Belgium, Germany, Luxembourg and Sweden (water supply service only) and France, Malta and the United Kingdom (water supply and wastewater services). Low water prices are however recorded in the Czech Republic, Lithuania, Poland and Romania. Interpreting this result is very difficult. Differences in prices may be driven by many factors, including the cost and quality of the water provision service, the application of the cost-recovery principle and the cross-subsidisation across users. It is indeed well-known that there is a high level of heterogeneity across countries with regards to the implementation of the cost-recovery principle through pricing. In many countries, water prices are distorted by subsidies (or cross-subsidies among types of water users) or due to the fact that the water sector is highly regulated and non-competitive. For instance, costs are almost fully recovered in Germany: 99 % of drinking water costs and 96 % of wastewater costs are directly paid for by the consumers. In Austria, the amount paid by consumers represents 93 % of drinking water costs and 78 % of wastewater costs (BDEW 2015). But in Croatia, an analysis for four utility companies showed service prices do not reflect real costs, with a cost recovery of 77 % for drinking water supply and 45 % for wastewater (ICPDR 2005). A similar situation is observed in Romania where an analysis of water and wastewater systems in the Cluj and Salaj counties revealed a recovery of investment cost equal to 38 % for water and wastewater (ICPDR 2005). In addition, within a given country, the cost-recovery principle might be applied differently depending on the sector considered. Industrial tariffs are generally higher than tariffs paid by households, even if it cannot be explained by differences in infrastructure or operation costs. This cross-financing phenomenon is common in the water sector but variable across countries. For instance, the ratio of commercial to household tariffs for water supply is 3.3 for Albania, 1.6 for Croatia and 2 for Montenegro (REC 2009).

It is finally interesting to have a look at how water consumption and water price have evolved over time. In terms of change in water consumption, there is a majority of countries where the per capita consumption has decreased (either moderately or strongly) over recent years. Cyprus is the only country where a significant increase in water consumption per capita has been recorded in the recent year. The water price has increased (either moderately or strongly) over recent years in most countries (16 of 28). The strongest rates of increase for the household water price are found in Cyprus, Estonia, Hungary, Italy, Malta and Slovakia.

1.5 A new set of household water demand functions for the EU-28

Based on the new dataset presented in the previous section, a household water demand function has been estimated for each country using the most possible disaggregated data (typically municipality, water service or NUTS 3 levels) and the most recent data (typically 2005-2012).

We summarise in this section the main findings of our cross-country analysis of household water demand in the EU-28. We focus in particular on price and income elasticities of household water demand.

1.5.1 Specifying the residential water demand function

To estimate Equation (1.1), a wide variety of functional forms have been applied in the water demand literature, including linear forms, semi or double logarithm forms and more complex forms such as the Stone-Geary specification and the quadratic almost ideal demand system (Vanhille 2012). The existing literature is however not very informative concerning the specification which should be preferred. Since the double-log model is the most common specification in the literature on residential water demand, we have adopted this specification in order to facilitate the comparison to other studies. Furthermore, the specification implies that coefficient estimates are also elasticity estimates. With a double-log specification, the residential water demand function writes:

$$\ln(y) = \alpha \ln(p) + \beta \ln(I) + \gamma \ln(Z)' \tag{1.4}$$

and the coefficients α and β can be directly interpreted as the price and the income elasticities of the water demand.

Depending on the data available for each country, this equation will be estimated using simple OLS or panel data methods. The interested reader may refer to each country case study for a presentation of the econometric method used for each country.

1.5.2 Validation of the household water demand models

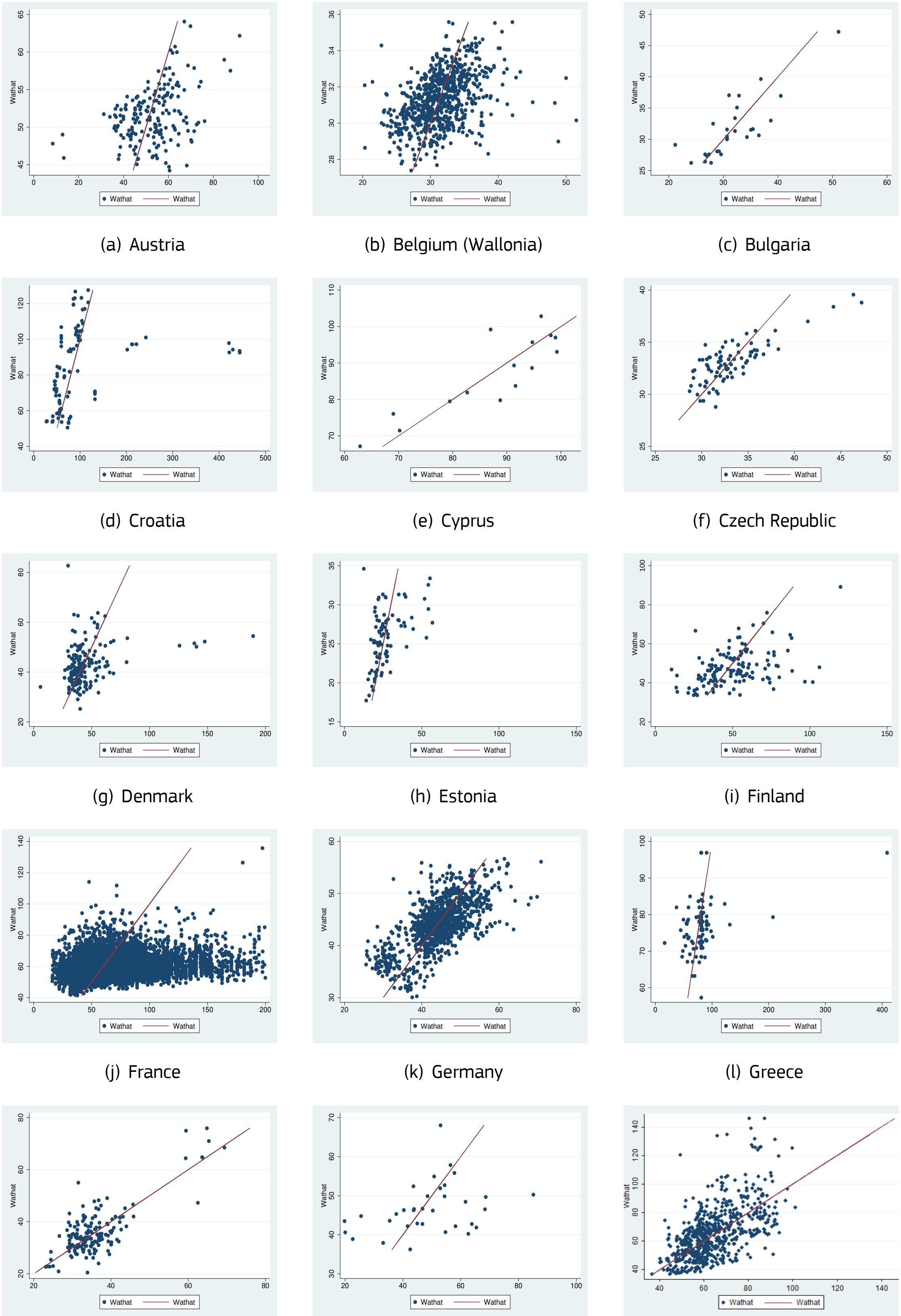
A possible way to assess the validity of the model is to compare the water consumption predicted by the demand function to the observed water consumption, see Figure 1.1 and Figure 1.2. For most of the countries in our dataset, the estimated water demand functions perform relatively well.

In the country-specific chapters, we have also computed the mean absolute percentage error from the predicted water consumption per capita. For a vast majority of countries, the mean absolute percentage error is lower than 20 %.

1.5.3 Main determinants of household water demands

In Table 1.6, we present our results in terms of main significant determinants of household water demand functions. We focus in particular on the impact of water price, household income, climate condition and some household characteristics, including the average household size of age structure. These variables have been previously shown to be the main determinants of household water use.

With the exception of a few countries (Cyprus, Finland, Ireland, Lithuania, Slovenia and Sweden), the water price is shown to have a significant and negative impact on household water use, which means that facing a price increase, households in most of the EU-28 countries will adjust their consumption by reducing it. Our



(a) Austria (b) Belgium (Wallonia) (c) Bulgaria

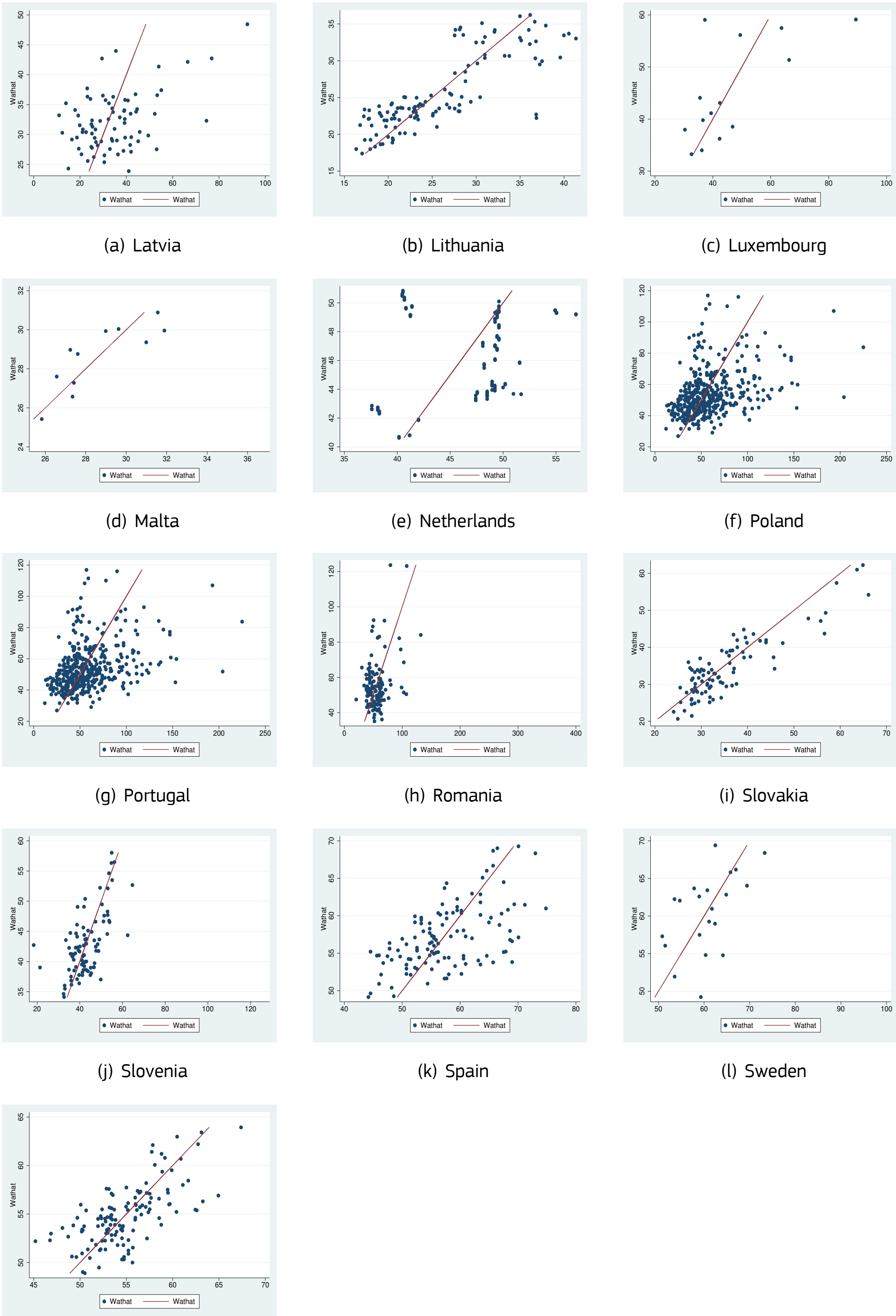
(d) Croatia (e) Cyprus (f) Czech Republic

(g) Denmark (h) Estonia (i) Finland

(j) France (k) Germany (l) Greece

(m) Hungary (n) Ireland (o) Italy

Figure 1.1: Predicted versus observed water consumption 1/2 (m3 per capita)



(a) Latvia (b) Lithuania (c) Luxembourg

(d) Malta (e) Netherlands (f) Poland

(g) Portugal (h) Romania (i) Slovakia

(j) Slovenia (k) Spain (l) Sweden

(m) United Kingdom (n) (o)

Figure 1.2: Predicted versus observed water consumption 2/2 (m3 per capita)

Table 1.6: Main determinants of household water demands in the EU-28

Country	Price	Income	Climate conditions	H. size	Pop. age	Other variables of interest
Austria	(−)***	(+)	(evap,+)***			
Belgium	(−)***	(+)***	(rain,+)***		(age,−)***	(density,+)***
Bulgaria	(−)***	(+)***	(evap,+)	(−)		
Croatia	(−)*	(−)	(rain,−)***	(−)***		
Cyprus	(−)	(+)***	(rain,−)			
Czech Republic	(−)**	(+)**	(rain,−)*		(pop1565,+)*	
Denmark	(−)**	(+)**	(rain,−)**		(pop9,+)	
Estonia	(−)*	(+)**	(norain,+)		(pop70,+)***	
Finland	(−)	(+)	(rain,−)***	(−)***	(age,−)***	
France	(−)***	(+)***	(rain,−)***, (norain,+)***			(density,−)***, (permanentHousing,−)***, (House,−)***
Germany	(−)***	(+)***	(rain,+)		(pop1565,−)***	(density,+)***
Greece	(−)*	(−)	(rain,−)	(−)***		(density,+)***
Hungary	(−)***	(+)***	(rain,−)***			
Ireland	(−)	(+)	(evap,+)		(pop65,+)*	
Italy	(−)***	(+)**	(norain,−)	(−)**		(rationing,−)
Latvia	(−)**	(+)**	(norain,−)		(pop18,−)	
Lithuania	(−)	(+)**	(rain,+)		(age,+)	
Luxembourg	(−)	(+)	(rain,−)***			
Malta	(−)**	(+)	(norain,−)			
Netherlands	(−)***	(+)**	(evap,+)*	(−)		
Poland	(−)***	(+)***	(rain,−)***		(pop9,−)***, (pop70,−)***	(dishwasher,+)***
Portugal	(−)*	(+)***	(rain,−)***		(pop14,−)	
Romania	(−)**	(+)	(norain,+)*		(pop15,−)	
Slovakia	(−)***	(+)**	(norain,+)		(age,−), (pop14,−)	
Slovenia	(−)	(+)**	(rain,+)		(pop14,+)	
Spain	(−)***	(+)	(rain,+)	(−)	(age,−)***	(density,−)
Sweden	(−)	(+)	(rain,−)		(age,+)**	
United Kingdom (England & Wales)	(−)***	(+)***	(rain,−)***			(meter,−)***

***, **, * for significant at 1 %, 5 % and 10 % respectively.
Price measures the price of water in (EUR per m3) paid by housholds.
Income represents the household income (sometimes proxied by the GDP per capita or by the average salary).
Rain measures rainfalls, norain is the number of day without rain and evap is the evapotranspiration.
H. size is the number of person per household.
Age is the average or median population age, pop9 (resp. pop14 pop18) is the population share below 9 (resp. 14, 18), pop1565 is the share of the population between 15 and 65, pop65 (resp. pop70) is the population share above 65 (resp. 70).
Density is the population density.

results are in line with previous works in Europe (and elsewhere in the world) showing that domestic water consumption reacts to changes in water prices. We will discuss our price elasticity results in more detail in the following paragraph.

We provide some evidence that water is a normal good for most EU-28 countries. The household water use tends to increase with household income (except for Greece and Croatia). Our results are consistent with the previous literature showing that domestic water consumption is positively correlated with income (Arbués, García-Valiñas, and Martińez-Espiñeira 2003). The income effect is however not significant for Austria, Croatia, Finland, Greece, Ireland, Malta, Romania, Spain and Sweden. Again we will discuss our income elasticity results in more detail in the following paragraph.

Concerning the climate variables, we obtain mixed evidence. For 13 Member States, at least one climate variable (rainfalls, evapotranspiration or the number of days without rain) is found to be significant. For these countries, we expect the household water consumption to be impacted by climate conditions. It is generally found that drier and hotter conditions will result in an increase in the household water use. This result is particularly important in a context of climate change.

Some household characteristics appear to be consistently significant across countries. This is the case, for instance, for the household size which seems to have a decreasing impact on household water use per capita. A large household size is associated with lower household water consumption per capita.[8] Since household size is an important determinant of water use, policymakers should need to include it in the design of demand-side water management measures. This is particularly important both for Western and Eastern European countries where we observe a decreasing trend in household size.

Population age and age structure of the population have mixed effects on household water use per capita. It is quite difficult to extract general and robust findings from the country estimates. We still need additional studies to understand the impact of age on household water use.

1.5.4 Price and income elasticities of household water demands

In Table 1.7, we discuss in more detail our results concerning price and income elasticities of the residential water demand function for EU-28 countries.

We find that household water demand function is price inelastic for most of the EU-28 countries, which means that the water consumption decreases by less than 1 % for every 1 % increase in price. The price-elasticity typically varies between -0.5 and -0.1, which is consistent with the existing literature. Our results have important policy implications. Indeed pricing reforms are often cited as the first measure to be implemented to signal water scarcity and to encourage a reasonable use of water. The effectiveness of any pricing policy in engaging water consumption depends, however, on the price elasticity of consumption. The larger the price elasticity, the more effective these policies are at reducing water consumption. Our country-specific price elasticities allow decision-makers to simulate the impact of change for water price on household water use per capita.

Our range of value for the income elasticities is much wider. For Austria, Croatia, France, Germany, Greece and Spain the income elasticity is very low (between 0.00 and 0.25). We do not expect any strong impact of change in household income on household water consumption per capita for these countries. The income elasticity is found to be much higher in Bulgaria, Cyprus, Estonia, Finland, Latvia, Lithuania, Portugal and Slovakia (greater than 0.50). This group of countries includes some Eastern European countries where both household

[8]An explanation of the negative relationship between per capita water consumption and household size proposed by Schleich and Hillenbrand (2009) is that several water uses such as washing, gardening or even cooking tend to increase less than proportionally to the household size.

Table 1.7: Estimated price and income elasticities of household water demand in the EU-28

Country	Spatial coverage	Time coverage	Elasticities	
			Price	Income
Austria	Mun (72)	Panel (2007-2009)	-0.20 ; -0.18	0.00
Belgium	Mun(249/308)	Panel (2004,2008,2011/2012-2013)	-0.12 ; -0.04	0.03 ; 0.12
Bulgaria	NUTS 3 (28)	CS (2010)	-0.27 ; -0.26	0.61 ; 0.62
Croatia	WS (21)	Panel (2000-2004)	-0.37 ; -0.14	0.00
Cyprus	NUTS 3 (1)	TS (1998-2012)	-0.33	1.09
Czech Republic	NUTS 3 (14)	Panel (2006-2011)	-0.28 ; -0.18	0.16 ; 0.46
Denmark	WS (56)	Panel (2010-2012)	-1.00 ; -0.33	-0.37 ; -0.50
Estonia	NUTS 3 (15)	Panel (2006-2012)	-0.63 ; -0.00	0.43 ; 1.70
Finland	Mun (140)	CS (2011)	-0.28	0.56
France	Mun (9,000-13,000)	Panel (2008-2011)	-0.43 ; -0.10	0.07 ; 0.26
Germany	NUTS 3 (370)	Panel (2004,2007,2010)	-0.45 ; -0.44	0.08 ; 0.14
Greece	Other(114)	CS (2010)	-0.10	0.01
Hungary	NUTS 3 (20)	Panel (2000-2007)	-0.79 ; -0.07	0.13 ; 1.10
Ireland	Other(34)	CS (2011)	0.00	0.16 ; 0.33
Italy	Mun (113)	Panel (2001-2011)	-0.58	0.31
Latvia	Mun (77)	CS (2013)	-0.40	0.61
Lithuania	NUTS 3 (10)	Panel (2001-2012)	-0.28	2.01
Luxembourg	Mun (14)	CS (2010)	-1.20	0.39
Malta	Country (1)	TS (2000-2010)	-0.31	0.44
Netherlands	NUTS 3 (40)	Panel (2009-2011)	-0.63 ; -0.13	0.06 ; 0.23
Poland	NUTS 3 (66)	Panel (2003-2012)	-0.39 ; -0.18	0.22 ; 0.55
Portugal	Mun (232)	Panel (2007,2009)	-0.27	0.67 ; 0.84
Romania	NUTS 3 (18)	Panel (2000-2010)	-0.58	0.26
Slovakia	NUTS 3 (8)	Panel (2001-2011)	-0.94 ; -0.66	0.62 ; 1.05
Slovenia	NUTS 3 (12)	Panel (2001-2011)	-0.30 ; -0.11	0.38 ; 0.44
Spain	NUTS 2 (17)	Panel (2004-2011)	-0.21 ; -0.00	-0.30 ; 0.05
Sweden	NUTS 3 (21)	CS (2011)	-0.58 ; -0.28	0.37 ; 0.40
United Kingdom (England & Wales)	WS (16)	Panel (2002-2009)	-0.18 ; -0.20	0.26

income and water pricing have significantly changed over the last 10 years.

1.5.5 Long-term price elasticities of household water demands

Water consumption may be at least somehow persistent over time due to household habits or to the time needed to adjust durable equipment (showers, for instance). With panel or time-series data, one way to take this time persistence characteristic of household water consumption into account is to introduce the lagged consumption as an additional independent variable in Equation (1.5). In our case, since we work with annual data, the lag water consumption corresponds to the water consumption for the previous year. The dynamic specification of our equation of interest then becomes:

$$\ln(y) = \alpha \ln(p) + \beta \ln(I) + \gamma \ln(Z)' + \mu \ln(\text{Lag}\, y) \tag{1.5}$$

where Lag y represents the lagged water consumption. From this specification it is then possible to derive the long-run price elasticity of the household water demand function which simply writes:

$$\epsilon_p^{LT} = \frac{\alpha}{1-\mu}. \tag{1.6}$$

In Table 1.8, we provide some estimates of the long-term price elasticities for countries for which a panel dataset is available. We then compare the short-term price elasticities obtained either with generalised least squares (GLS) or generalised least squares with instrumental variables (GLSiv) models with the corresponding long-term price elasticities.

Table 1.8: Estimated sort-term and long-term price elasticities of household water demands in selected European countries

Country	GLS		GLSiv	
	Short-term	Long-term	Short-term	Long-term
Croatia	-0.14*	-1.16	1.1	-0.78
Cyprus	-0.33	-0.51		
Czech Republic	-0.20***	0.08**	-0.28**	-0.61**
Denmark	-0.33**	-1.28***	-1.00**	-0.90*
Estonia	-0.17	-0.70*	-0.52*	-2.08***
France	-0.05***	-0.06***	-0.5	4.13***
Germany	-0.44***	-0.50***	-0.45***	2.00
Hungary	-0.06**	-0.42***	-0.79***	-0.69***
Italy	-0.22***	-0.29***	-0.58***	-0.25
Lithuania	-0.21**	-0.33**		
Malta	-0.31*	-0.36*		
Poland	-0.18***	-0.25*	-0.34	-1.30
Romania	0.00	-0.06	-0.58**	-0.05
Slovakia	-0.66***	-1.03***	-0.94***	-1.14***
Slovenia	-0.11	-0.17**	-0.30	-0.66**
Spain	-0.21***	-0.24	0.14	0.64
United Kingdom (England & Wales)	-0.20***	-0.28**		

***, **, * for significant at 1 %, 5 % and 10 % respectively.

The household water demand is still price inelastic in the long term. However, we find higher estimated price elasticities (in absolute values) in the long term compared to short term. From a policy perspective, it means that even if households do not react immediately to a change in the water price, public authorities may expect that they will modify their behaviour in the long term. So the benefits (in terms of reducing the water consumption) from a water price increase may be visible only a few years after having implemented the price change. It should be noted that the higher responsiveness of household water consumption in the long term to change in water price is in line with the existing literature (Nauges and Thomas 2000, Musolesi and Nosvelli 2007, Hortová and Kristoufek 2014).

1.5.6 Household water demand functions

In this paragraph we graphically represent the household water demand function for each country. We plot the predicted household water use (m3 per capita per year) as a function of the water price (EUR per m3). All other variables (household income, climate conditions and household characteristics) are fixed at the sample mean for the year considered. As a result, the shape of the household water demand functions represented in Figure 1.3 and in Figure 1.4 depends on the estimated price elasticities and on the specific functional form we have used (log-log form).

1.6 Conclusion

1.6.1 Main message

Economists have been working on household water use for a long time, but water demand modelling has taken on new importance with the need to better understand the potential role economic instruments might have to reduce abstraction and polluted discharges, for instance. To this end, economists have developed a great variety of models in order to predict water demands for industrial, agricultural and domestic users. For the latter, the level of knowledge is quite advanced. Estimations of domestic water demand functions have been undertaken for a substantial number of countries all over the world, and the existing literature has already been summarised and reviewed by several authors (Arbués, García-Valiñas, and Martińez-Espiñeira 2003, Worthington and Hoffman 2008, Tanverakul and Lee 2012). In Europe, the recent report from the European Environmental Agency (EEA, 2013) has stressed, however, that most available reference studies date back 10 or 20 years and that new case studies with primary data are required in order to provide fresh and relevant evidence that accounts for the socio-economic, management and technological changes that have taken place in the last 20 years.

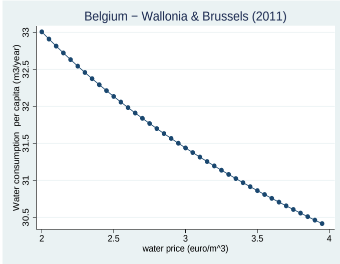
This document has provided an update on the current knowledge on household water use in Europe.

We have first reviewed the existing scientific literature on household water demand modelling in Europe. By doing so, we have not been able to find any estimate of the household water demand function for 11 of the EU-28 countries (Austria, Belgium, Bulgaria, Croatia, Estonia, Finland, Hungary, Ireland, Latvia, Lithuania and Slovenia). For the 17 remaining countries, it should be pointed out that existing estimates of the household water demand function rely on data posterior to 2010 for six of them only (Cyprus, the Czech Republic, Germany, Luxembourg, Romania and the United Kingdom). For Denmark and Sweden, the more recent studies date back to 1990 and 1992, respectively. Despite these limitations, this literature provides some indications on the empirical determinants of household water use in Europe.

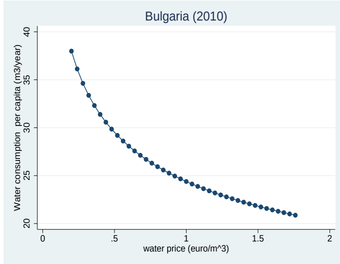
Second, we have assembled a new dataset with a NUTS 3 resolution and an EU-28 coverage with data on household water consumption and household water price. The typical source of data includes national statistical offices, regulators of water and wastewater services, national associations of water and wastewater services and national associations of municipalities.

Third, we have provided some new estimates of household water demand functions for all EU-28 countries using consistent data and econometric methods. Primary data on household water consumption, on household water prices and on household characteristics supposed to have an impact on water consumption have been

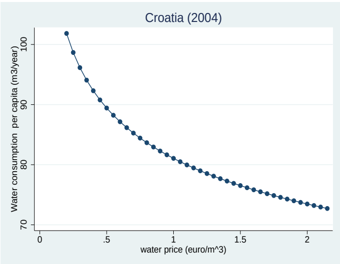
(a) Austria



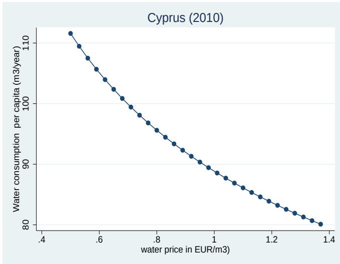
(b) Belgium (Wallonia)



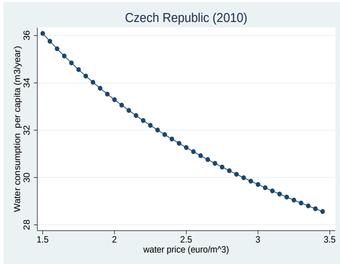
(c) Bulgaria



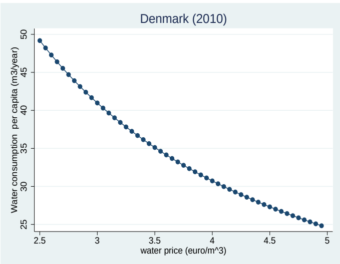
(d) Croatia



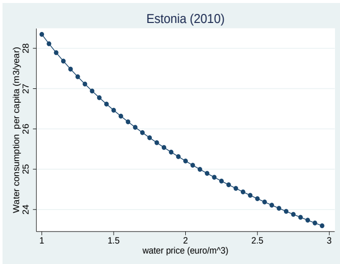
(e) Cyprus



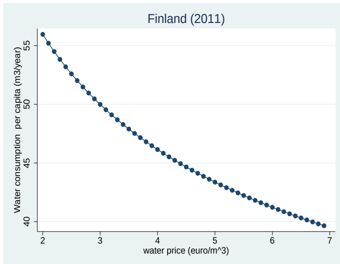
(f) Czech Republic



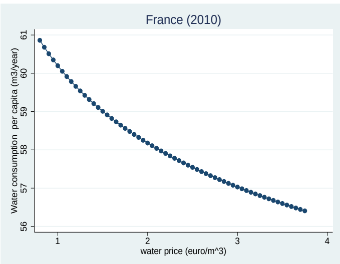
(g) Denmark



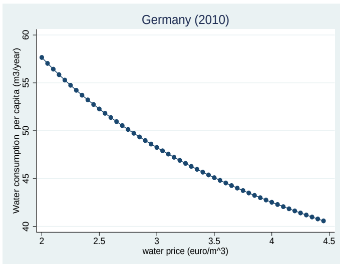
(h) Estonia



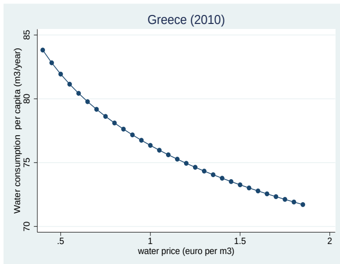
(i) Finland



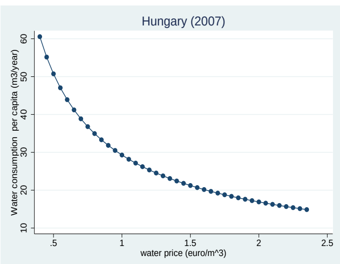
(j) France



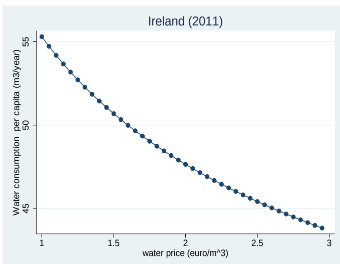
(k) Germany



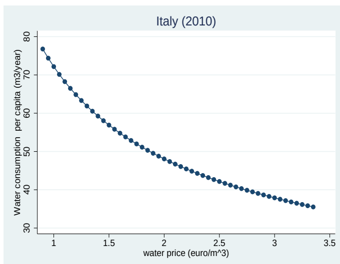
(l) Greece



(m) Hungary

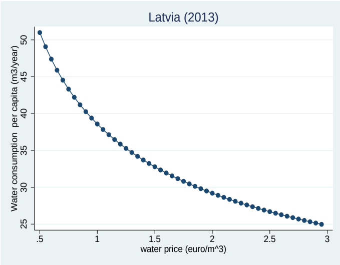


(n) Ireland

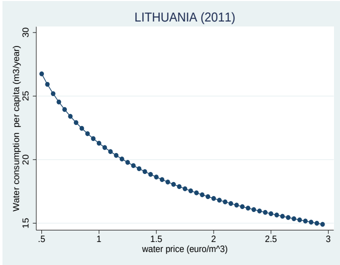


(o) Italy

Figure 1.3: Plot of the household water demand function 1/2 (m3 per capita per year)



(a) Latvia



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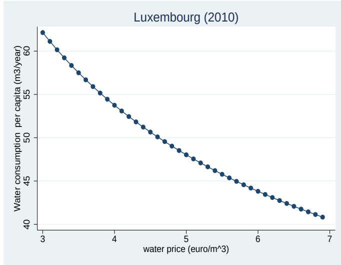

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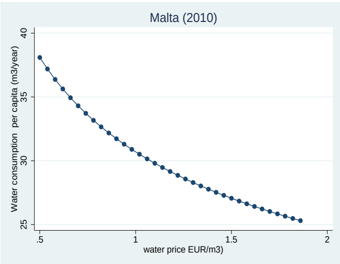

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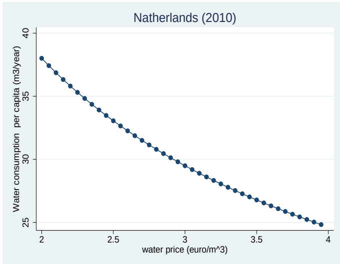

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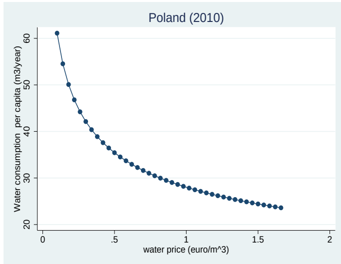

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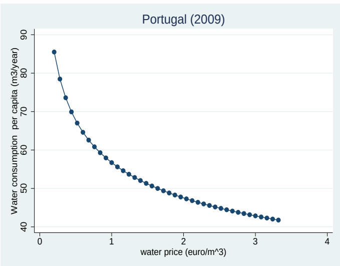
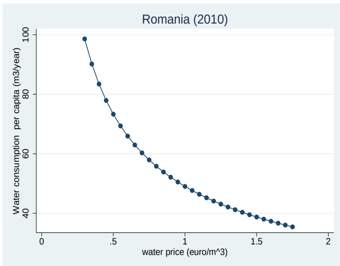


(g) Portugal



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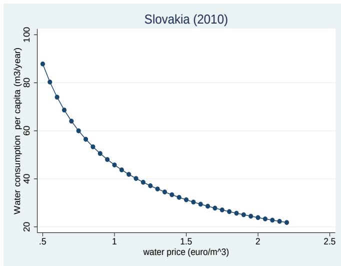

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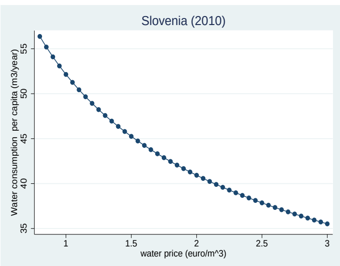
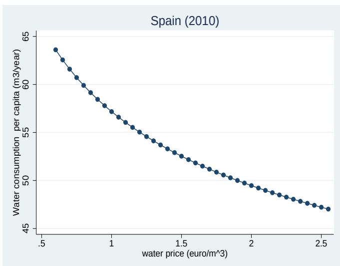
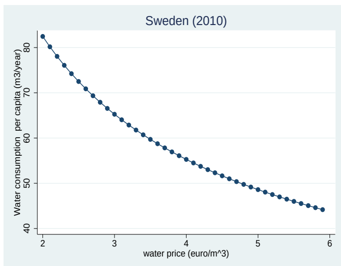


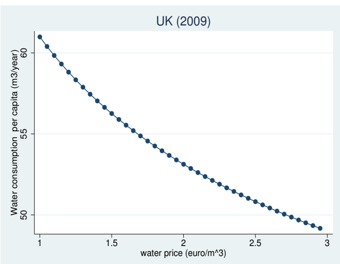
(j) Slovenia



(k) Spain



(l) Sweden



(m) United Kingdom

(n)

(o)

Figure 1.4: Plot of the household water demand function 2/2 (m3 per capita per year)

collected, assembled and checked for each one of the EU-28 countries. Then, a household water demand function has been estimated for each country using the most possible disaggregated data (typically municipality, water service or NUTS 3 levels) and the most recent data (typically 2005-2012). The econometric estimates allow us to identify the determinants of the household water demand for each country.

We also provide a new set of price and income elasticities. For most of the countries, the estimated price elasticity of the household water demand is found to be negative. Facing a price increase, EU households will react by reducing their water consumption. It is then demonstrated that water price may play a role towards signalling water scarcity or water cost to households. In addition, we have found that household water demand functions are typically price inelastic for most of the EU-28 countries. This means that the household water consumption decreases by less than 1 % for every 1 % increase in price. The price-elasticities typically vary between -0.5 and -0.1 across countries. Facing a price increase by 10 %, it is then expected that the household water consumption will be reduced by 1 to 5 %. This result has important policy implications. Indeed, pricing reforms are often cited as the first measure to be implemented in order to signal water scarcity and to encourage a *reasonable* use of water. The effectiveness of any pricing policy in engaging water consumption depends, however, on the price elasticity of consumption. The larger the price elasticity, the more effective these policies are at reducing water consumption. Our country-specific price elasticities allow decision-makers to simulate the impact of change in the water price on household water use per capita. To achieve more significant reductions of the household water consumption, public authorities should complement their price policies with non-price policies such as education or awareness campaigns.

Household water consumption may be, at least somehow, persistent over time due to household habits or to the time needed to adjust durable equipment (showers, for instance). It is then expected that households may react to a change in the water price in the long term rather than in the short term. Using the panel-data structure for some countries, we have shown that long-term price elasticity is in general greater (in absolute value) than short-term price elasticity. From a policy perspective, it means that even if households do not immediately react to a change in the water price, public authorities may expect them to modify their behaviour in the long term. So the benefits (in terms of reducing the water consumption) of a water price increase may be visible only a few years after having implemented the price change. It should be noted that the higher responsiveness of household water consumption in the long run to change in water price is in line with the existing literature (Nauges and Thomas 2000, Musolesi and Nosvelli 2007, Hortová and Kristoufek 2014).

Our range of value for income elasticities is much wider. For Austria, Croatia, France, Germany, Greece and Spain the income elasticity is very low (between 0.00 and 0.25). We do not expect any strong impact of change of household income on household water consumption per capita for these countries. The income elasticity is found to be much higher in Bulgaria, Cyprus, Estonia, Finland, Latvia, Lithuania, Portugal and Slovakia (greater than 0.50). This group of countries includes some Eastern European countries where both household income and water pricing have significantly changed over the last 10 years. For these countries, the expected trend in water consumption is a priori difficult to assess since it will be the result of two opposite effects. First, since household income is expected to increase in these countries (income convergence process), one may expect an increase in the water consumption per capita (income effect). On the other hand, we may anticipate some price increases for these countries, in particular due to the implementation of the full cost-recovery principle for water and wastewater services. This price effect should result in a decreasing impact on water consumption per capita. The combined impact of the income and price effects on water consumption is then a priori undetermined.

1.6.2 The way forward

Mapping of household water use per capita at the EU scale Having access to reliable and disaggregated data on water use is a prerequisite for designing any efficient water management policy. The main limitation faced by policymakers is then the lack of detailed and up-to-date water withdrawal statistics. One solution consists in disaggregating national public water withdrawal statistics (from Eurostat, for example) to a regional level (NUTS 3) using geographical information system (GIS) techniques (Vandecasteele, Bianchi, Batista e Silva, Lavalle, and Batelaan 2014). These disaggregation procedures are however subject to caution since they require making strong assumptions on population distributions and household water consumption behaviour.

In this report we have shown that it is in fact possible to collect data for the EU-28 countries, mainly from national statistical offices, on household water use per capita at a spatial resolution that corresponds to NUTS 3 at least. It is then possible to map this NUTS 3 data on household water use with an EU-28 coverage, therefore avoiding to implement any spatial disaggregation procedure as done in Vandecasteele's publication (2014). Alternatively, one may use the estimated water demand models to predict the water use per capita at regional level (NUTS 3) for all EU countries.

As an example we provide two maps at EU-level taken from (Bernhard, Reynaud, Lanzanova, and deRoo 2015). In the first map, the water demand functions are used to estimate the water use at regional level (NUTS 3) per capita for all EU countries. In the second map, the water demand models are combined with a detailed population map and demographic projections. This results in a 5 km grid with the household water use per cell.

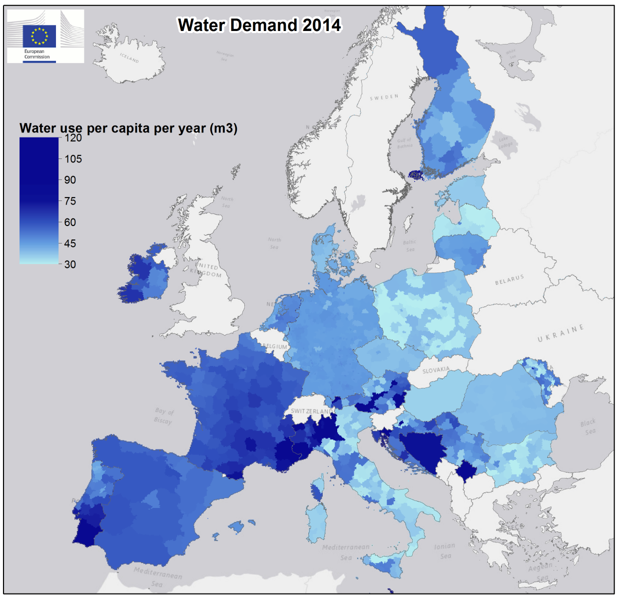
Integration of residential water demand functions in hydro-economic modelling tools at EU scale We have started the process of integrating the estimated household water demand functions into the Lisflood model, calibrated at the European level.[9] The main methodological improvement is to incorporate feedback between household water use and the rest of the system modelled. For instance, any change to climate conditions will affect the hydrological part of the model but also household water needs. This updated modelling framework may then be used for the evaluation of programmes of measures under the Water Framework Directive.

Scenario analysis Pricing reforms is often cited as the first measure to be implemented to signal water scarcity and to encourage a *reasonable* use of water. The effectiveness of any pricing policy in engaging water consumption depends, however, on the price elasticity of consumption. The larger the price elasticity, the more effective these policies are at reducing water consumption. The water demand function can be used for assessing the impact of change in water price for a specific country or for the whole EU-28 area. Alternatively, a scenario of economic growth or climate change can be also evaluated.

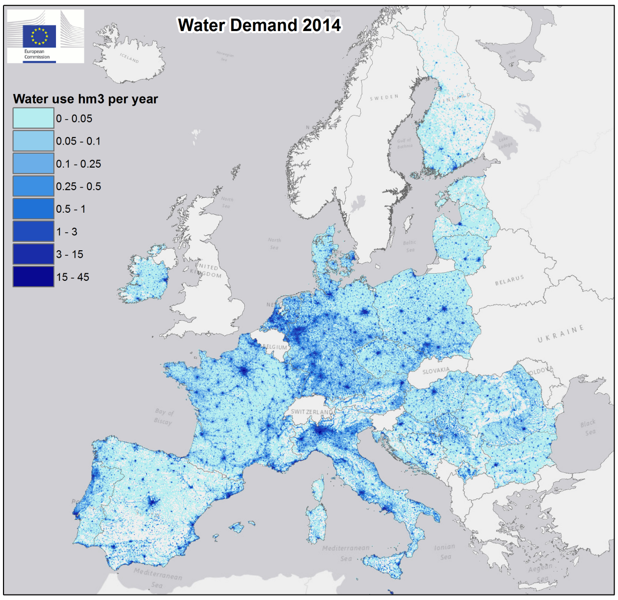
The water demand models predictions can be combined with scenarios of demographic change, either for a given country or across Europe. As an example, we provide in figure 1.6 a map showing the change in water demand by 2030 if water prices grow 10 % faster than gross domestic product, (Bernhard, Reynaud, Lanzanova, and deRoo 2015) for additional details.

Welfare analysis The demand functions defined in this report are useful for measuring the consumer (Marshallian) surplus derived from water consumption, which is basically the difference between what a consumer would have been ready to pay for a good and what he really pays (expressed in monetary terms). As a result

[9] The Lisflood model is a hydrological rainfall-runoff model that is capable of simulating the hydrological processes that occur in a catchment. Lisflood has been developed by the floods group of the natural hazards project of the Joint Research Centre of the European Commission.



(a) Predicted household water use per capita in 2014



(b) Predicted aggregated water use in hm3 in 2014

Figure 1.5: Use of the water demand functions to predict household water use in Europe

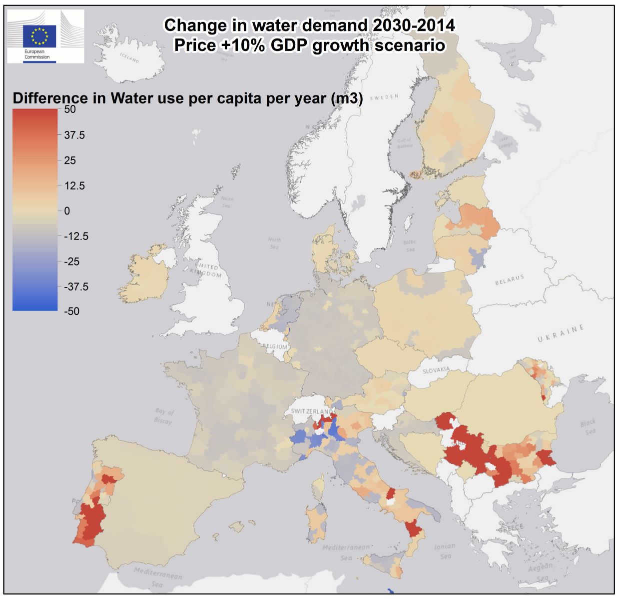


Figure 1.6: Scenario analysis and use of the water demand functions

the water demand functions provide us with tools for realising some applied welfare analysis. We can then measure the consumer welfare losses due to restricting water consumption, for instance. Alternatively, the loss of welfare resulting from a price increase can be measured, and eventually for different groups of households that are segmented based on their income (Reynaud 2015).

Assessing the impact of full cost recovery of water services on EU households The estimated household water demand functions can be used to assess the impact of full cost recovery (FCR) of water services on EU households. This is the work carried out in Reynaud (2015) in which the assessment relies on three dimensions. First the author of this work measures how household water consumption will react to the price change induced by implementing the FCR principle. Second, he provides a measure of the resulting welfare losses for households. Third, he evaluates how water affordability for households is impacted. This assessment, which relies on a household water demand function approach, has been conducted for eight European countries (Austria, Bulgaria, the Czech Republic, Estonia, France, Greece, Portugal and Spain). For most of the countries considered, Reynaud (2015) shows that implementing the FCR principle will not lead to substantial water affordability issues. Bulgaria and Estonia are two exceptions, since households in the first income decile will have to devote about 3 % of their income to paying their water and wastewater bill. The fact that water affordability might be an issue under FCR for some countries gives some ground for public authorities to develop specific policies targeted at poor households.

Extension of spatial coverage The data collection constitutes the main difficulty for conducting the cross-country analysis of household water use in the EU-28. One may argue that the collection has been made easy due to the fact that all countries belong to the EU. This is clear that this has helped, but one should mention at this stage that we have already estimated a set of preliminary household water demand functions using similar data for countries not belonging to the EU. The set of countries for which we already have some estimates includes Bosnia and Herzegovina, Kosovo, Moldova, Montenegro, Serbia, Ukraine, Norway and Turkey.

Chapter 2

Austria

2.1 Existing literature

To our best knowledge, there doesn't exist any published article having estimated a residential water demand function in Austria.

2.2 Urban water sector in Austria

The Austria water supply sector consists of a very high number of municipal services (about 2,000) and very small cooperative utilities (in total another 3,500), see (Neunteufel, Perfler, Schwarz, Bachner, and Bednar-Friedl 2015). The wastewater sector is organized in a similar way.

Water tariff levels are set by municipalities (owners of the utilities) but have to be in accordance with the legal framework. The "user pays" principle and the "polluter pays" principle, respectively are implemented. In general, the annual water bill paid by water users is composed of an annual fixed fee and a single water tariff rate independent of actual water consumption (i.e. no increasing block water tariff or similar tarification schemes).

2.3 Data

Our panel data set consists of municipality-level data on household water consumption, household water price, household's socioeconomic conditions income and on climate condition for years 2007--209. Most of the data come from the annual publication Cities in Figures published by the Statistical Office of Austria. We will then consider only the largest municipalities in Austria (about 70 municipalities). The data consist of aggregate data at municipality-level on water consumption per capita and water prices. The data have been combined with information on household's income, climate conditions, and household characteristics mainly from Statistics Austria.

Water consumption data Volume of water from the public network per capita from 2007 to 2009 at municipal level.

Water price data Our main source of data are the annual reports *Cities in Figures*. As a price indicator, we use the average price paid by households for the water service (in euros per m3).

Household income We use the average gross domestic product per capita available from Statistics Austria from 2007 to 2009 at Nuts3.

Other socioeconomic variables Other socio-economic variables from 2007 to 2011 come from Statistics Austria.

Climate data All meteorological data come from JRC climate database. Grid data (5km $\times$ 5km) on rainfalls, temperatures and evapotranspiration have been aggregated at regional level. We have historical data from 1990 to 2013.

2.4 Empirical analysis of residential water consumption

In this section, we provide a statistical analysis or residential water consumption and water price for Austria.

Table 2.1: Household water consumption and price in Austria

Year	Water consumption (m3 per capita per year)	Water price (euros per m3)
2007	54.746	1.358
2008	53.649	1.366
2009	53.070	1.378
Average	53.821	1.367

Table 2.1 gives the annual residential water consumption (m3 per capita and per year) and the water price (average water price, in euros m3) in Austria from 2007 to 2009. In 2009, the average annual consumption per inhabitant amounted to 53.8 m3. There has been a decreasing trend in domestic water consumption since 2007. Over the period 2007-2009, the average water price (only for the water service) has increased from 1.36 euros per m3 to 1.38 euros per m3 .

Table 2.2 gives the annual residential water consumption (m3 per capita and per year) and the water price per county (Nuts 3) in 2009. As it can be seen, there are some differences across regions, both in terms of water consumption and water prices. With more than 100 m3 per capita per year, the water consumption is the higher in the Nordburgenland Nuts3. On contrary, a low water consumption is reported in the Unterkärnten county (40.0 m3 per capita per year).

2.5 Water demand function estimate

2.5.1 Specifying the residential water demand function

The residential water demand function can be derived from solving the utility optimization problem of a consumer. Under the assumption of a weak separability of water with respect to other goods consumed, the Marshallian demand in water can be written as:

$$y = y^*(p, I, Z) \tag{2.1}$$

where y is the water consumption either per capita or per household, p and I denote the unit water price (representing both water supply and the sewage treatment services) and the representative household income, respectively. Z is a vector of exogenous variables assumed to influence water consumption (climate conditions, household and housing characteristics, etc.).

To estimate Equation (2.1), a wide variety of functional forms have been applied in the water demand literature, including linear forms, semi or double logarithm forms and more complex forms such as the Stone-Geary specification. The existing literature is however not very informative concerning the specification which should be preferred. Since the double-log model is the most common specification in the residential water demand literature, we have adopted this model in order to facilitate comparison to other studies. Furthermore, the specification implies that coefficient estimates are also elasticity estimates. With a double-log specification, the residential water demand function writes:

$$\ln(y) = \alpha \ln(p) + \beta \ln(I) + \gamma \ln(Z)' \tag{2.2}$$

Table 2.2: Regional household water consumption and price in Austria

	Water consumption (m3 per capita per year)	Water price (euros per m3)
Bludenz-Bregenze Wald	42.979	1.448
Graz	45.443	2.067
Innsbruck	66.019	1.412
Innviertel	47.871	1.586
Klagenfurt-Villach	47.948	1.363
Linz-Wels	50.404	1.247
Mostviertel-Eisenwurzen	48.185	1.276
Niederösterreich	51.313	1.237
Nordburgenland	103.204	1.409
Oberkärnten	50.602	0.960
Osttirol	58.856	1.140
Pinzgau-Pongau	45.465	0.959
Rheintal-Bodenseegebiet	49.023	0.996
Salzburg und Umgebung	54.776	1.450
St. Pölten	61.046	1.282
Steyr-Kirchdorf	55.845	1.534
Tiroler Unterland	52.712	1.122
Traunviertel	51.507	1.689
Unterkärnten	40.931	1.018
Waldviertel	54.478	1.711
Weinviertel	47.987	1.622
Westliche Obersteiermark	53.929	1.184
Wien	53.655	1.358
Wiener Umland-Nordteil	61.244	1.341
Wiener Umland-Südteil	67.320	1.305
Östliche Obersteiermark	55.632	1.375
Average	53.070	1.378

Table 2.3: Estimation of the household water demand in Austria

	AustriaOLS	AustriaGLS	AustriaGLSiv
	b/se	b/se	b/se
$\ln$ Water price (in euros per m3)	-0.176**	-0.203**	0.355
	(0.09)	(0.08)	(0.41)
$\ln$ Household income (in euros per capita)	0.031	0.047	0.058
	(0.08)	(0.13)	(0.11)
$\ln$ Share of groundwater abstraction	0.027***	0.014	
	(0.01)	(0.01)	
$\ln$ summer evapotranspiration	0.482***	0.376***	0.412***
	(0.14)	(0.14)	(0.16)
Constant	3.167***	3.103**	2.818**
	(0.87)	(1.33)	(1.21)
R-squared	0.127		
N. of obs.	187.000	187.000	187.000

and the coefficients α and β can be directly interpreted as the price and the income elasticities of the water demand. Specification tests for the functional form will be conducted in the empirical part but we don't expect the choice of the particular form to have a fundamental influence on the estimation of the parameters of interest.

2.5.2 Estimation methods

Let $i = \{1, .., I\}$ indexes municipalities and $t = \{1, .., T\}$ years. Our equation of interest becomes:

$$\ln(y_{it}) = \alpha \ln(p_{it}) + \beta \ln(I_{it}) + \gamma \ln(Z_{it})' + \epsilon_{it} \tag{2.3}$$

where ϵ_{it} is the usual random term. Two panel data estimators may be used namely the fixed effects (or dummy variable) model and the random effects (or error components) model. We propose to use these two estimators and to conduct some specification tests (Hausman test) to decide which is the most appropriate to our data.

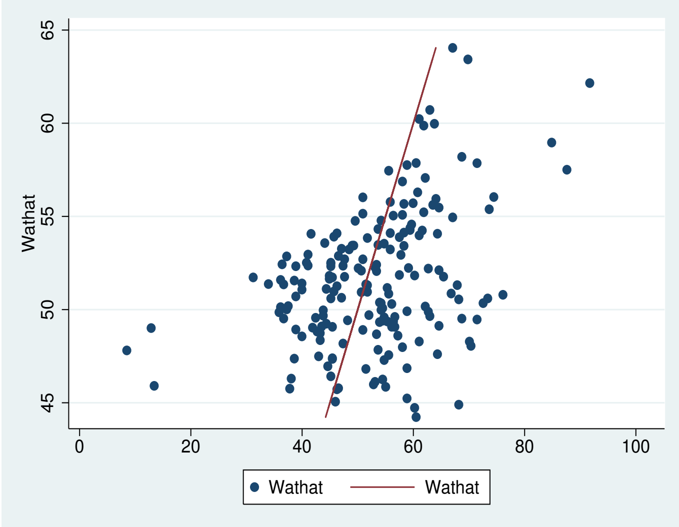
2.5.3 Results

We report here our estimate for the residential water demand function in Austria, based on our municipality dataset for Austria (2007 to 2009). The first model estimated in Table 2.3 corresponds to simple OLS whereas in the second model we estimate Equation (2.4) with a random parameter estimator. In the third model, we account for potential endogeneity of the price by using an instrumental variable approach.

Table 2.3 present the main significant variables explaining household water consumption in Austria. The price elasticity varies across models, from --0.18 with the OLS to --0.20 with the GLS (not significant with GLSiv). Based on the GLS models, a 10% increase in water price results in a 2.0% decrease in short-run water consumption in Austria. Water demand in Austria is inelastic, i.e. the estimated price elasticity in absolute values is lower than one.

The income elasticity is not significant.

Figure 2.1: Observed versus predicted household water consumption in Austria



Climate conditions play a significant role. The higher is the summer evapotranspiration, the higher with be the consumption per capita.

A possible way to assess the validity of the model is to compare the water consumption predicted by the demand function to the observed water consumption, see Figure 2.1. For most of the municipalities the model performs quite well. The mean absolute percentage error is 20.1.

Water consumption may to be at least somehow persistent over time due to household habits or due to the time needed to adjust durable equipments (shower for instance). With panel or time-series data, one way to take into this time persistence characteristic of household water consumption is to introduce the lagged consumption as an additional independent variable in Equation (2.2). The dynamic specification of our equation of interest becomes then :

$$\ln(y) = \alpha \ln(p) + \beta \ln(I) + \gamma \ln(Z)' + \mu \ln(\text{Lag}\, y) \tag{2.4}$$

where Lag y represents the lagged water consumption. From this specification is is then possible to derive the long-run price elasticity of the household water demand function which simply writes:

$$\epsilon_p^{LT} = \frac{\alpha}{1-\mu}. \tag{2.5}$$

We provide in Table 2.4 our estimates for the household water demand function where the lagged consumption has been introduced as an additional independent variable. With the AustriaGLSlag model, the long-term price elasticity is estimated to be -0.22 but not significantly different from zero. With the AustriaGLSivlag model, the long-term price elasticity is estimated to be -1.45 but not significantly different from zero.

Table 2.4: Estimation of the household water demand with lagged water consumption in Austria

	AustriaGLSlag	AustriaGLSivlag
	b/se	b/se
ln Water price (in euros per m3)	-0.017	-0.168
	(0.04)	(0.16)
ln Household income (in euros per capita)	0.016	0.015
	(0.04)	(0.05)
ln Lag of water consumption per capita	0.922***	0.887***
	(0.03)	(0.04)
Constant	0.128	0.314
	(0.39)	(0.52)
R-squared		
N. of obs.	126.000	120.000

Chapter 3

Belgium

3.1 Existing literature

Vanhille (2012) has recently explored the role of socio-demographic household characteristics in the Flemish context of water pricing. Using the case of volumetric wastewater charges in Flanders, she employs observed price heterogeneity between different water pricing areas to model a quadratic almost ideal demand system, allowing to estimate households' differential price responsiveness. Vanhille (2012) finds that that all households in Flanders are responsive to prices, regardless of their relative income position or size. The estimated price elasticity evaluated at the population average is -0.615 and the income elasticity reaches 0.62. She also reports very different price and income elasticity between household groups. Lower income households and smaller size households are found to be more responsive to increased prices than higher income households and larger size households.

3.2 Urban water sector in Belgium

Analysis of the urban water sector in Belgium is made difficult by the fact that there are strong institutional differences between the three Belgian regions (Flanders , Brussels-Capital region and the Walloon region).

For the Walloon region, there were 51 water distributors of water in 2011 (AQUAVAL 2012). All of Walloon region's water distributors are 100% state owned. The legal form of the operator varies across distributors: regional company (société régionale), inter-municipal company (''intercommunale''), municipal water service (''service communal des eaux''), or municipal water regie (''régie communale des eaux''). Since 2005, a single rate structure applies to all Wallonia consumers. This structure is based on the notion of the true cost of water (AQUAVAL 2012). A Water Social Fund fee and 6% VAT are then added get the final price paid by water users.

The supply of drinking water in Flanders is organized at the municipality level. Since each municipality has different options for organising its supply of drinking water, there is a huge diversity the way water and wastewater service provision. According to VMM (2012), on 1st January 2012, the public water distribution network in the 308 Flemish municipalities is managed by 11 operators.

In the Brussels-Capital region, the distribution of the water to households is assured by Hydrobru, an inter-municipal company owned by the 18 municipalities of the region.

3.3 Data

3.3.1 Wallonia and Brussels-Capital

Our panel data set consists of municipality-level data on household water consumption, household water price, household's socioeconomic conditions income and on climate condition for years 2004, 2008 and 2011. Most of the data come from the national or regional statistical office (be.STAT, WalStat) and from the Union of public water cycle operators (Aquawal in Wallonia). The data consist of aggregate data at municipal-level on water consumption per capita and water prices. The data have been combined with information on income, weather, and household characteristics mainly from the the National Statistics Institute.

Water consumption data From WalStat, we have at the municipality level for the Walloon and for Brussels-Capital regions the volume of water distributed per connected household for years 2004, 2008 and 2011 (in m3 per household).[1] Using the average household size per municipality, we have then the water consumption per capita in each municipality (m3/ inhab.).

[1] A household is defined as a water user consuming less than 250 m3 per year.

Water price data We rely annual report "Walloon drinking water and waste-water treatment statistics" published by Aquawal. From these reports we have the total bill for water service corresponding to an annual consumption of 100 m3. From this information we have computed an average price per cubic meter. This information is available at the water service level. Each municipality has been matched to the corresponding water operator. As a price indicator, we use the average price paid by households for the drinking water service (in euro m3 for an annual water consumption equal to 100 m3).

Household income We use the median taxable income per municipality (euros per households) available from Statistics Belgium for years 2004, 2008 and 2011.

Other socioeconomic variables Other socio-economic variables for years 2004, 2008 and 2011 comes from Statistics Belgium.

Climate data All meteorological data come from the JRC climate database. Grid data (5km $\times$ 5km) on rainfalls, temperatures and evapotranspiration have been aggregated at regional level. We have historical data from 1990 to 2013.

3.3.2 Flanders

Our panel data set consists of municipality-level data on household water consumption, household water price, household's socioeconomic conditions income and on climate condition for years 2012 and 2013. Most of the data come from the national or regional statistical office (be.STAT) and from the Environment Agency in Flanders (VMM). The data consist of aggregate data at municipal-level on water consumption per capita and water prices. The data have been combined with information on income, weather, and household characteristics mainly from the the National Statistics Institute.

Water consumption data We use the annual reports "Watermeter - Drinking water production and distribution in figures" published by the Environment Agency in Flanders (VMM). From these reports, we have the volume of water distributed per household per year for different type of households (1 to 5 persons per household). Using the average household size per municipality, we have then the water consumption per capita in each municipality (m3/ inhab.).

Water price data We use the annual reports "Watermeter - Drinking water production and distribution in figures" published by the Environment Agency in Flanders (VMM). From these reports we have the total bill for water service corresponding to different type of households. From this information we have computed an average price per cubic meter. This information is available at the water service level. Each municipality has been matched to the corresponding water operator. As a price indicator, we use the average price paid by households for the drinking water service (in euro m3).

Household income We use the median fiscal income per municipality (euros per households) available from Statistics Belgium for years 2012 and 2013.

Other socioeconomic variables Other socio-economic variables for years 2012 and 2013 come from Statistics Belgium.

Climate data All meteorological data come from the JRC climate database. Grid data (5km × 5km) on rainfalls, temperatures and evapotranspiration have been aggregated at regional level. We have historical data from 1990 to 2013.

3.4 Empirical analysis of residential water consumption

In this section, we provide a statistical analysis or residential water consumption and water price for Belgium.

3.4.1 Wallonia and Brussels-Capital

Table 3.1 gives the annual residential water consumption (m3 per capita and per year) and the water price (average water price for 100 m3, in euros m3) in Belgium (Wallonia and Brussels-Capital) from 2004 to 2011. In 2011, the average annual consumption per inhabitant amounted to 30.3 m3. The water consumption per capita slightly decreased from 2004 to 2011. Over the period 2004-2011, the average water price has increased very quickly from 2.5 euros per m3 in 2004 to 4.2 euros per m3 in 2011.

Table 3.2 gives the annual residential water consumption (m3 per capita and per year) and the water price per Nuts 3 in 2011. As it can be seen, at Nuts3 level, both water consumption and water prices are relatively homogeneous.

Table 3.1: Household water consumption and price in Belgium (Wallonia and Brussels-Capital)

Year	Water consumption (m3 per capita per year)	Water price (euros per m3)
2004	32.548	2.541
2008	31.890	3.242
2011	30.279	4.165
Average	31.713	4.050

3.4.2 Flanders

Table 3.3 gives the annual residential water consumption (m3 per capita and per year) and the water price (average water price in euros per m3) in Belgium (Flanders) for 2012 and 2013. In 2012, the average annual consumption per inhabitant amounted to 38.4 m3. The water consumption per capita has slightly decreased from 2012 to 2013. Over the same period, the average water price has slightly increased from 1.68 euros per m3 in 2012 to 1.7 euros per m3 in 2013. The household water price in the Flemish region tends to be lower than in the Brussels-Capital region and the Walloon region.

Table 3.4 gives the annual residential water consumption (m3 per capita and per year) and the water price per Nuts 3 in 2012. As it can be seen, at Nuts3 level, both water consumption and water prices are relatively homogeneous. The average water consumption per capita varies from 35.3 m3 per capita in the Tielt Nuts3 to 45 m3 per capita in the Antwerpen Nuts3.

3.5 Water demand function estimate

Table 3.2: Regional household water consumption and price in Belgium (Wallonia and Brussels-Capital)

	Water consumption (m3 per capita per year)	Water price (euros per m3)
Arr. Arlon	34.124	4.009
Arr. Ath	27.009	4.009
Arr. Bastogne	30.725	4.009
Arr. Charleroi	30.604	4.009
Arr. Dinant	29.240	3.894
Arr. Huy	30.918	4.011
Arr. Liége	33.251	4.112
Arr. Marche-en-Famene	29.814	3.951
Arr. Mons	31.234	4.009
Arr. Mouscron	27.810	4.009
Arr. Namur	32.530	4.003
Arr. Neufchâteau	30.338	4.009
Arr. Nivelles	32.782	3.789
Arr. Philippeville	26.870	3.934
Arr. Soignies	28.690	4.009
Arr. Thuin	28.710	3.944
Arr. Tournai	26.498	4.009
Arr. Verviers	34.758	3.955
Arr. Virton	31.547	4.009
Arr. Waremme	31.758	4.009
Arr. de Bruxelles-Capitale	33.158	6.680
Average	31.769	4.671

Table 3.3: Household water consumption and price in Belgium (Flanders)

Year	Water consumption (m3 per capita per year)	Water price (euros per m3)
2012	38.397	1.681
2013	37.269	1.723
Average	37.833	1.702

Table 3.4: Regional household water consumption and price in Belgium (Flanders)

	Water consumption (m3 per capita per year)	Water price (euros per m3)
Arr. Aalst	37.000	1.901
Arr. Antwerpen	45.054	1.569
Arr. Brugge	37.799	1.799
Arr. Dendermonde	36.679	1.889
Arr. Diksmuide	36.222	1.739
Arr. Eeklo	37.000	1.855
Arr. Gent	36.616	1.903
Arr. Halle-Vilvo	36.727	1.795
Arr. Hasselt	35.713	1.451
Arr. Ieper	36.324	1.785
Arr. Kortrijk	36.848	1.826
Arr. Leuven	35.993	1.683
Arr. Maaseik	35.332	1.414
Arr. Mechelen	41.605	1.494
Arr. Oostende	37.000	1.878
Arr. Oudenaarde	36.227	1.883
Arr. Roeselare	36.374	1.789
Arr. Sint-Niklaa	36.765	1.820
Arr. Tielt	35.318	1.713
Arr. Tongeren	35.355	1.415
Arr. Turnhout	40.947	1.439
Arr. Veurne	36.918	1.589
Average	38.397	1.681

3.5.1 Specifying the residential water demand function

The residential water demand function can be derived from solving the utility optimization problem of a consumer. Under the assumption of a weak separability of water with respect to other goods consumed, the Marshallian demand in water can be written as:

$$y = y^*(p, I, Z) \tag{3.1}$$

where y is the water consumption either per capita or per household, p and I denote the unit water price (representing both water supply and the sewage treatment services) and the representative household income, respectively. Z is a vector of exogenous variables assumed to influence water consumption (climate conditions, household and housing characteristics, etc.).

To estimate Equation (3.1), a wide variety of functional forms have been applied in the water demand literature, including linear forms, semi or double logarithm forms and more complex forms such as the Stone-Geary specification. The existing literature is however not very informative concerning the specification which should be preferred. Since the double-log model is the most common specification in the residential water demand literature, we have adopted this model in order to facilitate comparison to other studies. Furthermore, the specification implies that coefficient estimates are also elasticity estimates. With a double-log specification, the residential water demand function writes:

$$\ln(y) = \alpha \ln(p) + \beta \ln(I) + \gamma \ln(Z)' \tag{3.2}$$

and the coefficients α and β can be directly interpreted as the price and the income elasticities of the water demand. Specification tests for the functional form will be conducted in the empirical part but we don't expect the choice of the particular form to have a fundamental influence on the estimation of the parameters of interest.

3.5.2 Estimation methods

Let $i = \{1, .., I\}$ indexes municipalities and $t = \{1, .., T\}$ years. Our equation of interest becomes:

$$\ln(y_{it}) = \alpha \ln(p_{it}) + \beta \ln(I_{it}) + \gamma \ln(Z_{it})' + \epsilon_{it} \tag{3.3}$$

where ϵ_{it} is the usual random term. Two panel data estimators may be used namely the fixed effects (or dummy variable) model and the random effects (or error components) model. We propose to use these two estimators and to conduct some specification tests (Hausman test) to decide which is the most appropriate to our data.

3.5.3 Results (Wallonia and Brussels-Capital)

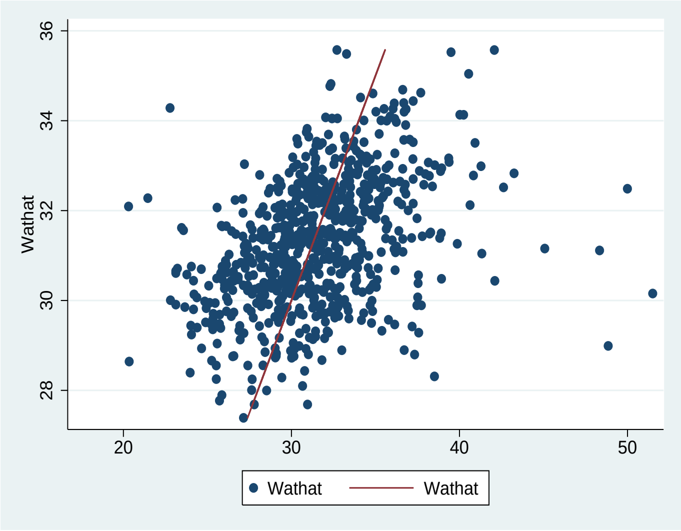
We report here our estimate for the residential water demand function in Belgium, based on our municipal dataset (2004, 2008 and 2011). The first model estimated in Table 3.5 corresponds simple OLS whereas in the second model we estimate Equation (3.3) with a random parameter estimator.

Table 3.5 presents the main significant variables explaining household water consumption in Belgium (Wallonia and Brussels-Capital). The price elasticity varies across models, from -0.04 with the OLS model to -0.12 with the GLS (significant at 10% and 1% respectively). Based on the GLS model, a 10% increase in water price results in a 1.2% decrease in short-run water consumption in Belgium. Water demand in Belgium is inelastic, i.e. the estimated price elasticity in absolute values is lower than one.

Table 3.5: Estimation of the household water demand in Belgium (Wallonia and Brussels-Capital)

	BelgiumWBOLS	BelgiumWBGLS
	b/se	b/se
$\ln$ Water price (in euros per m3)	-0.038*	-0.120***
	(0.02)	(0.02)
$\ln$ Household median income (in euros per household)	0.096***	0.063***
	(0.02)	(0.02)
$\ln$ Average population age (years)	-0.262**	-0.320**
	(0.11)	(0.13)
$\ln$ Population density (inabitants per km2)	0.033***	0.034***
	(0.00)	(0.01)
$\ln$ average of daily rainfall in summer (mm per day)	0.320***	0.119***
	(0.03)	(0.02)
Constant	2.982***	3.819***
	(0.44)	(0.49)
R-squared	0.217	
N. of obs.	744.000	744.000

Figure 3.1: Observed versus predicted household water consumption in Belgium (Wallonia and Brussels-Capital)



The income elasticity is quite consistent with all models. It varies between 0.10 and 0.06 and the income elasticity is significantly different from zero with both models. This suggests that there is an increasing relationship between water consumption and household income. The positive significant coefficient for income indicates that, based on the GLS model, a 10% increase in income will result in a 0.6% increase in water consumption.

We find that the water consumption per capita tends to decrease with the average population age.

Climate conditions play also a significant role but with an unexpected sign. An increase of summer rainfall by 10% will imply an increase in water consumption by 1.2%.

A possible way to assess the validity of the model is to compare the water consumption predicted by the demand function to the observed water consumption, see Figure 3.1. For most of the municipalities the model performs quite well. The mean absolute percentage error is 8.35.

3.5.4 Results (Flanders)

We report here our estimate for the residential water demand function in Belgium (Flanders), based on our municipal dataset (2012 and 2013). The first model estimated in Table 3.6 corresponds to simple OLS whereas in the second model we estimate Equation (3.3) with GLS (random parameter estimator).

Table 3.6: Estimation of the household water demand in Belgium (Flanders)

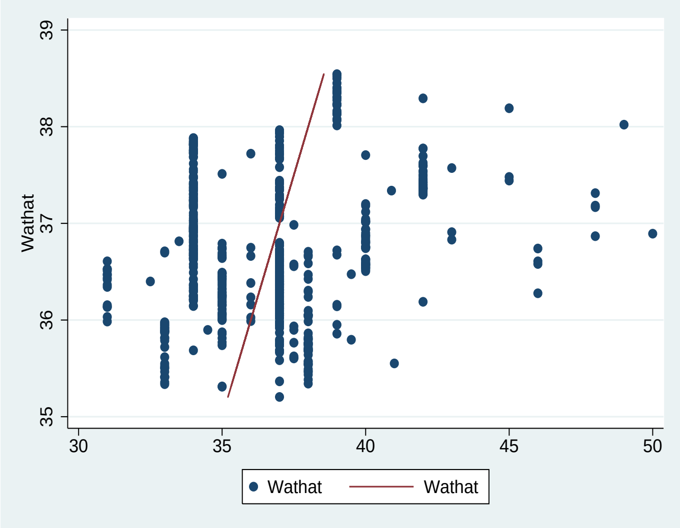
	BelgiumFLOLS b/se	BelgiumFLGLS b/se
$\ln$ Water price (in euros per m3)	-0.102***	-0.124***
	(0.02)	(0.03)
$\ln$ Household median income (in euros per household)	0.115***	0.032
	(0.03)	(0.04)
$\ln$ average of daily rainfall in summer (mm per day)	0.076***	0.053***
	(0.01)	(0.01)
Constant	2.468***	3.313***
	(0.28)	(0.39)
R-squared	0.081	
N. of obs.	616.000	616.000

Table 3.6 presents the main significant variables explaining household water consumption in Belgium (Flanders).

The price elasticity varies across models, from -0.10 with the OLS model to -0.12 with the GLS (significant at 1%). Based on the GLS model, a 10% increase in water price results in a 1.2% decrease in short-run water consumption in Belgium (Flanders). Water demand in Belgium (Flanders) is inelastic, i.e. the estimated price elasticity in absolute values is lower than one.

The income elasticity varies across models between 0.03 and 0.10. The income elasticity is significantly different from zero with the GLS model. The positive coefficients for the income variable suggest that there is an increasing relationship between water consumption and household income. The positive significant coefficient for income indicates that, based on the GLS model, a 10% increase in income will result in a 0.3% increase in water consumption.

Figure 3.2: Observed versus predicted household water consumption in Belgium (Flanders)



Climate conditions play also a significant role. An increase of summer rainfall by 10% will imply an increase in water consumption by 0.5%.

A possible way to assess the validity of the model is to compare the water consumption predicted by the demand function to the observed water consumption, see Figure 3.2. For most of the municipalities the model performs quite well. The mean absolute percentage error is 5.99.

Chapter 4

Bulgaria

4.1 Existing literature

To our best knowledge, there doesn't exist any published article having estimated a residential water demand function in Bulgaria. There are some descriptive papers on household water consumption in Bulgaria. Clark and Finley (2007) work on household water consumption in Blagoevgrad, Bulgaria. They use household data (728 questionnaires collected in summer 2003). They employ the theory of planned behavior as a theoretical framework for evaluating determinants of intention to implement a set of specific water conservation behaviors among Blagoevgrad residents.

4.2 Urban water sector in Bulgaria

Water availability This paragraph is based on MRD (2014). Bulgaria is characterized by a situation of limited water stress. The projected total domestic water consumption (3,340 million cubic meters in 2035 excluding hydro energy and nuclear power plants) is lower than the multi-year average internal water resource (18,547 million cubic meters excluding the Danube River) over the period 1974-2008. Before 1990, Bulgaria was close to be considered as a water-scarce country. Since then, water abstractions have fallen drastically both for agricultural and industrial purposes.

Organization of the water sector According to the report WorldBank (2015a) Bulgaria has 64 water and sanitation service providers, of which 56 are state owned. The 29 regional water companies provide services to 76% of the population, with the rest of service providers serving single municipalities. Fourteen multi-city utilities are state-owned water companies. They cover the largest area of the country, and they are managed by the Ministry of Regional Development. The other utilities are owned by municipalities. The Sofia water service is the only water concession awarded to a private company for 25 years (WorldBank 2015a). In 2005, a joint water and energy regulator (State Energy and Water Regulatory Commission-SEWRC) was established. The Water and Sanitation Services Regulation Act is the basis for the regulation of WSSCs.

Water and wastewater coverage The rate of access to piped water in Bulgaria is high by European standards with 99 percent of the population of Bulgaria having access to piped water. Only two districts in Bulgaria have less than full coverage from centralized piped water. At the national level, about 670,000 people living in agglomerations greater than 2,000 person equivalents need to be connected to wastewater collection and approximately 1.8 millions people need to be connected to a wastewater treatment plant in order to comply with EU regulations. Bulgaria has to increase both wastewater collection and the connection to urban wastewater treatment plants from the current coverage levels of 66 percent and 50 percent respectively in order to comply with the regulations. Non-revenue water is reported to be 60 percent (MRD 2014).

4.3 Data

Our data set consists of Nuts3-level (county) data on household water consumption, household water price, household's socioeconomic conditions income and on climate condition for year 2010. Most of the data come from the National Statistical Office of Bulgaria. The data consist of aggregate data at Nuts3-level on water consumption per capita and water and sewerage prices. The data have been combined with information on household's income, climate conditions, and household characteristics mainly from National Statistical Office Bulgaria.

Water consumption data From the Statistical Office of Bulgaria we have the water used by households from public water supply by statistical region and by district (average per capita) from 2000 to 2010. Our endogenous variable is then the annual water consumption per capita (in m3 per year per capita).

Water price data Our main source of data is the State Energy and Water Regulatory Commission of Bulgaria.[1]. We have the price paid by households for the water service (not for wastewater) in 2010 for 61 water services in Bulgaria. The price information is then almost exhaustive for Bulgaria. We have then matched each water service with the corresponding Nuts3.

Household income Our proxy for household income is the average annual salary of employees under labor contract. This information is available from the National Statistical Office of Bulgaria from 2006 to 2011 at Nuts3 level.

Other socioeconomic variables Other socio-economic variables from 2000 to 2011 come from the National Statistical Office of Bulgaria.

Climate data All meteorological data come from the JRC climate database. Grid data (5km $\times$ 5km) on rainfalls, temperatures and evapotranspiration have been aggregated at regional level. We have historical data from 1990 to 2013.

4.4 Empirical analysis of residential water consumption

In this section, we provide a statistical analysis or residential water consumption and water price for Bulgaria.

Table 4.1: Household water consumption and price in Bulgaria

Year	Water consumption (m3 per capita per year)	Water price (euros per m3)
2001	34.979	.
2002	33.045	.
2003	35.003	.
2004	34.393	.
2005	33.998	.
2006	35.464	.
2007	36.892	.
2008	36.335	.
2009	36.476	.
2010	35.864	0.900
Average	35.252	0.900

[1] The State Energy and Water Regulatory Commission is the regulator of the water and energy sectors. I has been established with a Decree of the Council of Ministers of the Republic of Bulgaria No 181 of 10 Sep 1999. The main duties of the regulator concerning the water sector is to regulate the quality of water and wastewater services and to carry out price regulation of the water and wastewater services.

Table 4.1 gives the annual residential water consumption (m3 per capita and per year) and the water price (average water price, in euros m3) in Bulgaria from 2001 to 2010. In 2010, the average annual consumption per inhabitant amounted to 35.9 m3. It has remained quite stable from 2001. In 2010, the average water price is 0.9 euros per m3. The report MRD (2014) provide some data on water price in Bulgaria. According to this report, the combined water and wastewater tariffs in Bulgaria have increased significantly since 2008 (0.80, 0.87, 0.92, 0.94 euro per m3 respectively in 2008, 2009, 2010 and 2011) , but continue to be lower than the combined tariffs in other European countries.

Table 4.2: Regional household water consumption and price in Bulgaria

Year	Water consumption (m3 per capita per year)	Water price (euros per m3)
Blagoevgrad	38.690	0.387
Burgas	40.515	0.478
Dobrich	26.645	1.145
Gabrovo	30.660	0.808
Haskovo	28.835	0.750
Kardzhali	29.200	0.660
Kyustendil	30.660	0.692
Lovech	30.660	0.701
Montana	31.025	0.360
Pazardzhik	32.120	0.433
Pernik	36.865	0.258
Pleven	34.310	0.739
Plovdiv	35.040	0.654
Razgrad	24.090	1.103
Ruse	36.500	0.803
Shumen	27.010	1.064
Silistra	27.740	0.987
Sliven	26.645	0.869
Smolyan	27.375	0.966
Sofia	32.850	0.578
Sofia cap.	51.100	0.532
Stara Zagora	28.105	1.033
Targovishte	21.170	0.663
Varna	35.405	0.997
Veliko Tarnovo	32.120	0.711
Vidin	29.565	0.849
Vratsa	32.485	0.931
Yambol	30.660	0.736
Average	35.864	0.900

Table 4.2 gives the annual residential water consumption (m3 per capita and per year) and the water price per county (Nuts 3) in 2010. As it can be seen, there are some differences across regions, both in terms of water consumption and water prices. With more than 50 m3 per capita per year, the water consumption is the

higher in the Sofia capital Nuts3. The Sofia capital Nuts3 corresponds to the bulagarian capital Sofia and is the most densely populated area of Bulgaria. On contrary, a low water consumption is reported in the Targovishte county (21.2 m3 per capita per year).

4.5 Water demand function estimate

4.5.1 Specifying the residential water demand function

The residential water demand function can be derived from solving the utility optimization problem of a consumer. Under the assumption of a weak separability of water with respect to other goods consumed, the Marshallian demand in water can be written as:

$$y = y^*(p, I, Z) \tag{4.1}$$

where y is the water consumption either per capita or per household, p and I denote the unit water price (representing both water supply and the sewage treatment services) and the representative household income, respectively. Z is a vector of exogenous variables assumed to influence water consumption (climate conditions, household and housing characteristics, etc.).

To estimate Equation (4.1), a wide variety of functional forms have been applied in the water demand literature, including linear forms, semi or double logarithm forms and more complex forms such as the Stone-Geary specification. The existing literature is however not very informative concerning the specification which should be preferred. Since the double-log model is the most common specification in the residential water demand literature, we have adopted this model in order to facilitate comparison to other studies. Furthermore, the specification implies that coefficient estimates are also elasticity estimates. With a double-log specification, the residential water demand function writes:

$$\ln(y) = \alpha \ln(p) + \beta \ln(I) + \gamma \ln(Z)' \tag{4.2}$$

and the coefficients α and β can be directly interpreted as the price and the income elasticities of the water demand. Specification tests for the functional form will be conducted in the empirical part but we don't expect the choice of the particular form to have a fundamental influence on the estimation of the parameters of interest.

4.5.2 Estimation methods

Let $i = \{1, .., I\}$ indexes Nuts3. Our equation of interest becomes:

$$\ln(y_i) = \alpha \ln(p_i) + \beta \ln(I_i) + \gamma \ln(Z_i)' + \epsilon_i \tag{4.3}$$

where ϵ_i is the usual random term.

4.5.3 Results

We report here our estimate for the residential water demand function in Bulgaria, based on our Nuts3 dataset for Bulgaria for year 2010. The first model estimated in Table 4.3 corresponds simple OLS whereas in the second model we estimate Equation (4.3) with an instrumental variable approach.

Table 4.3 present the main significant variables explaining household water consumption in Bulgaria. The price elasticity is consistent across models, from -0.26 with the OLS to -0.27 with the OLSiv (always significant).

Table 4.3: Estimation of the household water demand in Bulgaria

	BulgariaOLS b/se	BulgariaOLSiv b/se
ln Water price (in euros per m3)	-0.256***	-0.275***
	(0.06)	(0.07)
ln Household income (in euros per capita)	0.613***	0.619***
	(0.16)	(0.16)
ln Household size	-0.355	-0.334
	(0.42)	(0.42)
ln summer evapotranspiration	0.040	0.061
	(0.24)	(0.24)
Constant	-1.339	-1.440
	(1.57)	(1.58)
R-squared	0.611	0.610
N. of obs.	28.000	28.000

Source: auto.dta

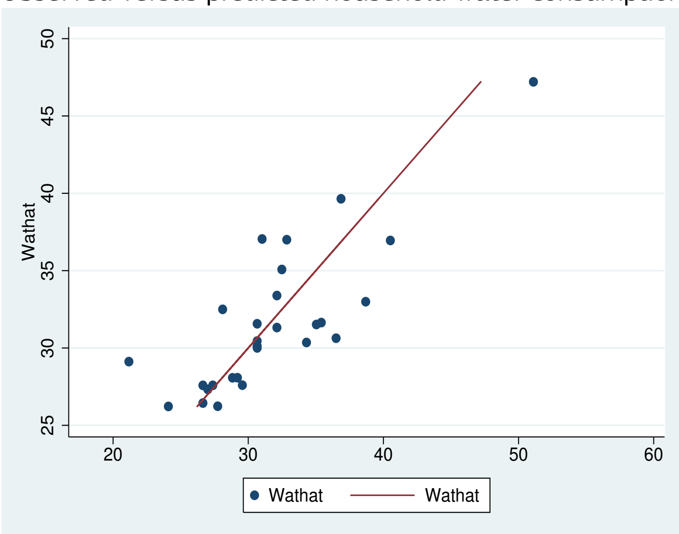
Based on the OLSiv models, a 10% increase in water price results in a 2.8% decrease in short-run water consumption in Bulgaria. Water demand in Bulgaria is inelastic, i.e. the estimated price elasticity in absolute values is lower than one.

The income elasticity varies between 0.61 and 0.62 and the income elasticity is significantly different from zero with the two models. This suggests that there is an increasing relationship between water consumption and household income. The positive significant coefficient for income indicates that, based on the GLS model, a 10% increase in income will result in a 6.2% increase in water consumption.

Climate conditions don't seem to play a significant role.

A possible way to assess the validity of the model is to compare the water consumption predicted by the demand function to the observed water consumption, see Figure 4.1. For most of the municipalities the model performs quite well. The mean absolute percentage error is 7.8.

Figure 4.1: Observed versus predicted household water consumption in Bulgaria



Chapter 5

Croatia

5.1 Existing literature

To our best knowledge, there is no previous estimate of the residential water demand in Croatia.

5.2 Urban water sector in Croatia

This paragraph is based on RepublicofCroatia (2010) and on WorldBank (2015b).

With around 24,495 m3 of renewable water per capita per year (FAO Aquastat 2015), Croatia is a water-rich country split between two river basin districts, the Danube basin and the Adriatic basin. Water supply comes mainly from groundwater (96%). Surface water provides 4% of overall drinking water supply (WorldBank 2015b). Most rivers flow into the Danube or one of its tributaries.

Local governments are responsible for water and sanitation services and provide them through 156 public utility companies (140 for water and sanitation service and only 16 for sanitation service). The largest utility (Zagreb Waterworks) serves 17% of the population. The next 84 largest multi-city companies serve 59% of the population. The remaining 24% of the population is either served by 55 small municipal providers (5%) or uses self-provision (19%) or individual water resources. Most utility companies provide both water and sewerage services, although in larger cities, separate utility companies may exist.

The coverage ratio (share of the population able to connect to the public water supply system) on the level of the Republic of Croatia is on the average 80-82% (RepublicofCroatia 2010). The connection ratio (share of the population connected to the public water supply system) is somewhat lower and it is estimated to be on average equal to 74%. There are significant differences in the level of coverage between regions.

5.3 Data

Our panel data set consists of water service-level data on household water consumption, household water price, household's socioeconomic conditions income and on climate condition for years 2000-2004. Most of the data related to water come from the International Benchmarking Network for Water and Sanitation Utilities (IBNET). We use a panel of water utilities made of 21 services for years 2000 to 2004. The water data have been combined with information at different administrative levels on income, weather, and household characteristics obtained mainly from the Croatian Bureau of Statistics. Each water utility has been matched with one of the 21 Croatian county (Nuts 3).

Water consumption data From IBNET, we have the residential water consumption (l/person/day) which has been converted in cubic meters per year and per capita. Our dependent variable is then the water supplied to households per capita and per year.

Water price data For each water service and each year, we have average revenue for the water and wastewater services (euros per cubic meter of water sold). We will use this average revenue as a proxy of the water price paid by households.

Household income The Croatian Bureau of Statistics provides the total gross disposable income of households at county-level for years 2000 to 2005. Using the data on population per county we have computed the gross disposable income of households per capita at county-level for years 2000 to 2005.

Other socioeconomic variables Other socio-economic variables from 2000 to 2005 come from the Croatian Bureau of Statistics.

Climate data All meteorological data come from the JRC climate database. Grid data (5km $\times$ 5km) on rainfalls, temperatures and evapotranspiration have been aggregated at regional level. We have historical data from 1990 to 2013.

5.4 Empirical analysis of residential water consumption

In this section, we provide a statistical analysis or residential water consumption and water price for Croatia based on the IBNET data.

Table 5.1: Household water consumption and price in Croatia

Year	Water consumption (m3 per capita per year)	Water price (euros per m3)
2000	103.259	0.613
2001	100.521	0.654
2002	99.281	0.723
2003	101.738	0.840
2004	101.045	1.059
Average	101.171	0.777

Table 5.1 gives the annual residential water consumption (m3 per capita and per year) and the water price (average water price, in euros m3) in Croatia from 2000 to 2004. In our sample of water utilities taken from IBNET, household water consumption has slightly fallen from 103 cubic meters to 101 cubic meters per capita and per year from 2000 to 2004. It should be mentioned that this figure is much higher than expected. Indeed according to the Statistical Yearbook 2012 of the Republic of Croatia, the volume of water distributed to households in 2010 was 189.3 millions of cubic meters. With a population connection rate to the water supply equal to 74% (as indicated in (RepublicofCroatia 2010)), this translates into a water consumption per capita equal to 58 cubic meters. Over the period 2010 to 2012, the average water price has increased from 0.6 euros per m3 to 1.1 euros per m3.

Table 5.2 gives the annual residential water consumption (m3 per capita and per year) and the water price per county (Nuts 3) in 2004. As it can be seen, there are some differences across counties, both in terms of water consumption and water prices.

5.5 Water demand function estimate

5.5.1 Specifying the residential water demand function

The residential water demand function can be derived from solving the utility optimization problem of a consumer. Under the assumption of a weak separability of water with respect to other goods consumed, the Marshallian demand in water can be written as:

$$y = y^*(p, I, Z) \tag{5.1}$$

Table 5.2: Regional household water consumption and price in Croatia

Year	Water consumption (m3 per capita per year)	Water price (euros per m3)
Bjelovarsko-bilogorska zupanija	47.815	1.867
Brodsko-posavska zupanija	444.205	0.056
Dubrovacko-neretvanska zupanija	55.480	1.433
Istarska zupanija	67.708	2.656
Karlovacka zupanija	85.775	0.144
Koprivnicko-krizevacka zupanija	50.005	1.622
Licko-senjska zupanija	110.230	0.700
Osjecko-baranjska zupanija	59.495	0.511
Pozesko-slavonska zupanija	44.165	0.767
Primorsko-goranska zupanija	108.952	1.578
Sibensko-kninska zupanija	91.980	0.922
Sisacko-moslavacka zupanija	201.845	0.833
Splitsko-dalmatinska zupanija	113.515	0.517
Zagrebacka zupanija	53.533	1.115
Average	101.045	1.059

where y is the water consumption either per capita or per household, p and I denote the unit water price (representing both water supply and the sewage treatment services) and the representative household income, respectively. Z is a vector of exogenous variables assumed to influence water consumption (climate conditions, household and housing characteristics, etc.).

To estimate Equation (5.1), a wide variety of functional forms have been applied in the water demand literature, including linear forms, semi or double logarithm forms and more complex forms such as the Stone-Geary specification. The existing literature is however not very informative concerning the specification which should be preferred. Since the double-log model is the most common specification in the residential water demand literature, we have adopted this model in order to facilitate comparison to other studies. Furthermore, the specification implies that coefficient estimates are also elasticity estimates. With a double-log specification, the residential water demand function writes:

$$\ln(y) = \alpha \ln(p) + \beta \ln(I) + \gamma \ln(Z)' \tag{5.2}$$

and the coefficients α and β can be directly interpreted as the price and the income elasticities of the water demand. Specification tests for the functional form will be conducted in the empirical part but we don't expect the choice of the particular form to have a fundamental influence on the estimation of the parameters of interest.

5.5.2 Estimation methods

Let $i = \{1, .., I\}$ indexes water services and $t = \{1, .., T\}$ years. Our equation of interest becomes:

$$\ln(y_{it}) = \alpha \ln(p_{it}) + \beta \ln(I_{it}) + \gamma \ln(Z_{it})' + \epsilon_{it} \tag{5.3}$$

where ϵ_{it} is the usual random term. Two panel data estimators may be used namely the fixed effects (or dummy variable) model and the random effects (or error components) model. We propose to use these two

Table 5.3: Estimation of the household water demand in Croatia

	CroatiaOLS b/se	CroatiaGLS b/se	CroatiaGLSiv b/se
$\ln$ Water price (in euros per m3)	-0.370***	-0.142*	1.099
	(0.07)	(0.08)	(1.41)
$\ln$ Household income (in euros per capita)	-0.076	-0.165	-2.766
	(0.51)	(0.23)	(3.03)
$\ln$ Household size	-2.780***	-3.722**	-1.222
	(0.73)	(1.47)	(3.27)
$\ln$ Average of daily rainfall in summer (mm per day)	-0.103	-0.072***	-0.010
	(0.12)	(0.03)	(0.09)
Constant	7.929*	9.777***	28.765
	(4.38)	(3.06)	(23.43)
R-squared	0.394		
N. of obs.	95.000	95.000	95.000

estimators and to conduct some specification tests (Hausman test) to decide which is the most appropriate to our data.

5.5.3 Results

We report here our estimate for the residential water demand function in Croatia, based on our water utility dataset for Croatia (2000 to 2004). The first model estimated in Table 5.3 corresponds to simple OLS whereas in the second model we estimate Equation (5.4) with a random parameter estimator. In the third model, we account for potential endogeneity of the price by using an instrumental variable approach.

Table 5.3 present the main significant variables explaining household water consumption in Croatia. The price elasticity varies across models, from -0.37 with the OLS to 1.10 with the GLSiv (not significant with the GLSiv). Based on the GLS model, a 10% increase in water price results in a 1.4% decrease in short-run water consumption in Croatia. Water demand in Croatia appears to be elastic, i.e. the estimated price elasticity in absolute values is greater than one.

The income elasticity is never significant.

Large households tend to have a lower water consumption per capita (OLS and GLS models).

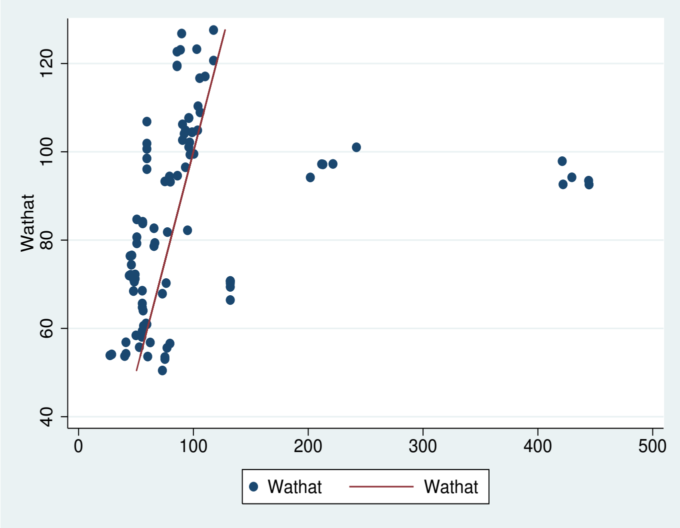
Climate conditions play also a significant role (GLS model). An increase by 10% of rainfall will imply a decrease in water consumption by 0.7% (GLS model).

A possible way to assess the validity of the model is to compare the water consumption predicted by the demand function to the observed water consumption, see Figure 5.1. For most of the water services the model performs quite well. The mean absolute percentage error is 33.6.

Water consumption may to be at least somehow persistent over time due to household habits or due to the time needed to adjust durable equipments (shower for instance). With panel or time-series data, one way to take into this time persistence characteristic of household water consumption is to introduce the lagged consumption as an additional independent variable in Equation (5.1). The dynamic specification of our equation of interest becomes then :

$$\ln(y) = \alpha \ln(p) + \beta \ln(I) + \gamma \ln(Z)' + \mu \ln(\text{Lag}\, y) \tag{5.4}$$

Figure 5.1: Observed versus predicted household water consumption in Croatia



where Lag y represents the lagged water consumption. From this specification is is then possible to derive the long-run price elasticity of the household water demand function which simply writes:

$$\epsilon_p^{LT} = \frac{\alpha}{1-\mu}. \tag{5.5}$$

We provide in Table 5.4 our estimates for the household water demand function where the lagged consumption has been introduced as an additional independent variable. With the CroatiaGLSlag model, the long-term price elasticity is estimated to be -1.16 and is significantly different from zero at 1%.

Table 5.4: Estimation of the household water demand with lagged water consumption in Croatia

	CroatiaGLSlag b/se	CroatiaGLSivlag b/se
$\ln$ Water price (in euros per m3)	-0.035*	-0.016
	(0.02)	(0.09)
$\ln$ Household income (in euros per capita)	0.051	-0.027
	(0.13)	(0.34)
$\ln$ Household size	-0.164	-0.137
	(0.19)	(0.25)
$\ln$ Average of daily rainfall in summer (mm per day)	-0.027	-0.025
	(0.03)	(0.03)
$\ln$ Lag of water consumption per capita	0.970***	0.980***
	(0.03)	(0.06)
Constant	-0.106	0.461
	(1.16)	(2.49)
R-squared		
N. of obs.	76.000	76.000

Source: auto.dta

Chapter 6

Cyprus

6.1 Existing literature

Hajispyrou, Koundouri, and Pashardes (2002) have estimated a residential water demand function for Cyprus using individual household data drawn from the Cyprus Family Expenditure Survey (1996-97). They estimate the price and income elasticities of residential demand for water and evaluate the welfare effects associated with potential changes in the current water pricing system. Depending upon household income, the price elasticity varies between -0.79 and -0.39. Income elasticities are found between 0.25 and 0.48.

Polycarpou and Zachariadis (2013) present the results of an econometric analysis of residential water demand in Cyprus, based on quarterly data for the Nicosia, Limassol and Larnaca water boards and for years 2001 to 2009. The average price elasticity is shown to be significant and equal to -0.25, whereas marginal price elasticity is estimated at -0.45. Income elasticity varies between 0.53 and 0.75.

6.2 Urban water sector in Cyprus

This paragraph is based on Sofroniou and Bishop (2014). Domestic and irrigation are the two main sectors of water demand in Cyprus. Based on the latest data from the Water Development Department, the total annual water demand in the Government controlled areas is 275 Mm3 per year, of which the dominated water use sector is agriculture (64% of the water use). Domestic water supply to households represents 28.4%, 4.7% corresponds to the tourist and hotel water demands and industrial suppliers make up the 2.9% water demands.

6.3 Data

Our data set consists of Nuts3-level (which correspond to the whole country for Cyprus) data on household water consumption, household water price, household's socioeconomic conditions income and on climate conditions for years 1995 to 2012 (15 years). Most of the data come from the Cyprus Statistical Service. The data consist of aggregate data at Nuts3-level (national) on water consumption per capita and water prices. The data have been combined with information on household's income, climate conditions, and household characteristics mainly from the Cyprus Statistical Service.

Water consumption data From the Cyprus Statistical Service we have the annual volume of water supplied to households users from the public water network from 1998 to 2012. The volume of water has been divided by the total population, assuming a 100% connection rate. Our endogenous variable is then the annual water consumption per capita to the public water supply network (in m3 per year per capita).

Water price data The Cyprus Statistical Service provides the price index for *Water supply and other services*. This index has been used for computing an average national price for the water service (the average price of water for household is 0.7 euros per cubic meters in 2007, the wastewater service is not included).

Household income We use the GDP per capita from the Cyprus Statistical Service.

Other socioeconomic variables Other socio-economic variables from 2000 to 2011 come from the Cyprus Statistical Service.

Climate data All meteorological data come from the JRC climate database. Grid data (5km $\times$ 5km) on rainfalls, temperatures and evapotranspiration have been aggregated at regional level. We have historical data from 1990 to 2013.

6.4 Empirical analysis of residential water consumption

In this section, we provide a statistical analysis or residential water consumption and water price for Cyprus.

Table 6.1: Household water consumption and price in Cyprus

Year	Water consumption (m3 per capita per year)	Water price (euros per m3)
1995	70.210	.
1996	73.945	.
1997	66.786	.
1998	62.877	0.405
1999	70.191	0.415
2000	69.020	0.420
2001	82.680	0.422
2002	88.782	0.488
2003	91.605	0.497
2004	94.643	0.512
2005	99.255	0.539
2006	98.136	0.563
2007	96.337	0.600
2008	79.456	0.640
2009	87.005	0.686
2010	98.987	0.766
2011	94.723	0.794
2012	91.330	0.896
Average	84.221	0.576

Table 6.1 gives the annual residential water consumption (m3 per capita and per year) and the water price (average water price, in euros m3) in Cyprus from 1998 to 2012. In 2012, the average annual consumption per inhabitant amounted to 91 m3. There has been an increasing trend in domestic water consumption since 1998.

In 2008, Cyprus faced one of the most acute and prolonged droughts (a fourth consecutive drought year) with the winter season being extremely dry. As a result severe restrictions in the use of water by households have been implemented in 2008, which might explained the low water consumption per capita for this year.

The average water price in 2012 was 0.9 euros per m3. It has steadily increased since 1998. The water price is consistent with Polycarpou and Zachariadis (2013) who reports an average water price equal to 0.58 euros per cubic meter for the period 2001-2009.

6.5 Water demand function estimate

6.5.1 Specifying the residential water demand function

The residential water demand function can be derived from solving the utility optimization problem of a consumer. Under the assumption of a weak separability of water with respect to other goods consumed, the Marshallian demand in water can be written as:

$$y = y^*(p, I, Z) \tag{6.1}$$

where y is the water consumption either per capita or per household, p and I denote the unit water price (representing both water supply and the sewage treatment services) and the representative household income, respectively. Z is a vector of exogenous variables assumed to influence water consumption (climate conditions, household and housing characteristics, etc.).

To estimate Equation (6.1), a wide variety of functional forms have been applied in the water demand literature, including linear forms, semi or double logarithm forms and more complex forms such as the Stone-Geary specification. The existing literature is however not very informative concerning the specification which should be preferred. Since the double-log model is the most common specification in the residential water demand literature, we have adopted this model in order to facilitate comparison to other studies. Furthermore, the specification implies that coefficient estimates are also elasticity estimates. With a double-log specification, the residential water demand function writes:

$$\ln(y) = \alpha \ln(p) + \beta \ln(I) + \gamma \ln(Z)' \tag{6.2}$$

and the coefficients α and β can be directly interpreted as the price and the income elasticities of the water demand. Specification tests for the functional form will be conducted in the empirical part but we don't expect the choice of the particular form to have a fundamental influence on the estimation of the parameters of interest.

6.5.2 Estimation methods

Let $t = \{1, .., T\}$ indexes years. Our equation of interest becomes:

$$\ln(y_t) = \alpha \ln(p_t) + \beta \ln(I_t) + \gamma \ln(Z_t)' + \epsilon_t \tag{6.3}$$

where ϵ_t is the usual random term.

6.5.3 Results

We report here our estimate for the residential water demand function in Cyprus. The model in Table 6.2 corresponds to simple OLS.

Table 6.2 present the main significant variables explaining household water consumption in Cyprus. The price elasticity varies is found to be -0.32, and is almost significantly different from zero at 10%. Based on the OLS model, a 10% increase in water price results in a 1.5% decrease in short-run water consumption in Cyprus. Water demand in Cyprus is inelastic, i.e. the estimated price elasticity in absolute values is lower than one.

The income elasticity is equal to 1.08 (significant at 1%), a value relatively high compared to the existing literature. This suggests that there is an increasing relationship between water consumption and household income. The positive significant coefficient for income indicates that a 10% increase in income will result in a 10.1% increase in water consumption.

The dummy variable for year 2008 is highly significant. Water consumption for this specific year seems to be 25% lower than what would have prevailed under normal climatic conditions. This result suggests that the

Table 6.2: Estimation of the household water demand in Cyprus

	CyprusOLS b/se
$\ln$ Water price (in euros per m3)	-0.329
	(0.20)
$\ln$ Household income (in euros per capita)	1.080***
	(0.28)
$\ln$ average of daily rainfall (mm per day)	-0.016
	(0.10)
dummy for 2008	-0.306**
	(0.11)
Constant	-6.261**
	(2.80)
R-squared	0.780
N. of obs.	15.000

restriction imposed on households on water consumption have had a significant impact. The average of daily rainfall is not significant.

A possible way to assess the validity of the model is to compare the water consumption predicted by the demand function to the observed water consumption, see Figure 6.1. For most of the municipalities the model performs quite well. The mean absolute percentage error is 5.2.

Water consumption may to be at least somehow persistent over time due to household habits or due to the time needed to adjust durable equipments (shower for instance). With panel or time-series data, one way to take into this time persistence characteristic of household water consumption is to introduce the lagged consumption as an additional independent variable in Equation (6.2). The dynamic specification of our equation of interest becomes then :

$$\ln(y) = \alpha \ln(p) + \beta \ln(I) + \gamma \ln(Z)' + \mu \ln(\text{Lag}\, y) \tag{6.4}$$

where Lag y represents the lagged water consumption. From this specification is is then possible to derive the long-run price elasticity of the household water demand function which simply writes:

$$\epsilon_p^{LT} = \frac{\alpha}{1-\mu}. \tag{6.5}$$

We provide in Table 6.3 our estimates for the household water demand function where the lagged consumption has been introduced as an additional independent variable. With the CyprusOLSlag model, the long-term price elasticity is estimated to be -0.51 but no significantly different from zero at 10%.

Figure 6.1: Observed versus predicted household water consumption in Cyprus

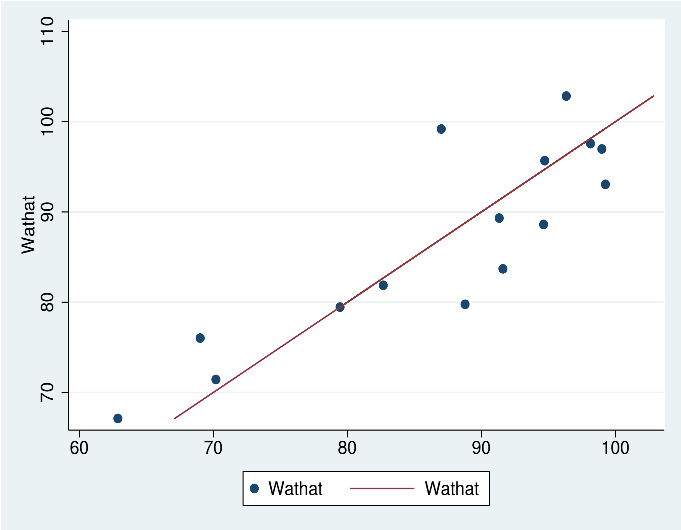


Table 6.3: Estimation of the household water demand with lagged water consumption in Cyprus

	CyprusOLSlag
	b/se
$\ln$ Water price (in euros per m3)	-0.249
	(0.16)
$\ln$ Household income (in euros per capita)	0.620*
	(0.29)
$\ln$ average of daily rainfall (mm per day)	-0.028
	(0.08)
dum2008	-0.288**
	(0.09)
$\ln$ Lag of water consumption per capita	0.512**
	(0.20)
Constant	-3.989
	(2.44)
R-squared	0.871
N. of obs.	15.000

Source: auto.dta

Chapter 7

Czech Republic

7.1 Existing literature

Hortová and Kristoufek (2014) use a panel of aggregate regional data from 2000 to 2011 to estimate of price and income elasticities of household water consumption the Czech Republic. The short-run price elasticity is estimated at --0.20 while the long-run price elasticity at --0.54. This indicates that a 1% increase in water price results in a 0.20% decrease in short-run water consumption but in the long-run, the same price change causes water consumption to decrease by 0.54%. The elasticity of water demand with respect to income is estimated to be 0.10.

7.2 Urban water sector in Czech Republic

Municipalities are responsible bodies for drinking water and wastewater services. The most dominant operating model is a private concession (46% of the population) in the form of a ''separate model'' based on long-term operating contracts (WorldBank 2015c). Mixed capital utilities (which provide services to 27% of the population), refers to utilities that operate and own infrastructure. Municipalities are shareholders in the utility and provide service to 10% of the population. Village administrations (departments or public services) provide water services to 11% of the population, and around 6% of the population operate their own wells or water sources. More than 95% of utilities provide both water and wastewater services (WorldBank 2015c).

At national level, the relevant authorities for the water sector are the Ministry of Agriculture and the Ministry of Environment. The Ministry of Finance also provides regulation and control over surface water fees and water and wastewater tariffs.

Water and wastewater market regulation is concentrated in two Acts. First, Act 254/2001 Coll on Water defines the rights and obligations of all entities whose activities may affect the quantity or quality of water. Second, Act 274/2001 Coll. on Public Water Supply Systems and Sewerage which establishes the public water supply and sewerage systems as a special branch network. It defines the owner of the infrastructure, the service provider and the system user.

It is considered that the population of the Czech Republic has full access to water and sanitation services (WorldBank 2015c).

7.3 Data

Our panel data set consists of Nuts3-level (county) data on household water consumption, household water price, household's socioeconomic conditions income and on climate condition for years 2006-2011. Most of the data come from the Statistical Office of the Czech Republic. The data consist of aggregate data at Nuts3-level on water consumption per capita and water and sewerage prices. The data have been combined with information on household's income, climate conditions, and household characteristics mainly from the Czech Statistical Office.

Water consumption data Our dependent variable is the annual volume of water sold to households per connected capita to the public water supply network at Nuts 3 from 2006 to 2011 (in m3 per year per capita). It is obtained by dividing overall Nuts3 water consumption by the number of people supplied with water in this Nuts3. All data come from the Czech Statistical Office.

Water price data As a price indicator, we use the average price paid by households for the water and wastewater services (in euros per m3 including VAT). The price information is available at Nuts3 from the Czech

Statistical Office for the period 2006 to 2011.

Household income We use the average annual gross wage of employees in each Nuts3 from the Czech Statistical Office for the period 2006 to 2011.

Other socioeconomic variables Other socio-economic variables from 2000 to 2011 come from the Czech Statistical Office

Climate data All meteorological data come from the JRC climate database. Grid data (5km $\times$ 5km) on rainfalls, temperatures and evapotranspiration have been aggregated at regional level. We have historical data from 1990 to 2013.

7.4 Empirical analysis of residential water consumption

In this section, we provide a statistical analysis or residential water consumption and water price for Czech Republic.

Table 7.1: Household water consumption and price in Czech Republic

Year	Water consumption (m3 per capita per year)	Water price (euros per m3)
2006	35.344	1.898
2007	35.595	1.883
2008	34.146	2.037
2009	33.597	2.195
2010	32.554	2.316
2011	32.239	2.451
Average	33.904	2.131

Table 7.1 gives the annual residential water consumption (m3 per capita and per year) and the water price (average water price, in euros m3) in Czech Republic from 2006 to 2011. In 2011, the average annual consumption per inhabitant amounted to 32.2 m3. There has been a decreasing trend in domestic water consumption since 2006. Over the period 2002-2011, the average water and wastewater price has increased from 1.9 euros per m3 to 2.5 euros per m3.

Table 7.2 gives the annual residential water consumption (m3 per capita and per year) and the water price per county (Nuts 3) in 2010. As it can be seen, there are some differences across regions, both in terms of water consumption and water prices. With almost 38 m3 per capita per year, the water consumption is the higher in the CZ010 Nuts3. The CZ010 Nuts3 includes the capital Prague and is the most densely populated area of Czech Republic. On contrary, a low water consumption is reported in the CZ072 county (28.8 m3 per capita per year).

7.5 Water demand function estimate

Table 7.2: Regional household water consumption and price in Czech Republic

Year	Water consumption (m3 per capita per year)	Water price (euros per m3)
Hlavníměsto Praha	37.939	2.336
Jihočeský kraj	31.511	2.269
Jihomoravský kraj	32.835	2.269
Karlovarský kraj	32.305	2.469
Karlovarskḱraj	29.233	2.078
Královéhradecký kraj	31.603	2.357
Liberecký kraj	31.748	2.760
Moravskoslezský kraj	34.463	2.107
Olomoucký kraj	30.750	2.078
Pardubický kraj	29.824	2.373
Plzeňský kraj	33.083	1.954
Středočeský kraj	32.681	2.373
Zlínský kraj	28.853	2.382
Ústecký kraj	30.357	2.785
Average	32.554	2.316

7.5.1 Specifying the residential water demand function

The residential water demand function can be derived from solving the utility optimization problem of a consumer. Under the assumption of a weak separability of water with respect to other goods consumed, the Marshallian demand in water can be written as:

$$y = y^*(p, I, Z) \tag{7.1}$$

where y is the water consumption either per capita or per household, p and I denote the unit water price (representing both water supply and the sewage treatment services) and the representative household income, respectively. Z is a vector of exogenous variables assumed to influence water consumption (climate conditions, household and housing characteristics, etc.).

To estimate Equation (7.1), a wide variety of functional forms have been applied in the water demand literature, including linear forms, semi or double logarithm forms and more complex forms such as the Stone-Geary specification. The existing literature is however not very informative concerning the specification which should be preferred. Since the double-log model is the most common specification in the residential water demand literature, we have adopted this model in order to facilitate comparison to other studies. Furthermore, the specification implies that coefficient estimates are also elasticity estimates. With a double-log specification, the residential water demand function writes:

$$\ln(y) = \alpha \ln(p) + \beta \ln(I) + \gamma \ln(Z)' \tag{7.2}$$

and the coefficients α and β can be directly interpreted as the price and the income elasticities of the water demand. Specification tests for the functional form will be conducted in the empirical part but we don't expect the choice of the particular form to have a fundamental influence on the estimation of the parameters of interest.

Table 7.3: Estimation of the household water demand in Czech Republic

	CzechOLS	CzechGLS	CzechGLSiv
	b/se	b/se	b/se
$\ln$ Water price (in euros per m3)	-0.178***	-0.201***	-0.281**
	(0.06)	(0.07)	(0.12)
$\ln$ Household income (in euros per capita)	0.456***	0.161**	0.255***
	(0.06)	(0.07)	(0.08)
$\ln$ Share population between 15 and 65	3.711***	2.173***	1.835*
	(0.52)	(0.63)	(0.96)
$\ln$ Average of daily rainfall (mm per day)	-0.001	-0.054**	-0.049*
	(0.03)	(0.03)	(0.03)
Constant	-16.752***	-7.186***	-6.433*
	(2.20)	(2.65)	(3.79)
R-squared	0.706		
N. of obs.	84.000	84.000	84.000

7.5.2 Estimation methods

Let $i = \{1, .., I\}$ indexes Nuts3 and $t = \{1, .., T\}$ years. Our equation of interest becomes:

$$\ln(y_{it}) = \alpha \ln(p_{it}) + \beta \ln(I_{it}) + \gamma \ln(Z_{it})' + \epsilon_{it} \tag{7.3}$$

where ϵ_{it} is the usual random term. Two panel data estimators may be used namely the fixed effects (or dummy variable) model and the random effects (or error components) model. We propose to use these two estimators and to conduct some specification tests (Hausman test) to decide which is the most appropriate to our data.

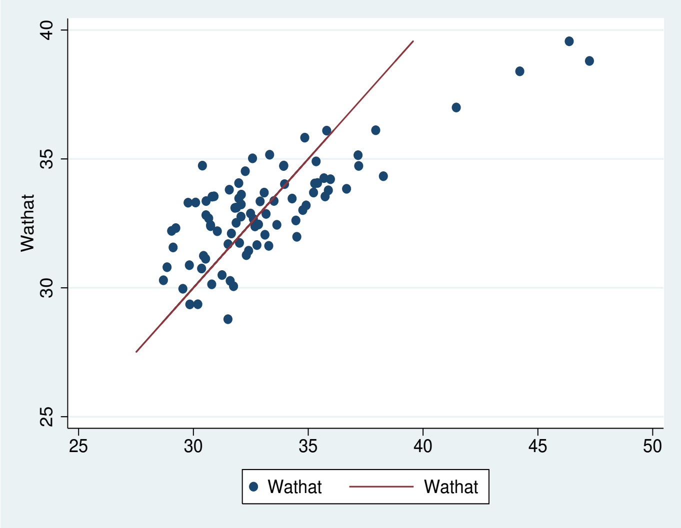
7.5.3 Results

We report here our estimate for the residential water demand function in Czech Republic, based on our Nuts3 dataset for Czech Republic (2006 to 2011). The first model estimated in Table 7.3 corresponds simple OLS whereas in the second model we estimate Equation (7.4) with a random parameter estimator. In the third model, we account for potential endogeneity of the price by using an instrumental variable approach. As instruments we have used the population density, the share of the population connected to the public network and the water loss rate in the distribution network.

Table 7.3 present the main significant variables explaining household water consumption in Czech Republic. The price elasticity are consistent across models, from -0.18 with the OLS to -0.28 with the GLSiv (always significant). Based on the GLSiv models, a 10% increase in water price results in a 2.8% decrease in short-run water consumption in Czech Republic. Water demand in Czech Republic is inelastic, i.e. the estimated price elasticity in absolute values is lower than one.

The income elasticity varies between 0.16 and 0.46 and the income elasticity is significantly different from zero with the three models. This suggests that there is an increasing relationship between water consumption and household income. The positive significant coefficient for income indicates that, based on the GLS model, a 10% increase in income will result in a 2.6% increase in water consumption.

Figure 7.1: Observed versus predicted household water consumption in Czech Republic



Climate conditions seem to play a significant role. An increase by 10% of average daily rainfall will reduce water consumption by 0.5% (GLSiv). Water consumption per capita appears to increase with the share of the population between 15 and 65.

A possible way to assess the validity of the model is to compare the water consumption predicted by the demand function to the observed water consumption, see Figure 7.1. For most of the municipalities the model performs quite well. The mean absolute percentage error is 5.0.

Water consumption may to be at least somehow persistent over time due to household habits or due to the time needed to adjust durable equipments (shower for instance). With panel or time-series data, one way to take into this time persistence characteristic of household water consumption is to introduce the lagged consumption as an additional independent variable in Equation (7.1). The dynamic specification of our equation of interest becomes then :

$$\ln(y) = \alpha \ln(p) + \beta \ln(I) + \gamma \ln(Z)' + \mu \ln(\mathrm{Lag}\, y) \tag{7.4}$$

where Lag y represents the lagged water consumption. From this specification is is then possible to derive the long-run price elasticity of the household water demand function which simply writes:

$$\epsilon_p^{LT} = \frac{\alpha}{1-\mu}. \tag{7.5}$$

We provide in Table 7.4 our estimates for the household water demand function where the lagged consumption has been introduced as an additional independent variable. With the CzechRepublicGLSivlag model, the long-term price elasticity is estimated to be -0.61 and is significantly different from zero at 1%.

Table 7.4: Estimation of the household water demand with lagged water consumption in Czech Republic

	CzechRepublicGLSlag	CzechRepublicGLSivlag
	b/se	b/se
$\ln$ Water price (in euros per m3)	-2.202**	-0.098**
	(1.03)	(0.05)
$\ln$ Household income (in euros per capita)	1.409	0.038
	(1.81)	(0.06)
$\ln$ Share population between 15 and 65	2.655	-0.004
	(12.79)	(0.38)
$\ln$ average of daily rainfall (mm per day)	-0.667	-0.009
	(0.58)	(0.02)
$\ln$ Lag of water consumption per capita	29.713***	0.840***
	(2.40)	(0.07)
Constant	-93.569*	0.283
	(56.04)	(1.64)
R-squared		
N. of obs.	70.000	70.000

Chapter 8

Denmark

8.1 Existing literature

Hansen (1996) estimate a residential water demand function on pooled time series data for the municipality of Copenhagen, Denmark. They report a price elasticity around -0.1. The dataset covers the period 1981-1990.

8.2 Urban water sector in Denmark

In Denmark, drinking-water production is almost exclusively based on groundwater which requires very little treatment and thus allows for a decentralised structure. This factor in combination with Danish traditions of self-organisation and user ownership has given rise to over 2,000 utilities supplying 5.5 million consumers (Sorensen 2010). However, two thirds of the water is supplied by around 80 municipal water utilities. The remaining utilities are consumer-owned, usually organised as cooperatives or partnerships (Sorensen 2010).

8.3 Data

Our panel data set consists of water service-level data on household water consumption, household water price, household's socioeconomic conditions income and on climate condition for years 2010-2012. Most of the data related to water come from the DANVA (Danish Association of Water and Wastewater utilities) benchmarking reports. We use a panel of water utilities made of respectively 56, 59 and 60 services for years 2010, 2011 and 2012 serving more than 50% of the population in Denmark. The water data have been combined with information at different administrative levels on income, weather, and household characteristics obtained mainly from the Statistics Denmark. Each water utility has been matched with one of the 99 Danish municipalities. For water utilities serving more than one municipalities, the water service has been affected to the municipality with the highest population size.

Water consumption data From the DANVA reports, we have the total annual quantity of water supplied to all users by each water utility. Additionally, we know the share of water which is used by households at county level. We use this information to compute the quantity of water delivered to households for each water utility. We have also in the DANVA reports the population served by each water service. Our dependent variable is then the water supplied to households per capita and per year.

Water price data For each water service and each year, we have the fixed charge and the marginal price for the water service. We compute then the average water price for a water consumption equal to 100 m3.

Household income We use the average income for families from Statistics Denmark from 1995 to 2010 (municipality level)

Other socioeconomic variables Other socio-economic variables from 2010 to 2012 come from Statistics Denmark.

Climate data All meteorological data come from the JRC climate database. Grid data (5km $\times$ 5km) on rainfalls, temperatures and evapotranspiration have been aggregated at regional level. We have historical data from 1990 to 2013.

8.4 Empirical analysis of residential water consumption

In this section, we provide a statistical analysis or residential water consumption and water price for Denmark.

Table 8.1: Household water consumption and price in Denmark

Year	Water consumption (m3 per capita per year)	Water price (euros per m3)
2010	44.557	2.832
2011	47.633	2.923
2012	46.713	3.107
Average	46.261	2.951

According to DANVA, household water consumption has fallen by 13.1% in the past 10 years. Table 8.1 gives the annual residential water consumption (m3 per capita and per year) and the water price (average water price, in euros m3) in Denmark from 2010 to 2012. In 2012, the average annual consumption per inhabitant amounted to 46.2 m3. Over the period 2010 to 2012, the average water price has increased from 2.9 euros per m3 to 3.1 euros per m3.

Table 8.2: Regional household water consumption and price in Denmark

Year	Water consumption (m3 per capita per year)	Water price (euros per m3)
Byen København	59.882	3.076
Fyn	44.450	2.766
Københavns omegn	38.560	3.302
Nordjylland	45.898	2.715
Nordsjælland	37.585	2.629
Sydjylland	40.031	2.658
Vest-og Sydsjæl	56.716	2.891
Vestjylland	40.879	2.722
Østjylland	38.897	2.828
Østsjælland	44.308	2.496
Average	44.557	2.832

Table 8.2 gives the annual residential water consumption (m3 per capita and per year) and the water price per region (Nuts 3) in 2010. As it can be seen, there are some differences across Nuts3, both in terms of water consumption and water prices. With more almost 60 m3 per capita per year, the water consumption is the higher in the Byen København Nuts3. On contrary, a low water consumption is reported in the Nordsjælland Nuts3 (37 m3 per capita per year).

8.5 Water demand function estimate

8.5.1 Specifying the residential water demand function

The residential water demand function can be derived from solving the utility optimization problem of a consumer. Under the assumption of a weak separability of water with respect to other goods consumed, the Marshallian demand in water can be written as:

$$y = y^*(p, I, Z) \tag{8.1}$$

where y is the water consumption either per capita or per household, p and I denote the unit water price (representing both water supply and the sewage treatment services) and the representative household income, respectively. Z is a vector of exogenous variables assumed to influence water consumption (climate conditions, household and housing characteristics, etc.).

To estimate Equation (8.1), a wide variety of functional forms have been applied in the water demand literature, including linear forms, semi or double logarithm forms and more complex forms such as the Stone-Geary specification. The existing literature is however not very informative concerning the specification which should be preferred. Since the double-log model is the most common specification in the residential water demand literature, we have adopted this model in order to facilitate comparison to other studies. Furthermore, the specification implies that coefficient estimates are also elasticity estimates. With a double-log specification, the residential water demand function writes:

$$\ln(y) = \alpha \ln(p) + \beta \ln(I) + \gamma \ln(Z)' \tag{8.2}$$

and the coefficients α and β can be directly interpreted as the price and the income elasticities of the water demand. Specification tests for the functional form will be conducted in the empirical part but we don't expect the choice of the particular form to have a fundamental influence on the estimation of the parameters of interest.

8.5.2 Estimation methods

Let $i = \{1, .., I\}$ indexes water services and $t = \{1, .., T\}$ years. Our equation of interest becomes:

$$\ln(y_{it}) = \alpha \ln(p_{it}) + \beta \ln(I_{it}) + \gamma \ln(Z_{it})' + \epsilon_{it} \tag{8.3}$$

where ϵ_{it} is the usual random term. Two panel data estimators may be used namely the fixed effects (or dummy variable) model and the random effects (or error components) model. We propose to use these two estimators and to conduct some specification tests (Hausman test) to decide which is the most appropriate to our data.

8.5.3 Results

We report here our estimate for the residential water demand function in Denmark, based on our Nuts3 dataset for Denmark (2010 to 2012). The first model estimated in Table 8.3 corresponds to simple OLS whereas in the second model we estimate Equation (8.4) with a random parameter estimator. In the third model, we account for potential endogeneity of the price by using an instrumental variable approach.

Table 8.3 present the main significant variables explaining household water consumption in Denmark. The price elasticity varies across models, from -0.33 with the GLS to -1.00 with the GLSiv (always significant). Based on the GLSiv model, a 10% increase in water price results in a 10% decrease in short-run water consumption in Denmark. Water demand in Denmark appears to be elastic, i.e. the estimated price elasticity in absolute values is greater than one. This result is not robust to the type of econometric model (OLS, GLS).

Table 8.3: Estimation of the household water demand in Denmark

	DenmarkOLS	DenmarkGLS	DenmarkGLSiv
	b/se	b/se	b/se
$\ln$ Water price (in euros per m3)	-0.543***	-0.327**	-1.003**
	(0.15)	(0.16)	(0.41)
$\ln$ Household income (in euros per capita)	-0.444***	-0.374*	-0.502**
	(0.16)	(0.21)	(0.20)
$\ln$ Share population below 9	0.282	0.617	0.662
	(0.52)	(0.68)	(0.64)
$\ln$ average of daily rainfall (mm per day)	-0.271***	-0.237***	-0.252***
	(0.10)	(0.09)	(0.10)
Constant	9.270***	6.842**	9.076***
	(2.69)	(3.46)	(3.30)
R-squared	0.114		
N. of obs.	175.000	175.000	175.000

The income elasticity varies between -0.37 and -0.50. The negative sign makes the interpretation of the coefficient in terms of income elasticity difficult.

Climate conditions play also a significant role. An increase by 10% of rainfall will imply a decrease in water consumption by 2.5% (GLSiv model).

A possible way to assess the validity of the model is to compare the water consumption predicted by the demand function to the observed water consumption, see Figure 8.1. For most of the municipalities the model performs quite well. The mean absolute percentage error is 23.5.

Water consumption may to be at least somehow persistent over time due to household habits or due to the time needed to adjust durable equipments (shower for instance). With panel or time-series data, one way to take into this time persistence characteristic of household water consumption is to introduce the lagged consumption as an additional independent variable in Equation (8.1). The dynamic specification of our equation of interest becomes then :

$$\ln(y) = \alpha \ln(p) + \beta \ln(I) + \gamma \ln(Z)' + \mu \ln(\text{Lag}\, y) \tag{8.4}$$

where Lag y represents the lagged water consumption. From this specification is is then possible to derive the long-run price elasticity of the household water demand function which simply writes:

$$\epsilon_p^{LT} = \frac{\alpha}{1-\mu}. \tag{8.5}$$

We provide in Table 8.4 our estimates for the household water demand function where the lagged consumption has been introduced as an additional independent variable. With the DenmarkGLSlag model, the long-term price elasticity is estimated to be -1.27 and is significantly different from zero at 1%. With the DenmarkGLSivlag model, the long-term price elasticity is estimated to be -1.67 and is significantly different from zero at 1%.

Figure 8.1: Observed versus predicted household water consumption in Denmark

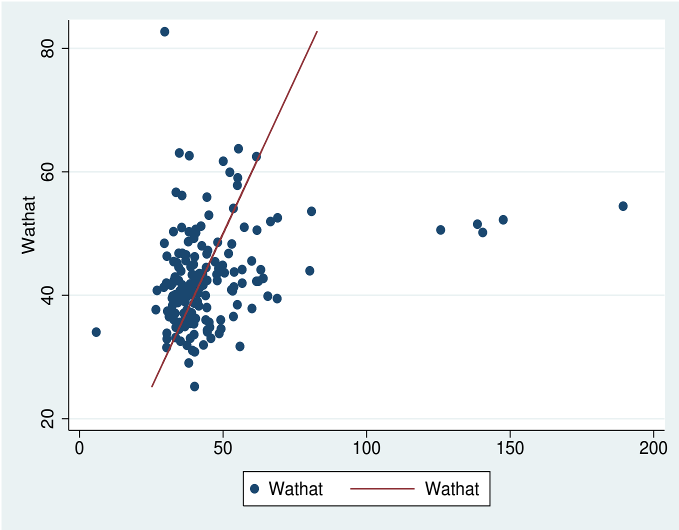


Table 8.4: Estimation of the household water demand with lagged water consumption in Denmark

	DenmarkGLSlag	DenmarkGLSivlag
	b/se	b/se
ln Water price (in euros per m3)	-0.649***	-0.895*
	(0.23)	(0.51)
ln Household income (in euros per capita)	-0.338*	-0.397*
	(0.20)	(0.23)
ln Share population below 9	-0.272	-0.257
	(0.65)	(0.66)
ln average of daily rainfall (mm per day)	-0.299***	-0.317***
	(0.11)	(0.11)
ln Lag of water consumption per capita	0.491***	0.465***
	(0.09)	(0.10)
Constant	8.286**	9.369**
	(3.58)	(4.11)
R-squared		
N. of obs.	104.000	104.000

Source: auto.dta

Chapter 9

Estonia

9.1 Existing literature

To our best knowledge, there doesn't exist any published article having estimated a residential water demand function in Estonia.

9.2 Urban water sector in Estonia

Estonia is a water rich country with 8600 m3 per capita available per year and a water exploitation index relatively low 4%. In the period 1990-2003, water abstraction (all types of use but excluding mining and cooling water) has dropped steadily from more than 400 hm3 in 1990 to a little bit less than 100 hm3 in 1991. In recent years (2004-2012), water abstraction has stayed around 100 million m3 (Antso and Hermet 2013). In 2011, a total of 35 hm3 of water was used for human consumption, 25.4 hm3 was used for manufacturing and 4 hm3 for agriculture.

Approximately 84% of the Estonian population is connected to the water supply and 75% to the sewerage systems (Peda 2012).[1] The Estonian water supply sector is highly fragmented. Of the 1235 waterworks operating in 2007, only 21 produced drinking water volumes greater than 1000 m3 per day, but these nevertheless supplied 61% of the Estonian population. At the same time, 1099 waterworks or 89% of the total produced less than 100 m3 a day.

In the mid-1990s, ownership of the former state owned water supply and wastewater facilities was transferred to local government bodies that became responsible for the provision of water and sewerage services. After the enactment of the Commercial Code in 1995, most of the municipal water utilities were transformed into public limited companies owned by local government. Today water services in 90% of Estonian cities (i.e. regional centres) are also still provided by fully publicly owned water companies. However, in the smaller towns and rural municipalities, there also exist other provision modes such as specialised water companies with mixed (public and private) ownership, production delegated to private companies or direct production by local government agencies (departments). The capital city of Tallinn is a different case since it sold the majority of shares in its water services company to international partners and later listed its shares on the stock exchange.

9.3 Data

Our panel data set consists of Nuts3-level (county) data on household water consumption, household water price, household's socioeconomic conditions income and on climate condition for years 2006-2012. Most of the data come from Statistics Estonia (the National Office of Statistics) and from the Estonian Association of Waterworks (EVEL). The data consist of aggregate data at Nuts3-level on water consumption per capita and water and sewerage prices. The data have been combined with information on income, weather, and household characteristics mainly from Statistics Estonia.

Water consumption data From Statistics Estonia we have the water used by households from 1991 to 2013 at Nuts3 level. Our dependent variable is the annual water consumption per capita connected to the public water supply network (in m3 per year per capita). We have assumed a connection rate equal to 87% (latest available figure).

[1] Most of the following paragraph is based on the Phd dissertation on the relationship between governance and performance in water services provision in Estonian municipalities by Peda (2012).

Water price data We rely on price data published on an annual basis by the Estonian Association of Waterworks (EVEL). As a price indicator, we use the average price paid by households for the water and wastewater services (in euros per m3). EVEL provides the price information at the water service level. We have then matched each service with the corresponding Nuts3.

Household income We use the average annual net salary per worker available from Statistics Estonia from from 1991 to 2012 at Nuts3.

Other socioeconomic variables Other socio-economic variables from 2006 to 2012 come from Statistics Estonia.

Climate data All meteorological data come from the JRC climate database. Grid data (5km $\times$ 5km) on rainfalls, temperatures and evapotranspiration have been aggregated at regional level. We have historical data from 1990 to 2013.

9.4 Empirical analysis of residential water consumption

In this section, we provide a statistical analysis of residential water consumption and water price for Estonia.

Table 9.1 gives the annual residential water consumption (m3 per capita and per year) and the water price (average water price, in euros m3) in Estonia from 1991 to 2012. In 2012, the average annual consumption per inhabitant amounted to 34.4 m3. There has been a decreasing trend in domestic water consumption from 1991 to 2012. Over the period 2007-2012, the average water price has increased from 1.6 euros per m3 to 2.5 euros per m3.

Table 9.2 gives the annual residential water consumption (m3 per capita and per year) and the water price per county (Nuts 3) in 2010. As it can be seen, there are some differences across regions, both in terms of water consumption and water prices. With almost 55 m3 per capita per year, the water consumption is the higher in the Ida-Viru Nuts3. On contrary, a low water consumption is reported in the Hiiu county (14 m3 per capita per year).

9.5 Water demand function estimate

9.5.1 Specifying the residential water demand function

The residential water demand function can be derived from solving the utility optimization problem of a consumer. Under the assumption of a weak separability of water with respect to other goods consumed, the Marshallian demand in water can be written as:

$$y = y^*(p, I, Z) \tag{9.1}$$

where y is the water consumption either per capita or per household, p and I denote the unit water price (representing both water supply and the sewage treatment services) and the representative household income, respectively. Z is a vector of exogenous variables assumed to influence water consumption (climate conditions, household and housing characteristics, etc.).

To estimate Equation (9.1), a wide variety of functional forms have been applied in the water demand literature, including linear forms, semi or double logarithm forms and more complex forms such as the Stone-Geary specification. The existing literature is however not very informative concerning the specification which

Table 9.1: Household water consumption and price in Estonia

Year	Water consumption (m3 per capita per year)	Water price (euros per m3)
1991	78.395	.
1992	77.146	.
1993	75.067	.
1994	71.558	.
1995	69.826	.
1996	69.769	.
1997	62.090	.
1998	50.355	.
1999	44.467	.
2000	41.367	.
2001	38.595	.
2002	36.885	.
2003	35.961	.
2004	34.635	.
2005	44.639	.
2006	35.690	.
2007	38.004	1.583
2008	40.520	1.618
2009	34.290	2.000
2010	33.808	2.154
2011	40.100	2.298
2012	34.359	2.503
Average	50.194	2.025

Table 9.2: Regional household water consumption and price in Estonia

Year	Water consumption (m3 per capita per year)	Water price (euros per m3)
Harju	38.526	2.361
Hiiu	14.054	2.615
Ida-Viru	54.277	1.671
Järva	24.770	2.280
Jõgeva	18.959	2.047
Lääne	27.376	2.196
Lääne-Viru	20.344	2.219
Pärnu	31.040	2.057
Põlva	19.794	1.707
Rapla	17.843	2.347
Saare	17.040	2.105
Tartu	27.144	1.974
Valga	27.724	2.546
Viljandi	27.146	2.015
Võru	24.001	2.153
Average	33.808	2.154

should be preferred. Since the double-log model is the most common specification in the residential water demand literature, we have adopted this model in order to facilitate comparison to other studies. Furthermore, the specification implies that coefficient estimates are also elasticity estimates. With a double-log specification, the residential water demand function writes:

$$\ln(y) = \alpha \ln(p) + \beta \ln(I) + \gamma \ln(Z)' \tag{9.2}$$

and the coefficients α and β can be directly interpreted as the price and the income elasticities of the water demand. Specification tests for the functional form will be conducted in the empirical part but we don't expect the choice of the particular form to have a fundamental influence on the estimation of the parameters of interest.

9.5.2 Estimation methods

Let $i = \{1, .., I\}$ indexes Nuts3 and $t = \{1, .., T\}$ years. Our equation of interest becomes:

$$\ln(y_{it}) = \alpha \ln(p_{it}) + \beta \ln(I_{it}) + \gamma \ln(Z_{it})' + \epsilon_{it} \tag{9.3}$$

where ϵ_{it} is the usual random term. Two panel data estimators may be used namely the fixed effects (or dummy variable) model and the random effects (or error components) model. We propose to use these two estimators and to conduct some specification tests (Hausman test) to decide which is the most appropriate to our data.

9.5.3 Results

We report here our estimate for the residential water demand function in Estonia, based on our Nuts3 dataset for Estonia (2006 to 2012). The first model estimated in Table 9.3 corresponds simple OLS whereas in the

Table 9.3: Estimation of the household water demand in Estonia

	EstoniaOLS	EstoniaGLS	EstoniaGLSiv
	b/se	b/se	b/se
$\ln$ Water price (in euros per m3)	-0.629***	-0.175	-0.598*
	(0.15)	(0.11)	(0.32)
$\ln$ Household income (in euros per capita)	1.702***	0.431*	0.936**
	(0.25)	(0.25)	(0.44)
$\ln$ Share population below 9	-0.993*	0.427	0.190
	(0.51)	(0.47)	(0.54)
$\ln$ Share population above 70	0.629	0.900**	1.297***
	(0.40)	(0.37)	(0.49)
$\ln$ number of summer days without rainfalls	0.347*	0.088	0.253
	(0.20)	(0.11)	(0.17)
Constant	-12.918***	1.724	-2.589
	(2.45)	(2.37)	(3.94)
R-squared	0.395		
N. of obs.	90.000	90.000	90.000

second model we estimate Equation (9.4) with a random parameter estimator. In the third model, we account for potential endogeneity of the price by using an instrumental variable approach.

Table 9.3 present the main significant variables explaining household water consumption in Estonia. The price elasticity varies across models, from -0.18 with the GLS to -0.63 with the OLS (not significant with GLS). Based on the GLSiv models, a 10% increase in water price results in a 6.0% decrease in short-run water consumption in Estonia. Water demand in Estonia is inelastic, i.e. the estimated price elasticity in absolute values is lower than one.

The income elasticity varies between 0.43 and 1.70 and the income elasticity is significantly different from zero with the three models. This suggests that there is an increasing relationship between water consumption and household income. The positive significant coefficient for income indicates that, based on the GLS model, a 10% increase in income will result in a 9.4% increase in water consumption.

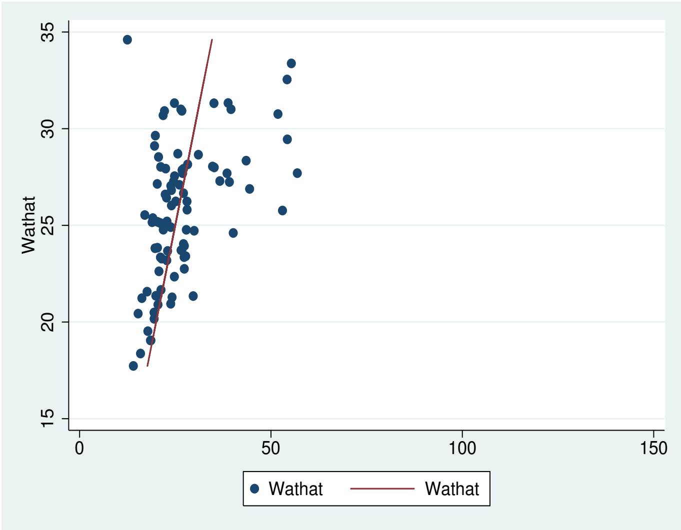
Climate conditions play also a significant role, together with some household characteristics. An increase of the number of days without rainfall by 10% will imply an increase in water consumption by 2.5% (OLS model). Older people tend to have a water consumption per capita higher than the rest of the population.

A possible way to assess the validity of the model is to compare the water consumption predicted by the demand function to the observed water consumption, see Figure 12.1. For most of the municipalities the model performs quite well. The mean absolute percentage error is 20.8.

Water consumption may to be at least somehow persistent over time due to household habits or due to the time needed to adjust durable equipments (shower for instance). With panel or time-series data, one way to take into this time persistence characteristic of household water consumption is to introduce the lagged consumption as an additional independent variable in Equation (9.1). The dynamic specification of our equation of interest becomes then :

$$\ln(y) = \alpha \ln(p) + \beta \ln(I) + \gamma \ln(Z)' + \mu \ln(\mathsf{Lag}\, y) \tag{9.4}$$

Figure 9.1: Observed versus predicted household water consumption in Estonia



where Lag y represents the lagged water consumption. From this specification is is then possible to derive the long-run price elasticity of the household water demand function which simply writes:

$$\epsilon_p^{LT} = \frac{\alpha}{1-\mu}. \tag{9.5}$$

We provide in Table 9.4 our estimates for the household water demand function where the lagged consumption has been introduced as an additional independent variable. With the EstoniaGLSlag model, the long-term price elasticity is estimated to be -0.70 and is significantly different from zero at 10%. With the EstoniaGLSivlag model, the long-term price elasticity is estimated to be -2.08 and is significantly different from zero at 1%.

Table 9.4: Estimation of the household water demand with lagged water consumption in Estonia

	EstoniaGLSlag	EstoniaGLSivlag
	b/se	b/se
$\ln$ Water price (in euros per m3)	-0.152	-0.901**
	(0.10)	(0.36)
$\ln$ Household income (in euros per capita)	0.398**	1.059***
	(0.19)	(0.39)
$\ln$ Share population below 9	-0.245	-0.494
	(0.31)	(0.42)
$\ln$ Share population above 70	0.289	0.450
	(0.26)	(0.35)
$\ln$ number of summer days without rainfalls	0.110	0.378*
	(0.12)	(0.20)
$\ln$ Lag of water consumption per capita	0.783***	0.568***
	(0.07)	(0.13)
Constant	-2.920*	-8.363**
	(1.74)	(3.32)
R-squared		
N. of obs.	90.000	90.000

Chapter 10

Finland

10.1 Existing literature

To our best knowledge, there is no previous estimate for a household water demand function in Finland. Rajala and Katko (2004) describe and analyse the trends and levels of water consumption, especially for households, in Finland. The study concentrates on the specific household water consumption (SHWC) of various types of housing, housing ownership, metering and billing arrangements. Based on 185 case studies in various parts of the country, the study shows that SHWC levels of about 120 l/capita/day, or even less, can be achieved, while maintaining a high standard of service levels. In addition to individual metering, proper management includes introduction of modern water fixtures and in-house piping, raising consumer awareness, and active follow-up. Explanations for declined consumption are quite site- and case specific. Simultaneously, decreasing consumption and the resulting fall in water sales are a challenge to water utilities.

10.2 Urban water sector in Finland

This paragraph is based on Heinoa, Takalaa, and Katkoa (2011). According to official statistics, more than 90% of the population in Finland is connected to public water distribution networks, and more than 80% are served by public sewer networks and urban wastewater treatment plants. Municipalities own most of the water services, but there are also numerous consumer-managed utilities, mostly cooperatives, especially in the rural areas. Approximately half a million people get their drinking water from private wells, and some 350.000 households rely on on-site sanitation

10.3 Data

Water consumption data The water volume distributed to residential water comes from the annual report published by the Finnish Water Utilities Association (FIWA)[1]. From these annual reports, we have extracted the total volume of water invoiced to residential consumers at water-service level for year 2011. These data have been matched with population by municipalities obtained from the national office of statistics in Finland (Statistics Finland). In addition, we have cross-checked water volume data using data obtained from the Finnish Institute of Environment (SYKE) at water-service level from 2000 to 2011. The average water consumption (based on 265 water services) is estimated to be 51.5 cubic meters per capita per year in 2011 (141 liters per day per capita).[2]

Water price data The water price for residential consumers comes also from the annual report published by the Finnish Water Utilities Association (FIWA). It includes the water and the sewerage services and is available at water service level. The unit price for an annual water consumption of 180 cubic meters is 4.67 euros per cubic meters. In some services, it reaches almost 9 euros per cubic meters.

Household income We use the annual average disposable household income at municipal-level obtained directly from Finland Statistics over the period 2000-2011. In 2011, the average disposable household income

[1]FIWA is the co-operation and member association of the Finnish water and wastewater utilities, established in 1956. FIWA's membership includes about 300 Finnish water utilities which cover about 90% of water services in Finland.

[2]The Helsinki water service indicates that customers consume an average of 158 litres of water per day (http://www.hsy.fi/en/waterservices/domestic_water_issues/Pages/water_consumption.aspx). Some variations in water consumption are observed among households. For instance, it is reported that 123 litres of water is consumed by each resident every day in detached houses, whereas in terraced houses the consumption is 149 litres per person per day.

at municipal-level is 33,391 euros per households.

Other socioeconomic variables We collected household socioeconomic characteristics at municipal-level from Finland Statistics (household size, population density, average age of population, etc.).

Climate data All meteorological data come from the JRC climate database. Grid data (5km $\times$ 5km) on rainfalls, temperatures and evapotranspiration have been aggregated at regional level. We have historical data from 1990 to 2013.

10.4 Empirical analysis of residential water consumption

In this section, we provide a statistical analysis or residential water consumption and water price for Finland.

Table 10.1: Household water consumption and price in Finland

Year	Water consumption (m3 per capita per year)	Water price (euros per m3)
2011	66.457	3.739

Table 10.1 gives the annual residential water consumption (m3 per capita and per year) and the water price (average water price, in euros m3) in Finland for year 2011. In 2011, the average annual consumption per inhabitant amounted to 66.5 m3. For the same year, the average water price was 3.74 euros per m3 .

Table 10.2 gives the annual residential water consumption (m3 per capita and per year) and the water price per Nuts3 in 2011. As it can be seen, there are some differences across regions, both in terms of water consumption and water prices. With 95.9 m3 per capita per year, the water consumption is the higher in the Uusimaa Nuts3 (Helsinki area). On contrary, a low water consumption is reported in the Etel$\ddot{a}$-Savo Nuts3 (40.8 m3 per capita per year).

10.5 Water demand function estimate

10.5.1 Specifying the residential water demand function

The residential water demand function can be derived from solving the utility optimization problem of a consumer. Under the assumption of a weak separability of water with respect to other goods consumed, the Marshallian demand in water can be written as:

$$y = y^*(p, I, Z) \tag{10.1}$$

where y is the water consumption either per capita or per household, p and I denote the unit water price (representing both water supply and the sewage treatment services) and the representative household income, respectively. Z is a vector of exogenous variables assumed to influence water consumption (climate conditions, household and housing characteristics, etc.).

To estimate Equation (10.1), a wide variety of functional forms have been applied in the water demand literature, including linear forms, semi or double logarithm forms and more complex forms such as the Stone-Geary specification. The existing literature is however not very informative concerning the specification which should be preferred. Since the double-log model is the most common specification in the residential water

Table 10.2: Regional household water consumption and price in Finland

Year	Water consumption (m3 per capita per year)	Water price (euros per m3)
Etelä-Karjala	52.004	3.728
Etelä-Pohjanmaa	53.776	4.185
Etelä-Savo	40.807	4.053
Itä-Uusimaa	59.990	3.812
Kainuu	52.240	3.505
Kanta-Häme	68.061	4.044
Keski-Pohjanmaa	45.454	3.300
Keski-Suomi	52.542	4.499
Kymenlaakso	46.400	3.848
Lappi	51.945	4.182
Pirkanmaa	59.499	3.761
Pohjanmaa	58.080	3.637
Pohjois-Karjala	49.163	3.760
Pohjois-Pohjanma	54.703	3.588
Pohjois-Savo	56.571	3.981
Päijät-Häme	59.577	3.850
Satakunta	59.279	3.655
Uusimaa	95.860	3.299
Varsinais-Suomi	64.226	4.128
Average	66.457	3.739

Table 10.3: Estimation of the household water demand in Finland

	finland
	b/se
Water price (in logs)	-0.278
	(0.19)
Household income (in logs)	0.555
	(0.44)
Number of persons per household (in logs)	-2.469***
	(0.56)
Average population age (in logs)	-1.882***
	(0.60)
$\ln$ average of daily rainfall (mm per day)	-0.993***
	(0.36)
Number of days without rain (in logs)	-0.238
	(0.69)
Constant	9.280
	(6.50)
R-squared	0.194
N. of obs.	139.000

Source: auto.dta

demand literature, we have adopted this model in order to facilitate comparison to other studies. Furthermore, the specification implies that coefficient estimates are also elasticity estimates. With a double-log specification, the residential water demand function writes:

$$\ln(y) = \alpha \ln(p) + \beta \ln(I) + \gamma \ln(Z)' \tag{10.2}$$

and the coefficients α and β can be directly interpreted as the price and the income elasticities of the water demand. Specification tests for the functional form will be conducted in the empirical part but we don't expect the choice of the particular form to have a fundamental influence on the estimation of the parameters of interest.

10.5.2 Estimation methods

Let $i = \{1, .., I\}$ indexes water service. Our equation of interest becomes:

$$\ln(y_i) = \alpha \ln(p_i) + \beta \ln(I_i) + \gamma \ln(Z_i)' + \epsilon_i \tag{10.3}$$

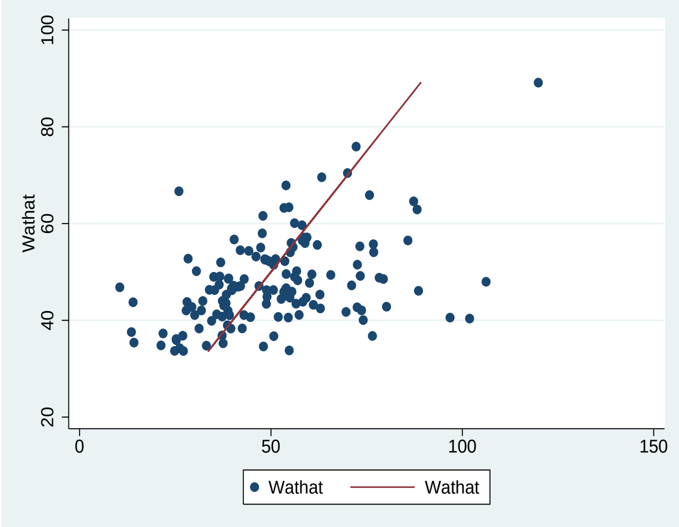
where ϵ_i is the usual random term.

10.5.3 Results

We report here our estimate for the residential water demand function in Finland, based on CS dataset made of municipal-level observations in 2011. We use a OLS estimator.

In Table 10.3, we report our estimates of the household water demand function for Finland using an OLS approach. Price and income are not significant, although the estimated coefficients exhibit the expected sign.

Figure 10.1: Observed versus predicted household water consumption in Finland



Although not significantly different from zero, the price and the income elasticities are -0.278 and 0.555 respectively. We notice a significant family size effect. The water consumption per capita tends to be smaller in larger households. Age of the population is also a significant determinant, older person having a lower water consumption per capita. Lastly, water consumption per capita is impacted by climate conditions. An increase in daily rainfalls by 10% will result in a decrease by 9.9% of residential water consumption. This may be related to rainwater harvesting or outdoor water use.

To assess the validity of the model, we have compared the water consumption predicted by the demand function to the observed water consumption, see Figure 10.1. For most of the municipalities the model performs relatively well with a mean absolute relative prediction error equal to 26.20%.

Chapter 11

France

11.1 Existing literature

There are some studies having estimated a household water demand function in France. The existing studies have however been conducted at the local scale (French region). We provide here the first estimate for France using a national sample of French municipalities. Compared to the existing studies which have relied on small sample of municipality-level data (<300), our unbalanced panel dataset of municipalities varies from a little bit more than 9000 to 13000 observations, depending upon the year.

Nauges and Thomas (2000) have estimated a water demand function on a panel of French municipalities. The impact of average household income, housing, and system features such as metering is investigated both on municipal consumption and price. They find evidence that the water price depends on municipality's characteristics, causing endogeneity of price in the demand equation. Estimated price and income elasticities are significant and close to previous household level studies.

Nauges and Reynaud (2001) use municipality-level panel data to estimate the residential water demand function in two French departments (Moselle and Gironde). Socio-economic and meteorologic variables have thus been introduced in the demand model, in addition to water consumption and price of water, in the demand function. The results demonstrate a statistically significant price-elasticity in the two departments, estimated at -0.22 and -0.08. The income elasticity is significant in one of the two departments (Moselle), and is evaluated at 0.01.

Nauges and Thomas (2003) have proposed a dynamic model of water consumption. Their estimation is conducted on a sample of French communities observed during the 1988-93 period. They find a long-run (on a six-year period) price elasticity equal to -0.40 higher, in absolute value, than the short-run price elasticity -0.26.

Rinaudo, Neverre, and Montginoul (2012) estimate the residential water demand on a cross section dataset of 300 municipalities in SouthWest of France (Languedoc Roussillon region). They report a price elasticity equal to -0.18 and an income elasticity equal to 0.42, both being significant at 1 percent.

11.2 Urban water sector in France

In France, all water and sanitation services fall within the responsibility of municipal authorities. The municipalities are free to manage the water services by themselves (through a local, public water authority) or to delegate their operation to a private company. Whatever the method chosen, the public authority remains responsible for the quality, smooth operation and sustainability of its service.

In France 36,600 municipal authorities and 4,500 intermunicipal bodies thus manage more than 31,000 public collective sanitation or water services.

11.3 Data

Our panel data set consists of municipality-level data on household water consumption, household water price, household's socioeconomic conditions income and on climate condition for years 2008-2011. Most of data related to water come from the French observatory on public water and sanitation services (SISPEA) initiated in November 2009 by the French National Agency for Water and Aquatic Environments (Onema). Our unbalanced panel dataset of municipalities varies from a little bit more than 9000 to 13000 observations, depending upon the year. The observatory is backed up by a national database that brings together information on the performance of public water and sanitation services. Data collected concern the features of the service (management method, type of water resources, billing details, pricing terms, etc.) and offer a technical and economic description (economic indicators, number of inhabitants supplied with drinking water, connected to a wastewater collection system or non-collective sanitation system, etc.)

Water consumption data We rely on municipal data from the SISPEA observatory. We have the annual volume of water sold to households for each municipality in France for year 2008-2011. To get the annual household water consumption per capita, we have divided this volume by the population connected to the public network in each municipality. The household water consumption in then measure in m3 of water sold to household per capita and per year.

Water price data We rely on municipal data from the SISPEA observatory. As a price indicator, we use the average price paid by households for the drinking water service (in euro m3 including VAT). According to SISPEA, in 2009 the average price in France France 1.90 euros per m3, which translates to an annual bill of 228 euros on the basis of annual consumption of 120 m3.

Household income We use the average taxable income (in euros per taxable income) obtained directly from the French National Institute of Statistics and Economic Studies (INSEE) at municipal-level for years 2008-2011

Other socioeconomic variables Other socio-economic variables for 2008-2011 comes from the Institut National de la Statistique et des Etudes Economiques (INSEE). Some variables describing housing characteristics are obtained from the French census.

Climate data All meteorological data come from the JRC climate database. Grid data (5km $\times$ 5km) on rainfalls, temperatures and evapotranspiration have been aggregated at regional level. We have historical data from 1990 to 2013.

11.4 Empirical analysis of residential water consumption

In this section, we provide a statistical analysis or residential water consumption and water price for France.

Table 11.1: Household water consumption and price in France

Year	Water consumption (m3 per capita per year)	Water price (euros per m3)
2008	63.126	2.118
2009	54.275	2.155
2010	49.513	2.022
2011	49.071	2.064
Average	53.210	2.084

Table 11.1 gives the annual residential water consumption (m3 per capita and per year) and the water price (retail water price for cold water in euros per m3) in France from 2008 to 2011. In 2009, the average annual consumption per inhabitant amounted to 54.3 m3. There has been a decreasing trend in domestic water consumption which started some ten years ago. There are several reasons to explain this continuous fall including increases in the price of water, eco-citizen behaviour and technical progress and technological innovation reducing water consumption of household appliances. There are strong geographic disparities in

particular due to climate conditions, the strong presence of individual homes and gardens or high local tourist activity. Minimum average consumption is observed in Loire Atlantique with 31 m3 per inhabitant per year whereas the maximum consumption is found on the Reunion Island with 91.3 m3 per inhabitant per year. From 2008 to 2011, the average water price has not significantly changed.

Table 11.2: Regional household water consumption and price in France

Year	Water consumption (m3 per capita per year)	Water price (euros per m3)
11	52.006	1.997
21	51.909	1.678
22	44.795	2.073
23	51.041	2.242
24	62.512	1.910
25	60.094	2.139
26	62.983	2.195
31	38.096	1.975
41	55.568	2.014
42	55.191	1.926
43	57.275	2.002
52	64.243	2.178
53	61.315	2.429
54	46.979	2.022
72	57.058	2.114
73	55.179	1.881
74	50.494	2.539
82	55.234	2.055
83	57.699	2.197
91	71.119	1.646
93	66.242	1.818
Average	49.513	2.022

Table 11.2 gives the annual residential water consumption (m3 per capita and per year) and the water price (retail water price for cold water in euros per m3) per region (Nuts 2) in 2010. As it can be seen, there are some differences across regions, both in terms of water consumption and water prices.

11.5 Water demand function estimate

11.5.1 Specifying the residential water demand function

The residential water demand function can be derived from solving the utility optimization problem of a consumer. Under the assumption of a weak separability of water with respect to other goods consumed, the Marshallian demand in water can be written as:

$$y = y^*(p, I, Z) \tag{11.1}$$

where y is the water consumption either per capita or per household, p and I denote the unit water price (representing both water supply and the sewage treatment services) and the representative household income, respectively. Z is a vector of exogenous variables assumed to influence water consumption (climate conditions, household and housing characteristics, etc.).

To estimate Equation (11.1), a wide variety of functional forms have been applied in the water demand literature, including linear forms, semi or double logarithm forms and more complex forms such as the Stone-Geary specification. The existing literature is however not very informative concerning the specification which should be preferred. Since the double-log model is the most common specification in the residential water demand literature, we have adopted this model in order to facilitate comparison to other studies. Furthermore, the specification implies that coefficient estimates are also elasticity estimates. With a double-log specification, the residential water demand function writes:

$$\ln(y) = \alpha \ln(p) + \beta \ln(I) + \gamma \ln(Z)' \tag{11.2}$$

and the coefficients α and β can be directly interpreted as the price and the income elasticities of the water demand. Specification tests for the functional form will be conducted in the empirical part but we don't expect the choice of the particular form to have a fundamental influence on the estimation of the parameters of interest.

11.5.2 Estimation methods

Let $i = \{1, .., I\}$ indexes municipalities (between 9000 and 13000 depending upon the year) and $t = \{1, .., T\}$ years. Our equation of interest becomes:

$$\ln(y_{it}) = \alpha \ln(p_{it}) + \beta \ln(I_{it}) + \gamma \ln(Z_{it})' + \epsilon_{it} \tag{11.3}$$

where ϵ_{it} is the usual random term. Two panel data estimators may be used namely the fixed effects (or dummy variable) model and the random effects (or error components) model. We propose to use these two estimators and to conduct some specification tests (Hausman test) to decide which is the most appropriate to our data.

11.5.3 Results

We report here our estimate for the residential water demand function in France, based on our municipal dataset for France (2008 to 2011). The first model estimated in Table 11.3 corresponds simple OLS whereas in the second model we estimate Equation (11.4) with a random parameter estimator. In the third model, we account for potential endogeneity of the price by using an instrumental variable approach.

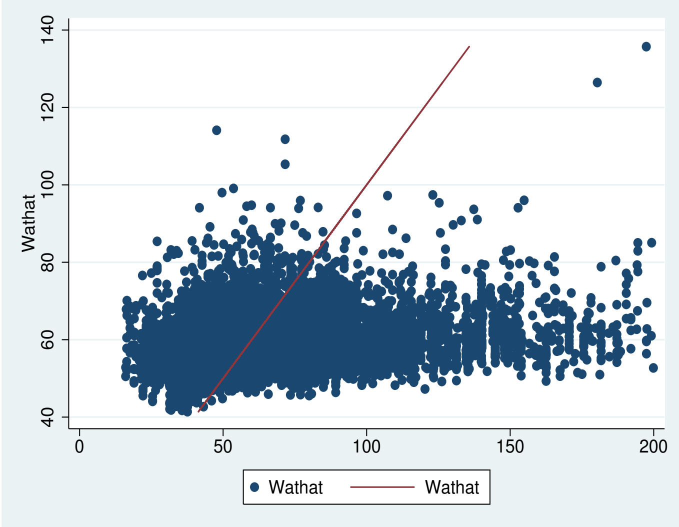
Table 11.3 present the main significant variables explaining household water consumption in France. The price elasticity is estimated to be -0.05 with the GLS model, and the estimated coefficient is significantly different from zero. The price elasticity varies across models, from -0.10 with the OLS to -0.43 with the instrumental variable approach (not significant in this last case). Based on the GLS model, a 10% increase in water price results in a 0.5% decrease in short-run water consumption in France. Water demand in France is inelastic, i.e. the estimated price elasticity in absolute values is lower than one.

The income elasticity is also quite consistent with the two models. It varies between 0.07 and 0.26 and the income elasticity is significantly different from zero with the three models. This suggests that there is an increasing relationship between water consumption and household income. The positive significant coefficient for income indicates that, based on the GLS model, a 10% increase in income will result in a 1.3% increase in water consumption.

Table 11.3: Estimation of the household water demand in France

	FranceOLS	FranceGLS	FranceGLSiv
	b/se	b/se	b/se
$\ln$ Water price (in euros per m3)	-0.099***	-0.049***	-0.431
	(0.01)	(0.01)	(0.64)
$\ln$ Household income (in euros per capita)	0.065***	0.133***	0.256**
	(0.01)	(0.01)	(0.12)
$\ln$ Population density	-0.056***	-0.058***	-0.063***
	(0.00)	(0.00)	(0.01)
$\ln$ number of summer days without rainfalls	0.058***	0.098***	0.100***
	(0.01)	(0.01)	(0.02)
$\ln$ average of daily rainfall in summer (mm per day)	-0.063***	-0.047***	-0.018
	(0.01)	(0.01)	(0.02)
Share of permanent housings	-0.467***	-0.460***	-0.506***
	(0.01)	(0.02)	(0.14)
Share of house	-0.348***	-0.354***	-0.245**
	(0.02)	(0.02)	(0.11)
Constant	4.316***	3.536***	2.572***
	(0.07)	(0.09)	(0.62)
R-squared	0.087		
N. of obs.	56041.000	56040.000	49110.000

Figure 11.1: Observed versus predicted household water consumption in France



Some characteristics of the population matters for explaining residential water consumption in France. In particular, the water consumption per capita will by higher in areas with a high population density. Climate conditions play also a significant role, together with the housing characteristics.

A possible way to assess the validity of the model is to compare the water consumption predicted by the demand function to the observed water consumption, see Figure 11.1. For most of the municipalities the model performs quite well. The mean absolute percentage error is 25.8.

Water consumption may to be at least somehow persistent over time due to household habits or due to the time needed to adjust durable equipments (shower for instance). With panel or time-series data, one way to take into this time persistence characteristic of household water consumption is to introduce the lagged consumption as an additional independent variable in Equation (11.2). The dynamic specification of our equation of interest becomes then :

$$\ln(y) = \alpha \ln(p) + \beta \ln(I) + \gamma \ln(Z)' + \mu \ln(\text{Lag}\, y) \tag{11.4}$$

where Lag y represents the lagged water consumption. From this specification is is then possible to derive the long-run price elasticity of the household water demand function which simply writes:

$$\epsilon_p^{LT} = \frac{\alpha}{1-\mu}. \tag{11.5}$$

We provide in Table 11.4 our estimates for the household water demand function where the lagged consumption has been introduced as an additional independent variable. With the FranceGLSlag model, the long-term price elasticity is estimated to be -0.06 significantly different from zero at 1%. With the FranceGLSivlag model, the long-term price elasticity is estimated to be 4.2.

Table 11.4: Estimation of the household water demand with lagged water consumption in France

	FranceGLSlag	FranceGLSivlag
	b/se	b/se
$\ln$ Water price (in euros per m3)	-0.022***	0.985***
	(0.01)	(0.06)
$\ln$ Household income (in euros per capita)	0.016*	0.063***
	(0.01)	(0.01)
$\ln$ Population density	-0.026***	-0.011***
	(0.00)	(0.00)
$\ln$ number of summer days without rainfalls	-0.040***	0.047***
	(0.01)	(0.01)
$\ln$ average of daily rainfall in summer (mm per day)	-0.070***	-0.044***
	(0.01)	(0.01)
Share of permanent housings	-0.207***	0.125***
	(0.02)	(0.02)
Share of house	-0.139***	-0.145***
	(0.02)	(0.02)
$\ln$ Lag of water consumption per capita	0.532***	0.766***
	(0.00)	(0.01)
Constant	2.326***	-0.370**
	(0.09)	(0.15)
R-squared		
N. of obs.	32909.000	29606.000

Chapter 12

Germany

12.1 Existing literature

Frondel and Messner (2008) use a household panel in the municipal area of Leipzig, Germany, covering the years 1998 through 2001. Based on an endogenous switching regression model, they provide an estimate of the water price elasticity of the residential water demand. They show that consumers' response to prices is significant but only for consumers who at least have a rough idea about average water prices. Depending upon the model they consider, the price elasticity varies between -0.35 (OLS) and -0.49 (switching regression). Income is found to be a significant driver of residential water consumption, the income elasticity varying around 0.3.

Schleich and Hillenbrand (2009) have estimated a residential water demand function for about 600 water supply areas in Germany. Besides prices, income and household size, they consider the effects of population age, the share of wells, housing patterns, precipitation and temperature. They use an instrumental variable (IV) approach but find no evidence that prices are endogenous. Their estimation results suggest that the price elasticity of water demand in Germany is around -0.24. The income elasticity is positive, decreases with higher income levels and is at least three times higher in the new federal states than in the old federal states. Current differences in prices and income levels explain about one third of the gap in residential water use between the two regions. Household size and the share of wells have a negative impact on per capita water demand, and water use increases with age. Finally, the findings provide some evidence that rainfall patterns rather than total rainfall affect water consumption, while temperature appears to have no impact at all.

Müller (2012) have estimated a residential water demand function based on a cross-sectional dataset of counties in Germany. Depending upon the model they consider, the price elasticity varies between -0.26 (OLS) and -0.46 (IV). Income effects do not seem to be important in their study (income elasticity varies between -0.01 and 0.04).

12.2 Urban water sector in Germany

With available water resources of 188 billion m3 Germany is a water-rich country. In 2007 around 32.0 billion m3 of water was abstracted from groundwater and surface waters by industry and for supplying private households (BMU 2011). This is less than 20% of the potential water supply. With 19.7 billion m3 abstracted for cooling water for energy production, thermal power plants represents the largest share of abstracted water followed by other industrial purposes (7.2 billion m3) and drinking water for populations (5.1 billion m3). According to BMU (2011), water withdrawals for agriculture only plays a minor role in Germany.

In Germany, water supply is a prerogative of the public authorities. Responsibility lies with the municipalities, which can use a range of organisational and legal forms to comply with this duty (in 2011 more than 6200 water services in Germany). They can supply water themselves, can establish water and special-purpose associations within the framework of municipal cooperation or can commission a third party with the task while retaining municipal supervision. The number of privately organised companies has increased in recent years, and they now represent more than 40% of water companies. They supply over 60% of the water volume. In contrast, almost all sewage companies in Germany are public, since German water law considers the treatment of waste water to be a sovereign task (Schleich and Hillenbrand 2009).

12.3 Data

Our panel data set consists of regional-level (Nuts3 or *Kreise* in German) data on household water consumption, household water price, household's socioeconomic conditions income and on climate condition for years 2004, 2010 and 2010. Most of the data come from Regionalstatistik (http://www.regionalstatistik.de/), the official portal of Federal and State Statistical Offices for municipal-, county-, and regional-level data.

Water consumption data We rely on regional data from the National Statistical Office. We have the annual volume of water distributed to households per region (Nuts3) in Germany for year 1998, 2001, 2004, 2007, 2010. To get the annual household water consumption per capita, we have divided this volume by the population connected to the public network in each region.

Water price data We use lander-level (nuts2) unit water price (water and wastewater service in euros per m3) available from 2004 to 2011 from the German Statistical Office.

Household income We use the annual disposable income per capita (at regional level) obtained directly from the German Statistical Office over the period 2004 to 2011.

Other socioeconomic variables We have collected regional household socioeconomic characteristics using the German Statistical Office (median population age, population density, etc.).

Climate data All meteorological data come from the JRC climate database. Grid data (5km $\times$ 5km) on rainfalls, temperatures and evapotranspiration have been aggregated at regional level. We have historical data from 1990 to 2013.

12.4 Empirical analysis of residential water consumption

In this section, we provide a statistical analysis or residential water consumption and water price for Germany.

Table 12.1: Household water consumption and price in Germany

Year	Water consumption (m3 per capita per year)	Water price (euros per m3)
2004	44.666	3.632
2007	43.938	3.730
2010	43.682	3.862
Average	44.635	3.741

Residential water consumption in Germany has changed substantially over the last two decades. From 1991 to 2004 it has decreased by about 13% to reach approximatively 45 m3 per capita and per year (Schleich and Hillenbrand 2009). Table 12.1 gives the annual residential water consumption (m3 per capita and per year) and the water price (retail water price for cold water in euros per m3) in Germany from 2004 to 2010. The annual residential water consumption per capita has decreased from 44.6 m3 per capita in 2004 to reach 43.7 m3 per capita in 2.012. Over the same period, the water price has increased from 3.6 euros per m3 in 2004 to 3.9 euros per m3 in 2012.

Table 12.2 gives the annual residential water consumption (m3 per capita and per year) and the water price (retail water price for cold water in euros per m3) by lander (Nuts 2) in 2010. As it can be seen, there are some differences across landers, both in terms of water consumption and water prices.

Table 12.2: Regional household water consumption and price in Germany

Year	Water consumption (m3 per capita per year)	Water price (euros per m3)
Schleswig-Holstein	49.350	3.450
Niedersachsen	45.856	3.500
Bremen	43.599	4.960
Nordrhein-Westfalen	48.451	4.090
Hessen	43.616	4.650
Rheinland-Pfalz	43.882	3.580
Baden-WUrttemberg	41.885	4.160
Bayern	46.637	3.190
Saarland	39.099	5.070
Brandenburg	37.909	4.870
Mecklenburg-Vorpommern	39.478	4.280
Sachsen	29.441	4.410
Sachsen-Anhalt	33.126	4.760
Thuringen	31.660	4.170
Average	43.675	3.862

12.5 Water demand function estimate

12.5.1 Specifying the residential water demand function

The residential water demand function can be derived from solving the utility optimization problem of a consumer. Under the assumption of a weak separability of water with respect to other goods consumed, the Marshallian demand in water can be written as:

$$y = y^*(p, I, Z) \tag{12.1}$$

where y is the water consumption either per capita or per household, p and I denote the unit water price (representing both water supply and the sewage treatment services) and the representative household income, respectively. Z is a vector of exogenous variables assumed to influence water consumption (climate conditions, household and housing characteristics, etc.).

To estimate Equation (12.1), a wide variety of functional forms have been applied in the water demand literature, including linear forms, semi or double logarithm forms and more complex forms such as the Stone-Geary specification. The existing literature is however not very informative concerning the specification which should be preferred. Since the double-log model is the most common specification in the residential water demand literature, we have adopted this model in order to facilitate comparison to other studies. Furthermore, the specification implies that coefficient estimates are also elasticity estimates. With a double-log specification, the residential water demand function writes:

$$\ln(y) = \alpha \ln(p) + \beta \ln(I) + \gamma \ln(Z)' \tag{12.2}$$

and the coefficients α and β can be directly interpreted as the price and the income elasticities of the water demand. Specification tests for the functional form will be conducted in the empirical part but we don't expect the choice of the particular form to have a fundamental influence on the estimation of the parameters of interest.

Table 12.3: Estimation of the household water demand in Germany

	GermanyOLS	GermanyGLS	GermanyGLSIV
	b/se	b/se	b/se
$\ln$ Water price (in euros per m3)	-0.433***	-0.452***	-0.439***
	(0.02)	(0.03)	(0.08)
$\ln$ Household income (in euros per capita)	0.135***	0.084***	0.133***
	(0.03)	(0.03)	(0.04)
Share of female in total population	0.082	1.103	0.067
	(0.64)	(0.92)	(0.66)
share of population between 15 and 65	-1.632***	-0.076	-1.627***
	(0.22)	(0.20)	(0.23)
$\ln$ Population density	0.068***	0.059***	0.068***
	(0.00)	(0.01)	(0.00)
$\ln$ average of daily rainfall (mm per day)	0.030	-0.001	0.030
	(0.02)	(0.01)	(0.02)
Constant	3.643***	2.697***	3.674***
	(0.49)	(0.61)	(0.62)
R-squared	0.454		
N. of obs.	1110.000	1110.000	1110.000

Source: auto.dta

12.5.2 Estimation methods

Let $i = \{1, .., I\}$ indexes regions (373 Nuts3 in Germany) and $t = \{1, .., T\}$ years. Our equation of interest becomes:

$$\ln(y_{it}) = \alpha \ln(p_{it}) + \beta \ln(I_{it}) + \gamma \ln(Z_{it})' + \epsilon_{it} \tag{12.3}$$

where ϵ_{it} is the usual random term. Two panel data estimators may be used namely the fixed effects (or dummy variable) model and the random effects (or error components) model. We propose to use these two estimators and to conduct some specification tests (Hausman test) to decide which is the most appropriate to our data.

12.5.3 Results

We report here our estimate for the residential water demand function in Germany, based on our regional dataset for Germany (2004, 2007, 2010). The first model estimated in Table 12.3 corresponds simple OLS whereas in the second model we estimate Equation (12.3) with a random parameter estimator. In the third model, we account for potential endogeneity of the price by using an instrumental variable approach.

Table 12.3 present the main significant variables explaining household water consumption in Germany. The short-term price elasticity is estimated to be -0.44, and the estimated coefficient is significantly different from zero. The price elasticity is highly consistent across models, varying from -0.43 to -0.45. This indicates that a 10% increase in water price results in a 4.4% decrease in short-run water consumption in Germany. Water demand in Germany is inelastic, i.e. the estimated price elasticity in absolute values is lower than one.

The income elasticity is also quite consistent with the two models. It varies between 0.08 and 0.14 and

Figure 12.1: Observed versus predicted household water consumption in Germany

the income elasticity is significantly different from zero. This suggests that there is an increasing relationship between water consumption and household income. The positive significant coefficient for income indicates that a 10% increase in income will result in a 0.8% to 1.3% increase in water consumption.

Some characteristics of the population matter for explaining residential water consumption in Germany. In particular, the water consumption per capita will by higher in areas with a high population density. Climate conditions play only a very minor role.

A possible way to assess the validity of the model is to compare the water consumption predicted by the demand function to the observed water consumption, see Figure 12.1. For most of the regions the model performs quite well. The mean absolute percentage error is 9.1.

Water consumption may to be at least somehow persistent over time due to household habits or due to the time needed to adjust durable equipments (shower for instance). With panel or time-series data, one way to take into this time persistence characteristic of household water consumption is to introduce the lagged consumption as an additional independent variable in Equation (12.1). The dynamic specification of our equation of interest becomes then :

$$\ln(y) = \alpha \ln(p) + \beta \ln(I) + \gamma \ln(Z)' + \mu \ln(\text{Lag}\, y) \tag{12.4}$$

where Lag y represents the lagged water consumption. From this specification is is then possible to derive the long-run price elasticity of the household water demand function which simply writes:

$$\epsilon_p^{LT} = \frac{\alpha}{1-\mu}. \tag{12.5}$$

We provide in Table 12.4 our estimates for the household water demand function where the lagged consumption has been introduced as an additional independent variable. With the GermanyGLSlag model, the long-term price elasticity is estimated to be -0.51 and is significantly different from zero at 1%. With the GermanyGLSivlag model, the long-term price elasticity is estimated to be 2.0 but not significantly different from 0.

Table 12.4: Estimation of the household water demand with lagged water consumption in Germany

	GermanyGLSlag	GermanyGLSivlag
	b/se	b/se
$\ln$ Water price (in euros per m3)	-0.090***	0.138**
	(0.01)	(0.06)
$\ln$ Household income (in euros per capita)	0.007	0.048**
	(0.02)	(0.02)
Share of female in total population	0.323	0.823**
	(0.33)	(0.39)
share of population between 15 and 65	-0.010	0.065
	(0.12)	(0.13)
$\ln$ Population density	0.008***	-0.005
	(0.00)	(0.00)
$\ln$ average of daily rainfall (mm per day)	0.001	0.002
	(0.01)	(0.01)
$\ln$ Lag of water consumption per capita	0.822***	0.931***
	(0.01)	(0.03)
Constant	0.512**	-0.832*
	(0.26)	(0.43)
R-squared		
N. of obs.	1101.000	1101.000

Chapter 13

Greece

13.1 Existing literature

Athanasiadis, Mentes, Mitkas, and Mylopoulos (2005) have estimated a household water demand function on a sample of 1356 households in the urban area of Thessaloniki, Greece. there analys is based on 17 municipalities and it covers the period January 1994 until the first 4 months of 2000 (19 time-series observations in total). They report a price elasticity equal to -0.34. The income elasticity is found to be 0.35.

Bithas and Chrysostomos (2006) examines domestic water use in the greater Athens area. Their study is based on annual aggregated time series on residential water demand for the metropolitan Athens area and water prices obtained from the Athens Water Company for the period 1981-1999. They report a price elasticity equal to -0.10. The income elasticity is found to be 0.72.

Vagiona and Mylopoulos (2009) have estimated a water demand function on a sample of 100 households In the city of Volos, Greece. They use 3-month period water consumption records from years 1997 to 2005. They report a price elasticity equal to -0.96.

13.2 Urban water sector in Greece

This paragraph relies on Koundouri, Papandreou, Remoundou, and Kountouris (2014). In Greece water supply is considered as a public service and it is mainly the municipalities which are responsible for water supply, waste water collection, treatment and disposal. In the largest cities of the country (Athens and Thessaloniki), some owned companies (non profit making corporations) own and operate the treatment plants. In the other cities of more than 10,000 inhabitants water supply is managed by municipal companies - operating as private enterprises DEYA (Municipal Enterprise for Water Supply and Sewerage) but owned by the municipalities. The pricing policy is determined by each DEYA on the basis of their cost and is approved by the Municipal Council.

13.3 Data

We work at the municipal unit level which corresponds to a subdivision of municipalities in Greece.[1] Our data related to water come from the river basin district management plans in Greece.[2] The data have been combined with information on household's income, climate conditions, and household characteristics mainly from the National Statistical Office of Greece.

Water consumption data We use data for five river basin districts for which relevant data could be extracted form the river basin district management plans: Western Sterea Ellada (GR04), Epirus (GR05), Thessaly (GR08), East Macedonia (GR11) and Thrace (GR12). According to the last figure from the Hellenic Statistical authority, the total water use by household for these 5 river basin district has represented 262 million cubic meters. This is around 30% of the total water use by household in Greece (excluding the river districts of Crete and of Aegean Islands for which no data is available). We have the population served and the volume of water consumed by households (excluding network losses) for 114 municipal units belonging to these five river basin districts in 2010 (all municipal units in GR11 and GR12 and the most important in terms of population for GR04, GR05 and

[1] In 2011, Greece is divided in 7 decentralized administrations, 13 regions, 75 regional units, 325 municipalities and 947 municipal units.

[2] Greece has 14 river basin districts, out of which 5 are international sharing water courses with Albania, FYROM and Bulgaria to the north and Turkey to the east. The river basin district management plans have been adopted in 12 basin districts. They are are available at http://wfd.ypeka.gr/.

GR08). Our endogenous variable is then the annual water consumption per capita in 2010 (in m3 per year per capita) for each municipal units.

Water price data From the river basin district management plans, we have the unit price paid by households for the water service and for the wastewater service (euros per m3).

Household income As a proxy of disposable household income, we use the average GDP per capita (euros per year per capita) available from 2000 to 2011 at Nuts3 from the Statistical Office of Greece. Notice that Bithas and Chrysostomos (2006) also use GDP per capita as a proxy of household income.

Other socioeconomic variables Other socio-economic variables come from the Statistical Office of Greece.

Climate data All meteorological data come from the JRC climate database. Grid data (5km $\times$ 5km) on rainfalls, temperatures and evapotranspiration have been aggregated at regional level. We have historical data from 1990 to 2013.

13.4 Empirical analysis of residential water consumption

In this section, we provide a statistical analysis or residential water consumption and water price for Greece.

Table 13.1: Household water consumption and price in Greece

Year	Water consumption (m3 per capita per year)	Water price (euros per m3)
2010	81.908	1.270

Table 13.1 gives the annual residential water consumption (m3 per capita and per year) and the water price (average water price, in euros m3) in Greece in 2010. In 2010, the average annual consumption per inhabitant amounted to 82 m3 (this volume does not account for the water losses which account for approximately 33% of the volume produced). The average water price in 2010 was 1.3 euros per m3.

Table 13.2: Regional household water consumption and price in Greece

Year	Water consumption (m3 per capita per year)	Water price (euros per m3)
GR04	78.352	1.101
GR05	93.557	1.709
GR08	74.676	1.435
GR11	88.781	0.897
GR12	73.085	1.484
Average	81.908	1.270

Table 13.2 gives the annual residential water consumption (m3 per capita and per year) and the water price aggregated at the river basin district in 2010. As it can be seen, there are some differences across river bassin districts , both in terms of water consumption and water prices. With 94 m3 per capita per year, the water

consumption is the highest in the Epirus river basin. On contrary, a low water consumption is reported in the Thrace river district (73.0 m3 per capita per year).

13.5 Water demand function estimate

13.5.1 Specifying the residential water demand function

The residential water demand function can be derived from solving the utility optimization problem of a consumer. Under the assumption of a weak separability of water with respect to other goods consumed, the Marshallian demand in water can be written as:

$$y = y^*(p, I, Z) \tag{13.1}$$

where y is the water consumption either per capita or per household, p and I denote the unit water price (representing both water supply and the sewage treatment services) and the representative household income, respectively. Z is a vector of exogenous variables assumed to influence water consumption (climate conditions, household and housing characteristics, etc.).

To estimate Equation (13.1), a wide variety of functional forms have been applied in the water demand literature, including linear forms, semi or double logarithm forms and more complex forms such as the Stone-Geary specification. The existing literature is however not very informative concerning the specification which should be preferred. Since the double-log model is the most common specification in the residential water demand literature, we have adopted this model in order to facilitate comparison to other studies. Furthermore, the specification implies that coefficient estimates are also elasticity estimates. With a double-log specification, the residential water demand function writes:

$$\ln(y) = \alpha \ln(p) + \beta \ln(I) + \gamma \ln(Z)' \tag{13.2}$$

and the coefficients α and β can be directly interpreted as the price and the income elasticities of the water demand. Specification tests for the functional form will be conducted in the empirical part but we don't expect the choice of the particular form to have a fundamental influence on the estimation of the parameters of interest.

13.5.2 Estimation methods

Let $i = \{1, .., I\}$ indexes municipal units. Our equation of interest becomes:

$$\ln(y_i) = \alpha \ln(p_i) + \beta \ln(I_i) + \gamma \ln(Z_i)' + \epsilon_i \tag{13.3}$$

where ϵ_t is the usual random term.

13.5.3 Results

We report here our estimate for the residential water demand function in Greece in 2010, based on our municipal unit level dataset for Greece (we have 114 municipal units). The model estimated in Table 13.3 corresponds simple OLS.

Table 13.3 present the main significant variables explaining household water consumption in Greece. The price elasticity vis found to be -0.10. A 10% increase in water price results in a 1.0% decrease in short-run water consumption in Greece. Water demand in Greece is inelastic, i.e. the estimated price elasticity in absolute values is lower than one.

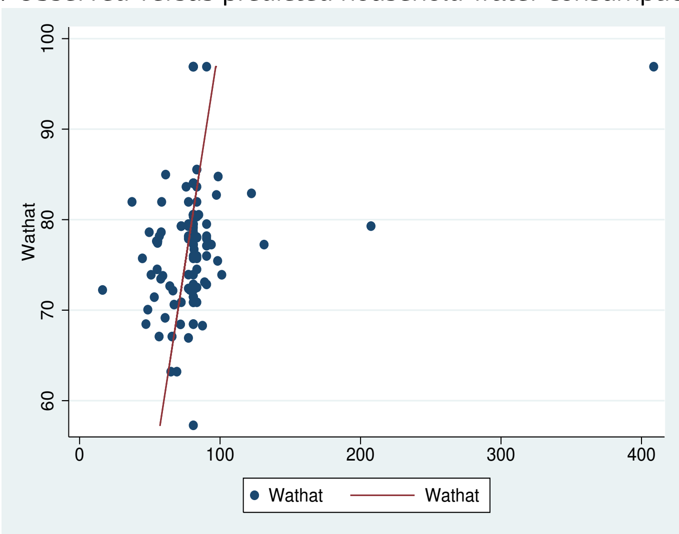
Table 13.3: Estimation of the household water demand in Greece

	GreeceOLS b/se
$\ln$ Water price (in euros per m3)	-0.095*
	(0.05)
$\ln$ Household income (in euros per capita)	0.008
	(0.19)
Share households with at least 5 persons	-2.460***
	(0.93)
$\ln$ average of daily rainfall (mm per day)	-0.029
	(0.12)
Constant	4.509**
	(1.80)
R-squared	0.086
N. of obs.	114.000

The share of households with at least 5 persons has a negative and significant impact on water consumption per capita. Large household tend to have a lower water consumption per capita.

A possible way to assess the validity of the model is to compare the water consumption predicted by the demand function to the observed water consumption, see Figure 13.1. For most of the municipalities the model performs quite well. The mean absolute percentage error is 18.7.

Figure 13.1: Observed versus predicted household water consumption in Greece



Chapter 14

Hungary

14.1 Existing literature

To our best knowledge, there doesn't exist any estimate of the residential water demand function in Hungary.

14.2 Urban water sector in Hungary

The total water abstraction in 2012 is about 6,000 million m3/year, 75% of which is for cooling water use (HITA 2013). Within the remaining segment, the public water supply is the major user with 40%, industry represents one quarter and agriculture uses the rest (irrigation 15%, fishponds 5% and animal breeding 15%).

Municipalities and the central government are responsible for service provision in Hungary (WorldBank 2015d). Depending on the ownership of assets, there is a mixed responsibility for service provision between the central government and municipalities. Before 2012, there were around 400 water utilities but the 33 largest water utilities used to represent 84% of the total consumer equivalent in the country. By 2017, the minimum required size to obtain a license for operation will be 150,000 population equivalent.

Hungarian utilities provide almost full access to drinking water services, and there is a declining gap between water and sewer connections. According to WorldBank (2015d), 97% of the population is connected to drinking water networks. The connection rate to the sewer system increased from 46% in 1990 to 74% in 2012.

Since 2012, the Hungarian Energy and Public Utility Regulatory Authority (HEA) has been the key institution that regulates and oversees the water sector.

14.3 Data

Our panel data set consists of Nuts3-level data on household water consumption, household water price, household's socioeconomic conditions income and on climate condition for years 2000-2007. Most of the data come from the Hungarian Central Statistical Office. The data consist of aggregate data at Nuts3-level on water consumption per capita and water prices. The data have been combined with information on income, climate, and household characteristics mainly from the Central Statistical office of Hungary.

Water consumption data We have used Nuts3-level annual water consumption per inhabitant connected to the water supply system (m3 per capita) available from 2003 to 2012 from the Hungarian Central Statistical Office.

Water price data Water prices come from the International Benchmarking Network for Water and Sanitation Utilities (IBNET) and are available at the water utility-level from 2000 to 2007. Water services have been matched to their respective Nuts3 (Nuts3 without a water service in the IBNET database are given a water price corresponding to the national average). As a price indicator, we use the average price (euros per m3) paid by households for the water service (based on a household annual water consumption equal to 72 m3).

Household income We use the average annual net earnings per employee at Nuts3-level from 2000 to 2012 from the Central Statistical Office of Hungary.

Other socioeconomic variables Other socio-economic variables from 2000 to 2007 come from the Central Statistical Office of Hungary.

Climate data All meteorological data come from the JRC climate database. Grid data (5km $\times$ 5km) on rainfalls, temperatures and evapotranspiration have been aggregated at regional level. We have historical data from 1990 to 2013.

14.4 Empirical analysis of residential water consumption

In this section, we provide a statistical analysis or residential water consumption and water price for Hungary.

Table 14.1: Household water consumption and price in Hungary

Year	Water consumption (m3 per capita per year)	Water price (euros per m3)
2000	41.030	0.343
2001	39.198	0.368
2002	40.073	0.439
2003	41.589	0.536
2004	39.045	0.641
2005	38.958	0.780
2006	38.829	0.696
2007	39.281	0.894
2008	37.832	.
2009	37.645	.
2010	35.766	.
2011	35.861	.
Average	38.769	0.586

According to HITA (2013), water consumption decreased by about 50% compared to the late 1980s. Today consumption remains stable with an average annual use per person of about 36-40 m3 of water on a national level. Table 14.1 gives the annual residential water consumption (m3 per capita and per year) and the water price (average water price, in euros m3) in Hungary from 2000 to 2011. In 2011, the average annual consumption per inhabitant amounted to 35.8 m3. There has been a decreasing trend in domestic water consumption from 2000 to 2011. Over the period 2000 to 2007, the average water price has increased from 0.3 euros per m3 to 0.9 euros per m3.

Table 14.2 gives the annual residential water consumption (m3 per capita and per year) and the water price per region (Nuts 3) in 2007. As it can be seen, there are some differences across regions, both in terms of water consumption and water prices. With almost 60 m3 per capita per year, the water consumption is the higher in the Budapest Nuts3. On contrary, a low water consumption is reported in the Nógrád region (24 m3 per capita per year).

14.5 Water demand function estimate

14.5.1 Specifying the residential water demand function

The residential water demand function can be derived from solving the utility optimization problem of a consumer. Under the assumption of a weak separability of water with respect to other goods consumed, the

Table 14.2: Regional household water consumption and price in Hungary

Year	Water consumption (m3 per capita per year)	Water price (euros per m3)
Baranya	29.851	1.169
Borsod-Abaúj-Zemplén	28.848	0.943
Budapest	59.356	0.577
Bács-Kiskun	39.255	0.954
Békés	35.704	0.954
Csongrád	40.045	0.932
Fejér	37.712	0.954
Gyr-Moson-Sopron	35.687	1.054
Hajdú-Bihar	32.753	0.543
Heves	33.912	1.571
Jász-Nagykun-Szolnok	34.346	0.954
Komárom-Esztergom	29.626	1.195
Nógrád	24.454	0.954
Pest	41.557	0.954
Somogy	35.217	0.577
Szabolcs-Szatmár	34.591	0.954
Tolna	33.624	0.958
Vas	35.089	0.865
Veszprém	35.310	0.843
Zala	36.785	1.174
Average	39.281	0.894

Marshallian demand in water can be written as:

$$y = y^*(p, I, Z) \tag{14.1}$$

where y is the water consumption either per capita or per household, p and I denote the unit water price (representing both water supply and the sewage treatment services) and the representative household income, respectively. Z is a vector of exogenous variables assumed to influence water consumption (climate conditions, household and housing characteristics, etc.).

To estimate Equation (14.1), a wide variety of functional forms have been applied in the water demand literature, including linear forms, semi or double logarithm forms and more complex forms such as the Stone-Geary specification. The existing literature is however not very informative concerning the specification which should be preferred. Since the double-log model is the most common specification in the residential water demand literature, we have adopted this model in order to facilitate comparison to other studies. Furthermore, the specification implies that coefficient estimates are also elasticity estimates. With a double-log specification, the residential water demand function writes:

$$\ln(y) = \alpha \ln(p) + \beta \ln(I) + \gamma \ln(Z)' \tag{14.2}$$

and the coefficients α and β can be directly interpreted as the price and the income elasticities of the water demand. Specification tests for the functional form will be conducted in the empirical part but we don't expect the choice of the particular form to have a fundamental influence on the estimation of the parameters of interest.

14.5.2 Estimation methods

Let $i = \{1, .., I\}$ indexes Nuts3 and $t = \{1, .., T\}$ years. Our equation of interest becomes:

$$\ln(y_{it}) = \alpha \ln(p_{it}) + \beta \ln(I_{it}) + \gamma \ln(Z_{it})' + \epsilon_{it} \tag{14.3}$$

where ϵ_{it} is the usual random term. Two panel data estimators may be used namely the fixed effects (or dummy variable) model and the random effects (or error components) model. We propose to use these two estimators and to conduct some specification tests (Hausman test) to decide which is the most appropriate to our data.

14.5.3 Results

We report here our estimate for the residential water demand function in Hungary, based on our Nuts3 dataset for Hungary (2000 to 2007). The first model estimated in Table 14.3 corresponds simple OLS whereas in the second model we estimate Equation (14.4) with a random parameter estimator. In the third model, we account for potential endogeneity of the price by using an instrumental variable approach.

Table 14.3 present the main significant variables explaining household water consumption in Hungary. The price elasticity varies across models, from -0.07 with the GLS to -0.80 with the GLSiv (always significant). Based on the GLSiv , a 10% increase in water price results in a 8% decrease in short-run water consumption in Hungary. Water demand in Hungary is inelastic, i.e. the estimated price elasticity in absolute values is lower than one.

The income elasticity varies between 0.13 and 1.1 and and is significantly different from zero with the three models. This suggests that there is an increasing relationship between water consumption and household

Table 14.3: Estimation of the household water demand in Hungary

	HungaryOLS b/se	HungaryGLS b/se	HungaryGLSiv b/se
ln Water price (in euros per m3)	-0.267***	-0.066***	-0.793***
	(0.04)	(0.02)	(0.30)
ln Household income (in euros per capita)	0.419***	0.126***	1.092***
	(0.07)	(0.03)	(0.39)
ln Population density	0.096***	0.141***	0.005
	(0.01)	(0.03)	(0.06)
ln Average of daily rainfall in summer (mm per day)	-0.105***	-0.061***	-0.081***
	(0.03)	(0.01)	(0.03)
Share of population connected to water supply	0.001	-0.002	
	(0.00)	(0.00)	
Constant	-0.522	2.034***	-5.748*
	(0.51)	(0.32)	(3.11)
R-squared	0.649		
N. of obs.	160.000	160.000	160.000

Figure 14.1: Observed versus predicted household water consumption in Hungary

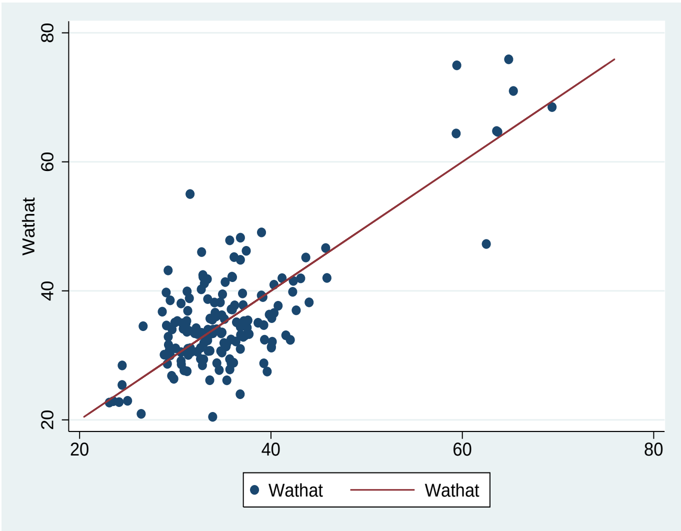


Table 14.4: Estimation of the household water demand with lagged water consumption in Hungary

	HungaryGLSlag	HungaryGLSivlag
	b/se	b/se
$\ln$ Water price (in euros per m3)	-0.058***	-0.122
	(0.02)	(0.08)
$\ln$ Household income (in euros per capita)	0.127***	0.225*
	(0.04)	(0.12)
$\ln$ Population density	-0.002	-0.008
	(0.01)	(0.01)
$\ln$ Average of daily rainfall in summer (mm per day)	-0.053***	-0.050***
	(0.01)	(0.01)
Share of population connected to water supply	0.000	
	(0.00)	
$\ln$ Lag of water consumption per capita	0.864***	0.821***
	(0.03)	(0.06)
Constant	-0.549**	-1.196
	(0.27)	(0.81)
R-squared		
N. of obs.	140.000	140.000

income. The positive significant coefficient for income indicates that, based on the GLSiv model, a 10% increase in income will result in a 10.1% increase in water consumption.

Climate conditions play also a significant role, together with the housing characteristics. An increase of summer rainfall by 10% will imply a reduction in water consumption by 0.8% (GLSiv model).

A possible way to assess the validity of the model is to compare the water consumption predicted by the demand function to the observed water consumption, see Figure 14.1. For most of the municipalities the model performs quite well. The mean absolute percentage error is 12.6.

Water consumption may to be at least somehow persistent over time due to household habits or due to the time needed to adjust durable equipments (shower for instance). With panel or time-series data, one way to take into this time persistence characteristic of household water consumption is to introduce the lagged consumption as an additional independent variable in Equation (14.2). The dynamic specification of our equation of interest becomes then :

$$\ln(y) = \alpha \ln(p) + \beta \ln(I) + \gamma \ln(Z)' + \mu \ln(\text{Lag}\, y) \tag{14.4}$$

where Lag y represents the lagged water consumption. From this specification is is then possible to derive the long-run price elasticity of the household water demand function which simply writes:

$$\epsilon_p^{LT} = \frac{\alpha}{1-\mu}. \tag{14.5}$$

We provide in Table 14.4 our estimates for the household water demand function where the lagged consumption has been introduced as an additional independent variable. With the HungaryGLSlag model, the long-term price elasticity is estimated to be -0.42 significantly different from zero at 1%. With the HungaryGLSivlag model, the long-term price elasticity is estimated to be -0.68 significantly different from zero at 1%.

Chapter 15

Ireland

15.1 Existing literature

To our best knowledge there is no estimate of the water demand function for households in Ireland. This might be due to the fact that, until 2014, most of the Irish households were not facing a formal price for water and wastewater services.

15.2 Urban water sector in Ireland

Ireland's water sector is characterised by a high level of fragmentation (around 3,500 water supply schemes in 2011 according to the Irish Environmental Agency). Indeed, there are numerous different ways in which water is supplied to the domestic and non-domestic sectors, depending on local circumstances and authorities. These include public water supplies (84.8%), public group water schemes (2.6% by a contractor on behalf of a local authority), private group water schemes (5.2%), small private supplies (0.7%), and exempted supplies (6.7%), see Zhao and Crosbie (2012).

In Ireland, average consumption per capita can only be roughly estimated at present due to the fact that the majority of households are not metered (Brady and Gray 2013). According to Zhao and Crosbie (2012), household water consumption was between 45-50 cubic meters per year and per person in 2000. More recent data suggest a water consumption per capita around 55 cubic meters per year and per person. Working of a sample of 1650 Irish households, Edgar (2014) find an average water consumption around 45 cubic meters per year and per person. This study is however only based on metered households and it covers only three months of observations. As a result, household water consumption could be underestimated.

One specificity of Ireland is that, until 2014, most of the Irish households were not facing a formal price for water and wastewater services. Domestic water charges were firstly abolished in Ireland in 1977, but were reintroduced with little success under the 1983 Local Government (Financial Provisions) Act. Thereafter, water charges were abolished again in 1997 and integrated into central taxation (more specifically through a road tax) after a general election in 1996, Zhao and Crosbie (2012).

Lastly, it is importance to notice that a significant portion (between 30-40%) of treated water in Ireland is unaccounted for that is lost through leakage in the distribution system before it reaches the customer.

15.3 Data

There are 34 local authorities (Water Services Authorities, WSA) responsible for local management and strategic planning of water and sewerage services in Ireland. Our data set consists then of WSA-level data on household water consumption, household water price, household's socioeconomic conditions income and on climate condition for year 2011. Data on water supplied come from the Environmental Protection Agency (SAFER-Data). The final data consist of aggregate data at WSA-level on water consumption per capita and water and sewerage prices. The data have been combined with information on household's income, climate conditions, and household characteristics mainly from the Central Statistical Office (CSO) of Ireland.

Water consumption data From Environmental Protection Agency, we have the water population supplied and the volume distributed for each supply scheme and each year from 2003 to 2013. The volume of water and the population have been aggregated at the WSA level (34 WSA). For each WSA we have the volume of water distributed to households (in m3 per capita).

Water price data As mentioned above, until 2014, most of the Irish households were not facing a formal price for water and wastewater services. As a result it is not possible to define a household water price for Ireland. We have decided to consider the commercial water price as a proxy of the household water price. The rational for this assumption is that commercial water price reflect the cost of the water service. As a result, we expect the household water price to be highly correlated to the commercial water price. For each WSA from 2007 to 2013, we have the average water and wastewater commercial charges for the period 2007 to 2013 from the publication IBEC (2013).

Household income We use the average disposable household income (euros per year per capita) available from 2000 to 2011 at county level from the Central Statistical Office (CSO) of Ireland. Irish counties have been matched to WSAs.

Other socioeconomic variables Other socio-economic variables from 2000 to 2011 come the Central Statistical Office (CSO) of Ireland.

Climate data All meteorological data come from the JRC climate database. Grid data (5km $\times$ 5km) on rainfalls, temperatures and evapotranspiration have been aggregated at regional level. We have historical data from 1990 to 2013.

15.4 Empirical analysis of residential water consumption

In this section, we provide a statistical analysis or residential water consumption and water price for Ireland. We limit our analysis to year 2011.

Table 15.1: Household water consumption and price in Ireland

Year	Water consumption (m3 per capita per year)	Water price (euros per m3)
2011	49.255	2.212
Average	49.255	2.212

Table 15.1 gives the annual residential water consumption (m3 per capita and per year) and the water commercial price (average water and wastewater price, in euros m3) in Ireland in 2011.[1] In 2010, the average annual consumption per inhabitant amounted to 49 m3. The average commercial water price in 2011 was 2.2 euros per m3.

Table 15.2 gives the annual residential water consumption (m3 per capita and per year) and the water price per WSA in 2010. As it can be seen, there are some differences across regions, both in terms of water consumption and water prices. With 85 m3 per capita per year, the water consumption is the higher in the Limerick City Council WSA. On contrary, a low water consumption is reported in the Westmeath County Council WSA (20 m3 per capita per year).

[1] As explained above, the commercial water price will serve a proxy of the household water price.

Table 15.2: Regional household water consumption and price in Ireland

Year	Water consumption (m3 per capita per year)	Water price (euros per m3)
Carlow County Council	40.334	2.300
Cavan County Council	63.858	2.510
Clare County Council	68.675	2.890
Cork City Council	43.652	2.350
Cork County Council	35.430	2.130
Donegal County Council	46.789	2.310
Dublin City Council	53.038	1.800
Dun Laoghaire-Rathdown	33.162	2.300
Fingal County Council	43.727	1.790
Galway City Council	54.444	1.750
Galway County Council	56.466	2.280
Kerry County Council	50.807	1.930
Kildare County Council	62.632	1.490
Kilkenny County	46.763	2.890
Laois County Council	42.530	2.450
Leitrim County Council	52.939	2.280
Limerick City Council	85.151	2.600
Limerick County Council	48.523	2.600
Longford County Council	19.805	2.400
Louth County Council	65.418	1.900
Mayo County Council	57.833	2.400
Meath County Council	41.639	2.650
Monaghan County Council	25.526	2.110
North Tipperary County Council	50.333	2.400
Offaly County Council	54.738	2.400
Roscommon County Council	58.208	2.770
Sligo County Council	61.677	2.420
South Dublin Council	43.854	1.880
South Tipperary County Council	68.405	2.100
Waterford City Council	44.971	2.350
Waterford County Council	54.412	2.660
Westmeath County Council	20.042	2.300
Wexford County Council	22.644	2.560
Wicklow County Council	37.710	3.040
Average	49.255	2.212

15.5 Water demand function estimate

15.5.1 Specifying the residential water demand function

Important remark Until 2014 most of the Irish households were not facing a formal price for water and wastewater services. As a result the concept of water demand function might not be adapted to model household water use. Interpretation of the estimates should be done with caution.

The residential water demand function can be derived from solving the utility optimization problem of a consumer. Under the assumption of a weak separability of water with respect to other goods consumed, the Marshallian demand in water can be written as:

$$y = y^*(p, I, Z) \tag{15.1}$$

where y is the water consumption either per capita or per household, p and I denote the unit water price (representing both water supply and the sewage treatment services) and the representative household income, respectively. Z is a vector of exogenous variables assumed to influence water consumption (climate conditions, household and housing characteristics, etc.).

To estimate Equation (15.1), a wide variety of functional forms have been applied in the water demand literature, including linear forms, semi or double logarithm forms and more complex forms such as the Stone-Geary specification. The existing literature is however not very informative concerning the specification which should be preferred. Since the double-log model is the most common specification in the residential water demand literature, we have adopted this model in order to facilitate comparison to other studies. Furthermore, the specification implies that coefficient estimates are also elasticity estimates. With a double-log specification, the residential water demand function writes:

$$\ln(y) = \alpha \ln(p) + \beta \ln(I) + \gamma \ln(Z)' \tag{15.2}$$

and the coefficients α and β can be directly interpreted as the price and the income elasticities of the water demand. Specification tests for the functional form will be conducted in the empirical part but we don't expect the choice of the particular form to have a fundamental influence on the estimation of the parameters of interest.

15.5.2 Estimation methods

Let $i = \{1, .., I\}$ indexes Water Services Authorities. Our equation of interest becomes:

$$\ln(y_i) = \alpha \ln(p_i) + \beta \ln(I_i) + \gamma \ln(Z_i)' + \epsilon_i \tag{15.3}$$

where ϵ_t is the usual random term.

15.5.3 Results

We report here our estimate for the residential water demand function in Ireland, based on our Council dataset for Ireland (2010). Both models estimated in Table 15.3 rely on simple OLS. In the first model the average commercial water price is introduced as a possible determinant whereas in the second model we estimate Equation (15.3) without any water price variable. Based on the above discussion related to the absence of water pricing for household in Ireland, the interpretation of the price coefficient should be done with caution.

Table 15.3: Estimation of the household water demand in Ireland

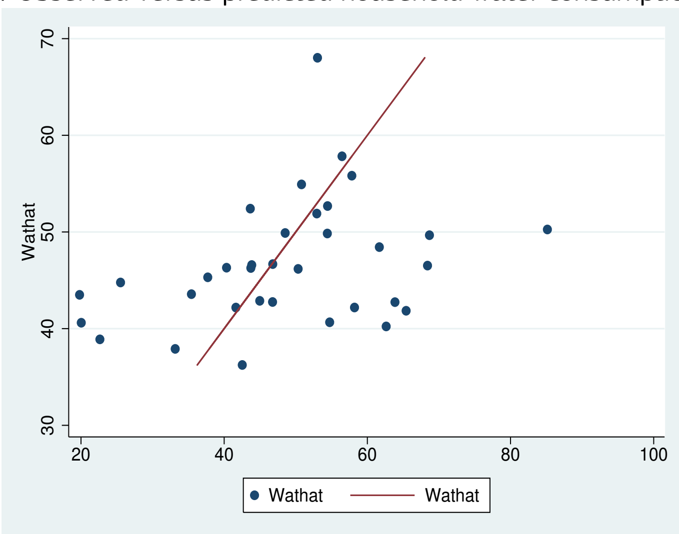
	IrelandWithPrice b/se	IrelandNoPrice b/se
$\ln$ Water price (in euros per m3)	-0.215	
	(0.44)	
$\ln$ Household income (in euros per capita)	0.155	0.327
	(1.34)	(1.27)
$\ln$ Share population above 65	0.818*	0.785*
	(0.40)	(0.39)
$\ln$ Share detached houses	0.024	0.018
	(0.14)	(0.14)
$\ln$ evapotranspiration	1.820	1.759
	(1.80)	(1.77)
Constant	-0.395	-2.135
	(13.48)	(12.82)
R-squared	0.146	0.139
N. of obs.	34.000	34.000

Table 15.3 presents the main significant variables explaining household water consumption in Ireland. The price elasticity is -0.22 in the first model, but not statistically different from zero. This is not a surprising results based on the fact that households don't face a formal water price in Ireland.

The income elasticity varies between 0.16 and 0.33 but is never significantly different from zero. The water consumption per capita increases with the share of the population above 65.

A possible way to assess the validity of the model is to compare the water consumption predicted by the demand function to the observed water consumption, see Figure 15.1. For most of the municipalities the model performs quite well. The mean absolute percentage error is 25.0.

Figure 15.1: Observed versus predicted household water consumption in Ireland



Chapter 16

Italy

16.1 Existing literature

Some papers have estimated a residential water demand function for Italy but based on regional or local data (Mazzanti and Montini 2006, Musolesi and Nosvelli 2007, Statzu and Strazzera 2011). Mazzanti and Montini (2006) use a panel dataset consisting of 125 municipalities in the Emilia-Romagna region observed over four years (1998-2001). The estimated water demand price elasticity is negative, showing values between -0.99 and -1.33. Income elasticity is significant within in a range between 0.40 and 0.71. The other socio-economic variables play only a very limited role in explaining residential water consumption: the number of inhabitants in the municipality, population density, household size, the shares of both old and young population do not present significant effects. Altitude seems to negatively influence water demand in a significant way. Musolesi and Nosvelli (2007) have studied household water demand in the Cremona Province. Statzu and Strazzera (2011) analyze a data set on residential water consumption in a Sardinia, for a period of six years (2000-2005), using aggregated data on municipalities. Statzu and Strazzera (2011) report a significant effect of price, with a price elasticity value of -0.146 together with a significant impact of income, the income elasticity being 0.105. Household size is significant, and its coefficient indicates that water consumption increases a little more than proportionally following an increase in the household size. The altitude variable has a significant negative effect on water consumption.

Recently, Romano, Salvati, and Guerrini (2014) have published the first estimate of a residential water demand using a national coverage. Using a linear mixed-effects model, Romano, Salvati, and Guerrini (2014) have estimated the determinants of residential water demand for the 103 provincial Italian capitals, over the period 2007-2009. Their results confirmed that the price has a negative effect on residential water consumption (price elasticy equal to -0.18) and that it is a relevant driver of domestic water consumption. Moreover, income per capita has a positive expected effect on water consumption. Among the other explanatory variables precipitation and altitude exert a strongly significant negative effect on water consumption, while temperature does not influence water demand.

16.2 Data

Water consumption data We rely on data from the Italian National Institute of Statistics (Istat). We use the average annual consumption of drinking water for domestic use in the 113 chief towns of each Italian province (i.e., meter per capita per year) from 2001 to 2011. On average, the annual consumption of drinking water for domestic use has decreased from 76.4 m3 per capita per year in 2001 to 64.0 m3 per capita per year in 2011. In addition, Istat indicates for each year if a restriction of water use has been implemented in a municipality.

Water price data We have used information on household expenses for the water and waste water services, reported in the annual surveys of the Federconsumatori (the main Italian consumer organization). Expenses reported include fees for water, wastewater and sewerage services, the fixed component, and value added tax (VAT). We have computed an average price for two levels of residential household use (100 and 200 cubic meters of water per year) for the chief town of each Italian province from 2002 to 2011 (missing data for year 2006 and 2007). The water price has increased from 1.01 euro per cubic meter in 2000 to reach 1.66 euros per cubic meter in 2011.

Household income We use the annual average households income (at regional level) obtained directly from Istat over the period 2002-2011. It varies from 25,287 euros in 2002 on average for Italy to 29,956 in 2011.

Other socioeconomic variables We collected household socioeconomic characteristics data using recent Istat data (household size, population density, etc.).

Climate data All meteorological data come from the JRC climate database. Grid data (5km $\times$ 5km) on rainfalls, temperatures and evapotranspiration have been aggregated at regional level. We have historical data from 1990 to 2013.

16.3 Empirical analysis of residential water consumption

In this section, we provide a statistical analysis or residential water consumption and water price for Italy.

Table 16.1: Household water consumption and price in Italy

Year	Water consumption (m3 per capita per year)	Water price (euros per m3)
2000	77.552	.
2001	78.498	.
2002	76.413	0.918
2003	74.917	0.951
2004	73.367	1.107
2005	72.543	1.164
2006	71.951	.
2007	69.940	.
2008	69.219	.
2009	68.465	1.300
2010	66.830	1.406
2011	64.245	1.515
Average	71.898	1.222

Table 16.1 gives the annual residential water consumption (m3 per capita and per year) and the water price (average water price, in euros m3) in Italy from 2000 to 2011. In 2011, the average annual consumption per inhabitant amounted to 64.2 m3. There has been a decreasing trend in domestic water consumption since 2000. Over the period 2002-2011, the average water price (only for the water service) has increased from 0.92 euros per m3 to 1.52 euros per m3 .

Table 16.2 gives the annual residential water consumption (m3 per capita and per year) and the water price per Italian region in 2010. As it can be seen, there are some differences across regions, both in terms of water consumption and water prices. With more than 83 m3 per capita per year, the water consumption is the higher in the Lazio region. On contrary, a low water consumption is reported in the Basilicata region (50.6 m3 per capita per year).

16.4 Water demand function estimate

Table 16.2: Regional household water consumption and price in Italy

Year	Water consumption (m3 per capita per year)	Water price (euros per m3)
Abruzzo	63.579	1.142
Basilicata	50.577	1.422
Calabria	69.914	.
Campania	60.594	1.186
Emilia-Romagna	58.716	1.715
Friuli-Venezia Giulia	63.235	0.980
Lazio	83.387	1.080
Liguria	62.594	1.762
Lombardia	78.128	0.754
Marche	55.624	1.694
Molise	53.634	.
Piemonte	71.690	1.337
Provincia Autonoma Bolzano / Bozen	59.152	1.131
Puglia	52.111	2.086
Sardegna	57.735	1.407
Sicilia	64.266	1.641
Toscana	53.647	2.241
Umbria	52.582	1.874
Valle d’Aosta	65.746	1.051
Veneto	62.160	1.287
Average	66.830	1.406

16.4.1 Specifying the residential water demand function

The residential water demand function can be derived from solving the utility optimization problem of a consumer. Under the assumption of a weak separability of water with respect to other goods consumed, the Marshallian demand in water can be written as:

$$y = y^*(p, I, Z) \tag{16.1}$$

where y is the water consumption either per capita or per household, p and I denote the unit water price (representing both water supply and the sewage treatment services) and the representative household income, respectively. Z is a vector of exogenous variables assumed to influence water consumption (climate conditions, household and housing characteristics, etc.).

To estimate Equation (16.1), a wide variety of functional forms have been applied in the water demand literature, including linear forms, semi or double logarithm forms and more complex forms such as the Stone-Geary specification. The existing literature is however not very informative concerning the specification which should be preferred. Since the double-log model is the most common specification in the residential water demand literature, we have adopted this model in order to facilitate comparison to other studies. Furthermore, the specification implies that coefficient estimates are also elasticity estimates. With a double-log specification, the residential water demand function writes:

$$\ln(y) = \alpha \ln(p) + \beta \ln(I) + \gamma \ln(Z)' \tag{16.2}$$

and the coefficients α and β can be directly interpreted as the price and the income elasticities of the water demand. Specification tests for the functional form will be conducted in the empirical part but we don't expect the choice of the particular form to have a fundamental influence on the estimation of the parameters of interest.

16.4.2 Estimation methods

Let $i = \{1, .., I\}$ indexes the 113 chief towns of each Italian and $t = \{1, .., T\}$ years. Our equation of interest becomes:

$$\ln(y_{it}) = \alpha \ln(p_{it}) + \beta \ln(I_{it}) + \gamma \ln(Z_{it})' + \epsilon_{it} \tag{16.3}$$

where ϵ_{it} is the usual random term. Two panel data estimators may be used namely the fixed effects (or dummy variable) model and the random effects (or error components) model. We propose to use these two estimators and to conduct some specification tests (Hausman test) to decide which is the most appropriate to our data.

16.4.3 Results

We report here our estimate for the residential water demand function in Italy, based on our panel dataset made of municipal-level observations from 2002 to 2011. The first model estimated in Table 16.3 corresponds to simple OLS whereas in the second model we estimate Equation (16.4) with a random parameter estimator. In the third model, we account for potential endogeneity of the price by using an instrumental variable approach.

A specific estimation issue arises due to the use of the average water price as an explanatory variable. Stated simply, the average price a consumer faces depends on his level of consumption but this level of consumption is also affected by the average price. This simultaneity violates standard assumptions regarding independence of the error term from explanatory variables. OLS are in such case inconsistent and a specific

Table 16.3: Estimation of the household water demand in Italy

	ItalyOLS	ItalyGLS	ItalyGLSiv
	b/se	b/se	b/se
Water price (in logs)	-0.282***	-0.219***	-0.587***
	(0.02)	(0.03)	(0.09)
Household income (in logs)	0.062	-0.258***	0.313**
	(0.08)	(0.08)	(0.15)
Population density (in logs)	0.033***	0.051***	
	(0.01)	(0.01)	
Number of persons per household (in logs)	-0.605***	-0.536***	-0.399**
	(0.11)	(0.13)	(0.17)
Dummy = 1 if water rationing	-0.010	-0.028	0.025
	(0.03)	(0.02)	(0.04)
Number of days without rain (in logs)	0.093	0.088*	-0.080
	(0.07)	(0.05)	(0.08)
Constant	3.355***	6.468***	1.811
	(1.03)	(0.91)	(1.54)
R-squared	0.517		
N. of obs.	332.000	332.000	332.000

Figure 16.1: Observed versus predicted household water consumption in Italy

estimation procedure is required. This simultaneity problem can be addressed by using instrumental variables (IV) techniques such as Two Stage Least Square (2SLS) regression.

In Table 16.3, we report our estimates of the household water demand function for Italy using an IV approach. The population density and the share of water volume lost in the distribution system have been used as instruments. To assess the validity of the model, we have compared the water consumption predicted by the demand function to the observed water consumption, see Figure 16.1. For most of the municipalities the model performs quite well with a mean absolute relative prediction error equal to 13.20%.

Table 16.3 gives the main significant variables explaining household water consumption in Italy.

The price elasticity varies across models, from -0.28 with the OLS to -0.59 with the GLSiv (not significant with GLSiv). The price elasticities belong to a range of values in line with the existing literature and the previous estimates available for Italy. Based on the GLS models, a 10% increase in water price results in a 5.9% decrease in short-run water consumption in Italy. Water demand in italy is inelastic, i.e. the estimated price elasticity in absolute values is lower than one.

The income elasticity is 0.311 with GLSiv model which is also consistent with previous results showing that there is an increasing relationship between water consumption and household income. Water rationing does not impact on water consumption, a result in line with what has been found previously by Statzu and Strazzera (2011) for Sardinia. Water consumption per capita decreases with household's size but is not impacted by climate conditions.

Water consumption may to be at least somehow persistent over time due to household habits or due to the time needed to adjust durable equipments (shower for instance). With panel or time-series data, one way to take into this time persistence characteristic of household water consumption is to introduce the lagged consumption as an additional independent variable in Equation (16.2). The dynamic specification of our equation of interest becomes then :

$$\ln(y) = \alpha \ln(p) + \beta \ln(I) + \gamma \ln(Z)' + \mu \ln(\mathsf{Lag}\, y) \tag{16.4}$$

where Lag y represents the lagged water consumption. From this specification is is then possible to derive the long-run price elasticity of the household water demand function which simply writes:

$$\epsilon_p^{LT} = \frac{\alpha}{1-\mu}. \tag{16.5}$$

We provide in Table 16.4 our estimates for the household water demand function where the lagged consumption has been introduced as an additional independent variable. With the ItalyGLSlag model, the long-term price elasticity is estimated to be -0.29 significantly different from zero at 1%. With the ItalyGLSivlag model, the long-term price elasticity is estimated to be -0.25 but not significantly different from zero at 10%.

Table 16.4: Estimation of the household water demand with lagged water consumption in Italy

	ItalyGLSlag	ItalyGLSivlag
	b/se	b/se
Water price (in logs)	-0.063***	-0.037
	(0.02)	(0.08)
Household income (in logs)	0.010	0.005
	(0.05)	(0.07)
Population density (in logs)	0.005	
	(0.01)	
Number of persons per household (in logs)	-0.122*	-0.087
	(0.07)	(0.06)
Dummy = 1 if water rationing	-0.003	-0.004
	(0.02)	(0.02)
Number of days without rain (in logs)	0.041	0.041
	(0.04)	(0.04)
$\ln$ Lag of water consumption per capita	0.784***	0.854***
	(0.03)	(0.09)
Constant	0.643	0.398
	(0.63)	(0.56)
R-squared		
N. of obs.	328.000	328.000

Chapter 17

Latvia

17.1 Existing literature

To our best knowledge, no previous estimate for the residential water demand function is available for Latvia.

17.2 Urban water sector in Latvia

Until November 2009, the water management sector was regulated by 16 independent municipal regulators. As of November 1, 2009 the water management sector became a responsibility of the Public Utilities Commission (PUC) of Latvia which has in charge to issue water licenses and to approve water tariffs.

17.3 Data

Water consumption data We used the national statistics report "2-Water. An overview of the use of water resources" published annually by the Latvian Environment, Geology and Meteorology Centre. These annual reports include information on the water delivered to domestic users at municipality level (*novads*), and also at parish level (*pagasts*) from 2008 to 2013. The annual consumption per capita has been computed using the resident population by statistical region, city and county obtained from the Latvian Central Statistical Bureau and assuming a population connection rate to the public water network equal to 75% (source Latvian water and wastewater works).

Water price data Data on water tariff have been obtained directly from the PUC of Latvia. The water price is the price per cubic meter paid by residential water consumers both for the water and the sewerage services. This price information is available at municipality level (*novads*), and also at parish level (*pagasts*) for year 2014. The average price in 2014 is 1.70 euros per cubic meters, varying from 0.66 to 2.73 euros per cubic meters depending upon the municipality considered.

Household income It has not been possible to obtain a measure of household disposable income in Latvia at municipality level. As a proxy of household income, we use the annual gross wages in municipalities and county obtain from the Latvian Central Statistical Bureau. The average annual gross wages is 5,141 euro per worker per year. It varies from 3,540 to 8,076 euros per worker depending upon the municipality considered.

Other socioeconomic variables Other household socioeconomic characteristics (share of the population below 18 years, population density) come from the Latvian Central Statistical Bureau.

Climate data All meteorological data come from the JRC climate database. Grid data (5km $\times$ 5km) on rainfalls, temperatures and evapotranspiration have been aggregated at regional level. We have historical data from 1990 to 2013.

17.4 Empirical analysis of residential water consumption

In this section, we provide a statistical analysis or residential water consumption and water price for Latvia.

Table 17.1 gives the annual residential water consumption (m3 per capita and per year) and the water price (average water price, in euros m3) in Latvia for year 2013. In 2013, the weighted average annual consumption

Table 17.1: Household water consumption and price in Latvia

Year	Water consumption (m3 per capita per year)	Water price (euros per m3)
2013	58.618	1.420

per inhabitant amounted to 58.6 m3. For the same year, the average water price (only for the water service) is 1.42 euros per m3.

Table 17.2: Regional household water consumption and price in Latvia

Year	Water consumption (m3 per capita per year)	Water price (euros per m3)
Kurzeme	45.483	1.512
Latgale	46.672	1.559
Pieriga	38.158	1.869
Riga	92.264	1.047
Vidzeme	37.257	1.733
Zemgale	35.687	1.724
Average	58.618	1.420

Table 17.2 gives the annual residential water consumption (m3 per capita and per year) and the water price per Nuts3 in 2013. As it can be seen, there are some differences across regions, both in terms of water consumption and water prices. With more than 92 m3 per capita per year, the water consumption is the higher in the Riga Nuts3. On contrary, a low water consumption is reported in the Zemgale, Vidzeme and Pieriga Nuts3 (less than 40.0 m3 per capita per year).

17.5 Water demand function estimate

17.5.1 Specifying the residential water demand function

The residential water demand function can be derived from solving the utility optimization problem of a consumer. Under the assumption of a weak separability of water with respect to other goods consumed, the Marshallian demand in water can be written as:

$$y = y^*(p, I, Z) \tag{17.1}$$

where y is the water consumption either per capita or per household, p and I denote the unit water price (representing both water supply and the sewage treatment services) and the representative household income, respectively. Z is a vector of exogenous variables assumed to influence water consumption (climate conditions, household and housing characteristics, etc.).

To estimate Equation (17.1), a wide variety of functional forms have been applied in the water demand literature, including linear forms, semi or double logarithm forms and more complex forms such as the Stone-Geary specification. The existing literature is however not very informative concerning the specification which should be preferred. Since the double-log model is the most common specification in the residential water demand literature, we have adopted this model in order to facilitate comparison to other studies. Furthermore, the specification implies that coefficient estimates are also elasticity estimates. With a double-log specification, the residential water demand function writes:

$$\ln(y) = \alpha \ln(p) + \beta \ln(I) + \gamma \ln(Z)' \tag{17.2}$$

and the coefficients α and β can be directly interpreted as the price and the income elasticities of the water demand. Specification tests for the functional form will be conducted in the empirical part but we don't expect the choice of the particular form to have a fundamental influence on the estimation of the parameters of interest.

17.5.2 Estimation methods

Let $i = \{1, .., I\}$ indexes municipalities. Our equation of interest becomes:

$$\ln(y_i) = \alpha \ln(p_i) + \beta \ln(I_i) + \gamma \ln(Z_i)' + \epsilon_i \tag{17.3}$$

where ϵ_i is the usual random term.

17.5.3 Results

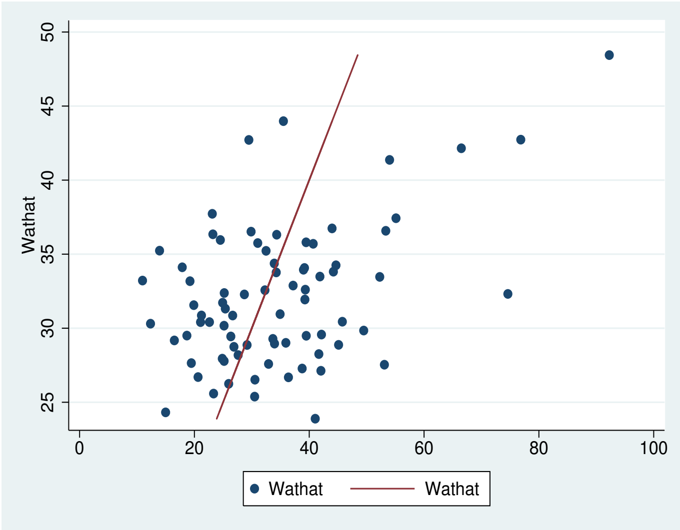
In Table 17.3, we report our estimate for the residential water demand function in Latvia, based on our CS dataset made of municipal-level observations for year 2013. We use a OLS estimator.

Table 17.3: Estimation of the household water demand in Latvia

	Latvia b/se
Water price (in logs)	-0.402**
	(0.16)
Household income (in logs)	0.613**
	(0.30)
Number of days without rain in summer (in logs)	-0.290
	(2.47)
Share of the population below 18 years (in logs)	-0.202
	(0.49)
Constant	-1.150
	(6.75)
R-squared	0.121
N. of obs.	77.000

Table 17.3 gives the main significant variables explaining household water consumption in Latvia. The price elasticity is estimated to be --0.40, a figure in line with the existing literature and the previous estimates available for Latvia. The income elasticity is 0.61 which is also consistent with previous results showing that there is an increasing relationship between water consumption and household income. None of the other variables introduced into the model (share of the population below 18 years, number of days without rain in summer) appears to be significant.

Figure 17.1: Observed versus predicted household water consumption in Latvia



To assess the validity of the model, we have compared the water consumption predicted by the demand function to the observed water consumption, see Figure 17.1. The mean absolute relative prediction error equal to 33.20%.

Chapter 18

Lithuania

18.1 Existing literature

To our best knowledge, no previous estimate for the residential water demand function is available for Lithuania.

18.2 Urban water sector in Lithuania

Municipalities and the central government are responsible for service provision in Lithuania. The National Commission for Energy Control and Prices (NCC) is an independent national regulatory in charge of regulating the water sector (approval of water prices, issuing of licenses). In 2012, there were 273 water suppliers in Lithuania.

18.3 Data

Our data set consists of annual county-level data on household water consumption, household water price, household's socioeconomic conditions income and on climate condition. Most of the data come from Statistics Lithuania, the national statistical office.

Water consumption data We rely on data from the Statistics Lithuania, the national statistical office. We have used the volume total of water distributed to households per municipality in Lithuania from 1995 to 2012 (county-level). To get the household water consumption per capita, we have divided this volume by the total population within each county.

Water price data We use county-level retail water price available from 2000 to 2012 from the Statistics Lithuania.

Household income We use the annual disposable income per capita (at county level) obtained directly from Statistics Lithuania over the period 2004-2013.

Other socioeconomic variables We collected household socioeconomic characteristics data using Statistics Lithuania data at municipal of at county levels (median population age, population density, etc.).

Climate data All meteorological data come from the JRC climate database. Grid data (5km $\times$ 5km) on rainfalls, temperatures and evapotranspiration have been aggregated at regional level. We have historical data from 1990 to 2013.

18.4 Empirical analysis of residential water consumption

In this section, we provide a statistical analysis or residential water consumption and water price for Lithuania.

Table 18.1 gives the annual residential water consumption (m3 per capita and per year) and the water price (retail water price for cold water in euros per m3) in Lithuania. The annual residential water consumption per capita has decreased from 27.3 m3 per capita in 2001 to reach 24.9 m3 per capita in 2.012. Over the same period, the water price has increased from 0.57 euros per m3 in 2001 to 0.78 euros per m3 in 2012.

Table 18.2 gives the annual residential water consumption (m3 per capita and per year) and the water price (retail water price for cold water in euros per m3) by county (Nuts 3) in 2010. As it can be seen, there are huge

Table 18.1: Household water consumption and price in Lithuania

Year	Water consumption (m3 per capita per year)	Water price (euros per m3)
2001	27.395	0.571
2002	25.553	0.579
2003	25.366	0.588
2004	26.005	0.594
2005	26.483	0.599
2006	28.171	0.603
2007	25.814	0.622
2008	25.354	0.651
2009	24.324	0.697
2010	24.134	0.728
2011	24.974	0.729
2012	24.847	0.777
Average	25.702	0.645

Table 18.2: Regional household water consumption and price in Lithuania

Year	Water consumption (m3 per capita per year)	Water price (euros per m3)
Alytus county	23.285	0.578
Kaunas county	29.999	0.695
Klaipeda county	27.584	0.633
Marijampole coun	25.427	0.710
Panevezys county	19.544	0.591
Siauliai county	16.799	0.861
Taurage county	17.950	0.915
Telsiai county	17.753	0.773
Utena county	23.015	0.833
Vilnius county	39.986	0.694
Average	24.134	0.728

differences across counties. The annual residential water consumption is the lowest in the Siauliai county (16.8 m3 per capita and per year). On the other extreme, the annual residential water consumption is the highest in the Vilnius county with 39.986 m3 per capita and per year. The heterogeneity across counties is lower for what concerns the residential water price.

18.5 Water demand function estimate

18.5.1 Specifying the residential water demand function

The residential water demand function can be derived from solving the utility optimization problem of a consumer. Under the assumption of a weak separability of water with respect to other goods consumed, the Marshallian demand in water can be written as:

$$y = y^*(p, I, Z) \tag{18.1}$$

where y is the water consumption either per capita or per household, p and I denote the unit water price (representing both water supply and the sewage treatment services) and the representative household income, respectively. Z is a vector of exogenous variables assumed to influence water consumption (climate conditions, household and housing characteristics, etc.).

To estimate Equation (18.1), a wide variety of functional forms have been applied in the water demand literature, including linear forms, semi or double logarithm forms and more complex forms such as the Stone-Geary specification. The existing literature is however not very informative concerning the specification which should be preferred. Since the double-log model is the most common specification in the residential water demand literature, we have adopted this model in order to facilitate comparison to other studies. Furthermore, the specification implies that coefficient estimates are also elasticity estimates. With a double-log specification, the residential water demand function writes:

$$\ln(y) = \alpha \ln(p) + \beta \ln(I) + \gamma \ln(Z)' \tag{18.2}$$

and the coefficients α and β can be directly interpreted as the price and the income elasticities of the water demand. Specification tests for the functional form will be conducted in the empirical part but we don't expect the choice of the particular form to have a fundamental influence on the estimation of the parameters of interest.

18.5.2 Estimation methods

Let $i = \{1, .., I\}$ indexes counties (10 counties in Lithuania) and $t = \{1, .., T\}$ years. Our equation of interest becomes:

$$\ln(y_{it}) = \alpha \ln(p_{it}) + \beta \ln(I_{it}) + \gamma \ln(Z_{it})' + \epsilon_{it} \tag{18.3}$$

where ϵ_{it} is the usual random term. Two panel data estimators may be used namely the fixed effects (or dummy variable) model and the random effects (or error components) model. We propose to use these two estimators and to conduct some specification tests (Hausman test) to decide which is the most appropriate to our data.

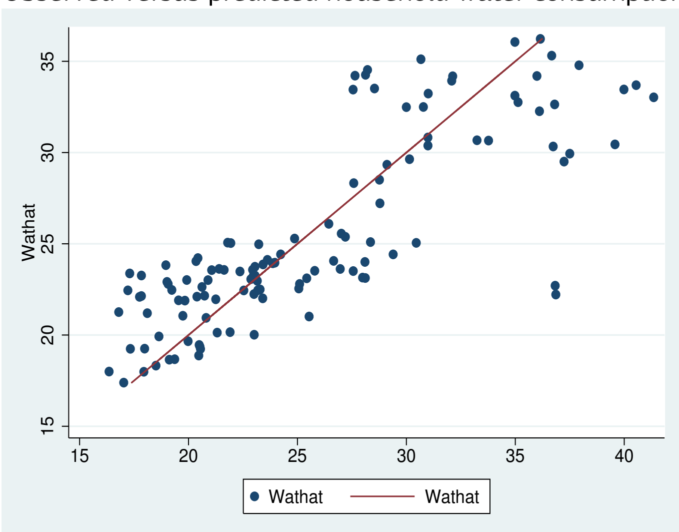
18.5.3 Results

Table 18.3 present the main significant variables explaining household water consumption in Lithuania. The first model estimated in Table 18.3 uses simple OLS whereas in the second model we estimate Equation (18.4) with a random parameter estimator.

Table 18.3: Estimation of the household water demand in Lithuania

	LithuaniaOLS	LithuaniaGLS
	b/se	b/se
$\ln$ Water price (in euros per m3)	-0.368***	-0.216**
	(0.08)	(0.10)
$\ln$ Household income (in euros per capita)	0.822***	0.426*
	(0.26)	(0.23)
$\ln$ evapotranspiration	0.757***	0.496**
	(0.28)	(0.25)
$\ln$ Median age of the population	-0.206	-0.078
	(0.32)	(0.33)
$\ln$ Household size	0.196	0.045
	(0.27)	(0.34)
Share of groundwater abstracted	-0.145***	-0.155**
	(0.05)	(0.07)
$\ln$ Population density	0.127	0.243***
	(0.08)	(0.09)
Constant	-3.857**	-1.198
	(1.70)	(1.63)
R-squared	0.687	
N. of obs.	119.000	119.000
R-squared	0.606	
N. of obs.	119.000	119.000

Figure 18.1: Observed versus predicted household water consumption in Lithuania



The short-term price elasticity is estimated to be -0.22 with the LithuaniaGLS model, and the estimated coefficient is significantly different from zero at 5%. This indicates that a 10% increase in water price results in 0.22% decrease in short-run water consumption in Lithuania. Water demand in Lithuania is inelastic both in the short-run, i.e. the estimated elasticities in absolute values are lower than one. .

The income elasticity varies between 0.43 and 0.82 depending upon the model considered. the income elasticity is significantly different from zero. This suggests that there is an increasing relationship between water consumption and household income. The positive significant coefficient for income indicates that a 10% increase in income will result in a 4.3% to 8.2% increase in water consumption.

Evapotranspiration is significant. Residential water consumption depends upon climate conditions.

A possible way to assess the validity of the model is to compare the water consumption predicted by the demand function to the observed water consumption, see Figure 18.1. For most of the counties the model performs quite well. The mean absolute percentage error is 10.48.

Water consumption may to be at least somehow persistent over time due to household habits or due to the time needed to adjust durable equipments (shower for instance). With panel or time-series data, one way to take into this time persistence characteristic of household water consumption is to introduce the lagged consumption as an additional independent variable in Equation (18.2). The dynamic specification of our equation of interest becomes then :

$$\ln(y) = \alpha \ln(p) + \beta \ln(I) + \gamma \ln(Z)' + \mu \ln(\text{Lag}\, y) \tag{18.4}$$

where Lag y represents the lagged water consumption. From this specification is is then possible to derive the long-run price elasticity of the household water demand function which simply writes:

$$\epsilon_p^{LT} = \frac{\alpha}{1-\mu}. \tag{18.5}$$

We provide in Table 18.4 our estimates for the household water demand function where the lagged consumption has been introduced as an additional independent variable. With the LithuaniaGLSlag model, the long-term price elasticity is estimated to be -0.33 significantly different from zero at 1%.

Table 18.4: Estimation of the household water demand with lagged water consumption in Lithuania

	LithuaniaGLSlag
	b/se
ln Water price (in euros per m3)	-0.136**
	(0.06)
ln Household income (in euros per capita)	0.449*
	(0.23)
ln evapotranspiration	0.388
	(0.26)
ln Median age of the population	-0.023
	(0.24)
ln Household size	0.015
	(0.20)
Share of groundwater abstracted	-0.039
	(0.04)
ln Population density	0.052
	(0.07)
ln Lag of water consumption per capita	0.588***
	(0.07)
Constant	-2.718*
	(1.53)
R-squared	
N. of obs.	108.000

Source: auto.dta

Chapter 19

Luxembourg

19.1 Existing literature

MECE (2012) have estimated a residential water demand function for Luxembourg using a sample of 77 municipalities. The price elasticity is estimated to be -0.33 and the income elasticity is 0.59.

19.2 Urban water sector in Luxembourg

Water is generally provided by the Service des Eaux of the Commune. However, in some areas of the country, the water supply is subcontracted to a private supplier.

19.3 Data

Our data set consists of municipality-level (below Nuts3) data on household water consumption, household water price, household's socioeconomic conditions income and on climate condition for year 2010. Most of the data come from the Luxembourg Statistical Service. The data consist of aggregate data at municipality-level on water consumption per capita and water and sewerage prices. The data have been combined with information on household's income, climate conditions, and household characteristics mainly from the Luxembourg Statistical Service.

Water consumption data We use the annual reports (''Rapport sur la qualité de l'eau potable''). We have by municipality the annual volume of water supplied to all users and the population served. In Luxembourg, 56% of the volume distributed by the public network is used by households (national average). We have applied this percentage to all municipalities in our sample. Our endogenous variable is then the annual water consumption per capita to the public water supply network (in m3 per year per capita).

Water price data Following MECE (2012) we use the average price for water and wastewater (source is Administration de la gestion de l'eau, circulaire number 2821).

Household income Our proxy for the household income is the housing rental price per squared meters obtained from the Luxembourg Statistical Service at municipal level..

Other socioeconomic variables Other socio-economic variables come from the Luxembourg Statistical Service.

Climate data All meteorological data come from the JRC climate database. Grid data (5km $\times$ 5km) on rainfalls, temperatures and evapotranspiration have been aggregated at regional level. We have historical data from 1990 to 2013.

19.4 Empirical analysis of residential water consumption

In this section, we provide a statistical analysis of residential water consumption and water price for Luxembourg.

Table 19.1 gives the annual residential water consumption (m3 per capita and per year) and the water price (average water price, in euros m3) in Luxembourg in 2010. In 2010, the average annual consumption per inhabitant was 51 m3 per capita.

Table 19.1: Household water consumption and price in Luxembourg

Water consumption (m3 per capita per year)	Water price (euros per m3)
51.186	5.697

Table 19.2: Regional household water consumption and price in Luxembourg

Region	Water consumption (m3 per capita per year)	Water price (euros per m3)
Bascharage	36.196	6.530
Bettembourg	36.574	5.880
Diekirch	37.256	6.470
Differdange	30.366	6.330
Ettelbruck	63.717	6.620
Hesperange	42.434	5.720
Luxembourg	66.340	5.230
Mamer	35.561	5.490
Mersch	42.339	5.490
Mondercange	46.828	6.150
Pétange	39.408	5.690
Sanem	32.633	6.630
Schifflange	49.474	4.560
Wiltz	89.401	6.280
Average	51.186	5.697

Table 19.2 provides some statistics for our municipal sample. Notice that we have only a sample made of 14 municipalities. However, these municipalities supply water services to a little bit less than 40% of the total population in the Luxembourg.

19.5 Water demand function estimate

19.5.1 Specifying the residential water demand function

The residential water demand function can be derived from solving the utility optimization problem of a consumer. Under the assumption of a weak separability of water with respect to other goods consumed, the Marshallian demand in water can be written as:

$$y = y^*(p, I, Z) \tag{19.1}$$

where y is the water consumption either per capita or per household, p and I denote the unit water price (representing both water supply and the sewage treatment services) and the representative household income, respectively. Z is a vector of exogenous variables assumed to influence water consumption (climate conditions, household and housing characteristics, etc.).

To estimate Equation (19.1), a wide variety of functional forms have been applied in the water demand literature, including linear forms, semi or double logarithm forms and more complex forms such as the Stone-Geary specification. The existing literature is however not very informative concerning the specification which should be preferred. Since the double-log model is the most common specification in the residential water demand literature, we have adopted this model in order to facilitate comparison to other studies. Furthermore, the specification implies that coefficient estimates are also elasticity estimates. With a double-log specification, the residential water demand function writes:

$$\ln(y) = \alpha \ln(p) + \beta \ln(I) + \gamma \ln(Z)' \tag{19.2}$$

and the coefficients α and β can be directly interpreted as the price and the income elasticities of the water demand. Specification tests for the functional form will be conducted in the empirical part but we don't expect the choice of the particular form to have a fundamental influence on the estimation of the parameters of interest.

19.5.2 Estimation methods

Let $i = \{1, .., I\}$ indexes municipalities. Our equation of interest becomes:

$$\ln(y_i) = \alpha \ln(p_i) + \beta \ln(I_i) + \gamma \ln(Z_i)' + \epsilon_i \tag{19.3}$$

where ϵ_i is the usual random term.

19.5.3 Results

We report here our estimate for the residential water demand function in Luxembourg. The model in Table 19.3 corresponds to simple OLS.

The price elasticity varies is found to be -1.3, but is not significantly different from zero.

The income elasticity is equal to 0.39 but is not significantly different from zero.

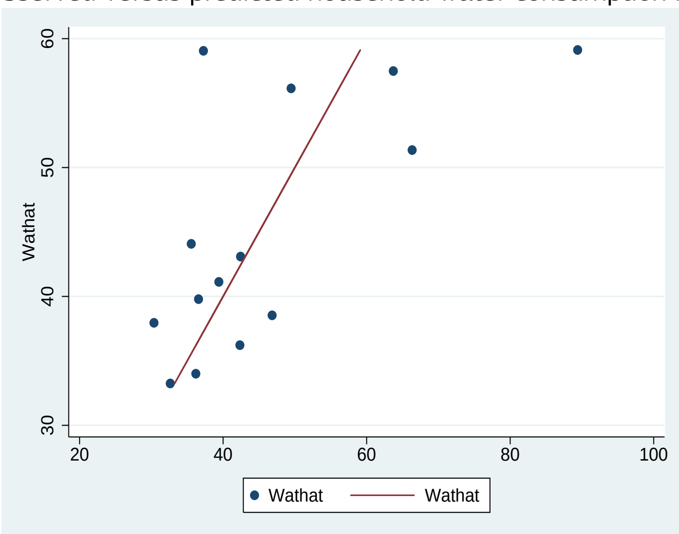
Climate conditions (summer precipitations) have a significant impact on household water consumption.

Table 19.3: Estimation of the household water demand

	LuxembourgOLS b/se
$\ln$ Water price (in euros per m3)	-1.289
	(0.84)
$\ln$ Household income (in euros per capita)	0.392
	(0.91)
$\ln$ Average age of the population	-0.020
	(2.37)
$\ln$ Average of daily rainfall in summer (mm per day)	-8.670**
	(3.36)
Constant	54.299**
	(18.40)
R-squared	0.467
N. of obs.	14.000

A possible way to assess the validity of the model is to compare the water consumption predicted by the demand function to the observed water consumption, see Figure 19.1. For most of the municipalities the model performs quite well. The mean absolute percentage error is 17.3.

Figure 19.1: Observed versus predicted household water consumption in Luxembourg



Chapter 20

Malta

20.1 Existing literature

Delia (2004) presents the results of an econometric analysis of residential water demand in Malta, based on annual data for years 1989 to 1999 (country-level time series). The price elasticity is shown to be significant and equal to -0.36 whereas the income elasticity is estimated to be 0.25.

20.2 Urban water sector in Malta

The Water Services Corporation (WSC) is a public utility body responsible for the supply, production and distribution of water in the Maltese Islands. It was set up by the Maltese Parliament in the Water Services Act XXIII 1991. The WSC operates desalination plants and it manages the municipal water distribution network.

20.3 Data

We use time-series national data on household water consumption, household water price, household's socioeconomic conditions income and on climate condition for years 2000 to 2010 (11 years). Most of the data come from the National Statistics Office of Malta. The data consist of aggregate national data on water consumption per capita and water and sewerage prices. The data have been combined with information on household's income, climate conditions, and household characteristics mainly from the Malta Statistical Service.

Water consumption data We rely on difference publication of the National Statistics Office of Malta (Environment Statistics report, Malta in Figures). From the Malta Statistical Service we have the annual volume of water billed to households users from the public water network from 1995 to 2010. The volume of water has been divided by the total population (around 100% of the population is connection to the public water supply in Malta). Our endogenous variable is then the annual water consumption per capita to the public water supply network (in m3 per year per capita).

Water price data Data come from the Central Bank of Malta which provides the price index for *Water services*. This index has been used for computing an average national price for water (the average price of water for household was 0.32 Lira per cubic meters in 2000).

Household income We use the household disposable income per capita available from the household budgetary surveys conducted by the National Statistics Office of Malta.

Other socioeconomic variables Other socio-economic variables from 2000 to 2011 come from the Malta Statistical Service.

Climate data All meteorological data come from the JRC climate database. Grid data (5km $\times$ 5km) on rainfalls, temperatures and evapotranspiration have been aggregated at regional level. We have historical data from 1990 to 2013.

20.4 Empirical analysis of residential water consumption

In this section, we provide a statistical analysis or residential water consumption and water price for Malta.

Table 20.1: Household water consumption and price in Malta

Year	Water consumption (m3 per capita per year)	Water price (euros per m3)
1995	32.204	0.711
1996	34.794	0.711
1997	36.875	0.712
1998	27.975	0.701
1999	29.217	0.701
2000	29.621	0.746
2001	28.988	0.743
2002	30.989	0.781
2003	31.560	0.781
2004	31.887	0.781
2005	27.605	0.891
2006	26.564	1.102
2007	27.413	1.147
2008	27.234	1.119
2009	27.347	1.769
2010	25.825	1.832
Average	29.756	0.952

Table 20.1 gives the annual residential water consumption (m3 per capita and per year) and the water price (average water price, in euros m3) in Malta from 1995 to 2010. In 2010, the average annual consumption per inhabitant amounted to 25.8 m3. There has been a decreasing trend in domestic water consumption since 2003. The average water price in 2012 was 1.8 euros per m3. It has steadily increased since 1995.

20.5 Water demand function estimate

20.5.1 Specifying the residential water demand function

The residential water demand function can be derived from solving the utility optimization problem of a consumer. Under the assumption of a weak separability of water with respect to other goods consumed, the Marshallian demand in water can be written as:

$$y = y^*(p, I, Z) \tag{20.1}$$

where y is the water consumption either per capita or per household, p and I denote the unit water price (representing both water supply and the sewage treatment services) and the representative household income, respectively. Z is a vector of exogenous variables assumed to influence water consumption (climate conditions, household and housing characteristics, etc.).

To estimate Equation (20.1), a wide variety of functional forms have been applied in the water demand literature, including linear forms, semi or double logarithm forms and more complex forms such as the Stone-Geary specification. The existing literature is however not very informative concerning the specification which should be preferred. Since the double-log model is the most common specification in the residential water demand literature, we have adopted this model in order to facilitate comparison to other studies. Furthermore, the specification implies that coefficient estimates are also elasticity estimates. With a double-log specification, the residential water demand function writes:

$$\ln(y) = \alpha \ln(p) + \beta \ln(I) + \gamma \ln(Z)' \tag{20.2}$$

and the coefficients α and β can be directly interpreted as the price and the income elasticities of the water demand. Specification tests for the functional form will be conducted in the empirical part but we don't expect the choice of the particular form to have a fundamental influence on the estimation of the parameters of interest.

20.5.2 Estimation methods

Let $t = \{1, .., T\}$ indexes years. Our equation of interest becomes:

$$\ln(y_t) = \alpha \ln(p_t) + \beta \ln(I_t) + \gamma \ln(Z_t)' + \epsilon_t \tag{20.3}$$

where ϵ_t is the usual random term.

20.5.3 Results

We report here our estimate for the residential water demand function in Malta. The model in Table 20.2 corresponds to simple OLS.

Table 20.2: Estimation of the household water demand in Malta

	MaltaOLS b/se
$\ln$ Water price (in euros per m3)	-0.311**
	(0.12)
$\ln$ Household income (in euros per capita)	0.436
	(0.41)
$\ln$ annual number of days without rainfalls	-0.309
	(0.26)
Constant	0.759
	(3.74)
R-squared	0.686
N. of obs.	11.000

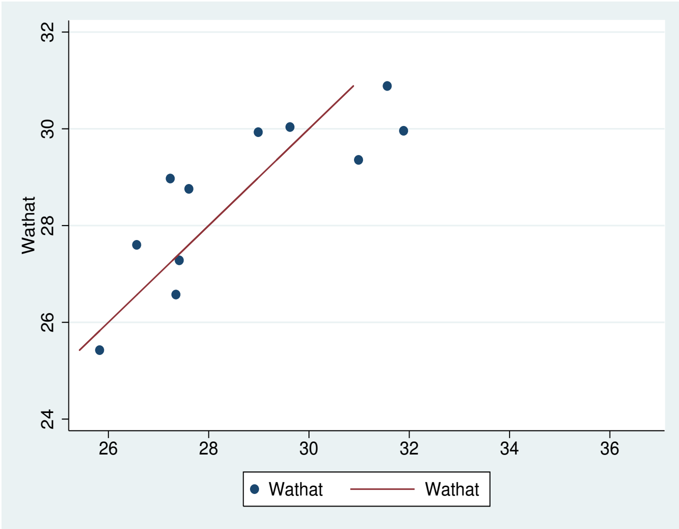
Table 20.2 present the main significant variables explaining household water consumption in Malta. The price elasticity varies is found to be -0.31, and is almost significantly different from zero at 10%. Based on the OLS model, a 10% increase in water price results in a 3.1% decrease in short-run water consumption in Malta. Water demand in Malta is inelastic, i.e. the estimated price elasticity in absolute values is lower than one.

The income elasticity is equal to 0.43, but is not significantly different from zero.

The annual number of days without rainfalls is not significant.

A possible way to assess the validity of the model is to compare the water consumption predicted by the demand function to the observed water consumption, see Figure 20.1. For most of the municipalities the model performs quite well. The mean absolute percentage error is 3.4.

Figure 20.1: Observed versus predicted household water consumption in Malta



Water consumption may to be at least somehow persistent over time due to household habits or due to the time needed to adjust durable equipments (shower for instance). With panel or time-series data, one way to take into this time persistence characteristic of household water consumption is to introduce the lagged consumption as an additional independent variable in Equation (20.2). The dynamic specification of our equation of interest becomes then :

$$\ln(y) = \alpha \ln(p) + \beta \ln(I) + \gamma \ln(Z)' + \mu \ln(\text{Lag}\, y) \tag{20.4}$$

where Lag y represents the lagged water consumption. From this specification is is then possible to derive the long-run price elasticity of the household water demand function which simply writes:

$$\epsilon_p^{LT} = \frac{\alpha}{1-\mu}. \tag{20.5}$$

We provide in Table 20.3 our estimates for the household water demand function where the lagged consumption has been introduced as an additional independent variable. With the MaltaOLSlag model, the long-term price elasticity is estimated to be -0.36 significantly different from zero at 10%.

Table 20.3: Estimation of the household water demand with lagged water consumption in Malta

	MaltaOLSlag
	b/se
$\ln$ Water price (in euros per m3)	-0.269*
	(0.14)
$\ln$ Household income (in euros per capita)	0.464
	(0.43)
$\ln$ annual number of days without rainfalls	-0.237
	(0.29)
$\ln$ Lag of water consumption per capita	0.252
	(0.39)
Constant	-0.762
	(4.57)
R-squared	0.706
N. of obs.	11.000

Source: auto.dta

Chapter 21

Netherlands

21.1 Existing literature

There are some studies having estimated a residential water demand function in Netherlands, but no recent one. Kooreman (1993) has estimated a water demand function on a panel of 60 municipalities in Netherlands (1998-1989). The estimated (short-run) price elasticity of domestic water use in the Netherlands is estimated to be -0.10. Linderhof (2001) uses a pool of 17 cross-sectional Netherlands Expenditure Survey data from 1978 to 1994 to estimate a residential water demand function. The sample used by Linderhof (2001) contains 28,210 households all over the Netherlands. The price and income elasticities of the residential water demand in the Netherlands are estimated to be -0.07 and 0.11, respectively.

21.2 Urban water sector in Netherlands

In Netherlands, there are 10 water distribution companies operating at the end of 2010. The water companies are public limited companies. Shareholders are the municipalities and provinces.

According to Vevin (2012), Dutch drinking water sales have showed a considerable increase over the previous century: from around 300 million m3 in 1950 to around 870 million m3 in 1970 and subsequently to 1,236 million m3 in 1990. Between 1990 and 1995 sales levels remained more or less stable. Between 1995 and 2004 the volume has started to decline to the current level of approximately 1147 million m3 per year (in 2010).

21.3 Data

Our panel data set consists of Nuts3-level data on household water consumption, household water price, household's socioeconomic conditions income and on climate condition for years 2009-2011. Most of data related to water come from the annual reports published by the Association of Dutch Water Companies (Vewin). Socio-economic variables at regional-level come from Statistics Netherlands, the Dutch National Office of Statistics.

Water consumption data We rely on water utility data from the Vewin for year 2009-2011. We have the annual volume of water sold to households for each water utility in Netherlands for year 2009-2011. To get the annual household water consumption per capita, we have divided this volume by the population connected to the public network in each water utility. The household water consumption in then measure in m3 of water sold to households per capita and per year. The report Vevin (2012) indicates also which municipalities are served by the 10 water services. We have used this information to compute annual household water consumption at Nuts3 for year 2009-2011.

Water price data We rely on water utility data from the Vewin for year 2009-2011. As a price indicator, we use the average price paid by households for the drinking water service (in euro m3 including VAT).

Household income We use the average disposable income (in euros per capita) obtained directly from Statistics Netherlands for years 2009-2011.

Other socioeconomic variables Other socio-economic variables for 2009-2011 comes from Statistics Netherlands.

Climate data All meteorological data come from the JRC climate database. Grid data (5km $\times$ 5km) on rainfalls, temperatures and evapotranspiration have been aggregated at regional level. We have historical data from 1990 to 2013.

21.4 Empirical analysis of residential water consumption

In this section, we provide a statistical analysis or residential water consumption and water price for Netherlands.

Table 21.1: Household water consumption and price in Netherlands

Year	Water consumption (m3 per capita per year)	Water price (euros per m3)
2009	48.093	1.365
2010	47.955	1.396
2011	47.503	1.406
Average	47.849	1.389

Table 21.1 gives the annual residential water consumption (m3 per capita and per year) and the water price (retail water price for cold water in euros per m3) in Netherlands from 2009 to 2011. In 2009, the average annual consumption per inhabitant amounted to 48.09 m3. There has been a decreasing trend in domestic water consumption which started some ten years ago. From 2009 to 2011, the average water price has slightly increased form 1.36 euros per m3 in 2009 to 1.41 euros per m3 in 2011.

Table 21.2: Regional household water consumption and price in Netherlands

Year	Water consumption (m3 per capita per year)	Water price (euros per m3)
Brabant Water	41.237	1.380
Dunea	38.305	1.680
Evides Drinkwater	50.197	1.570
Oasen	41.169	1.780
PWN aterleidingbedrijf Noord-Holland	49.220	1.670
Vitens	49.434	1.310
WML	48.214	1.570
Waterbedrijf Groningen	40.541	1.230
Waterleidingmaat-schappij Drenthe	56.881	1.300
Waternet	50.976	1.690
Average	47.955	1.396

Table 21.2 gives the annual residential water consumption (m3 per capita and per year) and the water price (retail water price for cold water in euros per m3) per water utility in 2010. As it can be seen, there are some differences across water utilities, both in terms of water consumption and water prices.

21.5 Water demand function estimate

21.5.1 Specifying the residential water demand function

The residential water demand function can be derived from solving the utility optimization problem of a consumer. Under the assumption of a weak separability of water with respect to other goods consumed, the Marshallian demand in water can be written as:

$$y = y^*(p, I, Z) \tag{21.1}$$

where y is the water consumption either per capita or per household, p and I denote the unit water price (representing both water supply and the sewage treatment services) and the representative household income, respectively. Z is a vector of exogenous variables assumed to influence water consumption (climate conditions, household and housing characteristics, etc.).

To estimate Equation (21.1), a wide variety of functional forms have been applied in the water demand literature, including linear forms, semi or double logarithm forms and more complex forms such as the Stone-Geary specification. The existing literature is however not very informative concerning the specification which should be preferred. Since the double-log model is the most common specification in the residential water demand literature, we have adopted this model in order to facilitate comparison to other studies. Furthermore, the specification implies that coefficient estimates are also elasticity estimates. With a double-log specification, the residential water demand function writes:

$$\ln(y) = \alpha \ln(p) + \beta \ln(I) + \gamma \ln(Z)' \tag{21.2}$$

and the coefficients α and β can be directly interpreted as the price and the income elasticities of the water demand. Specification tests for the functional form will be conducted in the empirical part but we don't expect the choice of the particular form to have a fundamental influence on the estimation of the parameters of interest.

21.5.2 Estimation methods

Let $i = \{1, .., I\}$ indexes Nuts3 (40) and $t = \{1, .., T\}$ years. Our equation of interest becomes:

$$\ln(y_{it}) = \alpha \ln(p_{it}) + \beta \ln(I_{it}) + \gamma \ln(Z_{it})' + \epsilon_{it} \tag{21.3}$$

where ϵ_{it} is the usual random term. Two panel data estimators may be used namely the fixed effects (or dummy variable) model and the random effects (or error components) model. We propose to use these two estimators and to conduct some specification tests (Hausman test) to decide which is the most appropriate to our data.

21.5.3 Results

We report here our estimate for the residential water demand function in Netherlands, based on our Nuts3 dataset for Netherlands (2009 to 2011). The first model estimated in Table 21.3 corresponds simple OLS whereas in the second model we estimate Equation (21.3) with a random parameter estimator. In the third model, we account for potential endogeneity of the price by using an instrumental variable approach.

Table 21.3 present the main significant variables explaining household water consumption in Netherlands. The price elasticity is estimated to be -0.13 with the GLS model, and the estimated coefficient is significantly different from zero. The price elasticity varies across models, from -0.28 with the OLS to -0.63 with the instrumental variable approach. Based on the NetherlandsGLSiv model, a 10% increase in water price results

Table 21.3: Estimation of the household water demand in the Netherlands

	NetherlandsOLS	NetherlandsGLS	NetherlandsGLSiv
	b/se	b/se	b/se
ln Water price (in euros per m3)	-0.275**	-0.129**	-0.626***
	(0.12)	(0.06)	(0.14)
ln Household income (in euros per capita)	0.201	0.064*	0.230***
	(0.19)	(0.03)	(0.08)
ln Household size	0.013	-0.029	-0.176
	(0.09)	(0.09)	(0.11)
ln summer evapotranspiration	-0.023	0.102***	0.075*
	(0.14)	(0.02)	(0.04)
Constant	2.001	3.165***	1.898***
	(1.88)	(0.34)	(0.72)
R-squared	0.069		
N. of obs.	120.000	120.000	120.000

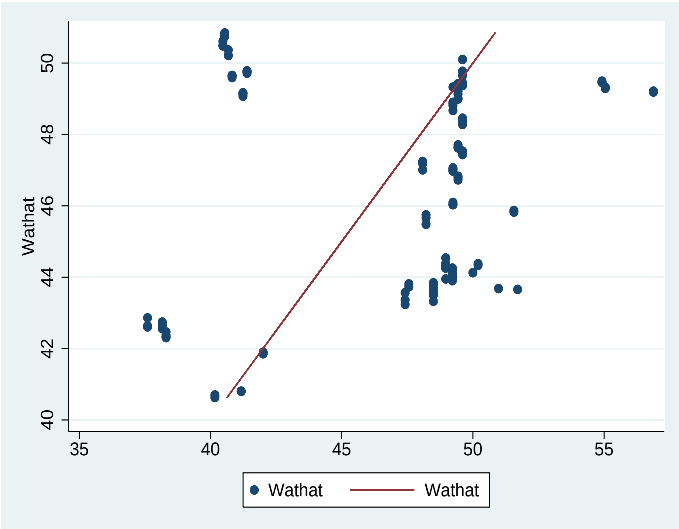
in a 6.3% decrease in short-run water consumption in Netherlands. Water demand in Netherlands is inelastic, i.e. the estimated price elasticity in absolute values is lower than one.

The income elasticity is also quite consistent with the three models. It varies between 0.06 and 0.23 and the income elasticity is significantly different from zero with the GLS and the IV estimators. This suggests that there is an increasing relationship between water consumption and household income. The positive significant coefficient for income indicates that, based on the NetherlandsGLSiv model, a 10% increase in income will result in a 2.3% increase in water consumption.

Climate conditions play also a significant role. According to the NetherlandsGLSiv estimate, increasing the summer evapotranspiration by 10% will result in increasing the residential water consumption by 0.8%.

A possible way to assess the validity of the model is to compare the water consumption predicted by the demand function to the observed water consumption, see Figure 21.1. For most of the municipalities the model performs quite well. The mean absolute percentage error is 9.6.

Figure 21.1: Observed versus predicted household water consumption in the Netherlands



Chapter 22

Poland

22.1 Existing literature

Bartczak, Kopanska, and Raczka (2009) have estimated the demand for water by households in Poland, using panel data from 39 municipal districts over the period 2001-2005. Their survey concentrates on medium- and large-sized cities with population more than 50.000. They found that water demand in urban areas in Poland is rather inelastic. The estimated price elasticity is around -0.2.

22.2 Urban water sector in Poland

Before 1989, water utilities in Poland were organized and managed in a decentralized system (based on county level) but with only a limited autonomy from the central state (Kantor and Horváth 2012). The adoption of the Act on Local Self-Government in March 1990 started a process of decentralization to local authorities. Nowadays, municipalities (*gmina*, the smallest administrative unit in Poland, are the responsible authority for water supply and sanitation connected to public services. The market is highly fragmented with about 2500 gminas (Kantor and Horváth 2012).

Residential water consumption in Poland has changed substantially over the last two decades. Daily water consumption per capita in the beginning of the Nineties was about 140 litres. However by 2005, this figure dropped by nearly 30% (Bartczak, Kopanska, and Raczka 2009).

22.3 Data

Our panel data set consists of Nuts3-level data on household water consumption, household water price, household's socioeconomic conditions income and on climate condition for years 2003-2012. Most of the data come from the Central Statistical Office of Poland (the National Office of Statistics). The data consist of aggregate data at Nuts3-level on water consumption per capita and water and sewerage prices. The data have been combined with information on income, weather, and household characteristics mainly from the Central Statistical office of Poland.

Water consumption data We have used the municipal water consumption per inhabitant (m3 per capita) available year year from 2003 to 2012 from the Central Statistical Office of Poland.

Water price data We rely on price data published by the the Central Statistical Office of Poland . As a price indicator, we use the average price paid by households for cold water (only drinking water service).

Household income We use the average annual available income per capita available from Statistics Poland from from 2003 to 2012 from the Central Statistical Office of Poland.

Other socioeconomic variables Other socio-economic variables from 2003 to 2012 come from the Central Statistical Office of Poland.

Climate data All meteorological data come from the JRC climate database. Grid data (5km $\times$ 5km) on rainfalls, temperatures and evapotranspiration have been aggregated at regional level. We have historical data from 1990 to 2013.

22.4 Empirical analysis of residential water consumption

In this section, we provide a statistical analysis or residential water consumption and water price for Poland.

Table 22.1: Household water consumption and price in Poland

Year	Water consumption (m3 per capita per year)	Water price (euros per m3)
2003	36.908	0.367
2004	35.775	0.397
2005	35.509	0.422
2006	35.598	0.430
2007	34.983	0.456
2008	35.318	0.508
2009	34.781	0.575
2010	34.546	0.622
2011	34.655	0.691
2012	34.618	0.760
2013	34.380	.
Average	35.186	0.523

Table 22.1 gives the annual residential water consumption (m3 per capita and per year) and the water price (average water price, in euros m3) in Poland from 2003 to 2012. In 2012, the average annual consumption per inhabitant amounted to 34.7 m3. There has been a decreasing trend in domestic water consumption from 2003 to 2013. Over the same period, the average water price has increased from 0.4 euros per m3 to 0.8 euros per m3.

Table 22.2 gives the annual residential water consumption (m3 per capita and per year) and the water price per region (Nuts 2) in 2010. As it can be seen, there are some differences across regions, both in terms of water consumption and water prices. With almost 40 m3 per capita per year, the water consumption is the higher in the Mazowieckie region. On contrary, a low water consumption is reported in the Podkarpackie region (24 m3 per capita per year).

22.5 Water demand function estimate

22.5.1 Specifying the residential water demand function

The residential water demand function can be derived from solving the utility optimization problem of a consumer. Under the assumption of a weak separability of water with respect to other goods consumed, the Marshallian demand in water can be written as:

$$y = y^*(p, I, Z) \tag{22.1}$$

where y is the water consumption either per capita or per household, p and I denote the unit water price (representing both water supply and the sewage treatment services) and the representative household income, respectively. Z is a vector of exogenous variables assumed to influence water consumption (climate conditions, household and housing characteristics, etc.).

Table 22.2: Regional household water consumption and price in Poland

	Water consumption (m3 per capita per year)	Water price (euros per m3)
Dolnoslaskie	35.499	0.671
Kujawsko-Pomorsk	36.189	0.551
Lodzkie	37.842	0.553
Lubelskie	29.165	0.482
Lubuskie	33.371	0.692
Malopolskie	29.695	0.643
Mazowieckie	39.834	0.586
Opolskie	32.530	0.578
Podkarpackie	24.466	0.659
Podlaskie	34.180	0.519
Pomorskie	36.503	0.551
Slaskie	33.718	0.869
Swietokrzyskie	27.172	0.600
Warminsko-Mazurs	34.267	0.523
Wielkopolskie	38.804	0.592
Zachodniopomorsk	37.536	0.580
Average	34.546	0.622

To estimate Equation (22.1), a wide variety of functional forms have been applied in the water demand literature, including linear forms, semi or double logarithm forms and more complex forms such as the Stone-Geary specification. The existing literature is however not very informative concerning the specification which should be preferred. Since the double-log model is the most common specification in the residential water demand literature, we have adopted this model in order to facilitate comparison to other studies. Furthermore, the specification implies that coefficient estimates are also elasticity estimates. With a double-log specification, the residential water demand function writes:

$$\ln(y) = \alpha \ln(p) + \beta \ln(I) + \gamma \ln(Z)' \tag{22.2}$$

and the coefficients α and β can be directly interpreted as the price and the income elasticities of the water demand. Specification tests for the functional form will be conducted in the empirical part but we don't expect the choice of the particular form to have a fundamental influence on the estimation of the parameters of interest.

22.5.2 Estimation methods

Let $i = \{1, .., I\}$ indexes Nuts3 and $t = \{1, .., T\}$ years. Our equation of interest becomes:

$$\ln(y_{it}) = \alpha \ln(p_{it}) + \beta \ln(I_{it}) + \gamma \ln(Z_{it})' + \epsilon_{it} \tag{22.3}$$

where ϵ_{it} is the usual random term. Two panel data estimators may be used namely the fixed effects (or dummy variable) model and the random effects (or error components) model. We propose to use these two estimators and to conduct some specification tests (Hausman test) to decide which is the most appropriate to our data.

Table 22.3: Estimation of the household water demand in Poland

	PolandOLS	PolandGLS	PolandGLSiv
	b/se	b/se	b/se
$\ln$ Water price (in euros per m3)	-0.393***	-0.182***	-0.339
	(0.04)	(0.03)	(0.40)
$\ln$ Household income (in euros per capita)	0.555***	0.222***	0.385
	(0.04)	(0.04)	(0.40)
$\ln$ Average of daily rainfall in summer (mm per day)	-0.259***	-0.025***	-0.024*
	(0.02)	(0.01)	(0.01)
$\ln$ Share population below 9	-1.276***	-0.405***	-0.293***
	(0.07)	(0.05)	(0.11)
$\ln$ Share population above 70	-0.671***	-0.515***	-0.615***
	(0.05)	(0.05)	(0.15)
Percentage of population with dishwasher	0.024***	0.009***	0.007***
	(0.01)	(0.00)	(0.00)
Constant	-5.954***	-0.697*	-2.199
	(0.47)	(0.41)	(3.87)
R-squared	0.568		
N. of obs.	660.000	660.000	660.000

22.5.3 Results

We report here our estimate for the residential water demand function in Poland, based on our Nuts3 dataset for Poland (2003 to 2012). The first model estimated in Table 22.3 corresponds simple OLS whereas in the second model we estimate Equation (22.4) with a random parameter estimator. In the third model, we account for potential endogeneity of the price by using an instrumental variable approach.

Table 22.3 present the main significant variables explaining household water consumption in Poland. The price elasticity varies across models, from -0.40 with the OLS to -0.18 with the GLS (not significant with GLSiv). Based on the OLS and GLS models, a 10% increase in water price results in a 1.8% to 4.0% decrease in short-run water consumption in Poland. Water demand in Poland is inelastic, i.e. the estimated price elasticity in absolute values is lower than one.

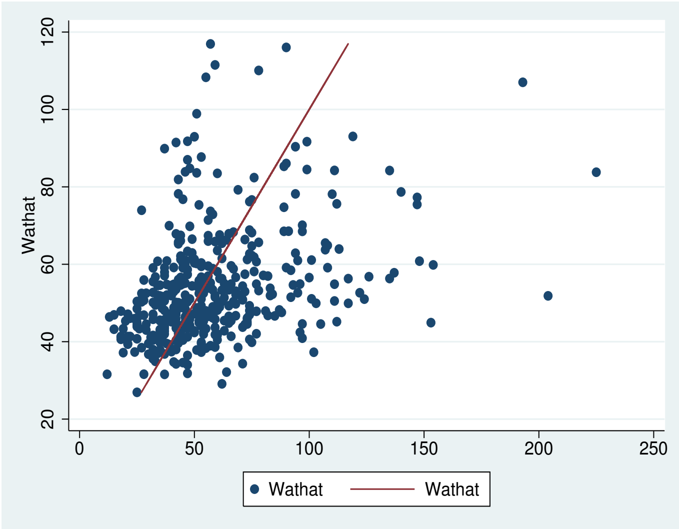
The income elasticity varies between 0.22 and 0.56 and the income elasticity is significantly different from zero with the OLS and the GLS models. This suggests that there is an increasing relationship between water consumption and household income. The positive significant coefficient for income indicates that, based on the GLS model, a 10% increase in income will result in a 2.2% increase in water consumption.

Climate conditions play also a significant role, together with the housing characteristics. An increase of summer rainfall by 10% will imply a reduction in water consumption by 2.6% (OLS model).

A possible way to assess the validity of the model is to compare the water consumption predicted by the demand function to the observed water consumption, see Figure 22.1. For most of the municipalities the model performs quite well. The mean absolute percentage error is 14.7.

Water consumption may to be at least somehow persistent over time due to household habits or due to the time needed to adjust durable equipments (shower for instance). With panel or time-series data, one way to take into this time persistence characteristic of household water consumption is to introduce the lagged consumption

Figure 22.1: Observed versus predicted household water consumption in Poland



as an additional independent variable in Equation (22.2). The dynamic specification of our equation of interest becomes then :

$$\ln(y) = \alpha \ln(p) + \beta \ln(I) + \gamma \ln(Z)' + \mu \ln(\text{Lag}\, y) \tag{22.4}$$

where Lag y represents the lagged water consumption. From this specification is is then possible to derive the long-run price elasticity of the household water demand function which simply writes:

$$\epsilon_p^{LT} = \frac{\alpha}{1-\mu}. \tag{22.5}$$

We provide in Table 22.4 our estimates for the household water demand function where the lagged consumption has been introduced as an additional independent variable. With the PolandGLSlag model, the long-term price elasticity is estimated to be -0.25 almost significantly different from zero at 10%. With the PolandGLSivlag model, the long-term price elasticity is estimated to be -1.30 but is not significantly different from zero at 10%.

Table 22.4: Estimation of the household water demand with lagged water consumption in Poland

	PolandGLSlag	PolandGLSivlag
	b/se	b/se
$\ln$ Water price (in euros per m3)	-0.013	-0.511
	(0.01)	(0.47)
$\ln$ Household income (in euros per capita)	0.038***	0.499
	(0.01)	(0.45)
$\ln$ Average of daily rainfall in summer (mm per day)	-0.029***	-0.037**
	(0.01)	(0.02)
$\ln$ Lag of water consumption per capita	0.946***	0.609***
	(0.01)	(0.06)
Constant	-0.128	-3.297
	(0.08)	(4.02)
R-squared		
N. of obs.	594.000	594.000

Chapter 23

Portugal

23.1 Existing literature

Martins and Adelino (2007) have used a panel data sample of 5 municipalities located in the Centre Region of Portugal with monthly observations from January 1998 to December 2003. They report a price elasticity equal to -0.558. The air temperature variable is statistically significant with a positive coefficient, suggesting that high temperatures increase the demand for water.

Monteiro and Roseta-Palma (2011) have estimated a residential water demand function based on annual data for the years 1998, 2000, 2002, and 2005 on water consumption and water and wastewater tariffs for 278 municipalities in mainland Portugal. Depending upon the model they consider, the price elasticity of the Portugese water demand varies between -0.133 and -0.051. The income elasticity is not found to be significantly different from zero. Climate condition matter. Water demand increases with temperature and decreases with precipitation.

Recently Monteiro, Cardoso, and Figueiredo (2014) have estimated a residential water demand function using a sample of 383 Portuguese households from 10 municipalities spread across mainland Portugal. On average, they report a price elasticity equal to -0.48 and an income elasticity equal to 0.254.

23.2 Urban water sector in Portugal

There are 21 utilities operating in the Portuguese wholesale market. Three of them provide drinking water, six just wastewater services and 12 drinking water and wastewater services together (Cruz, Marques, Romano, and Guerrini 2012). One of these entities is a private concessionaire while the other 20 are public. At retail level, this sector is fairly fragmented. According to ERSAR (2013), it is composed by a high number of operators, 380, generally small and focused on providing the service inside each municipality. More than half the population is served by retail services under direct management in 70% of the municipalities. In this sector, municipalities are the most common submodel, providing this service to nearly 3.1 million inhabitants in 191 administrative territories. A relatively high number (113) of very small operators is still active, namely parishes and consumers' associations, and serve 77 thousand inhabitants.

23.3 Data

Our panel data set consists of municipality-level data on household water consumption, household water price, household's socioeconomic conditions income and on climate condition for years 2007 and 2009. Most of the data come from Statistics Portugal (the National Office of Statistics) and from the Water and Waste Services Regulation Authority (ERSAR) for what concerns water and sewerage prices. The data consist of aggregate data at municipal-level on water consumption per capita and water and sewerage prices. The data have been combined with information on income, weather, and household characteristics mainly from the the National Statistics Institute.

Water consumption data We have used the municipal water consumption per inhabitant (m3/ inhab.) available for years 2007 and 2009 from Statistics Portugal. Data source is the *Inventário Nacional de Sistemas de Abastecimento de Água e de Águas Residuais*.

Water price data We rely on price data published by the Water and Waste Services Regulation Authority (ERSAR). As a price indicator, we use the average price paid by households for the drinking water service and the wastewater service (in euro m3 for an annual water consumption equal to 120 m3).

Household income We use the average annual earning (euros per capita) available from Statistics Portugal from 2006 to 2009.

Other socioeconomic variables Other socio-economic variables for 2008-2011 comes from Statistics Portugal.

Climate data All meteorological data come from the JRC climate database. Grid data (5km $\times$ 5km) on rainfalls, temperatures and evapotranspiration have been aggregated at regional level. We have historical data from 1990 to 2013.

23.4 Empirical analysis of residential water consumption

In this section, we provide a statistical analysis or residential water consumption and water price for Portugal.

Table 23.1: Household water consumption and price in Portugal

Year	Water consumption (m3 per capita per year)	Water price (euros per m3)
2006	50.431	.
2007	54.355	1.123
2008	59.693	.
2009	63.523	1.229
Average	56.672	1.174

Table 23.1 gives the annual residential water consumption (m3 per capita and per year) and the water price (average water and wasterwater price for 120 m3, in euros m3) in Portugal from 2006 to 2009. In 2009, the average annual consumption per inhabitant amounted to 63.5 m3. There has been an increasing trend in domestic water consumption from 2006 to 2009. Over the same period, the average water price has increased from 1.12 euros per m3 to 123 euros per m3.

Table 23.2 gives the annual residential water consumption (m3 per capita and per year) and the water price per region (Nuts 2) in 2010. As it can be seen, there are some differences across regions, both in terms of water consumption and water prices. With almost 138 m3 per capita per year, the water consumption is the higher in Algarve. On contrary, a low water consumption is reported in the Ave region.

23.5 Water demand function estimate

23.5.1 Specifying the residential water demand function

The residential water demand function can be derived from solving the utility optimization problem of a consumer. Under the assumption of a weak separability of water with respect to other goods consumed, the Marshallian demand in water can be written as:

$$y = y^*(p, I, Z) \tag{23.1}$$

where y is the water consumption either per capita or per household, p and I denote the unit water price (representing both water supply and the sewage treatment services) and the representative household income,

Table 23.2: Regional household water consumption and price in Portugal

	Water consumption (m3 per capita per year)	Water price (euros per m3)
Alentejo Central	76.749	0.986
Alentejo Litoral	92.112	0.908
Algarve	137.764	1.164
Alto Alentejo	62.297	0.791
Alto Trás-os-Montes	59.346	0.963
Ave	26.216	1.263
Baixo Alentejo	63.083	0.885
Baixo Mondego	100.824	1.197
Baixo Vouga	69.185	1.279
Beira Interior Norte	65.957	1.419
Beira Interior Sul	72.173	1.604
Cova da Beira	44.554	1.847
Cávado	56.803	1.122
Douro	51.355	1.223
Dâo-Lafôes	42.688	1.008
Entre Douro e Vouga	23.589	1.548
Grande Lisboa	58.253	1.164
Grande Porto	67.754	1.395
LezÃŋria do Tejo	75.085	0.848
Minho-Lima	45.591	1.329
Médio Tejo	59.073	1.314
Oeste	59.730	1.840
Península de Setúbal	89.870	1.159
Pinhal Interior Norte	45.997	0.866
Pinhal Interior Sul	46.234	0.714
Pinhal Litoral	74.588	1.374
Serra da Estrela	32.366	1.335
Tâmega	32.150	1.249
Average	63.523	1.229

respectively. Z is a vector of exogenous variables assumed to influence water consumption (climate conditions, household and housing characteristics, etc.).

To estimate Equation (23.1), a wide variety of functional forms have been applied in the water demand literature, including linear forms, semi or double logarithm forms and more complex forms such as the Stone-Geary specification. The existing literature is however not very informative concerning the specification which should be preferred. Since the double-log model is the most common specification in the residential water demand literature, we have adopted this model in order to facilitate comparison to other studies. Furthermore, the specification implies that coefficient estimates are also elasticity estimates. With a double-log specification, the residential water demand function writes:

$$\ln(y) = \alpha \ln(p) + \beta \ln(I) + \gamma \ln(Z)' \tag{23.2}$$

and the coefficients α and β can be directly interpreted as the price and the income elasticities of the water demand. Specification tests for the functional form will be conducted in the empirical part but we don't expect the choice of the particular form to have a fundamental influence on the estimation of the parameters of interest.

23.5.2 Estimation methods

Let $i = \{1, .., I\}$ indexes municipalities and $t = \{1, .., T\}$ years. Our equation of interest becomes:

$$\ln(y_{it}) = \alpha \ln(p_{it}) + \beta \ln(I_{it}) + \gamma \ln(Z_{it})' + \epsilon_{it} \tag{23.3}$$

where ϵ_{it} is the usual random term. Two panel data estimators may be used namely the fixed effects (or dummy variable) model and the random effects (or error components) model. We propose to use these two estimators and to conduct some specification tests (Hausman test) to decide which is the most appropriate to our data.

23.5.3 Results

We report here our estimate for the residential water demand function in Portugal, based on our municipal dataset for Portugal (2007 and 2011). The first model estimated in Table 23.3 corresponds simple OLS whereas in the second model we estimate Equation (23.3) with a random parameter estimator. In the third model, we account for potential endogeneity of the price by using an instrumental variable approach.

The price elasticity is estimated to be -0.02 with the GLS model, and the estimated coefficient is significantly different from zero.

Table 23.3 present the main significant variables explaining household water consumption in Portugal. The price elasticity varies across models, from -0.269 with the GLSiv to -0.00 with the OLS (not significant with OLS or GLS). Based on the GLSiv model, a 10% increase in water price results in a 2.7% decrease in short-run water consumption in Portugal. Water demand in Portugal is inelastic, i.e. the estimated price elasticity in absolute values is lower than one.

The income elasticity is quite consistent with all models. It varies between 0.67 and 0.84 and the income elasticity is significantly different from zero with the three models. This suggests that there is an increasing relationship between water consumption and household income. The positive significant coefficient for income indicates that, based on the GLSiv model, a 10% increase in income will result in a 8.4% increase in water consumption.

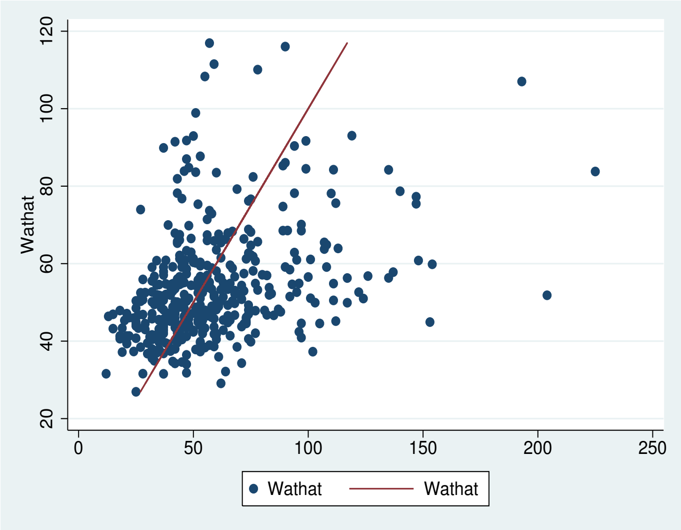
Climate conditions play also a significant role, together with the housing characteristics. An increase of summer rainfall by 10% will imply a reduction in water consumption by 2%.

Table 23.3: Estimation of the household water demand in Portugal

	PortugalOLS	PortugalGLS	PortugalGLSiv
	b/se	b/se	b/se
$\ln$ Water price (in euros per m3)	-0.007	-0.020	-0.269*
	(0.04)	(0.05)	(0.15)
$\ln$ Household income (in euros per capita)	0.673***	0.690***	0.840***
	(0.14)	(0.16)	(0.17)
$\ln$ Average of summer rainfall (in mm per day)	-0.217***	-0.154***	-0.200***
	(0.03)	(0.03)	(0.04)
$\ln$ Share population below 14	-0.261**	-0.240*	-0.110
	(0.11)	(0.13)	(0.15)
Constant	-1.112	-1.170	-1.947*
	(1.00)	(1.16)	(1.14)
R-squared	0.209		
N. of obs.	419.000	419.000	419.000

A possible way to assess the validity of the model is to compare the water consumption predicted by the demand function to the observed water consumption, see Figure 23.1. For most of the municipalities the model performs quite well. The mean absolute percentage error is 36.0.

Figure 23.1: Observed versus predicted household water consumption in Portugal



Chapter 24

Romania

24.1 Existing literature

Ciomos, Ciataras, and Alina (2012) estimate a residential water demand function using time-series data (9 years from 2002 to 2010) for the municipality of Cluj-Napoca, Romania. They report a price elasticity equal to of -0.70.

24.2 Urban water sector in Romania

Before 1990, water utilities in Romania operated as public services at county level (42 multi-utilities at county), without any central authority or ministry who coordinated their activities (Vinke-de Kruijf, Dinica, and Augustijn 2009). Infrastructure was owned by county councils who had integrated public companies taking care of most public services (e.g. water, waste and energy). After 1990, the organization of water services changed. Romania returned to the local autonomy principle and major responsibilities have been transferred to the local communities (more than 800 services). After 2000, a process of regrouping utilities at regional level started.

According to the National Regulatory Authority for Municipal Services (ANRSC), there are in 2011 a little bit more than 1000 water supply and sewage in Romania including, 42 regional operators, 2 large municipal utilities and 200 local utilities (serving 10% of the population). Frone and Frone (2013) indicate that in 2009 the situation of the development of water and wastewater infrastructures was still critical in Romania, especially in rural areas. The main problematic issues were inadequate water treatment, poor sewerage network and low access to water and wastewater systems. According to ANRSC, the percentage of the population connected to the water supply network was 56.5% in 2011, 60% in 2012 and approximately 64% in 2013. Most of the water consumption is metered (90%).

24.3 Data

Our panel data set consists of Nuts3-level data on household water consumption, household water price, household's socioeconomic conditions income and on climate condition for years 2000-2012. Most of the data come from the National Institute of Statistics of Romania. The data consist of aggregate data at Nuts3-level on water consumption per capita and water and sewerage prices. The data have been combined with information on income, weather, and household characteristics mainly from the National Institute of Statistics of Romania.

Water consumption data We have the quantity of drinking water supplied to household by Nuts3 from 2000 to 2012, together with the population connected to public water supply for each county and year (National Institute of Statistics of Romania). We have then computed the annual household water consumption per connected inhabitant (m3 per capita) in each county from 2003 to 2012.

Water price data Water prices come from the International Benchmarking Network for Water and Sanitation Utilities (IBNET) and are available at the water utility-level from 2000 to 2010. Water services have been matched to their respective Nuts3 (Nuts3 without a water service in the IBNET database are given a water price corresponding to the national average). As a price indicator, we use the average price (euros per m3) paid by households for the water service (based on a household annual water consumption equal to 72 m3).

Household income We use the GDP per capita available from the National Institute of Statistics of Romania from 1995 to 2010 (Nuts2-level)

Other socioeconomic variables Other socio-economic variables from 2000 to 2012 come from the National Institute of Statistics of Romania.

Climate data All meteorological data come from the JRC climate database. Grid data (5km $\times$ 5km) on rainfalls, temperatures and evapotranspiration have been aggregated at regional level. We have historical data from 1990 to 2013.

24.4 Empirical analysis of residential water consumption

In this section, we provide a statistical analysis or residential water consumption and water price for Romania.

Table 24.1: Household water consumption and price in Romania

Year	Water consumption (m3 per capita per year)	Water price (euros per m3)
2000	105.047	0.240
2001	94.234	0.202
2002	77.763	0.220
2003	68.632	0.525
2004	66.883	0.511
2005	60.157	0.701
2006	60.866	0.729
2007	61.151	0.885
2008	60.987	1.267
2009	57.285	0.966
2010	55.803	0.807
2011	54.371	.
2012	55.253	.
Average	67.802	0.809

Table 24.1 gives the annual residential water consumption (m3 per capita and per year) and the water price (average water price, in euros m3) in Romania from 2003 to 2012. In 2012, the average annual consumption per inhabitant amounted to 55.2 m3. There has been a decreasing trend in domestic water consumption from 2000 to 2012. The water consumption per capita has been almost divided by two. Over the period 2000 to 2010, the average water price has increased from 0.2 euros per m3 to 0.8 euros per m3.

Table 24.2 gives the annual residential water consumption (m3 per capita and per year) and the water price per region (Nuts 3) in 2010. As it can be seen, there are some differences across Nuts3, both in terms of water consumption and water prices. With more than 100 m3 per capita per year, the water consumption is the higher in the Dolj Nuts3. On contrary, a low water consumption is reported in the Botosani district (29 m3 per capita per year).

24.5 Water demand function estimate

Table 24.2: Regional household water consumption and price in Romania

	Water consumption (m3 per capita per year)	Water price (euros per m3)
Alba	41.516	0.588
Arad	45.771	1.205
Arges	47.626	0.342
Bacau	44.217	.
Bihor	46.871	.
Bistrita-Nasaud	46.715	0.829
Botosani	29.527	.
Braila	30.276	0.652
Brasov	54.782	0.989
Bucharest Municipality	96.363	.
Buzau	47.501	0.790
Calarasi	53.465	.
Caras-Severin	47.200	.
Cluj	59.950	0.617
Constanta	57.600	1.106
Covasna	59.182	.
Dambovita	37.106	.
Dolj	101.360	.
Galati	50.231	.
Giurgiu	44.825	.
Gorj	56.756	.
Harghita	49.272	0.617
Hunedoara	43.370	.
Ialomita	49.994	.
Iasi	58.339	1.049
Ilfov	85.093	.
Maramures	53.931	0.691
Mehedinti	50.884	0.718
Mures	38.292	0.812
Neamt	35.803	.
Olt	71.798	.
Prahova	35.266	.
Salaj	52.898	.
Satu Mare	38.984	0.827
Sibiu	79.000	0.684
Suceava	45.184	.
Teleorman	77.356	.
Timis	55.331	0.635
Tulcea	46.276	.
Valcea	48.567	.
Vaslui	45.256	.
Vrancea	51.658	1.245
Average	55.803	0.807

24.5.1 Specifying the residential water demand function

The residential water demand function can be derived from solving the utility optimization problem of a consumer. Under the assumption of a weak separability of water with respect to other goods consumed, the Marshallian demand in water can be written as:

$$y = y^*(p, I, Z) \tag{24.1}$$

where y is the water consumption either per capita or per household, p and I denote the unit water price (representing both water supply and the sewage treatment services) and the representative household income, respectively. Z is a vector of exogenous variables assumed to influence water consumption (climate conditions, household and housing characteristics, etc.).

To estimate Equation (24.1), a wide variety of functional forms have been applied in the water demand literature, including linear forms, semi or double logarithm forms and more complex forms such as the Stone-Geary specification. The existing literature is however not very informative concerning the specification which should be preferred. Since the double-log model is the most common specification in the residential water demand literature, we have adopted this model in order to facilitate comparison to other studies. Furthermore, the specification implies that coefficient estimates are also elasticity estimates. With a double-log specification, the residential water demand function writes:

$$\ln(y) = \alpha \ln(p) + \beta \ln(I) + \gamma \ln(Z)' \tag{24.2}$$

and the coefficients α and β can be directly interpreted as the price and the income elasticities of the water demand. Specification tests for the functional form will be conducted in the empirical part but we don't expect the choice of the particular form to have a fundamental influence on the estimation of the parameters of interest.

24.5.2 Estimation methods

Let $i = \{1, .., I\}$ indexes Nuts3 and $t = \{1, .., T\}$ years. Our equation of interest becomes:

$$\ln(y_{it}) = \alpha \ln(p_{it}) + \beta \ln(I_{it}) + \gamma \ln(Z_{it})' + \epsilon_{it} \tag{24.3}$$

where ϵ_{it} is the usual random term. Two panel data estimators may be used namely the fixed effects (or dummy variable) model and the random effects (or error components) model. We propose to use these two estimators and to conduct some specification tests (Hausman test) to decide which is the most appropriate to our data.

24.5.3 Results

We report here our estimate for the residential water demand function in Romania, based on our Nuts3 dataset for Romania (2000 to 2010). The first model estimated in Table 24.3 corresponds simple OLS whereas in the second model we estimate Equation (24.4) with a random parameter estimator. In the third model, we account for potential endogeneity of the price by using an instrumental variable approach.

Table 24.3 present the main significant variables explaining household water consumption in Romania. The price elasticity varies across models, from -0.58 with the GLSiv to 0.00 with the GLS (not significant with OLS and GLS). Based on the GLSiv model, a 10% increase in water price results in a 5.8% decrease in short-run water consumption in Romania. Water demand in Romania is inelastic, i.e. the estimated price elasticity in absolute values is lower than one.

Table 24.3: Estimation of the household water demand in Romania

	RomaniaOLS	RomaniaGLS	RomaniaGLSiv
	b/se	b/se	b/se
ln Water price (in euros per m3)	-0.097	0.000	-0.580**
	(0.07)	(0.05)	(0.27)
ln Household income (in euros per capita)	-0.130	-0.205***	0.255
	(0.09)	(0.07)	(0.23)
ln annual number of days without rainfalls	0.126	0.455***	0.467*
	(0.18)	(0.15)	(0.28)
Share population below 15	-0.100	2.706	1.837
	(2.48)	(2.40)	(3.15)
Constant	4.566**	3.246**	-1.327
	(1.75)	(1.30)	(3.75)
R-squared	0.128		
N. of obs.	124.000	124.000	124.000

Figure 24.1: Observed versus predicted household water consumption in Romania

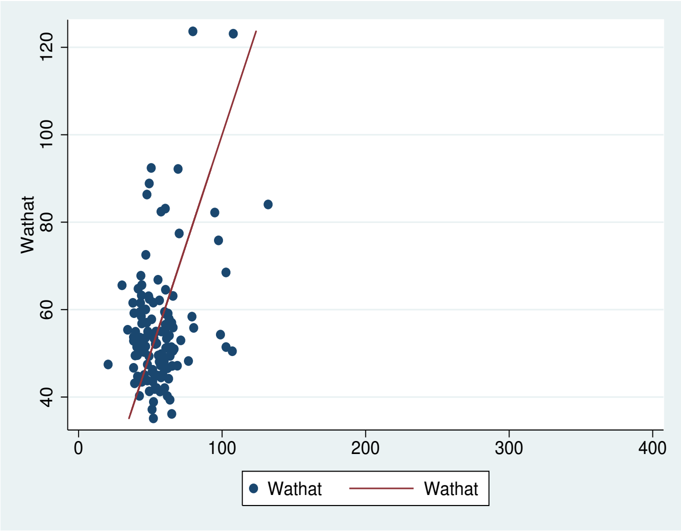


Table 24.4: Estimation of the household water demand with lagged water consumption in Romania

	RomaniaGLSlag	RomaniaGLSivlag
	b/se	b/se
$\ln$ Water price (in euros per m3)	-0.037	-0.125
	(0.05)	(0.23)
$\ln$ Household income (in euros per capita)	-0.072	0.046
	(0.06)	(0.18)
$\ln$ annual number of days without rainfalls	0.256*	0.232
	(0.15)	(0.22)
$\ln$ Lag of water consumption per capita	0.402***	0.531***
	(0.07)	(0.08)
Constant	1.716	0.161
	(1.14)	(2.69)
R-squared		
N. of obs.	124.000	124.000

Source: auto.dta

The income elasticity varies between 0.20 and 0.26 and the income elasticity is significantly different from zero only with the GLS models.

Climate conditions play also a significant role. An increase by 10% of the number of days without any rainfall will imply a increase in water consumption by 4.7% (GLSiv model).

A possible way to assess the validity of the model is to compare the water consumption predicted by the demand function to the observed water consumption, see Figure 24.1. For most of the regions the model performs quite well. The mean absolute percentage error is 25.9.

Water consumption may to be at least somehow persistent over time due to household habits or due to the time needed to adjust durable equipments (shower for instance). With panel or time-series data, one way to take into this time persistence characteristic of household water consumption is to introduce the lagged consumption as an additional independent variable in Equation (24.2). The dynamic specification of our equation of interest becomes then :

$$\ln(y) = \alpha \ln(p) + \beta \ln(I) + \gamma \ln(Z)' + \mu \ln(\text{Lag}\, y) \tag{24.4}$$

where Lag y represents the lagged water consumption. From this specification is is then possible to derive the long-run price elasticity of the household water demand function which simply writes:

$$\epsilon_p^{LT} = \frac{\alpha}{1-\mu}. \tag{24.5}$$

We provide in Table 24.4 our estimates for the household water demand function where the lagged consumption has been introduced as an additional independent variable. With the RomaniaGLSlag model, the long-term price elasticity is estimated to be -0.06 but not significantly different from zero at 10%. With the RomaniaGLSivlag model, the long-term price elasticity is estimated to be -0.27 again not significantly different from zero at 10%.

Chapter 25

Slovakia

25.1 Existing literature

Dalmas and Reynaud (2005) investigates the residential water demand in the Slovak Republic. The demand model is estimated on a sample of 71 municipalities observed from 1999 to 2001. Three different functional forms for water demand have been estimated and compared: a lin-lin specification, a log-log form and a Stone-Geary function. Dalmas and Reynaud (2005) find that the residential water demand in the Slovak Republic appears to be inelastic, but imperfectly, with the three econometric specifications. Using the Stone-Geary specification for instance, they get a short-term price elasticity varying from -0.35 to -0.50. Slovak consumers are price reactive and the water price can be used as an economic tool to indicate resource scarcity. Second, the price sensitivity threshold using the Stone-Geary specification is estimated at 31.5 cubic meters per person and per year, a level still lower than the average water consumption per person in 2001, 41.5 cubic meters.

25.2 Urban water sector in Slovakia

Municipalities as asset owners are responsible for water services provision in the Slovak Republic (WorldBank 2015e). The most dominant model is the mixed-capital operating company in which municipalities own the majority of shares. Ten mixed capital companies provide services to 60% of the population. Only 3 privately owned companies (separate model) provide service to 20% of the population, on the basis of long-term concession contracts. Another 4 purely municipal companies render services to 2% of the population, and 400 village administrations provide water to 5% of inhabitants living in rural areas. The remaining inhabitants rely on self-provision (13%). All utilities provide both water and wastewater services (WorldBank 2015e).

According to MinistryEnvironment (2011), 86.56% out of the population of the Slovak Republic was connected to the public water supply network. In 2010 the number of municipalities with public water supply network was 2,297 which is 79.5% of the total number of municipalities of the Slovak Republic. The level of public water supply network is not the same in all regions (picture on the page 35). The highest share of supplied inhabitants is in Bratislava region.

25.3 Data

Our panel data set consists of Nuts3-level (county) data on household water consumption, household water price, household's socioeconomic conditions income and on climate condition for years 2001-2011. Most of the data come from the Statistical Office of the Slovak Republic. The data consist of aggregate data at Nuts3-level on water consumption per capita and water and sewerage prices. The data have been combined with information on household's income, climate conditions, and household characteristics mainly from Statistics Slovakia.

Water consumption data From the Statistical Office of Slovakia we have the annual volume of water supplied to urban users from the public water network from 2002 to 2012 at Nuts3 level (this volume can be invoiced or not invoiced). We have used the annual national percentage of water used by households to get the annual volume of water supplied to household from the public water network from 2002 to 2012 at Nuts3 level. The volume of water has been divided by the population connected to the water network in each Nuts 3 (total population multiplied by the share of the population served by the water network). Our dependent variable is then the annual water consumption per connected capita to the public water supply network (in m3 per year per capita).

Water price data Data are annually published by the Ministry of Agriculture, Water and Soil Management (Green Reports on Water Management in the Slovak Republic). The price includes a 10 percent VAT on water services. The water price corresponds to an average price (euros per m3) for the drinking water supply service and the wastewater water service. The water price is available only at the national level.

Household income We use the average disposable household income (euros per year per capita) available from 2000 to 2011 at Nuts3 from the Statistical Office of the Slovak Republic.

Other socioeconomic variables Other socio-economic variables from 2000 to 2011 come from the Statistical Office of the Slovak Republic.

Climate data All meteorological data come from the JRC climate database. Grid data (5km $\times$ 5km) on rainfalls, temperatures and evapotranspiration have been aggregated at regional level. We have historical data from 1990 to 2013.

25.4 Empirical analysis of residential water consumption

In this section, we provide a statistical analysis or residential water consumption and water price for Slovakia.

Table 25.1: Household water consumption and price in Slovakia

Year	Water consumption (m3 per capita per year)	Water price (euros per m3)
2001	42.536	0.618
2002	41.746	0.641
2003	39.617	0.824
2004	35.900	0.900
2005	35.450	1.065
2006	32.832	1.242
2007	33.801	1.490
2008	33.407	1.560
2009	30.899	1.680
2010	30.128	1.770
2011	29.592	1.820
Average	35.070	1.239

Table 25.1 gives the annual residential water consumption (m3 per capita and per year) and the water price (average water price, in euros m3) in Slovakia from 2001 to 2011. In 2011, the average annual consumption per inhabitant amounted to 29.6 m3. There has been a decreasing trend in domestic water consumption since 2001. Over the period 2002-2011, the average water price has been multiplied by 3. It has increased from 0.6 euros per m3 to 1.8 euros per m3.

Table 25.2 gives the annual residential water consumption (m3 per capita and per year) and the water price per county (Nuts 3) in 2010.[1] As it can be seen, there are some differences across regions in terms

[1] For the water and wastewater price, we have only a national average.

Table 25.2: Regional household water consumption and price in Slovakia

	Water consumption (m3 per capita per year)	Water price (euros per m3)
Region of Banská Bystrica	29.421	1.770
Region of Bratislava	45.611	1.770
Region of Kosice	27.956	1.770
Region of Nitra	26.826	1.770
Region of Presov	24.939	1.770
Region of Trenèí	28.642	1.770
Region of Trnava	31.741	1.770
Region of Zilina	28.592	1.770
Average	30.128	1.770

of water consumption. With almost 46 m3 per capita per year, the water consumption is the higher in the Brastislava Nuts3. The Brastislava Nuts3 includes the capital Brastislava and is the most densely populated area of Slovakia. On contrary, a low water consumption is reported in the PreÅąov county (25.0 m3 per capita per year).

25.5 Water demand function estimate

25.5.1 Specifying the residential water demand function

The residential water demand function can be derived from solving the utility optimization problem of a consumer. Under the assumption of a weak separability of water with respect to other goods consumed, the Marshallian demand in water can be written as:

$$y = y^{*}(p, I, Z) \tag{25.1}$$

where y is the water consumption either per capita or per household, p and I denote the unit water price (representing both water supply and the sewage treatment services) and the representative household income, respectively. Z is a vector of exogenous variables assumed to influence water consumption (climate conditions, household and housing characteristics, etc.).

To estimate Equation (25.1), a wide variety of functional forms have been applied in the water demand literature, including linear forms, semi or double logarithm forms and more complex forms such as the Stone-Geary specification. The existing literature is however not very informative concerning the specification which should be preferred. Since the double-log model is the most common specification in the residential water demand literature, we have adopted this model in order to facilitate comparison to other studies. Furthermore, the specification implies that coefficient estimates are also elasticity estimates. With a double-log specification, the residential water demand function writes:

$$\ln(y) = \alpha \ln(p) + \beta \ln(I) + \gamma \ln(Z)' \tag{25.2}$$

and the coefficients α and β can be directly interpreted as the price and the income elasticities of the water demand. Specification tests for the functional form will be conducted in the empirical part but we don't expect the choice of the particular form to have a fundamental influence on the estimation of the parameters of interest.

Table 25.3: Estimation of the household water demand in Slovakia

	SlovakOLS	SlovakGLS	SlovakGLSiv
	b/se	b/se	b/se
$\ln$ Water price (in euros per m3)	-0.659***	-0.659***	-0.940***
	(0.08)	(0.08)	(0.20)
$\ln$ Household income (in euros per capita)	0.625***	0.625***	1.048**
	(0.16)	(0.16)	(0.51)
$\ln$ Average population age	-0.233	-0.233	-1.795
	(1.58)	(1.58)	(5.84)
$\ln$ Share population below 14	-0.341	-0.341	-0.860
	(0.44)	(0.44)	(1.77)
$\ln$ number of summer days without rainfalls	0.057	0.057	0.157
	(0.05)	(0.05)	(0.12)
Constant	-1.379	-1.379	-0.342
	(5.20)	(5.20)	(20.73)
R-squared			
N. of obs.	88.000	88.000	48.000

25.5.2 Estimation methods

Let $i = \{1, .., I\}$ indexes Nuts3 and $t = \{1, .., T\}$ years. Our equation of interest becomes:

$$\ln(y_{it}) = \alpha \ln(p_{it}) + \beta \ln(I_{it}) + \gamma \ln(Z_{it})' + \epsilon_{it} \tag{25.3}$$

where ϵ_{it} is the usual random term. Two panel data estimators may be used namely the fixed effects (or dummy variable) model and the random effects (or error components) model. We propose to use these two estimators and to conduct some specification tests (Hausman test) to decide which is the most appropriate to our data.

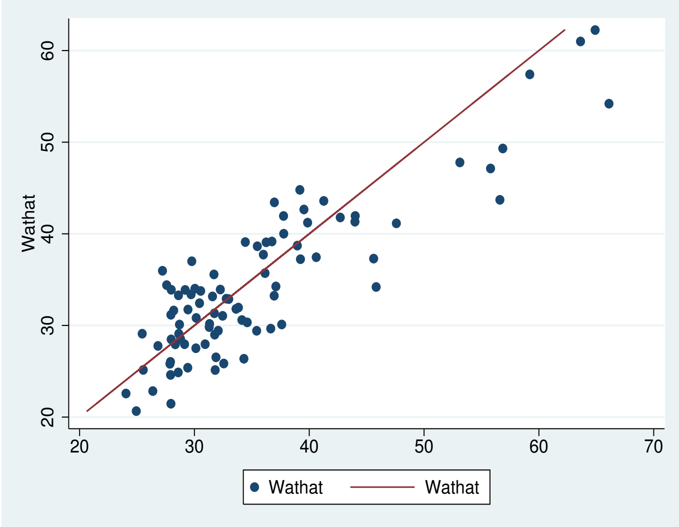
25.5.3 Results

We report here our estimate for the residential water demand function in Slovakia, based on our Nuts3 dataset for Slovakia (2002 to 2011). The first model estimated in Table 25.3 corresponds simple OLS whereas in the second model we estimate Equation (25.4) with a random parameter estimator. In the third model, we account for potential endogeneity of the price by using an instrumental variable approach.

In the GLSiv model we have considered two instruments namely the share on non-revenue water and the average price of water for non-household users. According to (MinistryEnvironment 2011), the amount of non-revenue water used to represent 32.1% of water intended for use in 2010. Out of this number the loss in pipe network represents 85.8%.

Table 25.3 present the main significant variables explaining household water consumption in Slovakia. The price elasticity varies across models, from -0.66 with the OLS to -0.94 with the GLSiv (always significant). Based on the GLSiv models, a 10% increase in water price results in a 9.4% decrease in short-run water consumption in Slovakia. Water demand in Slovakia is inelastic, i.e. the estimated price elasticity in absolute values is lower than one.

Figure 25.1: Observed versus predicted household water consumption in Slovakia



The income elasticity varies between 0.63 and 1.0 and the income elasticity is significantly different from zero with the three models. This suggests that there is an increasing relationship between water consumption and household income. The positive significant coefficient for income indicates that, based on the GLS model, a 10% increase in income will result in a 10% increase in water consumption.

Climate conditions don't seem to play a significant role.

A possible way to assess the validity of the model is to compare the water consumption predicted by the demand function to the observed water consumption, see Figure 25.1. For most of the municipalities the model performs quite well. The mean absolute percentage error is 10.25.

Water consumption may to be at least somehow persistent over time due to household habits or due to the time needed to adjust durable equipments (shower for instance). With panel or time-series data, one way to take into this time persistence characteristic of household water consumption is to introduce the lagged consumption as an additional independent variable in Equation (25.2). The dynamic specification of our equation of interest becomes then :

$$\ln(y) = \alpha \ln(p) + \beta \ln(I) + \gamma \ln(Z)' + \mu \ln(\text{Lag}\, y) \tag{25.4}$$

where Lag y represents the lagged water consumption. From this specification is is then possible to derive the long-run price elasticity of the household water demand function which simply writes:

$$\epsilon_p^{LT} = \frac{\alpha}{1-\mu}. \tag{25.5}$$

We provide in Table 25.4 our estimates for the household water demand function where the lagged consumption has been introduced as an additional independent variable. With the SlovakiaGLSlag model, the long-term price elasticity is estimated to be -1.00 significantly different from zero at 1%. With the SlovakiaGLSivlag model, the long-term price elasticity is estimated to be -1.14 significantly different from zero at 1%.

Table 25.4: Estimation of the household water demand with lagged water consumption in Slovakia

	SlovakiaGLSlag	SlovakiaGLSivlag
	b/se	b/se
$\ln$ Water price (in euros per m3)	-0.325***	-0.586**
	(0.10)	(0.28)
$\ln$ Household income (in euros per capita)	0.508***	0.916*
	(0.15)	(0.50)
$\ln$ Average population age	-0.838	-1.394
	(1.16)	(3.29)
$\ln$ Share population below 14	-0.219	-0.309
	(0.37)	(1.05)
$\ln$ number of summer days without rainfalls	-0.008	-0.019
	(0.05)	(0.11)
$\ln$ Lag of water consumption per capita	0.683***	0.488**
	(0.08)	(0.23)
Constant	-0.331	-1.018
	(3.91)	(12.03)
R-squared		
N. of obs.	80.000	40.000

Source: auto.dta

Chapter 26

Slovenia

26.1 Existing literature

To our best knowledge, there doesn't exist any published article having estimated a residential water demand function in Slovenia.

26.2 Urban water sector in Slovenia

This paragraph is based on Globevnik (2013). Slovenia has sufficient water resources to provide continuous drinking water supply. Groundwater represents the most important source of drinking water in Slovenia, supplying about 97% of the population. Some areas suffer from periodic deficits particularly in the eastern part of the country. It is considered by Globevnik (2013) that the expected growth of drinking water demand can become a limiting factor for development in the near future, not so much due to the lack of resources (quantity), but rather due to bad management and weak investments dynamics.

According to the Environment Protection Act, drinking water supply is under the responsibility of local communities and is performed as a mandatory public service. The facilities and infrastructure needed to perform public service are the property of local communities. Local communities should carry out a management plan for drinking water supply that has to be certified by state authority. The monitoring data show that more than 91% of the population receive water in compliance with the current regulations. The water supply system is quite fragmented since most of the systems in Slovenia supply drinking water to 20,000 to 50,000 persons.

26.3 Data

Our panel data set consists of Nuts3-level (county) data on household water consumption, household water price, household's socioeconomic conditions income and on climate condition for years 2001-2011. Most of the data come from the Statistical Office of Slovenia. The data consist of aggregate data at Nuts3-level on water consumption per capita and water and sewerage prices. The data have been combined with information on houshol's income, climate conditions, and household characteristics mainly from Statistics Slovenia.

Water consumption data From the Statistical Office of Slovenia we have the annual volume of water supplied from the public water network to households from 2002 to 2012 at Nuts3 level. The volume of water has been divided by the population connected to the water network in each Nuts 3 (total population multiplied by the share of the population served by the water network). Our endogenous variable is then the annual water consumption per connected capita to the public water supply network (in m3 per year per capita).

Water price data Our main source of data is the report LMVeritas (2012) which describe the price for the water and the wastewater service for more than 200 municipalities in Slovenia. This report covers the period 2000 to 2011. As a price indicator, we use the average price paid by households for the water and wastewater services (in euros per m3). LMVeritas (2012) provides the price information at the municipality level. We have then matched each municipality with the corresponding Nuts3.

Household income We use the average gross domestic product per capita available from Statistics Slovenia from from 2000 to 2011 at Nuts3 as a proxy of household's income.

Other socioeconomic variables Other socio-economic variables from 2000 to 2011 come from Statistics Slovenia.

Climate data All meteorological data come from the JRC climate database. Grid data (5km $\times$ 5km) on rainfalls, temperatures and evapotranspiration have been aggregated at regional level. We have historical data from 1990 to 2013.

26.4 Empirical analysis of residential water consumption

In this section, we provide a statistical analysis of residential water consumption and water price for Slovenia.

Table 26.1: Household water consumption and price in Slovenia

Year	Water consumption (m3 per capita per year)	Water price (euros per m3)
2002	48.179	1.121
2003	50.360	1.440
2004	47.437	1.447
2005	46.352	1.519
2006	46.933	1.526
2007	47.973	1.575
2008	47.929	1.603
2009	45.912	1.861
2010	44.809	1.972
2011	44.505	1.993
2012	45.139	.
Average	46.851	1.670

Table 26.1 gives the annual residential water consumption (m3 per capita and per year) and the water price (average price for water and wastewater services, in euros m3) in Slovenia from 2002 to 2012. In 2012, the average annual consumption per inhabitant amounted to 45.1 m3. There has been a decreasing trend in domestic water consumption since 2007. Over the period 2002-2011, the average water price has increased from 1.1 euros per m3 to 1.9 euros per m3.

Table 26.2 gives the annual residential water consumption (m3 per capita and per year) and the water price per county (Nuts 3) in 2010. As it can be seen, there are some differences across regions, both in terms of water consumption and water prices. With almost 64 m3 per capita per year, the water consumption is the higher in the Osrednjeslovensk Nuts3. The Osrednjeslovensk Nuts3 includes the Slovene capital Ljubljana and is the most densely populated area of Slovenia. On contrary, a low water consumption is reported in the Zasavska county (21.4 m3 per capita per year).

26.5 Water demand function estimate

26.5.1 Specifying the residential water demand function

The residential water demand function can be derived from solving the utility optimization problem of a consumer. Under the assumption of a weak separability of water with respect to other goods consumed, the Marshallian demand in water can be written as:

$$y = y^*(p, I, Z) \tag{26.1}$$

Table 26.2: Regional household water consumption and price in Slovenia

	Water consumption (m3 per capita per year)	Water price (euros per m3)
Gorenjska	43.866	1.677
Goriska	41.054	2.668
Jugovzhodna Slovenija	35.583	1.937
Koroska	41.215	2.245
Notranjsko-kraska	38.747	2.313
Obalno-kraska	41.354	2.656
Osrednjeslovenska	64.647	2.087
Podravska	40.048	1.535
Pomurska	32.895	1.884
Savinjska	33.477	1.906
Spodnjeposavska	35.686	1.932
Zasavska	21.365	1.509
Average	44.809	1.972

where y is the water consumption either per capita or per household, p and I denote the unit water price (representing both water supply and the sewage treatment services) and the representative household income, respectively. Z is a vector of exogenous variables assumed to influence water consumption (climate conditions, household and housing characteristics, etc.).

To estimate Equation (26.1), a wide variety of functional forms have been applied in the water demand literature, including linear forms, semi or double logarithm forms and more complex forms such as the Stone-Geary specification. The existing literature is however not very informative concerning the specification which should be preferred. Since the double-log model is the most common specification in the residential water demand literature, we have adopted this model in order to facilitate comparison to other studies. Furthermore, the specification implies that coefficient estimates are also elasticity estimates. With a double-log specification, the residential water demand function writes:

$$\ln(y) = \alpha \ln(p) + \beta \ln(I) + \gamma \ln(Z)' \tag{26.2}$$

and the coefficients α and β can be directly interpreted as the price and the income elasticities of the water demand. Specification tests for the functional form will be conducted in the empirical part but we don't expect the choice of the particular form to have a fundamental influence on the estimation of the parameters of interest.

26.5.2 Estimation methods

Let $i = \{1, .., I\}$ indexes Nuts3 and $t = \{1, .., T\}$ years. Our equation of interest becomes:

$$\ln(y_{it}) = \alpha \ln(p_{it}) + \beta \ln(I_{it}) + \gamma \ln(Z_{it})' + \epsilon_{it} \tag{26.3}$$

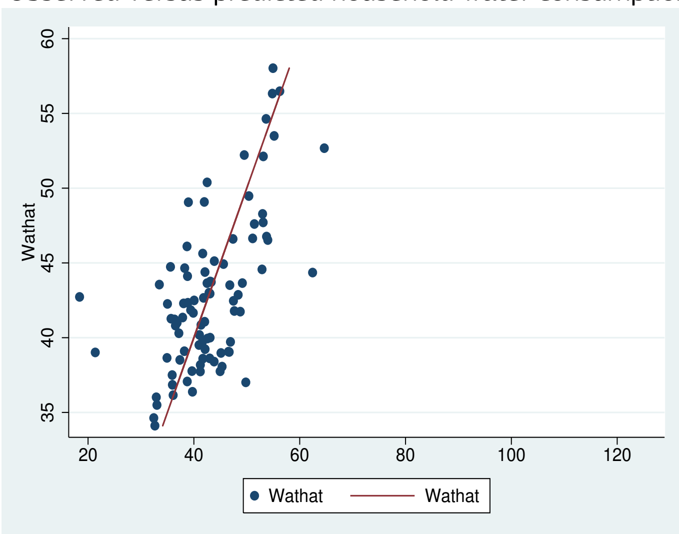
where ϵ_{it} is the usual random term. Two panel data estimators may be used namely the fixed effects (or dummy variable) model and the random effects (or error components) model. We propose to use these two estimators and to conduct some specification tests (Hausman test) to decide which is the most appropriate to our data.

26.5.3 Results

Table 26.3: Estimation of the household water demand in Slovenia

	SloveniaOLS	SloveniaGLS	SloveniaGLSiv
	b/se	b/se	b/se
ln Water price (in euros per m3)	-0.100	-0.108	-0.299
	(0.08)	(0.09)	(0.38)
ln Household income (in euros per capita)	0.409***	0.381***	0.443**
	(0.08)	(0.12)	(0.20)
ln Share population below 14	0.057***	0.049*	0.030
	(0.02)	(0.03)	(0.03)
ln average of daily rainfall (mm per day)	0.040	-0.018	0.036
	(0.07)	(0.08)	(0.09)
Constant	-0.959	-0.519	-0.792
	(0.82)	(1.20)	(1.66)
R-squared	0.359		
N. of obs.	89.000	89.000	78.000

Figure 26.1: Observed versus predicted household water consumption in Slovenia



We report here our estimate for the residential water demand function in Slovenia, based on our Nuts3 dataset for Slovenia (2002 to 2011). The first model estimated in Table 26.3 corresponds simple OLS whereas in the second model we estimate Equation (26.4) with a random parameter estimator. In the third model, we account for potential endogeneity of the price by using an instrumental variable approach.

Table 26.3 present the main significant variables explaining household water consumption in Slovenia. The price elasticity varies across models, from -0.10 with the OLS to -0.30 with the GLSiv (not significant with GLSiv). Based on the GLSiv models, a 10% increase in water price results in a 3.0% decrease in short-run water consumption in Slovenia. Water demand in Slovenia is inelastic, i.e. the estimated price elasticity in absolute values is lower than one.

The income elasticity varies between 0.38 and 0.44 and the income elasticity is significantly different from

Table 26.4: Estimation of the household water demand with lagged water consumption in Slovenia

	SloveniaGLSlag	SloveniaGLSivlag
	b/se	b/se
$\ln$ Water price (in euros per m3)	-0.127*	-0.617**
	(0.07)	(0.31)
$\ln$ Household income (in euros per capita)	0.298***	0.466***
	(0.08)	(0.16)
$\ln$ Share population below 14	0.052***	0.010
	(0.02)	(0.03)
$\ln$ average of daily rainfall (mm per day)	-0.038	0.049
	(0.06)	(0.08)
$\ln$ Lag of water consumption per capita	0.234**	0.067
	(0.09)	(0.14)
Constant	-0.584	-0.825
	(0.68)	(1.02)
R-squared		
N. of obs.	86.000	75.000

Source: auto.dta

zero with the three models. This suggests that there is an increasing relationship between water consumption and household income. The positive significant coefficient for income indicates that, based on the GLS model, a 10% increase in income will result in a 4.44% increase in water consumption.

Climate conditions don't seem to play a significant role. Water consumption per capita appears to increase with the share of the population below 14.

A possible way to assess the validity of the model is to compare the water consumption predicted by the demand function to the observed water consumption, see Figure 26.1. For most of the municipalities the model performs quite well. The mean absolute percentage error is 11.5.

Water consumption may to be at least somehow persistent over time due to household habits or due to the time needed to adjust durable equipments (shower for instance). With panel or time-series data, one way to take into this time persistence characteristic of household water consumption is to introduce the lagged consumption as an additional independent variable in Equation (26.2). The dynamic specification of our equation of interest becomes then :

$$\ln(y) = \alpha \ln(p) + \beta \ln(I) + \gamma \ln(Z)' + \mu \ln(\text{Lag}\, y) \tag{26.4}$$

where Lag y represents the lagged water consumption. From this specification is is then possible to derive the long-run price elasticity of the household water demand function which simply writes:

$$\epsilon_p^{LT} = \frac{\alpha}{1-\mu}. \tag{26.5}$$

We provide in Table 26.4 our estimates for the household water demand function where the lagged consumption has been introduced as an additional independent variable. With the SloveniaGLSlag model, the long-term price elasticity is estimated to be -0.17 significantly different from zero at 5%. With the SloveniaGLSivlag model, the long-term price elasticity is estimated to be -0.66 significantly different from zero at 5%.

Chapter 27

Spain

27.1 Existing literature

Martínez-Espiñeira (2002) estimates a domestic water demand functions using unbalance panel of monthly aggregate data from 132 municipalities located in the Northwest of Spain (1993-1999). Overall marginal price elasticity estimates lie between -0.12 and -0.17. Summer-only elasticities and elasticities associated with uses beyond the effectively free allowances seem significantly higher. Climatic variables significantly affect monthly use, although probably less than in other wealthier and drier areas. Domestic water use appears to be a normal good.

Arbués, Barberán, and Villanúa (2004) use household-level data (1,596 users of the domestic water supply) for estimating the residential water demand function for the city of Zaragoza in Spain. Their analysis cover the years 1996-1998. They report a price elasticity ranging from -0.029 to -0.058. The average income elasticity ranges from 0.074 to 0.208. Arbués and Villanúa (2006) presents an empirical study to estimate the urban residential water demand in Zaragoza, Spain. The empirical application suggests that domestic demands are inelastic with respect to price.

García-Valiñas, Martínez-Espiñeira, and González-Gómez (2010) use a sample of 301 Andalusian municipalities for year 2005. Using a Stone-Geary utility function, the minimum water threshold is estimated to be 128 m3 per household per year.

27.2 Urban water sector in Spain

In Spain, urban water supply, sanitation and wastewater treatment services are under municipal jurisdiction (García-Rubio, Ruiz-Villaverde, and González-Gómez 2015). These services can be managed directly or indirectly but regardless of the form of management, tariffs must be approved by the public administration. The most frequently employed tariff is the two-part tariff composed of fixed and variable fees. However, there is wide variability among municipalities.

27.3 Data

Our panel data set consists of Nuts2-level (Autonomous Community) data on household water consumption, household water price, household's socioeconomic conditions income and on climate condition for years 2004-2011. Most of the data come from the National Statistics Institute (INE) of Spain. The data consist of aggregate data at Nuts2-level on water consumption per capita and water and sewerage prices. The data have been combined with information on income, climate, and household characteristics mainly from the National Statistics Institute of Spain.

Water consumption data Water consumption data at Nuts2-level (Autonomous Community) comes INE indicators on water. We have the volume of water registered and distributed to household per capita by Nuts2 from 2004 to 2011 We have then computed the annual household water consumption per capita (m3 per capita) in each Nuts2 from 2004 to 2011.

Water price data Water prices come from the the National Statistics Institute (INE) of Spain and are available at the Nuts2-level from 1996 to 2011. As a price indicator, we use the average price (euros per m3) paid by households for the water and sewerage services.

Household income We use the average net annual income per household by Autonomous Community from 2003 to 2011.

Other socioeconomic variables Other socio-economic variables come from National Statistics Institute (INE) of Spain.

Climate data All meteorological data come from JRC climate database. Grid data (5km $\times$ 5km) on rainfalls, temperatures and evapotranspiration have been aggregated at regional level. We have historical data from 1990 to 2013.

27.4 Empirical analysis of residential water consumption

In this section, we provide a statistical analysis or residential water consumption and water price for Spain.

Table 27.1: Household water consumption and price in Spain

Year	Water consumption (m3 per capita per year)	Water price (euros per m3)
2004	63.824	0.947
2005	62.187	1.008
2006	59.785	1.087
2007	57.196	1.264
2008	56.182	1.316
2009	54.377	1.438
2010	52.442	1.520
2011	51.629	.
Average	57.079	1.231

Table 27.1 gives the annual residential water consumption (m3 per capita and per year) and the water price (average water price, in euros m3) in Spain from 2004 to 2011. In 2011, the average annual consumption per inhabitant amounted to 51.3 m3. There has been a decreasing trend in domestic water consumption from 2004 to 2011. Over the period 2004 to 2010, the average water price has increased from 0.95 euros per m3 to 1.52 euros per m3 (by more than 50%).

Table 27.2 gives the annual residential water consumption (m3 per capita and per year) and the water price per region (Nuts2) in 2010. As it can be seen, there are some differences across Nuts2, both in terms of water consumption and water prices. With more than 63 m3 per capita per year, the water consumption is the higher in the Cantabria Autonomous Community. On contrary, a low water consumption is reported in the Baleares Islands of in the La Rioja Autonomous Community (44 m3 per capita per year).

27.5 Water demand function estimate

27.5.1 Specifying the residential water demand function

The residential water demand function can be derived from solving the utility optimization problem of a consumer. Under the assumption of a weak separability of water with respect to other goods consumed, the

Table 27.2: Regional household water consumption and price in Spain

	Water consumption (m3 per capita per year)	Water price (euros per m3)
Andalucía	52.195	1.360
Aragón	52.560	1.340
Canarias	54.385	1.900
Cantabria	63.145	1.140
Castilla y León	60.955	0.980
Castilla-La Mancha	55.480	1.310
Cataluña	48.545	1.830
Ciudad Autónoma de Ceuta	59.495	1.330
Comunidad Foral de NAvarra	46.720	1.360
Comunidad Valenciana	57.305	1.690
Comunidad de Madrid	51.100	1.640
Extremadura	58.400	1.230
Galicia	48.180	1.010
Illes Balears	44.165	2.690
La Rioja	44.530	0.910
País Vasco	44.530	1.140
Principado de As	58.035	1.070
Región de Murcia	57.670	2.170
Average	52.442	1.520

Marshallian demand in water can be written as:

$$y = y^*(p, I, Z) \tag{27.1}$$

where y is the water consumption either per capita or per household, p and I denote the unit water price (representing both water supply and the sewage treatment services) and the representative household income, respectively. Z is a vector of exogenous variables assumed to influence water consumption (climate conditions, household and housing characteristics, etc.).

To estimate Equation (27.1), a wide variety of functional forms have been applied in the water demand literature, including linear forms, semi or double logarithm forms and more complex forms such as the Stone-Geary specification. The existing literature is however not very informative concerning the specification which should be preferred. Since the double-log model is the most common specification in the residential water demand literature, we have adopted this model in order to facilitate comparison to other studies. Furthermore, the specification implies that coefficient estimates are also elasticity estimates. With a double-log specification, the residential water demand function writes:

$$\ln(y) = \alpha \ln(p) + \beta \ln(I) + \gamma \ln(Z)' \tag{27.2}$$

and the coefficients α and β can be directly interpreted as the price and the income elasticities of the water demand. Specification tests for the functional form will be conducted in the empirical part but we don't expect the choice of the particular form to have a fundamental influence on the estimation of the parameters of interest.

27.5.2 Estimation methods

Let $i = \{1, .., I\}$ indexes Nuts2 and $t = \{1, .., T\}$ years. Our equation of interest becomes:

$$\ln(y_{it}) = \alpha \ln(p_{it}) + \beta \ln(I_{it}) + \gamma \ln(Z_{it})' + \epsilon_{it} \tag{27.3}$$

where ϵ_{it} is the usual random term. Two panel data estimators may be used namely the fixed effects (or dummy variable) model and the random effects (or error components) model. We propose to use these two estimators and to conduct some specification tests (Hausman test) to decide which is the most appropriate to our data.

27.5.3 Results

We report here our estimate for the residential water demand function in Spain, based on our Nuts2 dataset for Spain (2004 to 2011). The first model estimated in Table 27.3 corresponds simple OLS whereas in the second model we estimate Equation (27.4) with a random parameter estimator. In the third model, we account for potential endogeneity of the price by using an instrumental variable approach.

Table 27.3 present the main significant variables explaining household water consumption in Spain. The price elasticity varies across models, from -0.21 with the GLSiv to -0.10 with the OLS (not significant with GLSiv). Based on the GLS model, a 10% increase in water price results in a 2.1% decrease in short-run water consumption in Spain. Water demand in Spain is inelastic, i.e. the estimated price elasticity in absolute values is lower than one.

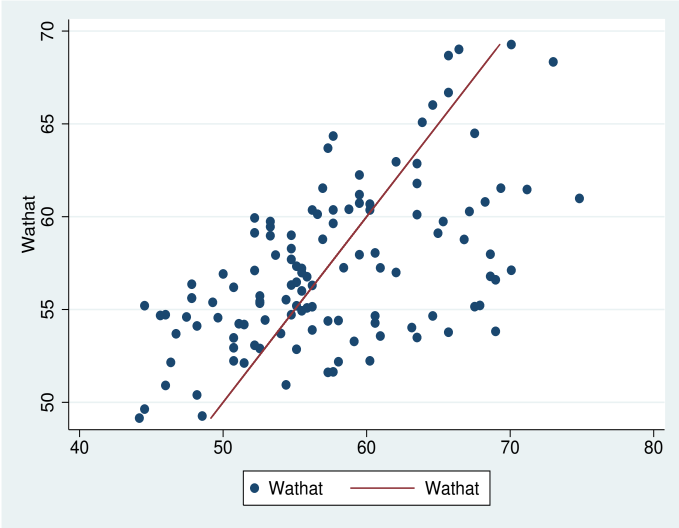
The income elasticity varies between -0.30 and 0.051 and the income elasticity is significantly different from zero only with the OLS model.

Climate conditions don't seem to play a significant role.

Table 27.3: Estimation of the household water demand in Spain

	SpainOLS	SpainGLS	SpainGLSiv
	b/se	b/se	b/se
$\ln$ Water price (in euros per m3)	-0.100*	-0.209***	0.138
	(0.05)	(0.04)	(0.11)
$\ln$ Household income (in euros per capita)	-0.295***	0.051	-0.032
	(0.10)	(0.11)	(0.14)
$\ln$ Household size	0.082	-0.475	0.696
	(0.41)	(0.43)	(0.64)
$\ln$ Age median	-0.858*	-1.979***	-2.161***
	(0.51)	(0.70)	(0.84)
$\ln$ Population density	-0.022	-0.061	-0.139***
	(0.02)	(0.04)	(0.05)
$\ln$ Share of female	3.494**	4.038	10.164***
	(1.43)	(2.58)	(3.47)
$\ln$ average of daily rainfall (mm per day)	-0.001	0.000	-0.001
	(0.00)	(0.00)	(0.00)
Constant	12.615***	14.364***	19.216***
	(2.97)	(4.19)	(5.25)
R-squared	0.417		
N. of obs.	119.000	119.000	119.000

Figure 27.1: Observed versus predicted household water consumption in Spain



Some household's characteristics matter. The water consumption per capita decreases significantly with the median age of the population and it increases with the share of women in the total population.

A possible way to assess the validity of the model is to compare the water consumption predicted by the demand function to the observed water consumption, see Figure 27.1. For most of the municipalities the model performs quite well. The mean absolute percentage error is 8.00.

Water consumption may to be at least somehow persistent over time due to household habits or due to the time needed to adjust durable equipments (shower for instance). With panel or time-series data, one way to take into this time persistence characteristic of household water consumption is to introduce the lagged consumption as an additional independent variable in Equation (27.2). The dynamic specification of our equation of interest becomes then :

$$\ln(y) = \alpha \ln(p) + \beta \ln(I) + \gamma \ln(Z)' + \mu \ln(\text{Lag}\, y) \tag{27.4}$$

where Lag y represents the lagged water consumption. From this specification is is then possible to derive the long-run price elasticity of the household water demand function which simply writes:

$$\epsilon_p^{LT} = \frac{\alpha}{1-\mu}. \tag{27.5}$$

We provide in Table 27.4 our estimates for the household water demand function where the lagged consumption has been introduced as an additional independent variable. With the SpainGLSlag model, the long-term price elasticity is estimated to be -0.24 but not significantly different from zero. With the SpainGLSivlag model, the long-term price elasticity is estimated to be 0.64 but not significantly different from zero.

Table 27.4: Estimation of the household water demand with lagged water consumption in Spain

	SpainGLSlag	SpainGLSivlag
	b/se	b/se
ln Water price (in euros per m3)	-0.024	0.054
	(0.03)	(0.05)
ln Household income (in euros per capita)	-0.013	-0.031
	(0.06)	(0.06)
ln Household size	-0.038	0.247
	(0.26)	(0.29)
ln Age median	-0.148	0.214
	(0.32)	(0.37)
ln Population density	-0.008	-0.009
	(0.01)	(0.01)
ln Share of female	0.365	0.347
	(0.90)	(0.93)
ln average of daily rainfall (mm per day)	0.000	0.000
	(0.00)	(0.00)
ln Lag of water consumption per capita	0.898***	0.916***
	(0.06)	(0.06)
Constant	1.395	-0.132
	(2.01)	(2.18)
R-squared		
N. of obs.	102.000	102.000

Chapter 28

Sweden

28.1 Existing literature

A few studies have estimated a household water demand function in Sweden, but all of them a quite old.

Hanke and Maré (1982) use a pooled cross-section series data on 1971-1978 for a sample of 69 single family houses in the town of Malmö. The dependent variable used is quantity of metered water per house, and the explanatory variables are real marginal price of water, real gross income per house, number of adults per house, number of children per house, rainfall, and a dummy variable for the age of the house. The price elasticity is estimated to be -0.15, and the income elasticity is estimated to be 0.11.

Höglund (1999) estimates a household demand function for water is using community level data for 282 Swedish communities studied annually over the period 1980-1992. Static and dynamic demand functions are estimated using panel data methods. The results show a long-run price elasticity of -0.10 in marginal price models and -0.20 in average price models. The income elasticity is estimated to be between 0.07 and 0.13.

28.2 Urban water sector in Sweden

This paragraph is based on Mattisson and Anna (2010). In Sweden the municipalities are responsible for the provision of water and sewage services and for the management of stormwater (Water and Sewage Act, SFS 2006:412). Both services are usually conducted by the same entity. The municipalities have the ability to decide how to arrange the provision of public services. As a consequence there are differences between municipalities in Sweden in terms of how the provision of services is organized. In-house or municipally owned corporations used to be the most common solution for organizing water and sewage services in Swedish municipalities. However, as the pressure on technological and environmental improvements and financial restraints has increased, different kinds of inter-municipal co-operations became more common. Sweden has slightly over 2000 publicly owned water works.

28.3 Data

Our data set consists of Nuts3-level (county) data on household water consumption, household water price, household's socioeconomic conditions income and on climate condition for years 2011. Most of the data come from the Statistical Office of Sweden. The data consist of aggregate data at Nuts3-level on water consumption per capita and water and sewerage prices. The data have been combined with information on household's income, climate conditions, and household characteristics mainly from Statistics Sweden.

Water consumption data From the Statistical Office of Sweden we have the annual volume of water supplied to households users from the public water network for 1995, 2000, 2005 and 2010 at Nuts3 level. The volume of water has been divided by the population in each Nuts 3, assuming a 100% connection rate. Our endogenous variable is then the annual water consumption per connected capita to the public water supply network (in m3 per year per capita).

Water price data Data are annually published by the Swedish Water & Wastewater Association for a subset of approximately 300 municipalities (almost 100% of the Swedish population) As water price, we have considered the user charge for a normal house (inclusive of VAT).[1]. The municipalities have been matched with their

[1] A normal house is a detached family house with 5 rooms, bathroom with toilets, laundry room, extra toilet room and a garage. Floor area is 150 m2 including garage 15 m2, garden area 800 m2. The annual water consumption is 150 m3 of water. The property is assumed to be connected to water, wastewater and stormwater.

respective Nust3 and a Nuts3 average water price has been computed (weighted by the population served in each municipality).

Household income We use the average disposable household income (euros per year per capita) available from 2000 to 2011 at Nuts3 from Sweden Statistics.

Other socioeconomic variables Other socio-economic variables from 2000 to 2011 come from Sweden Statistics.

Climate data All meteorological data come from the JRC climate database. Grid data (5km $\times$ 5km) on rainfalls, temperatures and evapotranspiration have been aggregated at regional level. We have historical data from 1990 to 2013.

28.4 Empirical analysis of residential water consumption

In this section, we provide a statistical analysis or residential water consumption and water price for Sweden.

Table 28.1: Household water consumption and price in Sweden

Year	Water consumption (m3 per capita per year)	Water price (euros per m3)
1995	69.751	.
2000	69.608	.
2005	62.038	.
2010	61.137	3.225
Average	65.546	3.225

Table 28.1 gives the annual residential water consumption (m3 per capita and per year) and the water price (average water price, in euros m3) in Sweden from 1995 to 2010. In 2010, the average annual consumption per inhabitant amounted to 61 m3. There has been a decreasing trend in domestic water consumption since 1995. The average water price in 2010 was 3.2 euros per m3.

Table 28.2 gives the annual residential water consumption (m3 per capita and per year) and the water price per county (Nuts 3) in 2010. As it can be seen, there are some differences across regions, both in terms of water consumption and water prices. With 73 m3 per capita per year, the water consumption is the higher in the JÃď’mtlands county. On contrary, a low water consumption is reported in the Kalmar county (50.8 m3 per capita per year).

28.5 Water demand function estimate

28.5.1 Specifying the residential water demand function

The residential water demand function can be derived from solving the utility optimization problem of a consumer. Under the assumption of a weak separability of water with respect to other goods consumed, the Marshallian demand in water can be written as:

$$y = y^*(p, I, Z) \tag{28.1}$$

Table 28.2: Regional household water consumption and price in Sweden

Year	Water consumption (m3 per capita per year)	Water price (euros per m3)
Blekinge län	53.552	4.381
Dalarnas län	64.855	3.602
Gotlands län	59.299	4.283
Gävleborgs län	69.408	3.635
Hallands län	60.721	3.075
Jämtlands län	73.289	2.999
Jönköpings län	62.466	3.037
Kalmar län	50.833	4.015
Kronobergs län	64.136	4.413
Norrbottens län	65.794	3.602
Skåne län	58.945	2.790
Stockholms län	66.971	2.329
Södermanlands län	54.684	3.477
Uppsala län	61.090	2.880
Värmlands län	60.351	3.996
Västerbottens län	61.719	3.184
Västernorrlands	62.401	4.311
Västmanlands län	53.517	3.398
Västra Götalands	59.009	3.434
Örebro län	57.824	2.902
Östergötlands län	51.482	3.455
Average	61.137	3.225

where y is the water consumption either per capita or per household, p and I denote the unit water price (representing both water supply and the sewage treatment services) and the representative household income, respectively. Z is a vector of exogenous variables assumed to influence water consumption (climate conditions, household and housing characteristics, etc.).

To estimate Equation (28.1), a wide variety of functional forms have been applied in the water demand literature, including linear forms, semi or double logarithm forms and more complex forms such as the Stone-Geary specification. The existing literature is however not very informative concerning the specification which should be preferred. Since the double-log model is the most common specification in the residential water demand literature, we have adopted this model in order to facilitate comparison to other studies. Furthermore, the specification implies that coefficient estimates are also elasticity estimates. With a double-log specification, the residential water demand function writes:

$$\ln(y) = \alpha \ln(p) + \beta \ln(I) + \gamma \ln(Z)' \tag{28.2}$$

and the coefficients α and β can be directly interpreted as the price and the income elasticities of the water demand. Specification tests for the functional form will be conducted in the empirical part but we don't expect the choice of the particular form to have a fundamental influence on the estimation of the parameters of interest.

28.5.2 Estimation methods

Let $i = \{1, .., I\}$ indexes Nuts3. Our equation of interest becomes:

$$\ln(y_i) = \alpha \ln(p_i) + \beta \ln(I_i) + \gamma \ln(Z_i)' + \epsilon_i \tag{28.3}$$

where ϵ_t is the usual random term.

28.5.3 Results

We report here our estimate for the residential water demand function in Sweden, based on our Nuts3 dataset for Sweden (2010). The first model estimated in Table 28.3 corresponds simple OLS whereas in the second model we estimate Equation (28.3) with an instrumental variable approach.

In the OLSiv model we have considered two instruments namely the share water used by non-household users and the logarithm of the average size of municipalities.

Table 28.3 presents the main significant variables explaining household water consumption in Sweden. The price elasticity varies across models, from -0.28 with the OLS to -0.58 with the OLSiv (always significant). Based on the OLSiv models, a 10% increase in water price results in a 5.8% decrease in short-run water consumption in Sweden. Water demand in Sweden is inelastic, i.e. the estimated price elasticity in absolute values is lower than one.

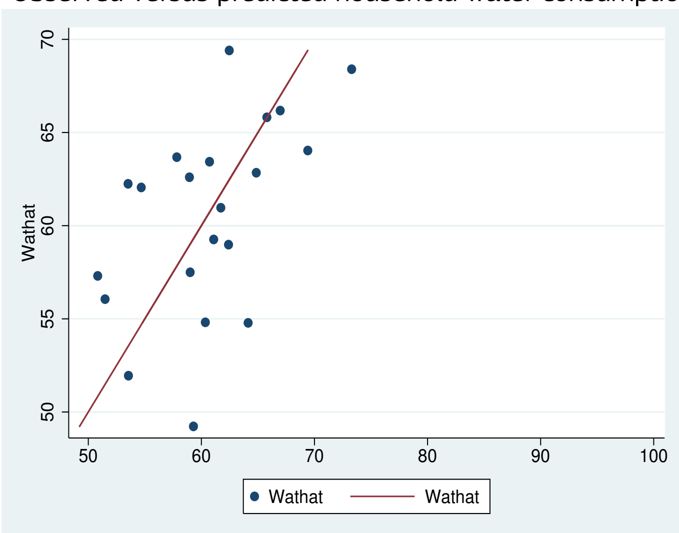
The income elasticity varies between 0.37 and 0.40 but is never significantly different from zero. The water consumption per capita increases with age.

A possible way to assess the validity of the model is to compare the water consumption predicted by the demand function to the observed water consumption, see Figure 28.1. For most of the municipalities the model performs quite well. The mean absolute percentage error is 7.5.

Table 28.3: Estimation of the household water demand in Sweden

	SwedenOLS	SwedenOLSiv
	b/se	b/se
ln Water price (in euros per m3)	-0.280*	-0.577**
	(0.14)	(0.24)
ln Household income (in euros per capita)	0.407	0.370
	(0.57)	(0.64)
ln Average age	2.021*	2.851**
	(1.04)	(1.28)
ln average of daily rainfall (mm per day)	-0.126	-0.180
	(0.15)	(0.17)
Constant	-6.985	-9.340
	(8.46)	(9.69)
R-squared	0.265	0.057
N. of obs.	21.000	21.000

Figure 28.1: Observed versus predicted household water consumption in Sweden



Chapter 29

United Kingdom (England & Wales)

Note to the reader The structure of the water industry in England and Wales differs from Scotland and Northern Ireland. In Scotland and Northern Ireland, government owned companies are subject to economic regulation (by the Water Industry Commission and the Utility Regulator respectively). In England and Wales, privately owned companies are subject to economic regulation (by Ofwat). Due to data availability, this chapter will only focus on **England and Wales**.

29.1 Existing literature

In a review paper, Parker and Wilby (2013) provides a brief history of household water demand management in the UK. They also summarize the existing literature in UK on water demand estimation and forecasting over the short- and long-term. They conclude that there is surprisingly little literature on UK household water demand estimation and forecasting, especially taking into account climate change. This probably reflects wider difficulties in recording, understanding and predicting the complexities of household water use.

Gardner (2011) provides the most detailed econometric analysis of a residential water demand function in UK, using data on a sample of 200 households (all metered) served by Veolia Water South East water utility for year 2008. The range of UK price elasticity estimates (from -0.177 to -0.286) suggests that price based demand management policies have scope to reduce residential water demand in UK. The log-log marginal price model gives a price elasticity of -0.286. UK summer demand was identified as being less price responsive than year round demand in a majority of (statistically significant) models.

29.2 Urban water sector in UK

Water resources and water use Globally, England and Wales are not under water stress. On average about 10 per cent of the freshwater resources are abstracted (excluding abstraction to support power production, which is often returned directly to the environment). There are however some regional disparities. South East and Eastern England can be classified as an area under stress from water abstraction, with more than 22 per cent of freshwater resources abstracted.

Water industry The water industry was privatised in 1989 when the water supply and sewerage functions of 10 publicly-owned regional water authorities were transferred to limited companies. There are now 19 licensed water companies across England and Wales: 10 water and sewerage companies and 9 water-only companies. Each company is appointed by the regulator (Ofwat) and holds a regional monopoly for providing water and sewerage services in a particular geographical area.

29.3 Data

Our panel data set consists of water service-level data on household water consumption, household water price, household's socioeconomic conditions income and on climate condition for years 2002-2009. Most of the data related to water come from reports published by Ofwat (in particular the annual reports "Security of supply, leakage and the efficient use of water" and "Water and sewerage charges"). We use a panel of water utilities made of 16 services (we cover most of the UK population) for years 2002 to 2009. The water data have been combined with information at different administrative levels on income, weather, and household characteristics obtained mainly from the Office for National Statistics.

Water consumption data From the Ofwat annual reports "Security of supply, leakage and the efficient use of water", we have the residential water consumption (l/person/day) which has been converted in cubic meters per year and per capita. Our dependent variable is then the water supplied to households per capita and per year. We have also the share of residential water consumption which is metered.

Water price data For each water service and each year, we have from the Ofwat annual reports "Water and sewerage charges" the water volumetric charges for metered households and the standing charges for household customers taking metered water supplies. An average price for the water service has then be computed using the fixed and variable part of the price scheme and the observed water consumption. The unit water price has been then expressed in euros per cubic meter.

Household income The Office for National Statistics provides the regional gross disposable household income annually at Nuts3 level. Regional gross disposable household income have been averaged for each water utility based on population distribution.

Other socioeconomic variables Other socio-economic variables from 2002 to 2009 come from the Office for National Statistics

Climate data All meteorological data come from the JRC climate database. Grid data (5km $\times$ 5km) on rainfalls, temperatures and evapotranspiration have been aggregated at regional level. We have historical data from 1990 to 2013.

29.4 Empirical analysis of residential water consumption

In this section, we provide a statistical analysis or residential water consumption and water price in England and Wales.

Table 29.1: Household water consumption and price in the United Kingdom

Year	Water consumption (m3 per capita per year)	Water price (euros per m3)
2002	55.044	1.189
2003	57.138	1.219
2004	55.692	1.294
2005	55.156	1.493
2006	54.620	1.608
2007	53.954	1.733
2008	53.632	1.845
2009	53.767	1.932
Average	54.875	1.539

Table 29.1 gives the annual residential water consumption (m3 per capita and per year) and the water price (average water price, in euros m3) in UK from 2002 to 2009. In our sample of water utilities, household water consumption has slightly diminished from 55.0 cubic meters to 53.8 cubic meters per capita and per year from 2002 to 2009. Changes in water pricing might be an explanation. Indeed, over the period 2002 to 2009, the

average water price has increased from 1.2 euros per m3 to 1.9 euros per m3. Another driver factor could be metering. Indeed, the percentage of households with a meter in England and Wales has increased steadily in the last 10 years.

Table 29.2: Regional household water consumption and price in the United Kingdom

	Water consumption (m3 per capita per year)	Water price (euros per m3)
Anglian	52.815	2.043
Bournemouth & W Hampshire	56.028	1.606
Bristol	52.889	1.936
Dwr Cymru	54.531	2.220
Dee Valley	52.377	1.671
Northumbrian North	52.122	2.012
Northumbrian South	57.378	1.655
Severn Trent	45.187	2.073
South East	62.597	1.740
South Staffordshire	50.224	1.630
South West	50.297	2.648
Sutton & East Surrey	60.882	1.628
Thames	59.495	1.782
United Utilities	49.129	2.250
Wessex	52.377	2.313
Yorkshire	51.939	1.701
Average	53.767	1.932

Table 29.2 gives the annual residential water consumption (m3 per capita and per year) and the water price per water utility in 2009. As it can be seen, there are some differences across water utilities, both in terms of water consumption and water prices. The water consumption per capita is the highest for the South East water utility (2.1 million customers in Kent, Sussex, Surrey, Hampshire and Berkshire). This is consistent with figures provided by the Environmental Agency in UK showing that there are considerable pressures on water resources in South East and Eastern England.

29.5 Water demand function estimate

29.5.1 Specifying the residential water demand function

The residential water demand function can be derived from solving the utility optimization problem of a consumer. Under the assumption of a weak separability of water with respect to other goods consumed, the Marshallian demand in water can be written as:

$$y = y^*(p, I, Z) \tag{29.1}$$

where y is the water consumption either per capita or per household, p and I denote the unit water price (representing both water supply and the sewage treatment services) and the representative household income, respectively. Z is a vector of exogenous variables assumed to influence water consumption (climate conditions, household and housing characteristics, etc.).

To estimate Equation (29.1), a wide variety of functional forms have been applied in the water demand literature, including linear forms, semi or double logarithm forms and more complex forms such as the Stone-Geary specification. The existing literature is however not very informative concerning the specification which should be preferred. Since the double-log model is the most common specification in the residential water demand literature, we have adopted this model in order to facilitate comparison to other studies. Furthermore, the specification implies that coefficient estimates are also elasticity estimates. With a double-log specification, the residential water demand function writes:

$$\ln(y) = \alpha \ln(p) + \beta \ln(I) + \gamma \ln(Z)' \tag{29.2}$$

and the coefficients α and β can be directly interpreted as the price and the income elasticities of the water demand. Specification tests for the functional form will be conducted in the empirical part but we don't expect the choice of the particular form to have a fundamental influence on the estimation of the parameters of interest.

29.5.2 Estimation methods

Let $i = \{1, .., I\}$ indexes water services and $t = \{1, .., T\}$ years. Our equation of interest becomes:

$$\ln(y_{it}) = \alpha \ln(p_{it}) + \beta \ln(I_{it}) + \gamma \ln(Z_{it})' + \epsilon_{it} \tag{29.3}$$

where ϵ_{it} is the usual random term. Two panel data estimators may be used namely the fixed effects (or dummy variable) model and the random effects (or error components) model. We propose to use these two estimators and to conduct some specification tests (Hausman test) to decide which is the most appropriate to our data.

29.5.3 Results

We report here our estimate for the residential water demand function in UK (England and Wales), based on our water utility dataset for UK (2002 to 2009). The first model estimated in Table 29.3 corresponds to simple OLS whereas in the second model we estimate Equation (29.4) with a random parameter estimator.

Figure 29.1: Observed versus predicted household water consumption in the United Kingdom

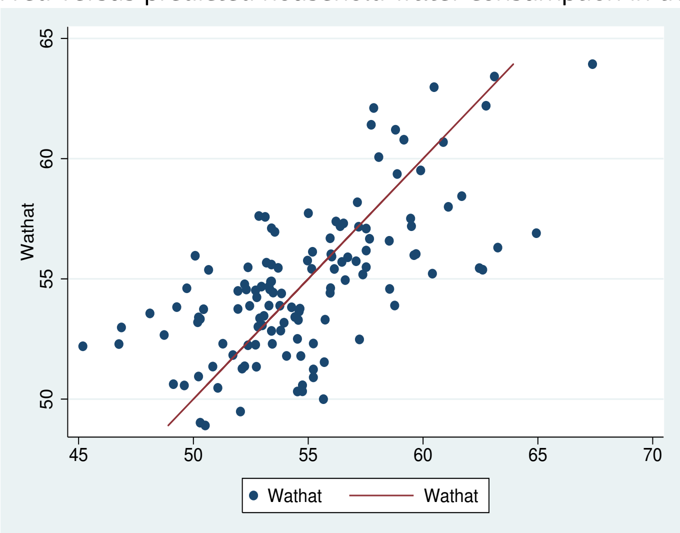


Table 29.3: Estimation of the household water demand in the United Kingdom

	UKOLS b/se	UKGLS b/se
$\ln$ Water price (in euros per m3)	-0.181***	-0.199***
	(0.02)	(0.03)
$\ln$ Household income (in euros per capita)	0.274***	0.266***
	(0.04)	(0.07)
$\ln$ average of daily rainfall (mm per day)	0.016	-0.052***
	(0.03)	(0.02)
Share of household metered water consumption	0.093	-0.120**
	(0.09)	(0.06)
Constant	1.340***	1.663**
	(0.37)	(0.67)
R-squared	0.456	
N. of obs.	128.000	128.000

Table 29.3 present the main significant variables explaining household water consumption in UK. The price elasticity varies across models, from -0.18 with the OLS to -0.20 with the GLS (all estimates are significant). Based on the GLS model, a 10% increase in water price results in a 2.0% decrease in short-run water consumption in UK. Water demand in UK appears to be inelastic, i.e. the estimated price elasticity in absolute values is smaller than one. Our price elasticity is consistent with previous findings in UK (Gardner 2011).

The income elasticity is significant with a positive sign. The income elasticity is highly consistent with the two models. It varies between 0.26 and 0.27. This suggests that there is an increasing relationship between water consumption and household income in UK. The positive significant coefficient for income indicates that, based on the GLS model, a 10% increase in income will result in a 2.7% increase in water consumption.

Climate conditions play also a significant but moderate role (GLS model). An increase by 10% of rainfall will imply a decrease in water consumption by 0.05% (GLS model).

Lastly, the share of household metered water consumption has an expected negative sign with the GLS model. Metered households tend to have a water consumption per capital smaller than unmetered ones. In terms of policy recommendations, this calls for intensifying the use of water meters.

A possible way to assess the validity of the model is to compare the water consumption predicted by the demand function to the observed water consumption, see Figure 29.1. For most of the municipalities the model performs quite well. The mean absolute percentage error is 4.2.

Water consumption may to be at least somehow persistent over time due to household habits or due to the time needed to adjust durable equipments (shower for instance). With panel or time-series data, one way to take into this time persistence characteristic of household water consumption is to introduce the lagged consumption as an additional independent variable in Equation (29.2). The dynamic specification of our equation of interest becomes then :

$$\ln(y) = \alpha \ln(p) + \beta \ln(I) + \gamma \ln(Z)' + \mu \ln(\text{Lag}\, y) \tag{29.4}$$

where Lag y represents the lagged water consumption. From this specification is is then possible to derive the long-run price elasticity of the household water demand function which simply writes:

$$\epsilon_p^{LT} = \frac{\alpha}{1-\mu}. \tag{29.5}$$

Table 29.4: Estimation of the household water demand with lagged water consumption in United Kingdom

	UKGLSlag b/se
ln Water price (in euros per m3)	-0.042**
	(0.02)
ln Household income (in euros per capita)	0.032
	(0.03)
ln average of daily rainfall (mm per day)	-0.023
	(0.02)
Share of household metered water consumption	-0.036
	(0.05)
ln Lag of water consumption per capita	0.848***
	(0.05)
Constant	0.361
	(0.23)
R-squared	
N. of obs.	112.000

We provide in Table 29.4 our estimates for the household water demand function where the lagged consumption has been introduced as an additional independent variable. With the UKGLSlag model, the long-term price elasticity is estimated to be -0.28 significantly different from zero at 5%.

Bibliography

Antso, K., and I. Hermet (2013): *Estonian environmental indicators 2012, Estonian Environment Information Centre, 2013*.

AQUAVAL (2012): "Walloon drinking water and waste-water treatment statistics 2012 report," .

Arbués, F., R. Barberán, and I. Villanúa (2004): "Price impact on urban residential water demand: A dynamic panel data approach," *Water Resources Research*, 40(11), n/a--n/a.

Arbués, F., M. A. García-Valiñas, and R. Martińez-Espiñeira (2003): "Estimation of Residential Water Demand: A State-of-the-art Review," *The Journal of Socio-Economics*, 32(1), 81--102.

Arbués, F., and I. Villanúa (2006): "Potential for Pricing Policies in Water Resource Management: Estimation of Urban Residential Water Demand in Zaragoza, Spain," *Urban Studies*, 43(13), 2421--2442.

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

Athanasiadis, I. N., A. K. Mentes, P. A. Mitkas, and Y. A. Mylopoulos (2005): "A Hybrid Agent-Based Model for Estimating Residential Water Demand," *SIMULATION*, 81(3), 175--187.

Bartczak, A., A. Kopanska, and J. Raczka (2009): "Residential water demand in a transition economy: Evidence from Poland," *Water Sci. Technol. Water Supply*, 9, 509--516.

BDEW (2015): "Comparison of European Water and Wastewater Prices-Survey," *Bundesverband der Energieund Wasserwirtschaft - German Association of Energy and Water Industries*.

Bernhard, J., A. Reynaud, D. Lanzanova, and A. deRoo (2015): "Household water demand, water price, and welfare loss: scenarios for future Europe," *Poster presented at the European Geosciences Union General Assembly 2015, Vienna, Austria 12-17 April 2015*.

Bithas, K., and S. Chrysostomos (2006): "Estimating urban residential water demand determinants and forecasting water demand for Athens metropolitan area, 2000-2010," *South-Eastern Europe Journal of Economics*, 1(1), 47--59.

BMU (2011): *Water Management in Germany Water Supply -- Waste Water Disposal, Federal Ministry for the Environment, Nature Conservation and Nuclear Safety, Berlin, Germany*.

Brady, J., and N. F. Gray (2013): "Analysis of water pricing in Ireland and recommendations towards a more efficient water sector," *Water Policy*, 15, 435--457.

Ciomos, V., D. Ciataras, and C. Alina (2012): "Price Elasticity of the Residential Water Demand. Case-Study: Investment Project in Cluj County, Romania," *Transylvanian Review of Administrative Sciences*, 8(36).

Clark, W. A., and J. C. Finley (2007): "Determinants of Water Conservation Intention in Blagoevgrad, Bulgaria," *Society & Natural Resources*, 20(7), 613--627.

Cruz, N. F. d., R. C. Marques, G. Romano, and A. Guerrini (2012): "Measuring the efficiency of water utilities: a cross-national comparison between Portugal and Italy," *Water Policy*, 14(5), 841.

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

Dalmas, L., and A. Reynaud (2005): *Residential water demand in the Slovak Republic*Edward Elgar Publishing, Inc., Cheltenham, UK.

Delia, C. (2004): "Economic Considerations Regarding Markets for Water in the Maltese Islands," *Report prepared for the FAO on Water Resources Review for the Maltese Islands*.

Domene, E., and D. Saurí (2006): "Urbanisation and Water Consumption: Influencing Factors in the Metropolitan Region of Barcelona," *Urban Studies*, 43(9), 1605--1623.

Edgar, M. (2014): "Final Report on Household Water Consumption Estimates," *Economic and Social Research Institute, Report for Irish Water*.

EEA (2013): "Assessment of cost recovery through water pricing," *EEA Technical report No 16/2013*.

ERSAR (2013): "Annual report on water and waste water in Portugal (2012) -- Executive Summary, The Water and Waste Services Regulation Authority," .

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

EuropeanCommission (2012): "A Blueprint to Safeguard Europe's Water Resources," *Coomunication from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committe of the Regions*.

Frondel, M., and F. Messner (2008): "Price Perception and ResidentialWater Demand: Evidence from a German Household Panel, presented at the 2008 EAERE meeting in Gothenburg, Sweden," .

Frone, S., and D. F. Frone (2013): "Promoting access to water supply and sanitation: Issues and Challenges in Romania," *Scientific Papers. Series "Management, Economic Engineering in Agriculture and rural development"*, 13(2), 165--170.

García-Rubio, M. A., A. Ruiz-Villaverde, and F. González-Gómez (2015): "Urban Water Tariffs in Spain: What Needs to Be Done?," *Water*, 7(4), 1456--1479.

García-Valiñas, M. (2005): "Efficiency and Equity in Natural Resources Pricing: A Proposal for Urban Water Distribution Service," *Environmental and Resource Economics*, 32(2), 183--204.

García-Valiñas, M. A., R. Martínez-Espiñeira, and F. González-Gómez (2010): "Affordability of residential water tariffs: Alternative measurement and explanatory factors in southern Spain," *Journal of Environmental Management*, 91(12), 2696 -- 2706.

Garcia-Valinas, M. d. l. A. (2006): "Analysing rationing policies: drought and its effects on urban usersâĂŹ welfare (Analysing rationing policies during drought)," *Applied Economics*, 38(8), 955--965.

Gardner, K. (2011): *Residential Water Demand Modelling and Behavioural Economics*. Phd dissertation, School of Economics and ESRC Centre for Competition Policy, University of East Anglia.

Gaudin, S., R. C. Griffin, and R. C. Sickles (2001): "Demand Specification for Municipal Water Management: Evaluation of the Stone-Geary Form," *Land Economics*, 77(3), 399--422.

Gilg, A., and S. Barr (2006): "Behavioural attitudes towards water saving? Evidence from a study of environmental actions," *Ecological Economics*, 57(3), 400 -- 414.

Globevnik, L. (2013): *Market Sector Scan of Water Management of Slovenia. Report for the Kingdom of the Netherlands, Embassy of the Kingdom of the Netherlands, Ljubljana, Slovenia*.

Grafton, R. Q., M. B. Ward, H. To, and T. Kompas (2011): "Determinants of residential water consumption: Evidence and analysis from a 10-country household survey," *Water Resources Research*, 47(8), n/a--n/a, W08537.

Hajispyrou, S., P. Koundouri, and P. Pashardes (2002): "Household demand and welfare: implications of water pricing in Cyprus," *Environment and Development Economics*, null, 659--685.

Hanke, S. H., and L. d. Maré (1982): "Residential water demand: A pooled, time series, cross section study of Malmö, Sweden," *Journal of the American Water Resources Association*, 18(4), 621--626.

Hansen, L. G. (1996): "Water and energy price impacts on residential water demand in Copenhagen," *Land Economics*, pp. 66--79.

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

Heinoa, O. A., A. J. Takalaa, and T. S. Katkoa (2011): "Challenges to Finnish water and wastewater services in the next 20-30 years," .

Hejazi, M., J. Edmonds, V. Chaturvedi, E. Davies, and J. Eom (2013): "Scenarios of global municipal water-use demand projections over the 21st century," *Hydrological Sciences Journal*, 58(3), 519--538.

HITA (2013): *The Hungarian Water and Sanitation Industry in the 21st century, Hungarian Investment and Trade Agency*.

Hortová, J., and L. Kristoufek (2014): "Price Elasticity of Household Water Demand in the Czech Republic," *IES Working Paper 38/2014. IES FSV. Charles University*.

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

IBEC (2013): "Addressing the Challenge of Local Authority Costs Commercial Rates and Water/Wastewater Charges, IBEC Commercial Rates and Water/Wastewater Charges 2013 Review," *Irish Business and Employers Confederation*.

ICPDR (2005): "The Danube River Basin District Management Plan - Annex 16: Case studies on the assessment of current levels of cost recovery in the Danube River Basin District," *ICPDR - International Commission for the Protection of the Danube River*.

Kantor, M., and N. Horváth (2012): *Central European Water Services in Transition--The Case of Poland*chap. 3, pp. 51--72.

Kooreman, P. (1993): “De prijsgevoeligheid van huishoudelijk watergebruik,(The price sensivity of the household demand for water),” *Economische Statistische Berichten*, 78, 181--âĂŞ3.

Koundouri, P., N. Papandreou, K. Remoundou, and Y. Kountouris (2014): “A Bird’s Eye View of the Greek Water Situation: The Potential for the Implementation of the EU WFD,” in *Water Resources Management Sustaining Socio-Economic Welfare*, ed. by P. Koundouri, and N. A. Papandreou, vol. 7 of *Global Issues in Water Policy*, pp. 1--24. Springer Netherlands.

Linderhof, V. G. M. (2001): “Household demand for energy, water and the collection of waste. A microeconometric analysis,” .

LMVeritas (2012): *Overview and analysis of prices for drinking water supply and for wastewater and rainwater in Slovania, Ljubljana, Slovenia*.

Martínez-Espiñeira, R. (2002): “Residential Water Demand in the Northwest of Spain,” *Environmental and Resource Economics*, 21(2), 161--187.

——— (2007): “An Estimation of Residential Water Demand Using Co-integration and Error Correction Techniques,” *Journal of Applied Economics*, 10(1), 161--184.

Martins, R., and F. Adelino (2007): “Residential water demand under block rates -- a Portuguese case study,” *Water Policy*, 9(2), 217--230.

Mattisson, O., and T. Anna (2010): “The water sector in Sweden,” *CIRIEC Working paper*, 12.

Mazzanti, M., and A. Montini (2006): “The determinants of residential water demand: empirical evidence for a panel of Italian municipalities,” *Applied Economics Letters*, 13(2), 107--111.

MECE (2012): “La fornation du prix de l’eau,” *Perspective de Politque Economique,Ministère de lŠEconomie et du Commerce Extérieur, Luxembourg, 2012*, 22.

Metcalf, L. (1926): “Effect of Water Rates and Growth in Population Upon per Capita Consumption,” *Journal (American Water Works Association)*, 15(1), 1--21.

Michelsen, A. M., J. T. McGuckin, and D. Stumpf (1999): “NONPRICE WATER CONSERVATION PROGRAMS AS A DEMAND MANAGEMENT TOOL1,” *JAWRA Journal of the American Water Resources Association*, 35(3), 593--602.

Millock, K., and C. Nauges (2010): “Household Adoption of Water-Efficient Equipment: The Role of Socio-Economic Factors, Environmental Attitudes and Policy,” *Environmental and Resource Economics*, 46(4), 539--565.

MinistryEnvironment (2011): *Report on Water Management in the Slovak Republic in 2010, Water Research Institute Bratislava, report for*.

Monteiro, H., L. Cardoso, and M. D. C. Figueiredo (2014): “Going Beyond Average Response: Modeling Portuguese Residential Water Demand with Quantile Regression,” *5th World Congress of Environmental and Resource Economists, Istanbul, Turkey*.

Monteiro, H., and C. Roseta-Palma (2011): “Pricing for scarcity? An efficiency analysis of increasing block tariffs,” *Water Resources Research*, 47(6).

MRD (2014): *Strategy for Development and Management of the Water Supply and Sanitation Sector in the Republic of Bulgaria 2014--2023, Volume 1, Ministry of Regional Development, Republic of Bulgaria, Approved by Council of Ministers decision No 269 of May 7, 2014*.

Müller, C. (2012): "Welfare Effects of Water Pricing in Germany, MPRA Paper No. 41638," .

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

Nauges, C., and A. Reynaud (2001): "Estimation de la demande domestique d'eau potable en France," *Revue économique*, 52(1), 167--185.

Nauges, C., and A. Thomas (2000): "Privately Operated Water Utilities, Municipal Price Negotiation, and Estimation of Residential Water Demand: The Case of France," *Land Economics*, pp. 68--85.

——— (2003): "Long-run Study of Residential Water Consumption," *Environmental and Resource Economics*, 26(1), 25--43.

Neunteufel, R., R. Perfler, D. Schwarz, G. Bachner, and B. Bednar-Friedl (2015): "Water Supply and Sanitation," in *Economic Evaluation of Climate Change Impacts*, ed. by K. W. Steininger, M. KÃ nig, B. Bednar-Friedl, L. Kranzl, W. Loibl, and F. Prettenthaler, Springer Climate, pp. 215--234. Springer International Publishing.

OECD (2015): "Water Resources Allocation: Sharing Risks and Opportunities, OECD Studies on Water," *OECD Studies on Water, OECD Publishing, Paris*.

Parker, J. M., and R. L. Wilby (2013): "Quantifying Household Water Demand: A Review of Theory and Practice in the UK," *Water Resources Management*, 27(4), 981--1011.

Peda, P. (2012): "The relationship between governance and performance in water services provision in Estonian municipalities," Ph.D. thesis, The Faculty of Economics and Business Administration, University of Tartu, Estonia.

Polycarpou, A., and T. Zachariadis (2013): "An Econometric Analysis of Residential Water Demand in Cyprus," *Water Resources Management*, 27(1), 309--317.

Rajala, R., and T. Katko (2004): "Household water consumption and demand management in Finland," *Urban Water Journal*, 1(1), 17--26.

REC (2009): "Strategies for reform: A manual for water utilities in South Eastern Europe," *REC - Regional Environmental Center for Central and Eastern Europe, 106 p*.

RepublicofCroatia (2010): "Implementation Plan (revised) for water utility directives," *Government of the Republic of Croatia, Zagreb*.

Reynaud, A. (2015): "Assessing the impact of full cost recovery of water services on European households," *Working paper Joint Research Center of the European Commission, Water Resources Unit*.

Rinaudo, J.-D., N. Neverre, and M. Montginoul (2012): "Simulating the Impact of Pricing Policies on Residential Water Demand: A Southern France Case Study," *Water Resources Management*, 26(7), 2057--2068.

Romano, G., N. Salvati, and A. Guerrini (2014): "Estimating the Determinants of Residential Water Demand in Italy," *Water*, 6(10), 2929--2945.

Schleich, J., and T. Hillenbrand (2009): "Determinants of residential water demand in Germany," *Ecological Economics*, 68(6), 1756 -- 1769, Eco-efficiency: From technical optimisation to reflective sustainability analysis.

Sebri, M. (2014): "A meta-analysis of residential water demand studies," *Environment, Development and Sustainability*, 16(3), 499--520.

Sofroniou, A., and S. Bishop (2014): "Water Scarcity in Cyprus: A Review and Call for Integrated Policy," *Water*, 6(10), 2898--2928.

Sorensen, E. M. (2010): *The Danish Water Sector Reform âĂŞ Economic Efficiency and Central-Local Relations, AKF, Danish Institute of Governmental Research*.

Statzu, V., and E. Strazzera (2011): "A panel data analysis of residential water demand in a Mediterranean tourist region The case of Sardinia," in *Economics of Sustainable Tourism*, ed. by F. Cerina, A. Markandya, and M. McAleer. Routledge, Critical studies in tourism, business and management serie.

Tanverakul, S. A., and J. Lee (2012): *Historical Review of U.S. Residential Water Demand*chap. 313, pp. 3122--3136.

Vagiona, D., and N. Mylopoulos (2009): "Water Price Elasticity And Public Acceptability On Conservation Options In The City Of Volos, Greece," *International Journal of Sustainable Development and Planning*, 4(4), 322--332.

Vandecasteele, I., A. Bianchi, F. Batista e Silva, C. Lavalle, and O. Batelaan (2014): "Mapping current and future European public water withdrawals and consumption," *Hydrology and Earth System Sciences*, 18(2), 407--416.

Vanhille, J. (2012): "A Social Gradient in HouseholdsâĂŹ Environmental Policy Responsiveness? The Case of Water Pricing in Flanders," *Paper Prepared for the 32nd General Conference of The International Association for Research in Income and Wealth, Boston, USA, August 5-11, 2012*.

Vevin (2012): "Dutch drinking water statistics 2012: The water cycle from source to tap," .

Vinke-de Kruijf, J., V. Dinica, and D. C. Augustijn (2009): "Reorganization of water and waste water management in Romania: from local to regional water governance," *Environmental Engineering and Management Journal*, 8(5), 1061--1071.

VMM (2012): "Watermeter 2012, Drinking water production and distribution in figures," .

WorldBank (2015a): "Water and Wastewater Services in the Danube Region - A State of the Sector Bulgaria Country note)," *Regional report, www.danube-water-program.org*.

——— (2015b): "Water and Wastewater Services in the Danube Region - A State of the Sector (Croatia Country note)," *Regional report, www.danube-water-program.org*.

——— (2015c): "Water and Wastewater Services in the Danube Region - A State of the Sector (Czech Republic Country note)," *Regional report, www.danube-water-program.org*.

——— (2015d): "Water and Wastewater Services in the Danube Region - A State of the Sector (Hungary Country note)," *Regional report, www.danube-water-program.org*.

——— (2015e): "Water and Wastewater Services in the Danube Region - A State of the Sector (Slovakia Country note)," *Regional report, www.danube-water-program.org*.

Worthington, A. C., and M. Hoffman (2008): "An Empirical Survey of residential Water Demand Modelling," *Journal of Economic Surveys*, 22(5), 842--871.

Zhao, Y., and D. Crosbie (2012): "Water pricing in Ireland: a techno-economic and political assessment," *International Journal of Environmental Studies*, 69(3), 427--442.

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