Price Elasticity of Residential Water Demand Using Household Five-Year-Every-Other-Month Data Before and After a Tariff Revision

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Abstract

In this study, the price elasticity of water demand was estimated using disaggregated data of approximately 30,000 households recorded over five years: two years before and three years after a tariff revision. From the results of the latent class analysis, the mean price elasticity was -0.1. The households were divided into three groups: 35%–55% of the households did not respond to the tariff revision, and households with high water demand prior to the revision had higher elasticity. In addition, no statistically significant difference was observed in elasticity between the first and third years after revision.

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Abstract

In this study, the price elasticity of water demand was estimated using disaggregated data of approximately 30,000 households recorded over five years: two years before and three years after a tariff revision. From the results of the latent class analysis, the mean price elasticity was − -0.1. The households were divided into three groups: 35%–55% of the households did not respond to the tariff revision, and households with high water demand prior to the revision had higher elasticity. In addition, no statistically significant difference was observed in elasticity between the first and third years after revision.

1 Introduction

Water is an indispensable commodity in our daily life and necessitates efficient supply and restricted use, and the tariff structure is strongly related to these factors (Elnaboulsi, 2009; Nauges & Whittington, 2016). Certainly, the cheaper the price, the better; but if it engenders water wastage, it will result in an overwhelming increase in supply costs. On the other hand, in Japan, where the study was conducted, the total population and number of households have decreased in many municipalities, and water tariffs have increased to recover the cost for renewing water pipes and water facilities.

In many countries, including Japan, tariff consists of a basic charge and an increasing block tariff. An important consideration is the design of a tariff structure from the viewpoint of user equity, and price elasticity is a useful economic measure incorporated in this discussion.

Many empirical studies have been conducted to date; a meta-analysis has been conducted to collect and analyze the data of the estimates of price elasticities (Espey et al., 1997; Brookshire et al., 2002; Dalhuisen et al., 2003; Klein et al., 2006; Sebri, 2014; Paola et al., 2019). The average price elasticity of water demand was -0.51 to -0.36. Few studies have found that household water demand is price elastic (Arbués et al., 2006; Arbués et al., 2010). Functional specification, aggregation level, data characteristics, and estimation issues are associated with different elasticity values. Spatial variations in price elasticities have also been documented. Dalhuisen et al. (2003) reported that price elasticities are lower in Europe than in the United States, and price elasticities within the United States are greater in the arid West with regard to the absolute value.

Thus, although it is known that the absolute value of elasticity is less than one, few studies have focused on the difference in households to discuss equity.

Water demand varies depending on socioeconomic attributes (number of households, age, occupation, income, attitude, size of house, age, etc.), as well as weather changes (Reynaud & Romano, 2018). These factors must be considered when estimating the appropriate elasticity (Hoyos & Artabe, 2017). In addition, while considering an increasing block tariff system, as price and demand are correlated, a biased elasticity is occasionally obtained by a simple analysis, especially using aggregated data. Moreover, if the rate of price change is small, households do not observe any variation in water use (elasticity value is 0).

However, the impact of income on price elasticity is unclear. Pashardes et al. (2002) demonstrated the price elasticity estimation for each income group and clarified that price elasticity increased with an increase in income (easy adjustment of demand). Brolinson (2020) used billing records and demographic data to indicate that wealthier households were more price elastic than lower-income households. On the other hand, lower-income groups were more price-responsive than higher-income groups. In Cyprus, Hajispyrou et al. (2002) reported a price elasticity of −0.79 for the lowest-income group, as compared to −0.39 for the highest-income group. In Belgium, the price elasticity for the lowest-income quintile was estimated as −0.76, as compared to −0.25 for the highest-income quintile (Vanhille, 2012).

In the analysis using aggregated data, short- and long-run elasticities were obtained using the lag term in the specification. Short-run elasticities are often lower than their long-run counterparts. This suggests that consumers may require time to adjust to water-using capital stocks and study the effects of use on their bills. However, the relationship between short- and long-run elasticities is unclear when disaggregated data are used.

To the best of our knowledge, analysis using disaggregated data has not been conducted in Japan. In addition, there is insufficient research on the difference in elasticity value depending on the consumer type and the change in elasticity after the revision.

Therefore, we estimated price elasticity using monthly data from approximately 30,000 households. The data were collected for a total of five years: two years before the tariff revision, and three years after the revision. Simultaneously, we presented the relationship between price elasticity and water usage using latent class analysis. Furthermore, we compared the elasticities between the first and third years after revision.

2 Methodology

Households usually recognize the average price that appears on the bill, which is the price of water used in most applications (Arbues & Villanua, 2006; Musolesi & Nosvelli, 2007; Pérez-Urdiales et al., 2016). In this study, the following two prices were defined, with the elasticity estimated for each.

- Price 1: Marginal cost

  The marginal cost is the change in the meter rate (cost increase per cubic meter).

- Price 2: Average cost

  A value obtained by dividing the water bill by water demand.

Price elasticity is the value obtained by dividing the rate of change in water demand by the rate of price change. Elasticity has a negative sign when water demand decreases due to rising prices.

We applied latent class analysis assuming that the price elasticities of households followed a mixed normal distribution and adjusted the average temperature difference (Shalizi, 2017), and used the flexmix package in the CRAN R for estimation (Grün & Leisch, 2008). Furthermore, we analyzed the relationship between price elasticity and water usage. Subsequently, a significant difference in elasticity was tested for 2016 and 2018, which were the first and third years after revision, respectively.

3 Data

The data for this analysis were obtained from households in Hadano City, Kanagawa Prefecture, Japan. The tariff revision was performed in April 2016 (Table 1). The monthly water demand and bill of each household for five years, that is, two years before the revision and three years after the revision from 2014 to 2018 were obtained. Unfortunately, information was not available on the household income or the number of households.

Table 1. *Tariff structure*

Tariff revision (April 2016)	Basic charge	Metered charge (m^3)					
	～8	9–20	21–30	31–50	51–100	101–500	501~
Before (Yen)	520	70	80	130	195	220	220
After (Yen)	680	85	95	140	205	225	245

In Hadano City, meter readings were performed bimonthly. Almost half of the households have meter reading during even-numbered months, while the rest have meter reading during odd-numbered months.

We selected households that paid a fee continuously for five years and used 16 m^3 of water for two months. Approximately 14,544 households in even-numbered months and 15,519 households in odd-numbered months were considered for this study. The data for May and April, which observed mixed effects before and after the revision, were not used. Monthly average temperatures were also collected over a period of five years.

Descriptive statistics are shown in Table 2. In this study, the value of the residential water demand before the tariff change was averaged from the data collected between 2014 and 2015, and the values post-revision were averaged from the data collected between 2016 and 2018. Therefore, we obtained five price elasticities for each household every month. If we assume that each household has one price elasticity, the variance of these price elasticities would be small.

Table 2. *Descriptive statistics*

	Tariff revision	Min.	1st Qu.	Median	Mean	3rd Qu.	Max.	Std.dev
Water demand (m^3/two months)	Before	16	34	45.5	48.6	59.5	147.5	387.8
	After	16	34	44.7	47.9	58.7	136.7	362.7
Price [Yen/m³] (definition 1)	Before	70	70	80.0	89.4	80	195	760.2
	After	85	85	95.0	103.2	95	205	654.7
Price [Yen/m³] (definition 2)	Before	70.1	73.1	75.0	78.2	78.8	137.5	73.1
	After	69.0	91.8	93.1	96.0	96.3	145.5	49.7
Average Temprature[°C]	Before	4.7	9.4	16.1	15.7	22.3	26.8	57.1
	After	3.9	8.2	16.8	16.0	22.3	27.9	60.6

Figure 1 shows a scatter plot of residential water demand before revision and the rate of change in unit price. The rate of change in tariffs was smaller for households that used more water. Figure 2 shows the changes in the average temperature and water demand in August and December for 2014–2018. Although the average water demand fluctuated over time, it decreased due to tariff revisions. In addition, the water demand in August, which had a high average temperature, increased when compared to that in December.

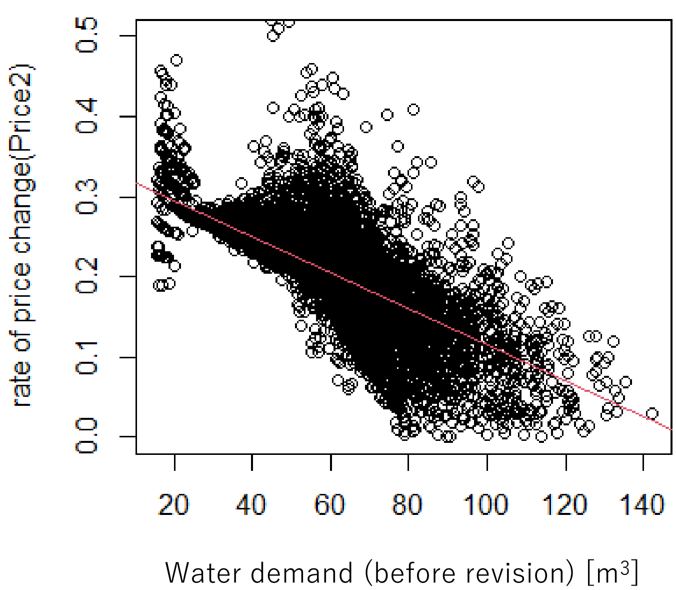

Figure 1. Scatterplot of water demand and rate of price change (Price 2)

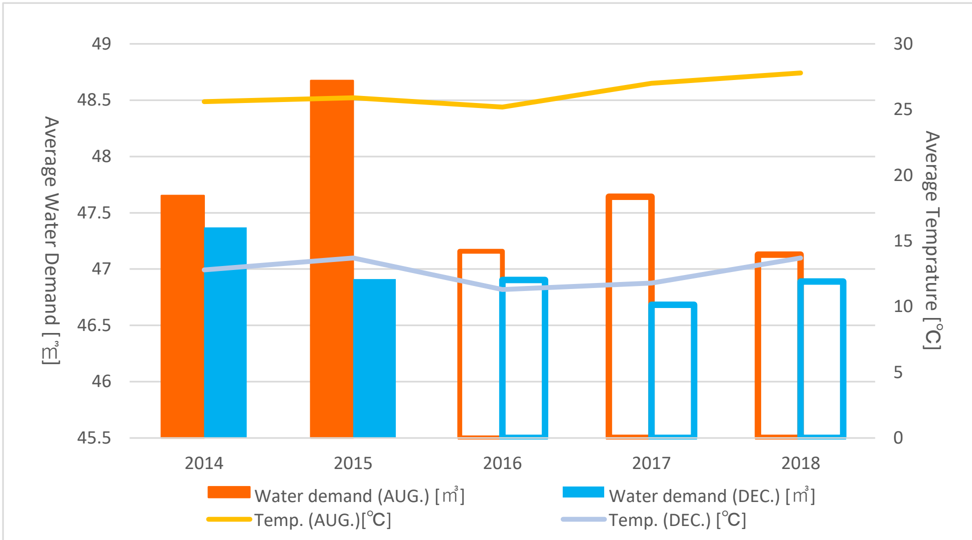

Figure 2. Change in average water demand and average temperature in August and December for 2014–2018

Note: The column bar for 2014-2015 is color filled whereas, that for 2016-2018 is not filled

4 Results

4.1 Relationship between water demand and elasticity

Figure 3 shows a scatter plot of the water demand before tariff revision and elasticity in June.

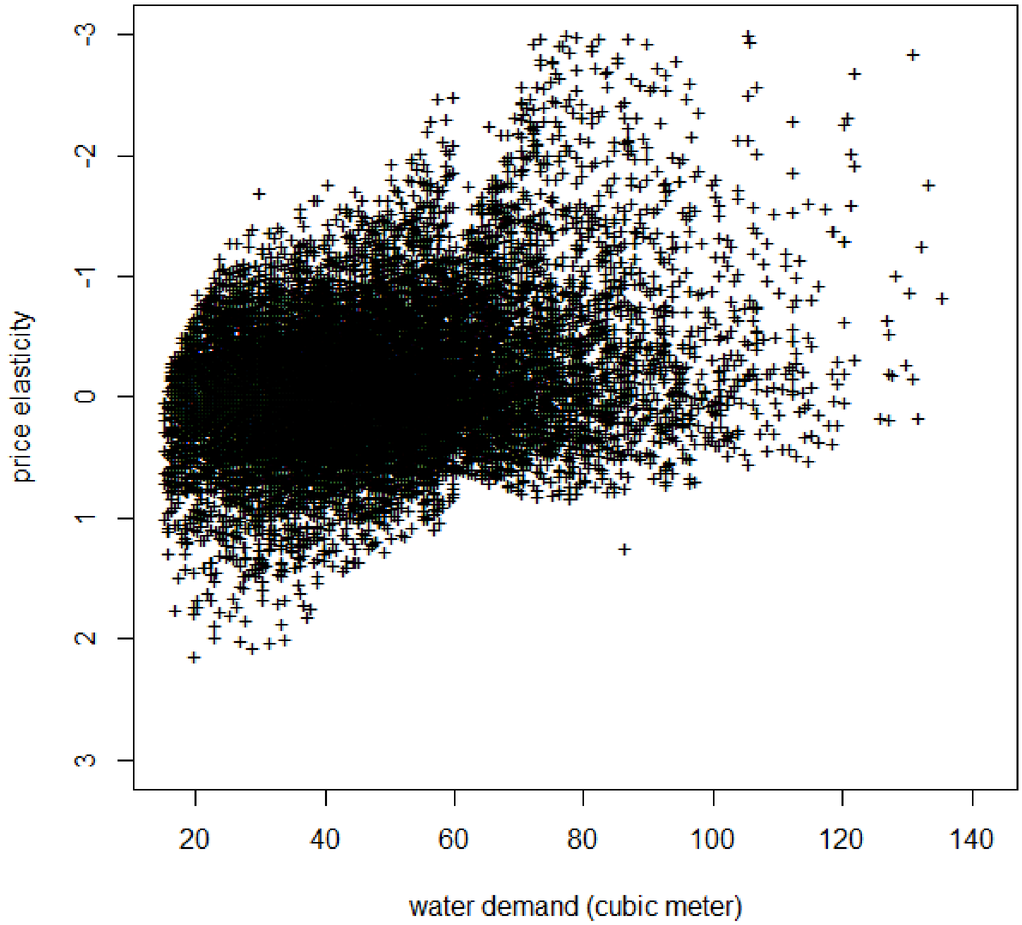

Figure 3. Residential water demand before the tariff revision versus price elasticity in June

Notably, many households had a positive elasticity. That is, the water demand increased after the rate revision. This does not imply that residential water demand has increased due to the price revision, but it should be interpreted as the change in residential water demand by the tariff revision being within a certain fluctuation range, and the households with increased water demand were unresponsive to price variations.

Next, observing the relationship of water demand prior to the revision, the higher the water demand in any month, the greater the elasticity. As shown in Fig. 2, the rate of change in unit price decreased for households that used more water, and such households had relatively larger elasticity. Conversely, it was difficult for households with relatively less water usage to reduce it further, even with a price change. In general, households that use large amounts of water tend to have higher incomes. As observed by Brolinson (2020), households with increased economic margins were more likely to adjust their demand.

The variation was relatively large for Price 1 (marginal cost) as compared to Price 2 (average cost), and had a higher proportion of households with an absolute value exceeding 1 (Figure 4). Therefore, we can conclude that Price 2 (average cost) is more appropriate and can be interpreted as households responding to average costs rather than marginal costs. In other words, consumers are less aware of marginal costs. If consumers scan their bills and notice higher water charges, the average cost is likely to be more reasonable.

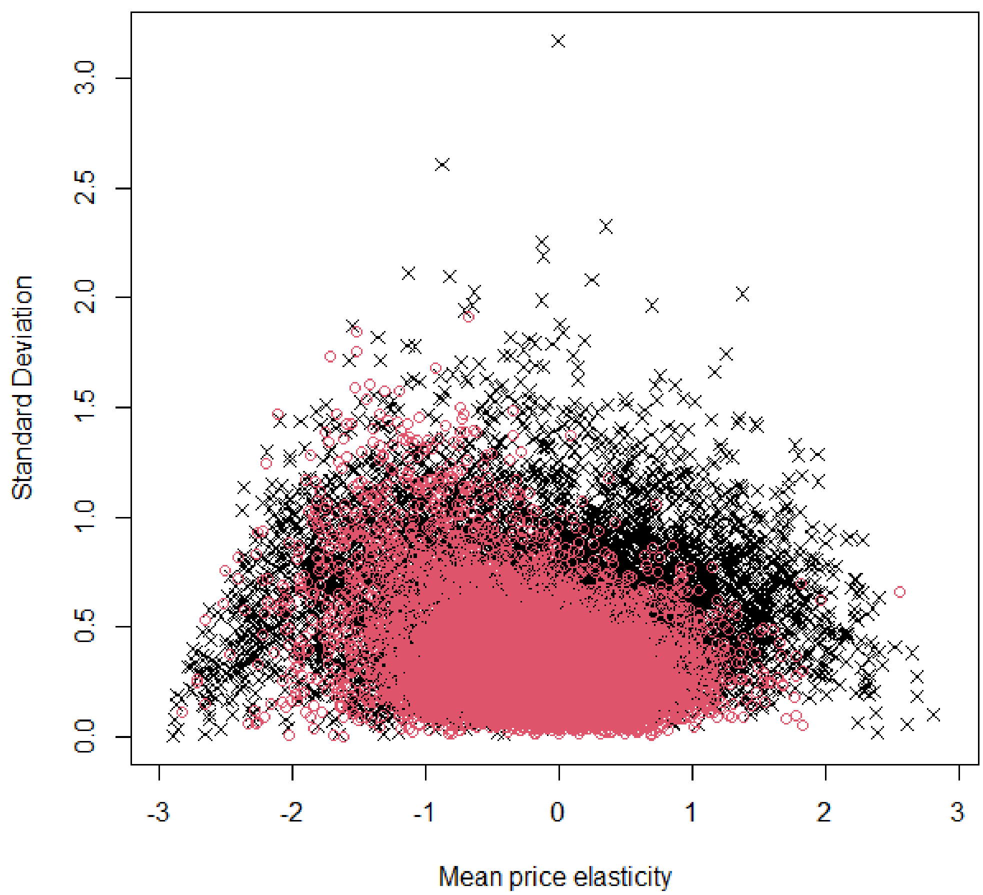

Figure 4. Mean versus standard deviation of price elasticity of each household in odd-numbered months (Black cross: Price 1 (marginal cost), Red circle: Price 2 (average cost))

4.2 Latent Class Analysis

Regression analysis was performed by treating each household as a random effect, using the difference in average temperature before and after the tariff revision as an explanatory variable. Next, the elasticity value was adjusted assuming that there was no visible temperature difference. We subsequently applied the flexmix package in the latent class analysis for even and odd months.

The results are shown in Table 3. In both even- and odd-numbered months, three classes were selected when the Akaike information criterion was used for the index: a class with high elasticity responded significantly to price revisions, a class with low elasticity responded slightly to the tariff revision, and a class with zero elasticity remained unresponsive to tariff revision. In addition, it was estimated that 35%–55% of households were unresponsive to the revision, and 5%–6% of households responded significantly to price variations.

Table 3. *Estimated results of latent class analysis*

Even-numbered months					Odd-numbered months			
Class ID	2	1	0		Class ID	2	1	0
share	0.06	0.59	0.35		share	0.05	0.41	0.55
mean	-0.55	-0.09	0.00		mean	-0.61	-0.16	0.00
std. dev.	0.05	0.01	0.01		std. dev.	0.03	0.01	0.01
weighted mean	-0.10				weighted mean	-0.11		

The weighted average of price elasticity was -0.10 and -0.11 in even-numbered and odd-numbered months, respectively. Interestingly, the households considered in both months were entirely different, but the estimated price elasticity was almost similar.

4.3 Difference in elasticity between the first year and the third year after revision

Finally, the elasticity values were compared after similarly adjusting the temperature difference for the first and third years post-revision.

The results are shown in Figure 5. There was no significant difference in price elasticity between even-numbered and odd-numbered months, and the effect of tariff revision was not confirmed for the three years.

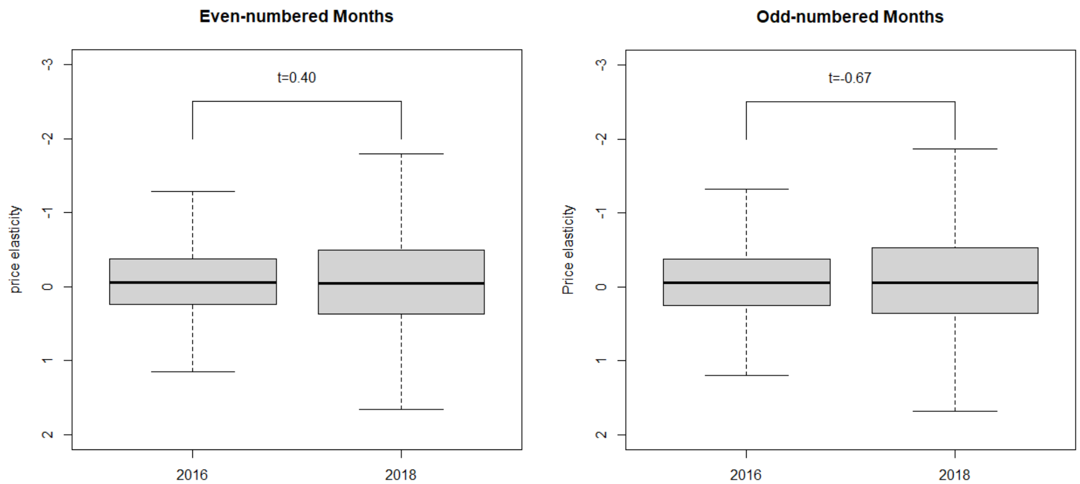

Figure 5. Comparison of price elasticity between the first year (2016) and the third year (2018) after the revision

Note: t in the figure shows t-value.

5 Conclusion

In this study, we analyzed the price elasticity of residential water demand using disaggregated data before and after price revision. We demonstrated that the price elasticity increased with increased water usage. It was estimated that approximately 5% of households responded significantly to price change, approximately 40% of households responded slightly, and approximately 45% were unresponsive to the changes. The estimated mean price elasticity ranged between -0.11 and -0.10. Furthermore, the difference in elasticity between the first and third years after revision was insignificant.

It was observed that households with low water demand had low elasticity and little room for adjustment due to tariff revisions. In the future, when increasing the tariff to cope with the increasing maintenance cost, it may be desirable to raise the price rate per unit rather than charging a flat rate.

Unfortunately, data attributed to households, such as income and household size, could not be obtained. Therefore, this elasticity may have omitted the variable bias. Furthermore, the optimal tariff structure that considers the impact on business water demand should be discussed in the next step (Elnaboulsi, 2009; Sibly & Tooth, 2014; Renzetti et al., 2015; Nauges and Whittington, 2016). For example, a time-varying tariff using a smart meter is a promising alternative (Lopez-Nicolas et. al., 2018).

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Data Policy: Data archiving is underway. We submitted our data to Dryad.
Tanishita, Masayoshi (2021), Water demand, price and temperature in 2014-18 in Hadano City, Kanagawa, Japan, Dryad, Dataset, https://doi.org/10.5061/dryad.pnvx0k6mk

References

Arbues, F., & Villanua, I. (2006). Potential for pricing policies in water resource management: Estimation of urban residential water demand in Zaragoza, Spain. *Urban Studies*, *43*(13), 2421–2442. doi.org/10.1080/00420980601038255

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

Brolinson, B. (2020). Does increasing block pricing decrease energy use? Evidence from the residential electricity market. Job Market paper. http://beckabrolinson.georgetown.domains/Brolinson_IBPs.pdf (Access: 03MAR2020)

Brookshire, D. S., Burness, H. S., Chermak, J. M., & Krause, K. (2002). Western urban water demand. *Natural Resources Journal*, *2*(4), 873–898.

Dalhuisen, J. M., Florax, R. J. G., de Groot, H. L. F., & Nijkanp, P. (2003). Price and income elasticities of residential water demand, A meta-analysis. *Land Economics*, *79*(2), 292–308.

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

Elnaboulsi, J.C. (2009). An incentive water pricing policy for sustainable water use. *Environmental and Resource Economics*, *42*, 451–469.

Grün, B., & Leisch, F. (2008). FlexMix version 2: Finite mixtures with concomitant variables and varying and constant parameters. *Journal of Statistical Software*, *28*(4), 1–35. doi: 10.18637/jss.v028.i04

Hajispyrou, S., Koundouri, P., & Pashardes, P. (2002). Household demand and welfare: Implications of water pricing in Cyprus. *Environment and Development Economics*, *7*, 659–685.

Hoyos, D., & Artabe, A. (2017). Regional differences in the price elasticity of residential water demand in Spain. *Water Resources Management*, *31*, 847–865. doi: 10.1007/s11269-016-1542-0

Klein, B., Kenney, D., Lowrey, J., & Goemans, C. (2006). *Factors influencing residential water demand: A review of the literature*. Working Draft. Center for Science & Technology Policy Research, University of Colorado, Boulder. https://sciencepolicy.colorado.edu/admin/publication_files/2006.28.pdf (Access: 03MAR2020)

Lopez-Nicolas, A., Pulido-Velazquez, M., Rouge, C., Harou, J. J., & Escriva-Bou, A. (2018). Design and assessment of an efficient and equitable dynamic urban water tariff. Application to the city of Valencia, Spain. *Environmental Modelling & Software*, *101*, 137–145.

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

Nauges, C., & Whittington, D. (2016). Evaluating the performance of alternative municipal water tariff designs: Quantifying the tradeoffs between equity, economic efficiency, and cost recovery. *World Development*, *91*, 125–143.

Paola, G., Grillia, L., & Marzanob, R. (2019). Price elasticity of water demand considering scarcity and attitudes. *Utilities Policy*, *59*, Issue C. doi: 10.1016/j.jup.2019.100927

Pashardes, P., & Hajispyrou, S. (2002). Consumer demand and welfare under increasing block pricing. Discussion Paper 2002-07, Department of Economics, University of Cyprus, 1–17.

Pérez-Urdiales, M., García-Valiñas, M.A., & Martínez-Espiñeira, R. (2016). Responses to changes in domestic water tariff structures: A latent class analysis on household-level data from Granada, Spain. *Environmental and Resource Economics*, *63*, 167–191. doi: 10.1007/s10640-014-9846-0

Renzetti, S., Dupont, D. P., & Chitsinde, T. (2015). An empirical examination of the distributional impacts of water pricing reforms. *Utilities Policy*, *34*, 63–69.

Reynaud, A., & Romano, G. (2018). Advances in the economic analysis of residential water use: An introduction. *Water*, *10*, 1162. doi:10.3390/w10091162

Sebri, M. (2014). A meta-analysis of residential water demand studies. *Environment, Development and Sustainability*, *16*, 499–520.

Shalizi, C.R. (2017). *Advanced data analysis from an elementary point of view*, Cambridge University Press

Sibly, H., & Tooth, R. (2014). The consequences of using increasing block tariffs to price urban 24 water. *Australian Journal of Agricultural and Resource Economics*, *58*, 223–243.

Vanhille, J. A. (2012). *Social gradient in households' environmental policy responsiveness? The case of water pricing in Flanders*. In Proceedings of the 32nd General Conference of the International Association for Research in Income and Wealth, Boston, MA, USA, 5–11.