Price and income elasticities for urban residential water demand: A publication bias corrected meta-analysis

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Abstract: This study provides reference own-price and income elasticity estimates for urban residential water demand, for a range of different contexts. The own-price elasticity sample consists of 1,020 estimates, drawn from 175 studies. The income elasticity sample consists of 516 estimates, drawn from 126 studies. For both the own-price and income elasticity literatures, publication bias appears to be present. Relative to sample mean values, the publication bias corrected income elasticity estimate falls by around one-half, and the publication bias corrected own-price elasticity estimate falls by around one-third. For countries where the income level falls into the World Bank classification of low-income through to lower-middle-income, we recommend default values of: -0.3 and -0.4 be assumed for the short-run and long-run indoor own-price elasticity; -0.6 and -0.7 be assumed for short-run and long-run outdoor own-price elasticity; and 0.1 be assumed as the income elasticity for all scenarios. For countries in the upper-middle and above income groups, we recommend default values of: -0.1 and -0.2 for the short-run and long-run indoor own-price elasticity; -0.4 and -0.5 for the short-run and long-run outdoor own-price elasticity; and that again 0.1 be assumed for the income elasticity, for all scenarios.

Key words: Elasticity; meta-regression analysis; publication bias; urban water demand

JEL classifications: Q21, Q25

Research categories: Demand and Price Analysis; Resource /Energy Economics and Policy

1. INTRODUCTION

Accelerated urbanization, population growth, and the pollution of major freshwater resources are placing significant pressure on urban water supply infrastructure (Santos et al., 2017; Wong and Brown, 2009). Traditional low-cost sources of potable water such as groundwater and surface water dams are depleting due to over-extraction and climate change impacts, and sourcing water through desalination and water recycling projects is costly (Marlow et al., 2013; Commonwealth of Australia, 2019). Given the increasing costs of water supply augmentation, much attention has been paid to demand management using pricing measures (Worthington and Hoffman, 2008);and there is now a large literature on the price and income elasticity of urban residential water demand. There is,however, also much heterogeneity in the water demand literature; and estimates may differ systematically with factors such as water use type(indoor use versus outdoor use) or the time frame under consideration (short-run versus long-run). Individual empirical studies provide valuable information on thefactors impacting water demand over a certain period of time, in a specific geographical location; but it is not clear that the results from any one study are suitable for use in a range of policy contexts.

In contrast to individual studies, systematic literature reviews can identify the factors that drive differences in reported elasticity estimates, and through this process generate synthetic meta-estimates that can be generalised to a wide variety of contexts. Meta-regression analysis is one specific type of quantitative systematic literature review. It involves combining empirical estimates from primary studies in a way that controls for the heterogeneity and methodological differences in the primary studies to provide quantitative references of the effect being studied. Once primary study estimates are aggregated, it is then possible to derivenumerical elasticity point estimates, and associated measures of uncertainty, adjusted to the context of an individual country or city.

Both Worthington and Hoffman (2008) and Arbues et al. (2003) are qualitative surveysof the empiricalwater demand literatureanddo not contain formal meta-regression analysis. Previous meta-regression studies of the water demand literature are detailed in Table 1, and we frame the contribution of this study in light of theseprevious works.[1]

The first contribution of this study is to substantially expand the sample of papers considered. The current study considers 176 papers, while the next largest study covered 124. Collecting studies from the grey literature is one strategy that can mitigate against publication bias. So, in addition to extending the number of peer-reviewed studies information fromworking papers, dissertations/thesis, discussion papers, and government reportsare also considered. In this study, the grey literature represents12% of the primary studies.

The second contribution is the weighting structureused for the meta-regression. Weighting primary study estimates by the inverse variance (standard error), or some function that includes the inverse variance, is the most efficient estimation strategy. Not all primary studies report information in a manner that allows standard errors (or approximate standard errors) for elasticity estimates to be easily calculated. As such,past meta-studies have used: no weighting structure (Espey et al., 1997; Dalhuisen et al., 2003);usedthe inverse sample size as a weighting structure (Sebri, 2014; Marzano et al., 2018); or focused only estimates from log-log demand models where both elasticity estimates and associated standard errors are reported directly (Havranek et al.,2018). In this study, we use estimates from all reported demand model types, and where the primary study does not report elasticity estimates directly, we derive elasticity estimates from the reported information, evaluated at the sample mean values for the data. Approximate standard errors are then derived using the delta method. An important feature of this approach is that it allows estimates from studies that

[1]Garrone et al. (2018) is a meta-analysis of the price elasticity of demand for water, however, the study shares the same dataset as Marzano et al. (2018), reporting identical results from the descriptive statistics including mean price elasticity estimates.

model water consumption as a two-part process comprising an essential,non-discretionary component (subsistence expenditure on water that does not respond to price), and a component that responds to price, to be included, while still maintaining estimation efficiency. To the extent that considering a non-discretionary subsistence component to residential water demand is consistent with the underlying data generating process, this is an important extension.[2]

The third major contribution is the treatment of publication bias. Methods to identify and 'correct' for publication bias, along with an understanding of the consequences of failing to correct for publication bias have evolved substantially in recent years. For example, low powered studies result in an overstatement of the true effect (Gelman and Carlin 2014); and there is evidence that there are many low power studies in the water demand literature. Specifically, Ioannidis et al. (2017) examined the log-log elasticity estimates reported in Dalhuisen et al. (2003) and found that of the 110 price elasticityestimates they could examine, 84% were underpowered. More generally,Ioannidis et al. (2017)examined 159 separate economics literaturesandfound that around 80% of the reported effects are exaggerated by a factor of two, and around one-third areinflated by a factor of four or more.

As detailed in Table 1, the two earliest studies (Espey et al., 1997; and Dalhuisen et al., 2003)did not test or correct for publication bias. Further, Espey et al. (1997);Dalhuisen et al. (2003); and Sebri (2014)did not includepositive price elasticity estimates and negative income elastic estimates, as such estimatesare not consistent with economic theory. Although an intuitively reasonable approach, in a meta-regression context,excluding these estimatesresults in an overestimate the effect being studied, relative to the true population parameter.In the context of the water demand literature, this implies a meta-estimate of the price elasticity that overstates the extent to which demand falls when price increases, and in

[2] The primary model of this type is the linear expenditure system, which is consistent with the Stone-Geary Utility function.

the case of the income elasticity, the extent to which water demand increases with income growth is overstated.

Havranek et al. (2018) is a comprehensive meta-analysis of income elasticity estimates and provides appropriate corrections for publication bias. Relative to Havranek et al. (2018), our contribution -- in addition to considering both income and price effects, and expanding the range of studies considered -- is to present results from two different publication bias correction methods. The first method we use is similar to that used in Havranek et al. (2018), except that to correct for the effect of publication biaswe follow Stanley and Doucouliagos (2014) and use estimate variance as a covariate in the meta-regression model, rather than estimate standard error. We do this asthe simulation results in Stanley and Doucouliagos (2014) suggest the use of the standard error tends to overcorrect for publication bias.The second publication bias correction we use is the method proposed in Ioannidis et al. (2017), which involves excluding low powered studies from the meta-regression. The final results we report are the weighted average of the publication bias-corrected estimates.

The final major contribution of the paper is to provide reference income and price elasticity estimates that can be used in a wide range of policy contexts, globally. Both Havranek et al. (2018) and Marzano et al. (2018) present interesting and valuable scenario analysis results, but due to the increased scope of coverage in this study, and the way we present summary results: grouped by country income category (high, medium, low) and elasticity type (short-run v long-run and indoor v outdoor), the summary results representsa material practical contribution. The results are intended to be used as reference estimates for governments and water utilities when primary data is not available.

Table 1: Contrasting the previous fivemeta-analyses with the current study

Study	Current study	Marzano et al. (2018)	Havranek et al. (2018)	Sebri (2014)	Dalhuisen et al. (2003)	Espey et al. (1997)
Study range	1963-2019	1963-2013	1972-2015	2002-2012	1963-2001	1967-1993
No. of studies	176	124	62	100	64	24
No. countries	55	31	Not reported	Not reported	Not reported	1 (USA)
Mean unweighted estimate	Price: -0.37 Income: 0.27	Price: -0.40	Income: 0.26	Price: -0.36 Income: 0.21	Price: -0.41 Income: 0.43	Price: -0.51
No.of observations	Price: 1,020 Income: 516	Price: 615	Income: 307	Price: 638 Income: 332	Price: 296 Income: 161	Price: 124
Pub. bias test	Yes	Funnel plot	Yes	Funnel plot	No	No
Pub. bias correct.	Yes	No	Yes	No	No	No
Weighting technique	Inverse variance	Inverse sample size	Inverse standard error	Inverse sample size	None	None

The remainder of the paper is structured as follows: Section 2 describes the data and methodology, including estimation strategy. Section 3 first presents the publication bias results, followed by the results for the price elasticity meta-regression model, and then the results for the income elasticity meta-regression model. Concluding comments are presented in section 4.

2. DATA AND METHODS

Datacompilation

To be considered as part of the sample, primary studies had to be: (i)available in English; (ii) estimate residential water demand using a statistical model; and (iii)provide sufficient information to allow the calculation of an elasticity estimate and the associated standard error, or approximate standard error via the delta method (see Table 2). No restriction in terms of publication date was considered, but the primary search for papers ceased in June 2019. The workflow used to identify the relevant sample of papers is detailed in Figure 1. The following online databases were used to search for the relevant primary studies: EBSCO, Science Direct, Scopus, Web of Science, Wiley, Springer, and Jstor. And the keywords used in the databases were: *"price elasticity" OR "price structure" OR "volumetric charge" OR "demand elasticity" AND "response" OR "elasticities" OR "residential demand" OR "consumption" AND "water" NOT energy NOT "irrigation water" NOT "water quality" NOT river NOT "fuel consumption" NOT "land use" NOT "industrial water" and NOT groundwater.*

Table 2: Demand equations and associated price and income elasticities

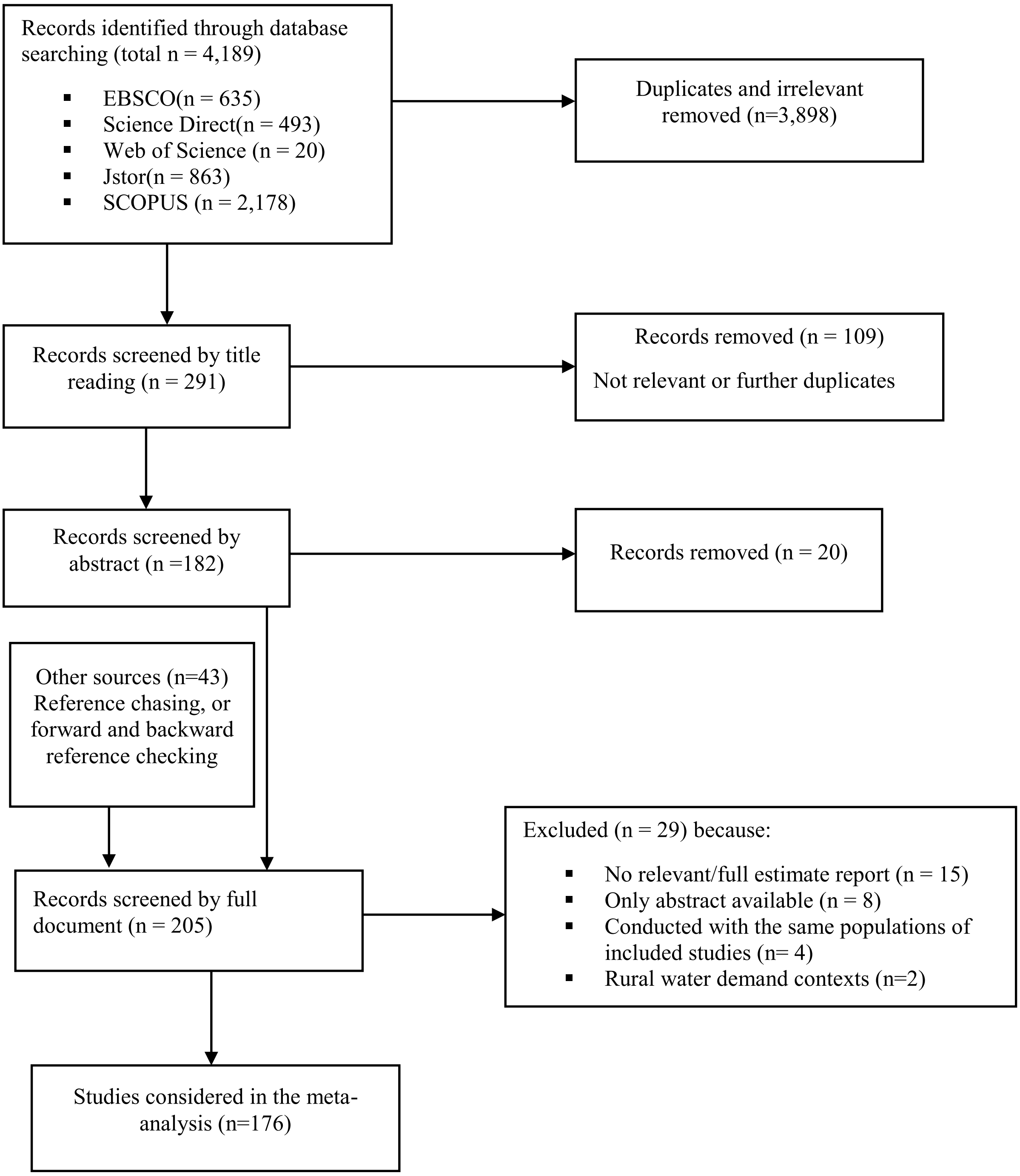
Model	Demand specification	Own-price elasticity	Income elasticity
Linear-Linear	$q_i = \alpha + \sum_j \beta_j p_j + \gamma M + e_i$	$\eta_{ii} = \hat{\beta}_i \frac{\bar{p}_i}{\bar{q}_i}$	$\eta_{iM} = \gamma \frac{\bar{M}}{\bar{q}_i}$
Log-Linear	$\log(q_i) = \alpha + \sum_j \beta_j p_j + \gamma M + e_i$	$\eta_{ii} = \hat{\beta}_i \bar{p}_i$	$\eta_{iM} = \beta_i \bar{M}$
Linear-Log	$q_i = \alpha + \sum_j \beta_j \log(p_j) + \gamma \log(M) + e_i$	$\eta_{ii} = \frac{\hat{\beta}_i}{\bar{q}_i}$	$\eta_{iM} = \frac{\gamma}{\bar{M}}$
Log-Log	$\log(q_i) = \alpha + \sum_j \beta_j \log(p_j) + \gamma \log(M) + e_i$	$\eta_{ii} = \hat{\beta}_i$	$\eta_{iM} = \gamma$
Stone-Geary	$p_i q_i = p_i c_i + \beta_i \left(M - \sum_j p_j c_j\right) + e_i$	$\eta_{ii} = -1 + \frac{\bar{p}_i \bar{c}_i}{\bar{p}_i \bar{q}_i}(1 + \hat{\beta}_i)$	$\eta_{iM} = \frac{\hat{\beta}_i \bar{M}}{\bar{p}_i \bar{q}_i}$

Note: Marshallian price elasticities are the focus;q_i denotes quantity, p_i denotes price, M denotes income,and c_i denotes subsistence consumption.

At the end of the primary database search,291 unique records of potential interest were identified. Some of these records differed only in terms of author order, or similar, and screening these records resulted in 182 primary studies of potential interest. The abstract was reviewed for all of these papers and 20 studies were removed as not relevant. The reference details in previous meta-studies were then consulted and a detailed process of forward and backward checkingindividual references was used to identify additional papers. This process identified a further 43 papersthat were likely to be of interest. Each of the remaining 205 papers was then reviewed in detail, and 176 papers had at least one usable price or income elastic estimate.Summary information on each study is reported in the appendix.

To compile the database, the first listed author searched and identified the relevant studies, extracted and compliedthe primary estimates. The second listed author systematically, and repeatedly, reviewed large randomly selected sub-samples of the primary papers to ensure agreement with the valuescomplied by the first author. The third listed author identified relevant databases, formulated search terms, and reviewed sub-samples of papers randomly. In addition to the primary information on the price and income elasticity, from each study information was collected on: sample size; types of water consumption (indoor, outdoor,or combined);nature of elasticity estimate (long-run, short-run, combined); publication type (peer-reviewed or grey); publication date; data format(panel, cross-sectional, time-series); estimation technique(OLS, GLS, IV, …) and whether endogeneity was explicitlyaddressed; functional form (linear, double-log, linear expenditure system,…); the level of the data in the study (household level, regional level, water utility level, …);country and or city;climate factors (e.g. was the study conducted during a period of drought); the sample period in years; water bill and water meter reading frequency (daily, monthly, quarterly, …); and whether or not income has been proxied via some measure or directly measured.

Figure 1. Flow chart for the identification of papers

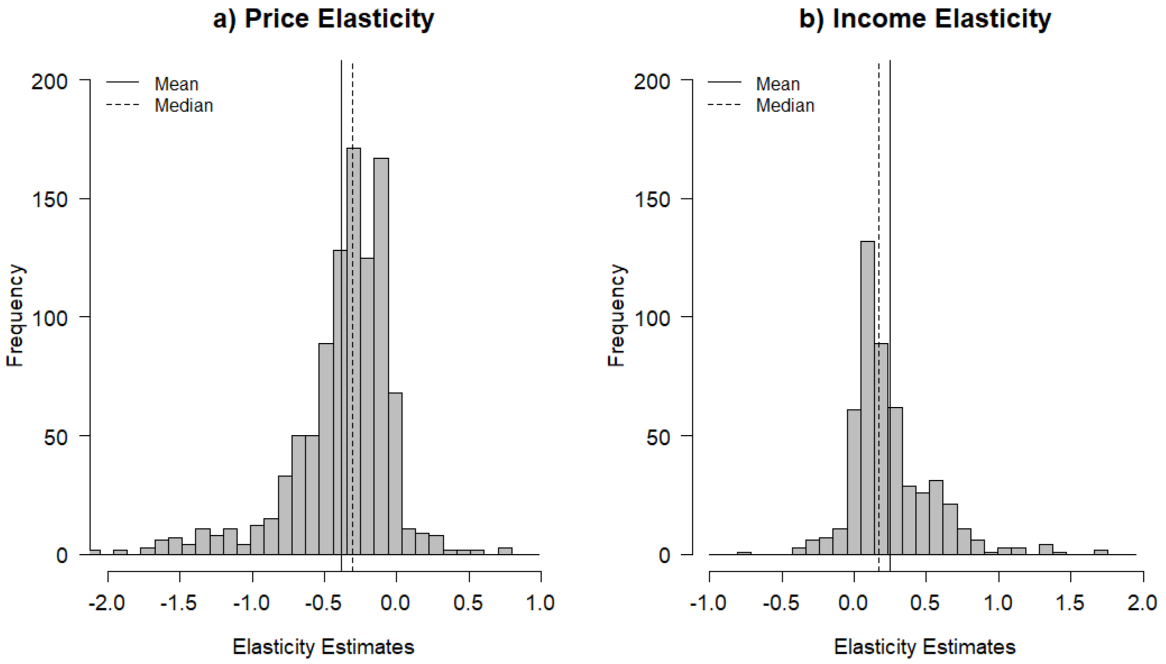


Summary Statistics

The price elasticity sample consists of 1,020 elasticity estimates drawn from 175 studies, and the income elasticity sample consists of 516 elasticity estimates drawn from 126 studies. In Table 3, summary statistics are reported for both the simple averages across all estimates, and for estimates weighted at the study level,so that primary studies with many estimates do not influence the mean value. Regardless of whether the data is simply averaged or weighted at the study level, the overall mean price and income elasticity values are approximately the same, and the mean price elasticity estimate is around -0.4, and the mean income elasticity estimate isaround 0.3. Figure 2 plots histograms for both the income and price elasticity information, and as can be seen, there is a significant variation in reported elasticity values. For the price elasticity estimates, therange is -4.4 to 3.5; and for the income elasticity estimates the range is -0.74 to 3.9; but despite the relatively large range for estimates, 93% of the own-price elasticity estimates are greater than minus one, and 96% of the income elasticity estimates are less than one.Thus, in general, it is reasonable to characterise the urban residential water as: price inelastic and a necessity.

The majority of estimates (48.9%) are from studies conducted in North America(NA), followed by the European Union (EU) (21.0%). Asian, and Middle Eastern and North African (MENA)countries account for 9.3% and 9.1% of the estimates, respectively. Australia and New Zealand (AUNZ), Latin America (LA), and Sub-Saharan Africa (SSA)account for 4.8%, 2.5%, and 1.8% of the estimates, respectively. The remaining estimates are from Non-EU European countries (Non-EU) (1.2%) and Central American countries (CA) (1.5%), respectively.

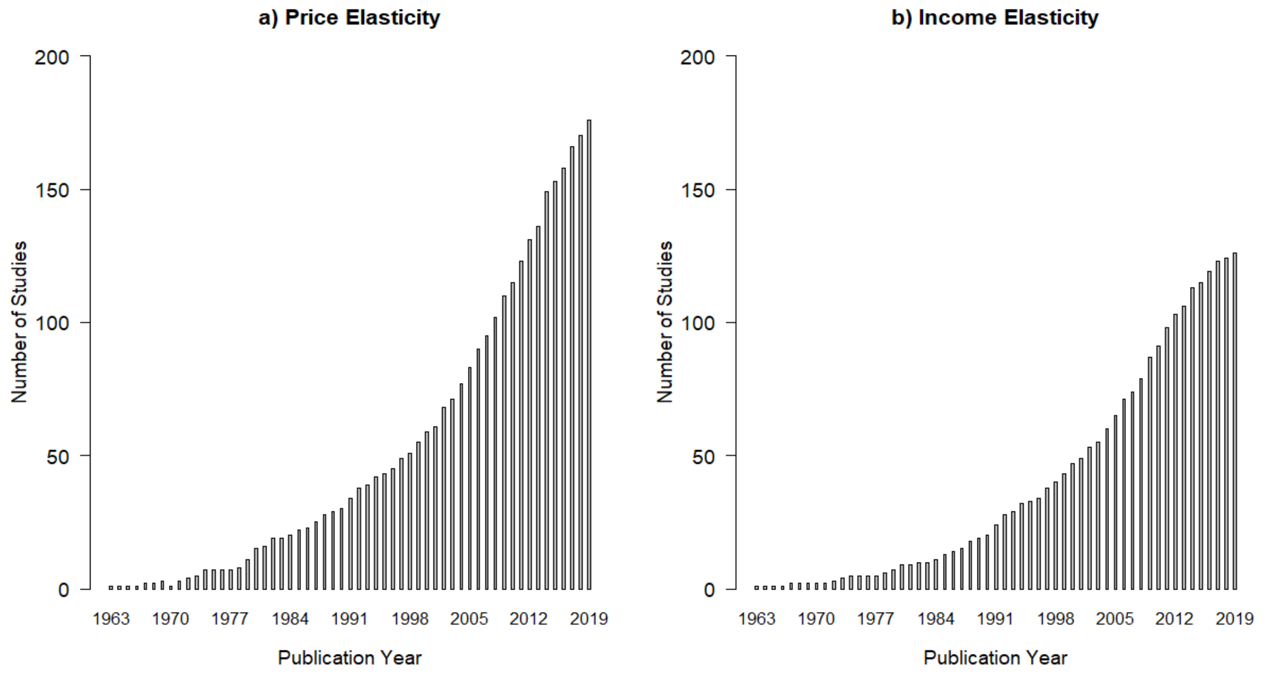
Figure 2. Histogram of income and price elasticity values



Note: The largest and smallest 1% of estimates have been trimmed from the plots

Figure 3 plots the cumulative number of studies reporting price and income elasticities through time. As can be seen, the interest in water demand research has grown through time, and 52% (n=92) price elasticity studies and 48% (n=61) income elasticity studies have been published in the last fifteen years.

Figure 3. Growth in studies reporting price and income elasticities of urban residential water demand



In general, the simple mean values and the study weighted values are similar, and so here we highlight some of the key comparisons from Table 3 for the data weighted at the study level only. The study weighted mean long-run price elasticity is -0.45, and the short-run price elasticity is -0.27. This suggests households take time to adjust to price changes. Consumption grows more with income,in the long-run, but the difference between the short run and long run income elasticity estimates(0.25 v 0.36) is modest.Disaggregated across indoor and outdoor water use, indoor use is both more price inelastic, and more of a necessity. It is common for residential water to be priced via an increasing block tariff structure. This in turn introducesan endogeneity problemwhen estimating the demand equation via methods such as least squares. Endogeneity is generally associated with attenuation bias,and in the water demand literaturestudies that do not explicitly address endogeneity report price elasticity estimates closer to zero than studies that do address endogeneity(-0.33 versus-0.43).For the data structure grouping, there is no clear pattern of effects across income and price elasticity estimates.

Table 3: Variable definition and summary statistics

	Unweighted mean values				Weighted (at study level) mean values			
	Price		**Income**		**Price**		**Income**	
	Mean (SE)	**Obs. (%)**	**Mean (SE)**	**Obs. (%)**	**Mean (SE)**	**Obs. (%)**	**Mean (SE)**	**Obs. (%)**
Dependent variable								
Elasticity	-0.37 (0.01)	1020 (100)	0.27 (0.02)	516 (100)	-0.38 (0.01)	175 (100)	0.29 (0.02)	126 (100)
Location (region)								
Asia, inc. Turkey	-0.33 (0.05)	85 (8.3)	0.19 (0.03)	58 (11.4)	-0.41 (0.05)	20 (11.4)	0.22 (0.03)	18 (14.3)
Australia and New Zealand	-0.42 (0.07)	50 (4.9)	0.30 (0.04)	23 (4.5)	-0.32 (0.06)	11 (6.3)	0.24 (0.04)	6 (4.8)
Central America	-0.28 (0.05)	13 (1.3)	0.12 (0.02)	10 (2.0)	-0.31 (0.06)	2 (1.1)	0.12 (0.03)	2 (1.6)
European Union	-0.34 (0.03)	200 (19.6)	0.30 (0.02)	118 (23.2)	-0.34 (0.03)	42 (23.9)	0.29 (0.02)	33 (26.2)
Latin America	-0.27 (0.05)	26 (2.6)	0.29 (0.11)	12 (2.4)	-0.32 (0.04)	4 (2.3)	0.30 (0.11)	4 (3.2)
Middle East and N. Africa	-0.31 (0.05)	104 (10.2)	0.15 (0.03)	35 (6.9)	-0.46 (0.06)	16 (9.1)	0.13 (0.03)	10 (7.9)
North America	-0.40 (0.02)	512 (50.2)	0.30 (0.03)	239 (46.7)	-0.39 (0.02)	74 (42.0)	0.37 (0.03)	49 (38.9)
Non-European Union	-0.14 (0.10)	15 (1.5)	0.57 (0.24)	3 (0.6)	-0.27 (0.10)	2 (1.1)	0.57 (0.24)	1 (0.8)
Sub-Saharan Africa	-0.41 (0.08)	15 (1.5)	0.24 (0.10)	13 (2.6)	-0.38 (0.08)	5 (2.8)	0.12 (0.12)	3 (2.4)
Elasticity type								
Average	-0.37 (0.02)	830 (81.4)	0.27 (0.01)	424 (82.2)	-0.38 (0.02)	150 (85.2)	0.29 (0.02)	110 (87.3)
Long-run	-0.40 (0.06)	100 (9.8)	0.32 (0.11)	47 (9.2)	-0.45 (0.07)	29 (16.5)	0.36 (0.09)	15 (11.9)
Short-run	-0.27 (0.04)	90 (8.8)	0.28 (0.08)	45 (8.8)	-0.27 (0.04)	28 (15.9)	0.25 (0.06)	15 (11.9)
Indoor	-0.32 (0.07)	18 (1.8)	0.53 (0.22)	11 (2.1)	-0.34 (0.07)	4 (2.3)	0.47 (0.18)	4 (3.2)
Outdoor	-0.79 (0.10)	24 (2.4)	0.73 (0.27)	16 (3.1)	-0.75 (0.10)	7 (4.0)	0.70 (0.22)	5 (4.0)
Total	-0.34 (0.02)	978 (95.9)	0.25 (0.01)	489 (95.3)	-0.37 (0.02)	171 (97.2)	0.28 (0.02)	124 (98.4)
Endogeneity addressed								
Addressed	-0.43 (0.02)	601 (58.9)	0.27 (0.02)	317 (61.4)	-0.45 (0.03)	90 (51.1)	0.28 (0.03)	66 (52.4)
Not addressed	-0.32 (0.03)	419 (41.1)	0.29 (0.03)	199 (38.6)	-0.33 (0.02)	125 (71.0)	0.30 (0.02)	90 (71.4)
Data type								
Panel	-0.36 (0.02)	702 (68.8)	0.26 (0.02)	317 (61.4)	-0.35 (0.02)	111 (63.1)	0.28 (0.02)	75 (59.5)
Cross-sectional	-0.38 (0.03)	229 (22.5)	0.25 (0.02)	173 (33.5)	-0.46 (0.03)	47 (26.7)	0.25 (0.02)	41 (32.5)
Time-series	-0.37 (0.04)	89 (8.7)	0.53 (0.1)	26 (5.0)	-0.37 (0.04)	18 (10.2)	0.56 (0.11)	10 (7.9)

Estimation framework

The meta-regression model can be developed as follows. Let $\boldsymbol{y}_j$index the $j = 1, \dots, m$ elasticity estimates from the primary studies, where each study has $k_j \geq 1$ estimates, and let $\boldsymbol{x}_j$ denote the associated $p \times 1$ vector of covariate information on aspects of the study, such as country, publication year, etc.,where $p < m$. Now stack the elasticity estimate vectors such that $\boldsymbol{Y}$=$(\boldsymbol{y}_1, \dots \boldsymbol{y}_m)'$ is an $n \times 1$ response variable vector, where $n = \sum_m k_j$, and stack the covariate vectors such that $\boldsymbol{X}$=$(\boldsymbol{x}_1, \dots \boldsymbol{x}_m)'$ is then $n \times p$ design matrix. The meta-regression model is then written as:

$$\boldsymbol{Y} = \boldsymbol{X\beta} + \boldsymbol{\varepsilon}, \tag{1}$$

where$\boldsymbol{\beta}$ is a $p \times 1$vector of coefficients to be estimated, and $\boldsymbol{\varepsilon}$=$(\boldsymbol{\varepsilon}_1, \dots \boldsymbol{\varepsilon}_m)'$ is an $n \times 1$ vector of zero mean residuals.

To obtain point estimates and associated standard errors for inference we use the Hedges et al. (2010) estimator, implemented via Fisher et al. (2017), where $\boldsymbol{\beta}$ and$\boldsymbol{V}(\boldsymbol{\beta})$ are found as:

$$\widehat{\boldsymbol{\beta}} = \left(\sum \boldsymbol{x}_j' \boldsymbol{w}_j \boldsymbol{x}_j\right)^{-1} \left(\sum \boldsymbol{x}_j' \boldsymbol{w}_j \boldsymbol{y}_j\right), \text{ and} \tag{2}$$

$$\boldsymbol{V}(\widehat{\boldsymbol{\beta}}) = \left(\sum \boldsymbol{x}_j' \boldsymbol{w}_j \boldsymbol{x}_j\right)^{-1} \left(\sum \boldsymbol{x}_j' \boldsymbol{w}_j \boldsymbol{e}_j \boldsymbol{e}_j' \boldsymbol{w}_j \boldsymbol{x}_j\right) \left(\sum \boldsymbol{x}_j' \boldsymbol{w}_j \boldsymbol{x}_j\right)^{-1} \tag{3}$$

where $\boldsymbol{e}_j$ is the $k_j \times 1$ residual vector for study j, and $\boldsymbol{w}_j$ is the weight matrix. Hedges et al. (2010) details two possible weighting structures for the $\boldsymbol{w}_j$:correlated effects, when the issue is the correlation in the errors induced by taking multiple estimates from the same study, and hierarchical effects where the issue is both the correlation of within-study estimates and correlation across studies due to repeated studies from the same lab, or similar.For this study,the issue is the correlation in the errors induced by taking multiple estimates from the same study, and so we use the study correlated effects weighting structure. The specific details are given in Hedges et al. (2010), but with this structure,the weight to an individual elasticity estimatefrom study j, depends on: the mean variance across the k_j estimates (the weight to all estimates from study j decreases as the mean variance associatedwith the elasticity estimates from study $j$increases);the number of estimates from the study (the weight to each estimate is $1/k_j$), and the between-study variance (the greater the between-study variance estimate, the greater the shrinkage towards equal weights) denoted τ^2. Formally, the weight given to each elasticity estimate can be written as $1/k_j(\bar{v}_j + \hat{\tau}^2)$, where $\bar{v}_j$ is the average variance for the estimates from study j and $\hat{\tau}^2$ is found using the Hedges et al. (2010) between-study variance estimator.

Tipton (2015) proposes small sample corrections to the Hedges variance estimator, but here we use the original corrections proposed in Hedges et al. (2010), which are to: (i) inflate the variance estimates by $m/(m-p)$, which adds a penalty when the number of parameters estimated (p)is large, relative to the number of studies (m); and (ii) use $m-p$ rather than $n-p$ degrees of freedom for hypothesis tests. For the context of this research, we deem the original corrections proposed in Hedges et al. (2010) to be appropriate as:(i) the context for the Tipton (2015) corrections is meta-regression analysis with 40 primary studies or less, which is much less than the number of studies we consider; and (ii) the main impact of the Tipton (2015) correction is via degrees of freedomcorrection that in turn is a function of the coefficient of variation of each covariate. In models that control for publication bias through the inclusion of either the estimate standard error or variance as a covariate, such a correction can result in implausibly large penalties, due to the nature of such covariates.

Publication bias

Publication bias exists when researchers, editors, and referees selectively report statistically significant results or results that are consistent with the conventional theory (Ioannidis et al., 2017; Stanley and Doucouliagos, 2012). The implication of publication bias is that larger and more significant effects will be overrepresented in the published academic literature, while estimates that contradict conventional theory and prior expectations are left unpublished.This phenomena is why it is argued collecting information from unpublished studies can mitigate against publication bias when conducting meta-studies, and this strategy has been followed for this study.

When publication bias is present in the literature, the reported effect size is correlated with its standard error (Stanley, 2008). As a preliminary test for detecting publication bias, we use funnel plots. In a funnel plot, the effect size is plotted on the horizontal,and a measure of estimate precision, usually the standard error, is plotted on the vertical. For this visual representation of the data,we aggregate to the study level and plot the average price and income elasticity from each study on the horizontal and the average standard error on the vertical. In the absence of publication bias, a funnel plot is symmetric about the mean effect size. We discuss the extent of asymmetryassessed visually as a measure of publication bias, wherethe funnel plotsarecreated using the procedure described in Viechtbauer (2010).

The formal test we use to detect publication bias is the standard regression based test, where primary study estimates are regressed on their standard error, an intercept term; and if appropriate, additional covariates to control for study level heterogeneity.With this approach,publication bias is deemed present if the point estimate on the standard error is statistically significant (Stanley and Doucouliagos, 2012). When publication bias is detected, we report results using two different corrections. The first correction follows Stanley and Doucouliagos (2014), and the variance associated with each individual estimate is included as a covariate in the meta-regression model. Using simulation studies,Stanley and Doucouliagos (2014) show that this approach outperforms the historical practice of including the estimate standard error as a control covariate.

The second correction follows Ioannidis et al. (2017).This method involves removingfrom the sample all studies that are deemed to have low powerto detect a reference effect size. Specifically, astudy estimate is deemed to have adequate power and hence is included in the sample, if the standard error associated with the estimate is sufficient to detect a reference estimate value (denoted θ) with the power of 0.8, and alpha 0.05. Low powered studies will only detect outsized effect sizes, and so by comparing the study estimate's ability to detect the reference effect size, rather than the actual effect size found in the study, those studies that have found exaggerated effect sizes are excluded. In this study, we use $\hat{\theta}$ to define the reference effect size estimate, and this value is obtained by regressing elasticity estimates on an intercept term using the Hedges et al. (2010) estimator. As this estimate does not control for publication bias, $\hat{\theta}$ is a liberal -- in the sense that at the margin it includes more rather than less primary studies -- reference estimate.In practice, implementation of the Ioannidis et al. (2017) correction involves excluding estimate i from study j when $SE_{ij}/2.8 > \hat{\theta}$. The logic that supports excluding studies that fail to meet this criterion is consistent with the arguments presented in Gelman and Carlin (2014).

Covariate selection

To mitigate against omitted variables bias, covariate selection for the final meta-regression models followed a general-to-specific approach. Conceptually this approach also extended to the number of levels included for factor variables, where at the initial stage each possible level is included, and then subject to testing, levels are collapsed into composite groups, if appropriate. The testing of joint coefficient constraints relies on Pustejovsky (2019).

3. Results

Publication Bias

Price and income elasticity funnel plots are shown in Figure 4. In each plot, the vertical solid lines indicate the precision-weightedsample mean; the dotted linesrepresent the 95% confidence interval; and the dashed line indicates zero.In the absence of publication bias, a funnel plot is symmetric about the mean effect size. In both plots there is strong visual evidence of asymmetry, and hence potential publication bias.Note, asymmetry may also be presented due to underlying heterogeneity due to genuine differences in population effect sizes across model functional forms, study areas, etc. (Nelson, 2011). The issue of heterogeneity and publication bias are jointly explored in the meta-regression analysis.

Figure 4. Funnel plot of precision using standard error

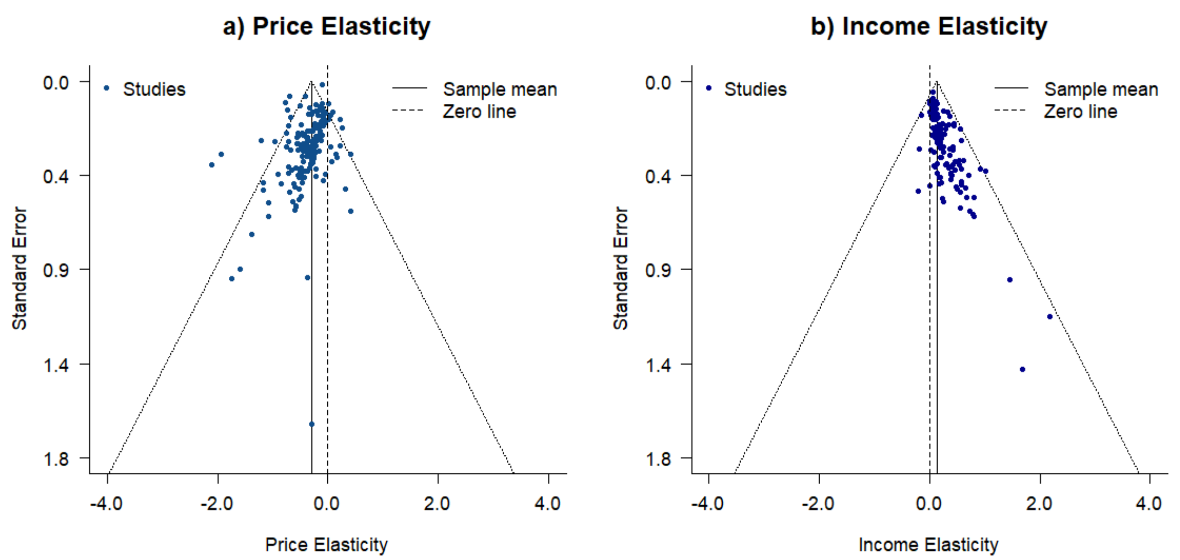


Table 4 presents summary information on the extent of publication bias, where potential sources of heterogeneity are not yet considered. These results provide a useful global reference point for understanding residential demand for water. The regression-based test finds strong evidence of publication bias, and as can be seen from the results reported in Table 4, the presence of publication bias works to push the elasticity estimates away from zero, but the impact is modest.The final columns of each panel of Table 4 provide an overall bias-corrected estimate, calculated using the traditional fixed-effect approach to pooling.The pooled publication bias-corrected price and income elasticity values are -0.27 (95% CI -0.31 to -0.23), and 0.14(95% CI 0.12 to 0.16), respectively. The overall publication bias estimates are therefore different to zero, but water demand is strongly price inelastic, and water consumption grows only modestly, with income.

When publication bias is present, more extreme observations have larger standard errors, and so while explicit publication bias correctionsare important, simply weighting observations by estimate precision also mitigatesagainst the impact of publication bias. The combined impact of weightingestimates by precision and the explicit publication bias correction can be seen by comparing the publication bias-corrected estimates reported in this study with the unweighted mean values reported in the summary statistics section of previous studies.For the residential water demand price elasticity, previous meta-studies reported simple mean values of: -0.51 (Espey et al., 1997); -0.41 (Dalhuisen et al., 2003); -0.36 (Sebri, 2014); and -0.40 (Marzano et al., 2018); and the publication bias-corrected estimatein the current study is one-third smaller than the mean value across these previous meta-studies. For the income elasticity, the previously reported simple mean values are: 0.43 (Dalhuisen et al., 2003); 0.21 (Sebri, 2014); and 0.26 (Havranek et al., 2018); and the publication bias-corrected estimate in the current study is less than one-half the mean value across these studies. If correcting for publication bias is seen as involving both the weighting of estimates by estimate precision, and the explicit publication bias correction, then the impact of publication bias is substantial: the income elasticity falls by more than one-half, and the price elasticity by one-third.

Table 4: Publication bias test and corrections

	Price Elasticity					Income Elasticity				
	RVE-WA	Bias test	S & D correct	Ioann.correct	Pooled est	RVE-WA	Bias test	S & D correct	Ioann.correct	Pooled est
Intercept	-.35***	-.23***	-.33***	-.25***	-.27***	.17***	.08***	.15***	.12***	.14***
	(.03)	(.03)	(.03)	(.02)	(.02)	(.01)	(.01)	(.01)	(.01)	(.01)
SE		-1.14***					1.60***			
		(.23)					(.18)			
Variance			-.47**					2.0***		
			(.23)					(.58)		
τ^2	.14	.16	.14	.11		.01	.01	.01	.12	
I^2	99.6	99.5	99.6	99.6		92.3	89.7	91.8	99.9	
Obs.	1020	1020	1020	681		516	516	516	230	
Studies	175	175	175	148		126	126	126	81	

Note: Robust standard errors in parenthesis; *, ** and *** indicate significance at the 90%, 95%, and 99% level.RVE-WA= Robust Variance Estimation Weighted Average, S & D correct = Stanley and Doucouliagos (2014), Ioann. correct =Ioannidis et al. (2017).

Price elasticity regression results

Table 5 contains the results for the meta-regression model that seeks to both control for sources of heterogeneity and correct for publication bias.The factors considered as sources of heterogeneity included: model functional form (as per Table 2); frequency of data collection (daily, monthly, quarterly and annual data); the inclusion of climate variables in the model; the type of the primary study (peer-reviewed versus grey literature); the country income group (lower-middle, upper-middle & high income countries); water use type (indoor use, outdoor use or both); whether or not endogeneity is addressed; the type of data used in the study (panel, cross-sectional and time-series); the elasticity type estimated (short-run, long-run or the average); the type of income data used (actual income, an income-proxy or no income variable); and aggregated (city level, state level, and national level data) versus disaggregated data (household level data).Factorsthat were not statistically significant were dropped from the model, and where possible,factor levels were combined if individual levels were not statistically different to each other.

The first column of Table 5 provides meta-regression results that control for sources of heterogeneity, but not for the effect of publication bias. The second column provides results for the publication bias test, with controls for heterogeneity, and shows that controlling for sources of heterogeneity there is still evidence publication bias is present. The final two columns of Table 5 provide the heterogeneity and publication bias corrected results, and the discussion focuses on these results.

The first row of Table 5 provides information on the difference in the price elasticity estimate between studies that control for endogenity and studies that do not control for endogeneity. Across both publication bias correction methods, studies that do not explicitly address endogeneity report elasticity estimates that,on average, are around 0.13 closer to zero than studies that do control for endogeneity. This is consistent with expectations (Hausman, 2001); and given the average price elasticity estimate is around -0.27, the extent of the attenuation effect is material.

Across all demand equations log-log, linear-linear, log-linear, and linear-log models were found to provide estimates that were not different to each other. These estimates were, however, different to estimates from models that allow for subsistence consumption. Specifically, models that do not allow for subsistence consumption find price elasticities that are further from zero. Again, given the overall mean price elasticity value is close to zero, differences of 0.20 for the Stanley and Doucouliagos correction and 0.13for the Ioannidis et al. correction are meaningful.

Estimates are available for three types of water use: indoor use, outdoor use, and combined total water use. The base categoryin Table 5 is total water use, and the results say, on average: indoor demand is less responsive to price than total water demand (but the difference is not statistically significant); and outdoor demand is more responsive than both total and indoor demand. As outdoor demand is about twice as responsive as indoor demand, the difference is large enough to be important from a policy development perspective. The results also make intuitive sense. For outdoor use there are more substitute options when price rises – access to groundwater, replanting gardens with plants that need less water, conversion of lawn to non-irrigated space, etc. – relative to indoor water use. Further, recycled water is also a substitute product that is becoming increasingly available for outdoor use (Iftekhar et al., 2021). So,with more substitute products, via the property of demand homogeneity,outdoor demand is more elastic than indoor demand.

The base category for the elasticity estimate timeframe is an average effect that does not explicitlyseek to identify short-run and long-run effects separately. Although neither short-run nor long-run estimates are statistically different from average estimates, short-run and long-run estimates are different from each other. As expected, long-run estimates are more price responsive than short-run estimates, and again this is an important finding, as it says that the effect of price changes will take several billing cycles for there to be complete adjustment. Note, as demand for outdoor water use is more responsive than indoor water use, the fixed difference between long-run and short-run estimates also implies that the speed of adjustment for outdoor water use is faster than for indoor water use. For example, reflecting (approximately) the values implied by Table 5, let the difference between the short-run and long-run price elasticity be 0.15, and assume a simple partial adjustment model framework. If the short-run indoor elasticity is -0.05, the long-run elasticity is -0.20, and the speed of adjustment is 25% per billing cycle. In contrast, if the short-run outdoor elasticity is -0.40, the long-run elasticity is then -0.55, and the implied speed of adjustment is 73% per billing cycle. Changes to water use can be implemented more quickly for outdoor applications, relative to indoor use, where changes may require the replacement items such as dishwashers, toilets, and clothes washing machines. As such, the result seems intuitively reasonable.

Countries were grouped into income categories based on World Bank definitions, and categories were then merged based on empirical testing. Water demand responsiveness was found to be closer to zero in upper-middle& high-income countries, relative to lower- and lower-middle income countries. That demand is less sensitive to price inhigher income countries than in lower income countries seems plausible.

For some factors, we had no a priori expectations on the sign for the possible effect.But controlling for other factors, studies that use panel data report price elasticities closer to zero, than studies relying on either cross-sectional or time-series data alone. The advantages(and limitations) of panel data have been widely documented (Hsiao, 2014). In the context of water demand studies, the ability to mitigate against omitted variablesand capture dynamics seem especially valuable features of panel data models. A feature of many primary studies was that a proxy for income was used. Example proxy variables included the value of housing, household expenditure, and tax returninformation. When actual income data was used in the primary study, which is always the preferred case, price elasticity estimates were found to be more inelastic.

Table 5: RVE estimates, publication bias test, and corrections

Variable	Raw model	Bias test	S & D correct	Ioann. correct
Intercept	-0.37***	-0.33***	-0.37***	-0.38***
	(0.12)	(0.11)	(0.12)	(0.12)
Endogeneity not treated [a]	0.14**	0.13**	0.13**	0.12**
	(0.06)	(0.06)	(0.06)	(0.05)
Non-subsistence consumption[b]	-0.20***	-0.15***	-0.20***	-0.13***
	(0.06)	(0.04)	(0.05)	(0.04)
Indoor [c]	0.05	0.06	0.05	0.04
	(0.13)	(0.10)	(0.13)	(0.11)
Outdoor [c]	-0.39**	-0.30**	-0.38**	-0.11
	(0.16)	(0.13)	(0.16)	(0.16)
Upper-middle& high income countries [d]	0.18*	0.19**	0.18*	0.21**
	(0.09)	(0.09)	(0.09)	(0.10)
Cross-sectional & time-series data [e]	-0.14**	-0.11*	-0.13**	-0.08
	(0.06)	(0.06)	(0.06)	(0.05)
Long-run elasticity [f]	-0.09	-0.07	-0.09	-0.06
	(0.09)	(0.09)	(0.09)	(0.11)
Short-run elasticity [f]	0.07	0.04	0.07	0.01
	(0.06)	(0.06)	(0.06)	(0.06)
Income proxy & no income data used [g]	0.10**	0.09*	0.10**	0.09*
	(0.05)	(0.05)	(0.05)	(0.05)
Standard error		-0.99***		
		(0.23)		
Variance			-0.39*	
			(0.23)	
I^2	99.5	99.5	99.5	99.6
τ^2	0.20	0.20	0.20	0.18
Obs.	1020	1020	1020	681
Studies	175	175	175	148

Note: Robust standard errors in parenthesis; * **and *** indicate significance at the 90%, 95%, and 99% level.S & D correct = Stanley and Doucouliagos (2014), Ioann. correct =Ioannidis et al. (2017).

[a] the baseline = Yes (endogeneity controlled)
[b]the baseline = Stone-Geary functional form
[c]the baseline = Total demand estimates
[d] the baseline = Lower-middle-income countries
[e] the baseline = Panel data
[f] the baseline = Average elasticity estimate
[g] the baseline = Actual income data included

The focus of Table 5 is to report results for a model that explains the heterogeneity in published estimates. In Table 6, we present what we suggest can be used as reference estimates for different contexts. These estimates based on the results reported in Table 5, where we correct for publication bias and set the other parameters at what we think are the most appropriate values: e.g. we set the demand equation type to Stone-Geary; the estimation method addresses endogeneity; the model estimated uses a panel data structure; and income rather than a proxy for income is used.We present estimates for each publication bias correction method separately, and also the fixed effect (inverse variance) pooled estimates.

Table 6: Best-reference price elasticity values

High and upper-middle income countries									
	Stanley and Doucouliagos correction			**Ioannidis et al. correction**			**Pooled reference estimates**		
Elasticity	Short-run	Long-run	Average	Short-run	Long-run	Average	Short-run	Long-run	Average
Indoor	-0.07 (0.15)	-0.23 (0.16)	-0.14 (0.14)	-0.11 (0.13)	-0.18 (0.15)	-0.13 (0.11)	-0.09 (0.10)	-0.21* (0.11)	-0.13 (0.09)
Outdoor	-0.50*** (0.18)	-0.66*** (0.19)	-0.57*** (0.17)	-0.27 (0.17)	-0.33* (0.19)	-0.27* (0.16)	-0.38*** (0.12)	-0.50*** (0.13)	-0.41*** (0.12)
Total	-0.12 (0.08)	-0.28** (0.12)	-0.18*** (0.06)	-0.16* (0.08)	-0.23* (0.13)	-0.17*** (0.05)	-0.14** (0.06)	-0.25*** (0.09)	-0.17*** (0.04)
Lower-middle-income countries									
Elasticity	Short-run	Long-run	Average	Short-run	Long-run	Average	Short-run	Long-run	Average
Indoor	-0.26 (0.18)	-0.41** (0.19)	-0.32* (0.17)	-0.33* (0.17)	- 0.40**(0.19)	-0.34** (0.16)	-0.30** (0.12)	-0.40*** (0.13)	-0.33*** (0.12)
Outdoor	-0.68*** (0.21)	-0.84*** (0.23)	-0.75*** (0.20)	-0.48** (0.21)	-0.55** (0.22)	-0.49** (0.19)	-0.58*** (0.15)	-0.69*** (0.16)	-0.61*** (0.14)
Total	-0.30** (0.13)	- 0.46***(0.16)	-0.37*** (0.12)	-0.37*** (0.14)	-0.44** (0.17)	-0.38*** (0.12)	-0.33*** (0.10)	-0.45*** (0.12)	-0.37*** (0.08)

Note: Robuststandard errors in parenthesis; *, **, and *** indicate significance at the 90%, 95%, and 99% and higher levels of confidence, respectively.

Figure 5: Implied distribution for long-run estimates: relatively high income countries

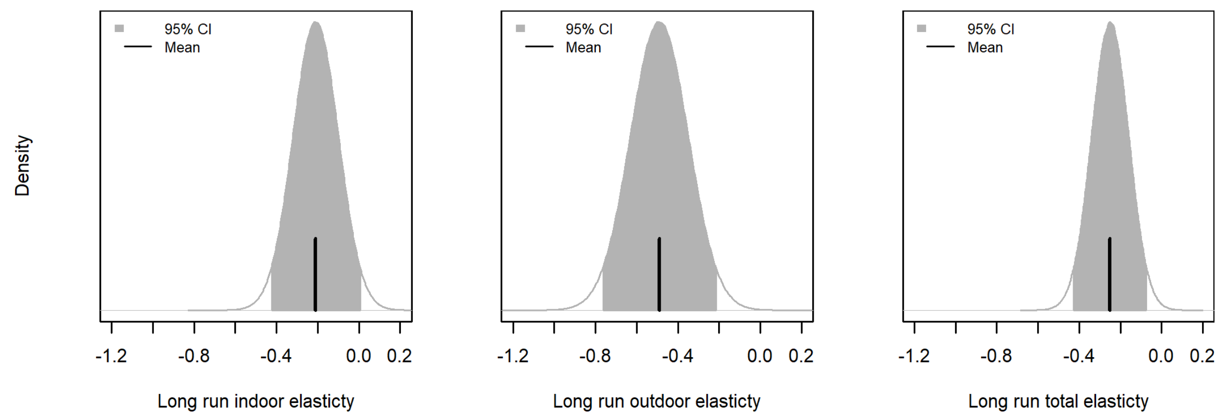
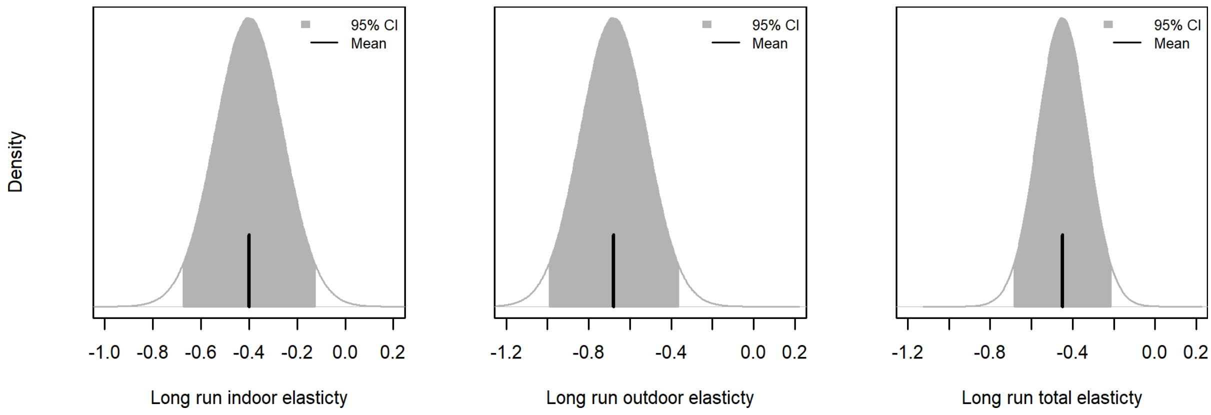


Figure 6: Implied distribution for long-run estimates: relatively low income



For high- and upper-middle-income countries,a traditional approach could be to say that for the long-run elasticitythere is insufficient evidence to reject the null of no response to a price change for indoor use. However, by considering the distribution implied for the pooled estimate (Figure 5), it can be seen that demand is likely to fall following a price increase. Overall, we recommend relying on a value of around -0.20 as a reference value for the long run indoor elasticity and a value of around -0.50 as the outdoor water response, for relatively high income countries. The total response can then be derived depending on the actual mix of indoor and outdoor use in any given relevant context.For lower and lower-middle-income countries, we recommend relying on a value of around -0.40 as a reference value for the long run indoor elasticity and a value of around -0.70 as the outdoor water response.

Income Elasticity

The meta-regression model of income elasticity values is based on515 estimates from 125 empirical studies. To identify sources of heterogeneity, we follow the same general-to-specific approach used for the price elasticity meta-regression, although we do not necessarily expect to find the same factors to be important in the income elasticity meta-regression. For example, Havranek et al. (2018) argue that income elasticities do not depend on whether or not a researcher addresses the problem of endogeneity, because only the price variable is endogenously determined. As such, we would not expect to find the endogeneity variable an important source of heterogeneity for income elasticity estimates. The final meta-regression results are reported in Table 7.

Controlling for other sources of heterogeneity, publication bias is still found to be an issue. As such, we again report estimates from both methods of correcting for publication bias. In general, we find few sources of systematic influence on the income elasticity estimates, but we donote that estimates from the Stone-Geary specification that allows for subsistence consumption are different to those from all other demand models.

Table 7: RVE estimates, publication bias test, and corrections for income elasticity

Variable	Raw model	Bias test	S & D correct	Ioann. correct
Intercept	0.16***	0.06	0.14***	0.13***
	(0.04)	(0.04)	(0.04)	(0.04)
Non-subsistence consumption [a]	0.12***	0.09**	0.11***	0.06**
	(0.03)	(0.03)	(0.03)	(0.03)
Daily, monthly & quarterly data [b]	-0.08**	-0.03	-0.06**	-0.06*
	(0.03)	(0.02)	(0.03)	(0.03)
No climate data [c]	-0.07**	-0.04	-0.05*	-0.05*
	(0.03)	(0.03)	(0.03)	(0.03)
Grey literature [d]	-0.09**	-0.06**	-0.08**	-0.03
	(0.04)	(0.03)	(0.03)	(0.04)
Standard error		1.47***		
		(0.20)		
Variance			1.82***	
			(0.55)	
I^2	91.5	89.4	90.9	99.9
τ^2	0.01	0.01	0.01	0.27
Obs.	515	515	515	228
Studies	125	125	125	80

Note: Robust standard errors in parenthesis; * ** and *** indicate significance at the 90%, 95%, and 99% level. S & D correct = Stanley and Doucouliagos (2014), Ioann. correct = Ioannidis et al. (2017). One study has been excluded from the model because of incomplete data.
a the baseline=Stone-Geary functional form
b the baseline = Annual data
c the baseline = Climate data included
d the baseline = Published studies

Again we focus on deriving estimates that can be used as best reference values, and to derive these estimates we set:the demand model asallowing for subsistence consumption;

data frequency to annual; assume the model includes climate control data and that the estimate was published in the peer-reviewed literature. For reporting purposes, as we find no difference for income level, we collapse the estimates to a single group. As can be seen in Table 8, the best reference estimate for the income elasticity is around 0.1, suggesting water use grows only very slowly with income. This estimate provides a useful reference value for planning purposes, and water utilities, water regulators, and governments can assume that as income grows, other factors held constant, water demand will grow at a rate one-tenth the rate of income growth. This estimate is consistent with the conclusion drawn in Havranek et al. (2018), but we have been able to substantially reduce the extent of uncertainty around the estimate. For example,Havranek et al. (2018) suggest "best-practice" income elasticity estimates of 0.08 (95% CI -0.24 to 0.41) when there is an average pricing tariff structure, and 0.17(95% CI -0.16 to 0.49) for marginal pricing structures.

Table 8: Best-reference income elasticity values

Estimate	S & D correction	Ioann. correction	Pooled estimate
Income elasticity	0.14***	0.13***	0.13***
	(0.04)	(0.04)	(0.03)

Note: Robuststandard errors in parenthesis; ******indicates significant at the 90%, 95%, and 99% confidence level.S & D correct = Stanley and Doucouliagos (2014), Ioann. correct = Ioannidis et al. (2017).

4. CONCLUSION

Residential water demandmanagement is a majorpolicy focus for governments, globally.Estimates of the price and income elasticity of demand for residential water use are key parameters for those working on water policy, and the extent of interest in these values is evidenced through the large number of empirical studies that estimate price and income elasticities. This meta-analysis found evidence of publication bias in the literature, for both price and income elasticityestimates, where the direction of the bias is away from zero. As such, simple averages or weighted averages taken from the literature: (i) overstate the quantity response to price changes; (ii) and overstate the growth in demand when income increases.

Elasticity estimates were shown to vary systematically with estimation approach, and for both price and income elasticities allowing for a subsistence component in the demand model was found to be important. In general, residential water pricing follows an increasing block tariff structure, and for estimation purposes, this induces an endogeneity problem. Failure to address endogeneity results in estimates of the price elasticity that are biased towards zero. One implication of our research is that primary studies of water demand should use specifications that allow for both subsistence consumption, and address endogeneity. When using the linear expenditure system, all goods are necessities, and all goods are normal goods. For water demand analysis these limitations are not binding constraints, so this expression for the water demand equation seems appropriate.

A specific focus of this study has been to not just explain the variation in published elasticity estimates but to provide estimates that can be used for policy planning purposes. For the price elasticity, correcting for publication bias, and controlling for demand equation attributes, we find that for countries where the income level falls into the World Bank classification of low-income through to lower-middle-income, for indoor water demand planning purposes reference estimates of -0.3 and -0.4 in the short-run and long-run, respectively, can be used. For outdoor water demand planning purposes, reference estimates of -0.6 and -0.7 in the short-run and long-run, respectively, can be used. For countries that fall into the World Bank classification of upper-middle through high-income countries, reference estimates of -0.1 and -0.2 in the short-run and long-run, respectively, can be used for indoor water demand; and for outdoor demand, reference estimates of -0.4 and -0.5 in the short-run and long-run, respectively, can be used.For income elasticity estimates, controlling for publication bias, and other factors, we found no systematic differences across countries with different income levels, therefore, for all countries, we suggest a reference income elasticity value of around 0.1be used.

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References

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

Commonwealth of Australia (Bureau of Meteorology) (2019) National performance report 2017–18: urban water utilities, part AFebruary 2019. URL: http://www.bom.gov.au/water/npr/npr_2017-18.shtml

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

Dos Santos, S., E. Adams, G. Neville, Y. Wada, A. De Sherbinin, E. M. Bernhardt and S. Adamo (2017) Urban growth and water access in sub-Saharan Africa: Progress, challenges, and emerging research directions. *Science of the Total Environment* 607: 497-508.

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.

Fisher, Z. Tipton E. and Zhipeng, H (2017)robumeta: Robust Variance Meta-Regression. R package version 2.0. https://CRAN.R-project.org/package=robumeta

Garrone, P., L. Grilli and R. Marzano (2019) Price elasticity of water demand considering scarcity and attitudes. *Utilities Policy* 59 (2019): 100927.

Gelman, A., & Carlin, J. (2014) Beyond power calculations: Assessing type S (sign) and type M (magnitude) errors. *Perspectives on Psychological Science*, *9*(6), 641-651.

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

Hsiao, C. (2014). *Analysis of panel data*. Cambridge university press.

Hausman, J. (2001) Mismeasured Variables in Econometric Analysis: Problems from the Right and Problems from the Left. *Journal of Economic Perspectives* 15 (4): 57–67.

Hedges, L. V., E. Tipton and M. C. Johnson (2010) Robust variance estimation in meta-regression with dependent effect size estimates. *Research synthesis methods* 1(1): 39-65.

Iftekhar, M. S., Blackmore, L., and Fogarty, J (2021) Non-residential demand for recycled water for outdoor use in a groundwater constrained environment. *Resources, Conservation and Recycling,* 164, 105168.

Ioannidis, J. P., T. D. Stanley and H. Doucouliagos (2017) The power of bias in economics research, *Oxford University Press Oxford*, UK.

Marlow, D. R., Moglia, M., Cook, S., and Beale, D. J. (2013) Towards sustainable urban water management: A critical reassessment. *Water research*, 47(20), 7150-7161.

Marzano, R., C. Rougé, P. Garrone, L. Grilli, J. J. Harou and M. Pulido-Velazquez (2018) Determinants of the price response to residential water tariffs: Meta-analysis and beyond. *Environmental Modelling & Software* 101: 236-248.

Nelson, J. P. (2011) Alcohol marketing, adolescent drinking and publication bias in longitudinal studies: a critical survey using meta-analysis. *Journal of Economic Surveys* 25(2): 191-232.

Pustejovsky, J (2019)clubSandwich: Cluster-Robust (Sandwich) Variance Estimators with Small-Sample Corrections. R package version 0.3.5. https://CRAN.R-project.org/package=clubSandwich

Sebri, M. (2014) A meta-analysis of residential water demand studies. *Environment, development and sustainability* 16(3): 499-520.

Stanley, T. D. (2008) Meta-regression methods for detecting and estimating empirical effects in the presence of publication selection. *Oxford Bulletin of Economics and statistics* 70(1): 103-127.

Stanley, T. D., and Doucouliagos, H. (2012) Meta-regression analysis in economics and business (Vol. 5). *Routledge*.

Stanley, T. D. and H. Doucouliagos (2014) Meta-regression approximations to reduce publication selection bias. *Research Synthesis Methods* 5(1): 60-78.

Tanner-Smith, E. E., E. Tipton and J. R. Polanin (2016) Handling complex meta-analytic data structures using robust variance estimates: A tutorial in R. *Journal of Developmental and Life-Course Criminology* 2(1): 85-112.

Tipton, E. (2015) Small sample adjustments for robust variance estimation with meta-regression. *Psychological methods* 20(3): 375.

Viechtbauer, W. (2010)Conducting meta-analyses in R with the metafor package. *Journal of Statistical Software*, 36(3), 1-48. URL: http://www.jstatsoft.org/v36/i03/

Wong, T. H. and R. R. Brown (2009) The water sensitive city: principles for practice. *Water science and technology* 60(3): 673-682.

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

Appendix

Papers details for studies included in the meta-regression analysis

			Price Elasticity			Income Elasticity		
ID	**Study Included**	**Country of Study**	**No. Est**	**Ave. Est**	**Ave. SE**	**No. Est**	**Ave. Est.**	**Ave. SE**
1	Gottlieb (1963)	USA	4	-0.58	0.36	4	0.55	0.28
2	Howe and Linaweaver (1967)	USA	4	-0.35	0.26	4	0.72	0.20
3	Turnovsky (1969)	USA	14	-0.28	0.11			
4	Wong (1972)	USA	6	-0.39	0.13	6	0.56	0.37
5	Morgan (1973)	USA				6	0.47	0.18
6	Young (1973)	USA	4	-0.52	0.27			
7	Morgan (1974)	USA	1	-0.49	0.17			
8	Sewell and Roueche (1974)	Canada	24	-0.31	0.16	4	0.26	0.33
9	Gibs (1978)	USA	1	-0.62	0.24	1	0.80	0.31
10	Cassuto and Ryan (1979)	USA	8	-0.22	0.10			
11	Danielson (1979)	USA	3	-0.65	0.18	3	0.35	0.04
12	Foster and Beattie (1979)	USA	6	-0.52	0.20			
13	Agthe and Billings (1980)	USA	9	-0.64	0.33	4	1.46	0.90
14	Berk et al. (1980)	USA	4	-0.24	0.12			
15	Billings and Agthe (1980)	USA	2	-0.38	0.88	1	1.68	1.90
16	Carver and Boland (1980)	USA	9	-0.20	0.08			
17	Hansen and Narayanan (1981)	USA	2	-0.47	0.06			
18	Billings (1982)	USA	4	-0.35	0.08			
19	Hanke and Mare (1982)	Sweden	1	-0.15	0.07	1	0.11	0.03
20	Howe (1982)	USA	1	-0.35	0.26			
21	Jones and Morris (1984)	USA	16	-0.22	0.21	3	0.48	0.26
22	Al Qunaibet and Johnston (1985)	Kuwait	4	-0.84	0.24	4	0.09	0.05
23	Williams (1985)	USA	20	-0.39	0.11	20	0.14	0.19
24	Williams and Suh(1986)	USA	5	-0.30	0.10	5	0.67	0.31
25	Agthe and Billings (1987)	USA	4	-0.48	0.10			
26	Moncur (1987)	USA	4	-0.14	0.06	8	0.08	0.01
27	Nieswiadomy and Molina (1988)	USA	3	0.31	0.26	3	0.21	0.13
28	Palencia (1988)	Philippines	1	-0.15	0.07	1	0.54	0.16
29	Thomas and Syme (1988)	Australia	4	-0.36	0.07	3	0.21	0.07
30	Nieswiadomy and Molina (1989)	USA	6	0.16	0.13	6	0.13	0.05
31	Griffin and Chang (1990)	USA	4	-0.28	0.14	2	0.39	0.2
32	Griffin and Chang (1991)	USA	24	-0.34	0.17	1	0.13	0.01
33	Nieswiadomy and Molina (1991)	USA	8	0.07	0.15	4	0.13	0.03
34	Rizaiza (1991)	Saudi Arabia	4	-0.52	0.07	4	0.22	0.04
35	Schneider and Whitlatch (1991)	USA	12	-0.14	0.04	12	0.22	0.07
36	Lyman (1992)	USA	2	-0.07	0.03	2	0.12	0.08
37	Martin and Wilder (1992)	USA	12	-0.42	0.10	2	0.11	0.03
38	Nieswiadomy (1992)	USA	4	-0.39	0.09	4	0.13	0.16
39	Stevens et al. (1992)	USA	12	-0.43	0.21	6	0.17	0.24
40	Nieswiadomy and Cobb (1993)	USA	4	-0.55	0.09	4	0.23	0.31

			Price Elasticity			Income Elasticity		
ID	Study Included	Country of Study	No. Est	Ave. Est	Ave. SE	No. Est	Ave. Est.	Ave. SE
41	Bachrach and Vaughan (1994)	Argentina	14	-0.17	0.05	3	0.003	0.01
42	Crane (1994)	Indonesia	2	-0.54	0.20	4	0.07	0.16
43	Woo (1994)	Hong Kong	2	-0.45	0.11	2	0.24	0.06
44	Hewitt and Hanemann (1995)	USA	5	-1.58	0.81	5	0.15	0.09
45	Barkatullah (1996)	Australia	2	0.02	0.03	3	0.06	0.01
46	Hansen (1996)	Denmark	4	-0.04	0.04			
47	Dandy et al. (1997)	Australia	6	-0.46	0.24	6	0.30	0.15
48	Malla and Gopalakrishnan (1997)	USA	3	-0.09	0.04	6	0.80	0.42
49	Rietveld et al. (1997)	Indonesia	1	-1.18	0.24	1	0.05	0.003
50	Saleth and Dinar (1997)	India	6	-0.56	0.07	3	-0.16	0.03
51	David and Inocencio (1998)	Philippines	8	-0.49	0.21	8	0.20	0.07
52	Renwick and Archibald (1998)	USA	6	-0.30	0.12	1	0.37	0.03
53	Corral and Fisher (1999)	USA	8	-0.16	0.11	2	0.40	0.20
54	Goodman (1999)	USA	3	-0.75	0.10	3	0.08	0.02
55	Hoglund (1999)	Sweden	7	-0.11	0.02	7	0.15	0.03
56	Pint (1999)	USA	16	-0.49	0.04			
57	Hewitt (2000)	USA	1	-0.30	2.68	1	2.17	1.27
58	Mimi and Smith (2000)	Palestine	8	-0.22	0.18	1	0.01	0.01
59	Nauges and Thomas (2000)	France	4	-0.22	0.02	4	0.19	0.05
60	Renwick and Green (2000)	USA	3	0.27	0.05	2	0.15	0.08
61	Gaudin et al. (2001)	USA	15	-0.29	0.03	15	0.02	0.11
62	Gunatilake et al. (2001)	Sri Lanka	1	-0.34	0.02	1	0.08	0.02
63	Acharya and Barbier (2002)	Nigeria	2	-0.07	0.02			
64	Agthe and Billings (2002)	USA	5	-0.53	0.32			
65	Ayadi et al. (2002)	Tunisia	28	-0.23	0.04			
66	Hajispyrou et al. (2002)	Cyprus	6	-0.59	0.36	6	0.31	0.16
67	Hussain et al. (2002)	Sri Lanka	9	-0.10	0.04	2	0.45	0.15
68	Martinez-Espineira (2002)	Spain	2	-0.60	0.26	16	0.37	0.10
69	Nauges and Blundell (2002)	Cyprus	10	-0.40	0.09	10	0.42	0.10
70	Martinez-Espineira (2003)	Spain	22	-0.15	0.04			
71	Nauges and Thomas (2003)	France	7	-0.28	0.06	6	0.30	0.04
72	Olmstead et al. (2003)	USA and Canada	3	0.14	0.12	3	0.14	0.02
73	Arbues et al. (2004)	Spain	3	-0.05	0.02	3	0.12	0.06
74	Campbell et al. (2004)	USA	1	-0.27	0.02			
75	Garcia and Reynaud (2004)	France	1	-0.25	0.05	2	0.10	0.03
76	Martinez-Espineira and Nauges (2004)	Spain	2	-0.30	0.14	1	0.10	0.07
77	Mylopoulos et al. (2004)	Greece	2	-0.78	0.01	2	0.43	0.04
78	Taylor et al. (2004)	USA	4	-0.42	0.07	3	0.36	0.13
79	Bar-Shira et al. (2005)	Israel	1	-0.06	0.02	1	0.14	0.09
80	Carter and Milon (2005)	USA	4	-1.21	0.08	4	0.06	0.05
81	Garcia-Valinas (2005)	Spain	2	-0.51	0.11	1	0.58	0.08
82	Kavezeri-Karuaihe et al. (2005)	Namibia	4	-0.10	0.01	2	-0.21	0.28
83	Martinez-Espineira (2005)	Spain	9	-0.51	0.18			

			Price Elasticity			Income Elasticity		
ID	**Study Included**	**Country of Study**	**No. Est**	**Ave. Est**	**Ave. SE**	**No. Est**	**Ave. Est.**	**Ave. SE**
84	Strand and Walker (2005)	Central American Countries	8	-0.19	0.08	5	0.06	0.02
85	Arbues and Villanua (2006)	Spain	1	-0.08	0.04	1	0.79	0.40
86	Domene and Sauri (2006)	Spain	4	0.42	0.39	4	0.58	0.18
87	Gaudin (2006)	USA	7	-0.34	0.06	6	0.29	0.16
88	Hoffman et al. (2006)	Australia	8	-0.72	0.19	4	0.25	0.02
89	Jansen and Schulz (2006)	South Africa	2	-0.18	0.05			
90	Kostas and Chrysostomos (2006)	Greece	16	-0.31	0.10	1	0.72	0.39
91	Mazzanti and Montini (2006)	Italy	1	-0.56	0.09	9	0.57	0.23
92	Dahan and Nisan (2007)	Israel	7	0.41	0.12			
93	Grafton and Kompas (2007)	Australia	2	-0.39	0.11			
94	Martins and Fortunato (2007)	Portugal	1	-0.10	0.07	1	-0.001	0.01
95	Musolesi and Nosvelli (2007)	Italy	2	-0.37	0.19	2	0.25	0.12
96	Olmstead et al. (2007)	USA and Canada	2	-0.48	0.30	2	0.12	0.03
97	Basani et al. (2008)	Cambodia	2	-0.47	0.11	2	0.19	0.06
98	Cheesman et al. (2008)	Vietnam	4	-0.18	0.05	2	0.07	0.07
99	Grafton and Ward (2008)	Australia	1	-0.17	0.03			
100	Kenney et al. (2008)	USA	2	-0.59	0.38			
101	Rujis et al. (2008)	Brazil	2	-0.45	0.15	2	0.42	0.11
102	Salman et al. (2008)	Jordan	4	0.004	0.01	4	0.02	0.01
103	Xayavong et al. (2008)	Australia	10	-1.08	0.42	6	0.55	0.14
104	Bartczak et al. (2009)	Poland	2	-0.22	0.07	2	0.14	0.07
105	Coleman (2009)	USA	9	-0.41	0.01	5	0.23	0.07
106	Diakite et al. (2009)	Cote d'Ivoire	3	-0.68	0.11	3	0.17	0.04
107	Grafton et al. (2009)	Global	10	-0.45	0.07	1	0.01	0.02
108	Nauges and Berg (2009)	Sri Lanka	2	0.05	0.10	2	0.04	0.07
109	Olmstead (2009)	USA and Canada	3	0.23	0.09	3	0.34	0.17
110	Schleich and Hillenbrand (2009)	Germany	6	-0.46	0.19	2	0.39	0.11
111	Statzu and Strazzera (2009)	Italy	5	-0.14	0.02	5	0.11	0.05
112	Arbus et al. (2010)	Spain	5	-0.71	0.05			
113	Garcia-Valinas et al. (2010)	Spain	2	-0.06	0.03	1	0.06	0.03
114	Monteiro (2010)	Portugal	8	-0.35	0.03	4	0.05	0.02
115	Polebitski and Palmer (2010)	USA	18	-0.34	0.17	14	0.13	0.07
116	Strong and Smith (2010)	USA	6	-0.34	0.13	3	0.20	0.13
117	Bell and Griffin (2011)	USA	13	-0.15	0.04	12	-0.19	0.1
118	Dharmaratna and Parasnis (2011)	Sri Lanka	6	-0.25	0.11	6	0.03	0.03
119	Horn (2011)	Cambodia	2	-0.28	0.15	2	0.62	0.15
120	Madhoo (2011)	Mauritius	2	-0.69	0.01	8	0.38	0.17
121	Mieno and Braden (2011)	USA	9	-1.18	0.27	2	-0.01	0.25
122	Miyawaki et al. (2011)	Japan	1	-0.71	0.08	4	0.29	0.05
123	Monterio and Roseta-Palma (2011)	Portugal	5	-0.10	0.03	4	0.06	0.02
124	Musolesi and Nosvelli (2011)	Italy	4	-0.05	0.04			
125	Abrams et al. (2012)	Australia	6	-0.09	0.02			
126	Ciomos et al. (2012)	Romania	1	-0.71	0.17			

			Price Elasticity			Income Elasticity		
ID	**Study Included**	**Country of Study**	**No. Est**	**Ave. Est**	**Ave. SE**	**No. Est**	**Ave. Est.**	**Ave. SE**
127	Dharmaratna and Harris (2012)	Sri Lanka	4	-0.12	0.02	5	0.11	0.02
128	Fenrick and Getachew (2012)	USA	14	-0.17	0.07	2	0.26	0.06
129	Kashian et al. (2012)	USA	3	-1.74	0.89			
130	Mansur and Olmstead (2012)	USA and Canada	10	-0.13	0.08	6	0.08	0.02
131	Rinaudo and Neverre (2012)	France	1	-0.18	0.07	1	0.42	0.16
132	Tabieh et al. (2012)	Jordan	6	-0.46	0.13	6	0.08	0.03
133	Fullerton et al. (2013)	Canada	3	-0.37	0.06			
134	Hortova (2013)	Czech Republic	12	-0.45	0.09	2	0.19	0.09
135	Kumaradevan (2013)	Australia	1	-2.1	0.16			
136	Polycarpou and Zachariadis (2013)	Cyprus	2	-0.35	0.10	2	0.64	0.26
137	Sebri (2013)	Tunisia	4	-0.68	0.03	4	0.44	0.04
138	Asci and Borisova (2014)	USA	12	-0.27	0.08	12	1.01	0.19
139	Baerenklau et al. (2014)	USA	7	-0.73	0.02	7	0.38	0.19
140	Binet et al. (2014)	France	4	-0.32	0.12	4	0.17	0.21
141	Coulibaly et al. (2014)	Jordan	4	-0.41	0.19			
142	Dhungel and Fiedler (2014)	USA	3	0.05	0.03			
143	Kanakoudis and Gonelas (2014)	EU	3	-0.27	0.13			
144	Khan (2014)	Pakistan	8	-0.55	0.06	2	0.91	0.18
145	Klaiber et al. (2014)	USA	2	-1.94	0.12			
146	Lopez-Mayan (2014)	Spain	10	-0.31	0.16			
147	Ma et al. (2014)	China	7	-1.38	0.54	7	0.22	0.23
148	Romano et al. (2014)	Italy	2	-0.24	0.04	2	0.20	0.09
149	Wichman (2014)	USA	10	-0.70	0.28			
150	Yoo et al. (2014)	USA	9	-1.07	0.33	1	0.04	0.01
151	Galaitsi et al. (2015)	Palestine	1	-0.28	0.09			
152	Ghimire et al. (2015)	USA	4	0.08	0.02	4	0.32	0.02
153	Lee and Tanverakul (2015)	USA	6	-0.51	0.01			
154	Zaied and Binet (2015)	Tunisia	5	-0.48	0.10	4	0.19	0.21
155	Almendarez-Hernandez et al. (2016)	Mexico	4	-0.40	0.07	5	0.18	0.10
156	Ghavidelfar et al. (2016)	New Zealand	2	-0.13	0.06	1	0.09	0.17
157	Perez-Urdiales et al. (2016)	Spain	12	-0.08	0.23			
158	Reynaud (2016)	9 EU countries	8	-0.26	0.14	6	0.49	0.27
159	Reynaud et al. (2016)	Serbia	3	-0.49	0.20	3	0.57	0.24
160	Ahmad et al. (2017)	Pakistan	4	-0.59	0.17	4	0.09	0.06
161	Asci et al. (2017)	USA	2	-0.11	0.003			
162	Clarke et al. (2017)	USA	2	-0.16	0.02			
163	Hala (2017)	UAE	14	-0.26	0.13			
164	Hoyos and Artable (2017)	Spain	4	-0.91	0.20	3	0.39	0.22
165	Hung and Chie (2017)	Taiwan	6	-0.53	0.21			
166	Kotagama et al. (2017)	Oman	1	-0.10	0.03	1	0.04	0.02
167	Lavin et al. (2017)	Colombia	8	0.22	0.03	3	0.55	0.05
168	Brent (2018)	USA	6	-0.23	0.01			
169	Klassert et al. (2018)	Jordan	20	-0.96	0.08	6	0.11	0.01

ID	Study Included	Country of Study	Price Elasticity			Income Elasticity		
			No. Est	Ave. Est	Ave. SE	No. Est	Ave. Est.	Ave. SE
170	Reynaud et al. (2018)	Andorra	4	-0.75	0.06			
171	Tastan (2018)	Turkey	12	-0.05	0.20			
172	Fercovic et al. (2019)	Chile	4	-0.15	0.06	4	0.26	0.10
173	Jiang et al.(2019)	China	5	-0.49	0.18			
174	Maas et al. (2019)	USA	6	-0.14	0.02			
175	Schleich and Hillenbrand (2019)	Germany	6	-0.09	0.05	6	0.08	0.12
176	Zaied et al. (2019)	Tunisia	4	-0.54	0.11			