

Price and Income Elasticities of Residential Water Demand: A Meta-Analysis

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ABSTRACT. *This article presents a meta-analysis of variations in price and income elasticities of residential water demand. Meta-analysis constitutes an adequate tool to synthesize research results by means of an analysis of the variation in empirical estimates reported in the literature. We link the variation in estimated elasticities to differences in theoretical microeconomic choice approaches, differences in spatial and temporal dynamics, as well as differences in research design of the underlying studies. The occurrence of increasing or decreasing block rate systems turns out to be important. With respect to price elasticities, the use of the discrete-continuous choice approach is relevant in explaining observed differences.* (JEL H31, Q25)

I. INTRODUCTION

Demand-oriented policy measures coping with the growing scarcity of potable water are increasingly seen as a necessary complement to more traditional supply-oriented policies. An assessment of the potential of such policies should be based on a thorough understanding of consumer responses to price and income changes. Detailed knowledge about price and income elasticities of residential water demand is available through a substantial number of empirical studies. Empirical estimates cover a sizeable range however, and depend on differences in population characteristics, site characteristics (such as precipitation), differences in tariff systems as well as biases and misspecifications in the econometric analyses used to determine the elasticities.

In this article, we use meta-analysis to identify important factors explaining the variation in estimated price and income elasticities of residential water demand. Meta-

analysis constitutes a set of statistical tools, developed primarily in the experimental sciences, and is well tailored to analyze research results obtained in previous studies. We follow up on earlier work by Espey, Espey, and Shaw (1997), although our approach differs in various respects. We consider a significantly larger set of studies, and extend the analysis to include income elasticities in addition to price elasticities. We also account for differences in income levels between studies by controlling for GDP per capita levels, and explicitly investigate the relevance of explanatory variables derived from the microeconomic theory on kinked demand curves. Specifically, we assess the effect of using the so-called discrete-continuous choice model (Hewitt and Hanemann 1995).

Our main results can be summarized as follows. First, variation in estimated elasticities is associated with differences in the underlying tariff system. Relatively high price elasticities and relatively low income elasticities are found in studies concerned with demand under the increasing block rate pricing schedule. Second, studies using prices different from marginal prices (such as flat, average, or Shin prices), and with controls for income differentials, a difference variable and/or a discrete-continuous choice specification, result in comparatively higher absolute values of price and income elasticities. Finally, differences in estimated elasticities are posi-

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tively correlated with differences in per capita income pertaining to the underlying study area. This is consistent with demand theory.

The remainder of this article is organized as follows. Section 2 concisely presents the theoretical microeconomic background of water demand studies and discusses salient econometric issues. We also introduce meta-analysis as an adequate tool to analyze the empirical literature. Section 3 explains the principles behind study retrieval, and presents the distribution of price and income elasticities of residential water demand. Section 4 presents the results of the meta-regression analyses, and Section 5 contains conclusions.

II. THEORY, ECONOMETRICS, AND META-ANALYSIS

The literature containing estimates of price and income elasticities of residential water demand is extensive, and partly focuses on the econometrics needed to adequately estimate microeconomic choices. Econometric complications are primarily caused by complex tariff systems prevailing in many countries (e.g., Hewitt and Hanemann 1995; OECD 1999). Below, we discuss several theoretical and econometric implications of quantity dependent price setting behavior of water suppliers. We also introduce meta-analysis, and describe the implications of modern theoretical and econometric approaches for the meta-analysis setup.

Theoretical Implications of Block Rate Pricing

Three main categories of tariff systems, oftentimes applied in conjunction with a fixed fee, can be distinguished: constant unit pricing, and increasing or decreasing block rate pricing. The consequences for the analysis of individual demand under block rate pricing cannot be ignored, because block rate pricing is at odds with the standard assumption that price setting is quantity-independent. Moffitt (1986) and Dalhuisen et al. (2001) provide a general overview of the implications of block rate pricing. Salient implications can be summarized as follows.

1. Price and income elasticities are gen-

erally non-constant, but increase in absolute value with income for goods with relatively high subsistence requirements (such as water).

2. Block rate pricing causes price and income elasticities to be non-constant as well as discontinuous, due to consumers being confronted with "jumps" in relevant marginal prices.
3. Increasing block rates result in income ranges where demand for the good to which block rates apply is unaffected by price and income changes.
4. Decreasing block rates imply the existence of an income level at which consumers "jump" from the first to the second block, and hence demand is discontinuous.

Econometric Aspects of Water Demand Models

Non-linearities and discontinuities in demand functions caused by block rate pricing have serious implications for the estimation of elasticities (Hausman 1985; Moffitt 1986). One implication is concerned with the behaviorally consistent specification of prices in water demand models and focuses on the adequacy of using average or marginal prices. The other is related to the prevalence of block rate pricing, and addresses the implications of block rate pricing for the functional specification of the model. We briefly discuss both issues and identify the implications for the meta-analysis.

Howe and Linaweaver (1967) argue that consumers react to marginal rather than average prices. Many studies include either the average price (Billings 1990; Hogarty and Mackay 1975) or the marginal price (Danielson 1979; Lyman 1992), or both (Opaluch 1982, 1984; Martin and Wilder 1992). Shin (1985) advocates using the so-called "perceived price," a combination of marginal and average prices, which is subsequently used in other studies as well (Nieswiadomy 1992). In the wake of work on electricity demand (Taylor 1975; Nordin 1976), econometric specifications are also extended with a difference variable accounting for (implicit) lump sum transfers caused by the existence

of block rates (Nieswiadomy and Molina 1989).

Most studies do, however, not explicitly model the consumers' position on the demand curve, and therefore ignore the specification of the block rate relevant to the consumer. Hewitt and Hanemann (1995) suggest applying the "two-error model," originally developed in the labor supply literature, to circumvent misspecification bias. The first error term captures factors influencing the utility function (i.e., the "heterogeneity error"), and the second error term covers the difference between optimal and observed levels of water demand (i.e., the "optimization error"). As a result, the heterogeneity error co-determines the discrete choice (in this case, the conditional demand or, more precise, the block in which consumption takes place), and the optimization error accounts for the difference between the observed value and the value determined by maximization of the utility function. The observed demand of water is thus modeled as the outcome of a discrete choice and a perception error that, dependent on its magnitude, places the consumption in a different block. Studies using this approach report rather high absolute values for the price elasticity, suggesting that reactions to price changes are elastic rather than inelastic (Hewitt and Hanemann 1995; Rietveld, Rouwendal, and Zwart 1997). Estimates for income elasticities based on the discrete-continuous choice approach are generally inelastic, and hence more in line with values reported in other studies.

Implications for the Meta-Analysis

The above developments in theory and concurrent econometrics have resulted in an abundant number of empirical studies. These studies show considerable heterogeneity in terms of the relevant tariff structure, model specification (functional form, definition of explanatory variables, estimator), type of data (frequency and unit of observation), number of observations, and publication status (published or unpublished). Meta-analysis constitutes an adequate tool for a

multivariate analysis of the variation in estimated price and income elasticities.

Meta-analysis has been developed in the context of the experimental sciences (particularly in medicine, psychology, marketing and education), and refers to the statistical analysis of empirical research results of previous studies (Stanley 2001). It differs from primary and secondary analysis, referring to an original and an extended investigation of a data set (Glass 1976), respectively, because meta-analysis uses aggregate statistical summary indicators from previous studies. In economics, these indicators are typically ratios, such as elasticities and multipliers, or (non-) market values. They are commonly referred to as "effect sizes" (Van den Bergh et al. 1997). The statistical techniques specifically developed for meta-analysis are covered in sufficient detail in, for instance, Hedges and Olkin (1985), and Cooper and Hedges (1994).

The theoretical and econometric developments in the literature have three major implications for the meta-analysis setup. First, the variation in elasticity estimates can be correlated with the nature of the price variable used in the primary studies. Second, the inclusion of a difference variable is a potential cause for differences in elasticity estimates. Finally, including the consumer's position on the demand curve, as in Hewitt and Hanemann (1995), avoids misspecification bias and can result in significantly different elasticity estimates.

III. DATA

The validity and the extent to which results of a meta-analysis can be generalized, depends on the thoroughness and completeness of the literature retrieval. Common desiderata in literature retrieval are high "recall" and high "precision." Recall is defined as the ratio of relevant documents retrieved to those in a collection that should be retrieved. Precision is defined as the ratio of documents retrieved and judged relevant to all those actually retrieved. Precision and recall tend to vary inversely (White 1994). Most researchers favor high precision, but in

the context of meta-analysis high recall is the more relevant desideratum.

We focused on high recall in study retrieval, and first exploited readily available literature reviews (Hewitt 1993; Baumann, Boland, and Hanemann 1998; OECD 1998, 1999) and the meta-analysis of Espey, Espey, and Shaw (1997). Subsequently, we identified additional studies through "reference chasing," and several authors were contacted by E-mail in order to acquire further published or unpublished results. We also used modern methods of literature retrieval, such as browsing Internet databases, in particular EconLit,¹ and located unpublished studies and research memoranda, up until 1998, through a search in NetEc (netec.wustl.edu), RepEc (www.repec.org), and Web sites of renowned universities and research institutes (for instance, CEPR, NBER, etc.). This retrieval procedure resulted in 64 studies, from which we derived 314 price elasticity estimates and 162 income elasticity estimates of residential water demand.² In addition, we collected and codified auxiliary information on statistical sample characteristics and research design.

Our sample is considerably larger than the Espey, Espey, and Shaw (1997) meta-sample of 124 price elasticities, and it also contains income elasticities and estimates using the two-error model specification. We deliberately use the variation between studies to explore the extent to which they result in significantly differing elasticity estimates, and include variations in spatio-temporal focus, research design, methodology, and tariff structure in the explanatory meta-analysis. The time coverage of the studies in our sample follows a well-distributed pattern, but over space a distinct bias towards the United States is present. Most studies are concerned with short-run elasticities, but show considerable variation in terms of the type of price used. Since the 1980s, most studies include a difference variable, but the discrete-continuous methodology is only used in three studies.

The top graph in Figure 1 shows the meta-sample distributions for price and income elasticities, ordered according to magnitude. The distribution of price elasticities has a

sample mean of $-.41$, a median of $-.35$, and a standard deviation of $.86$. The minimum and maximum values in the sample are -7.47 and 7.90 , respectively. In line with theoretical expectations, most estimates are negative. However, the number of estimates deviating from -1 is considerably larger for estimates greater than -1 than for those smaller than -1 , providing substantial evidence for water demand being price inelastic.

The distribution of income elasticities has a mean of $.43$ and a median of $.24$, but the range of values is smaller than for price elasticities (standard deviation $.79$). Approximately 10% of the estimates is greater than 1 and hence, again corroborating theoretical expectations, water demand appears to be inelastic in terms of income changes. We refer to Dalhuisen et al. (2001) for a more extensive description of the dataset, including an exploratory ANOVA-type of overview of differences in means for price and income elasticities.

In subsequent analyses, we exclude two outliers in the price elasticity sample, the extreme values -7.47 and 7.90 . Their inclusion would have a disproportional influence on the quantitative analysis, in particular, because a dummy variable for segment elasticities (of which these observations are a sub-sample) would not adequately pick up these extreme values given their opposite sign. We also exclude the positive elasticities in the price elasticity sample because of their "perverse" nature.³ The size of the sample for price elasticity estimates therefore reduces to

¹ EconLit (see <http://www.econlit.org>) is a comprehensive, indexed bibliography with selected abstracts of the world's economic literature, produced by the American Economic Association.

² A bibliography of the studies included in the database is available at <http://www.feweb.vu.nl/re/> master-point. On this site we also provide the database and an exhaustive tabular overview of the studies, including the main dimensions of variation and the (range of) value(s) of the elasticity estimates.

³ This is in accordance with Espey, Espey, and Shaw (1997). It would be desirable to include probability values for the estimated elasticities in the analysis. This is, however, not possible for specifications other than the doublelog specification, because there is not sufficient sample information available to determine the standard errors of the elasticities.

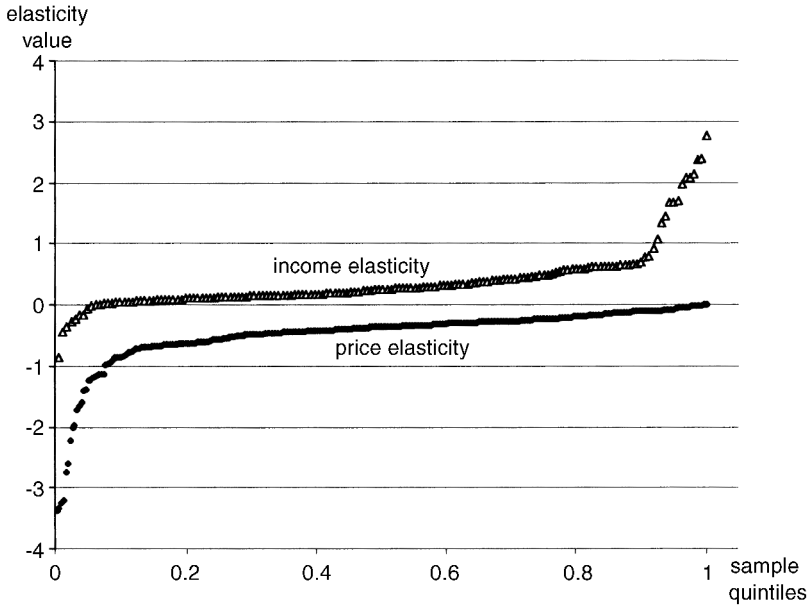
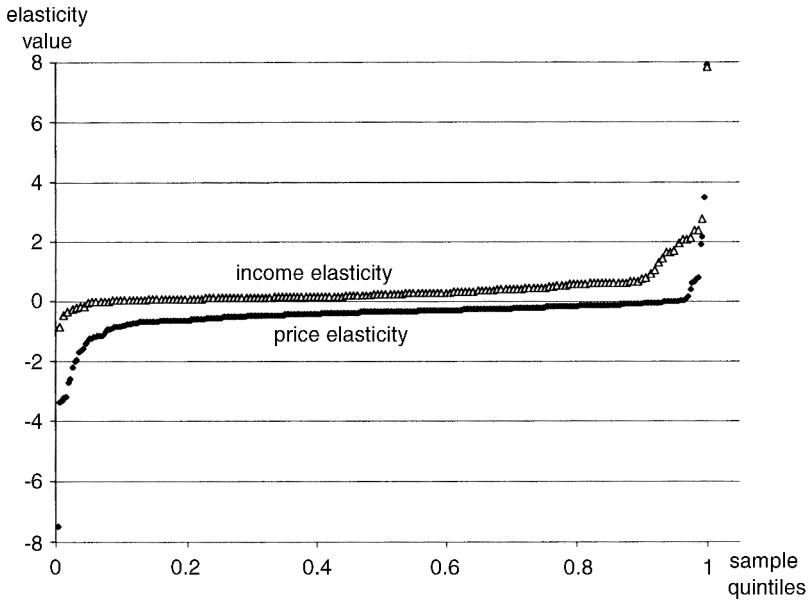


FIGURE 1

THE DISTRIBUTION OF PRICE AND INCOME ELASTICITIES, ORDERED IN META-SAMPLE QUINTILES ACCORDING TO SIZE, INCLUDING ALL OBSERVATIONS (TOP) AND EXCLUDING OUTLIERS (BOTTOM)

296 observations. From the income elasticities sample a segment elasticity of $-.86$ is excluded, because it cannot be represented as a separate category and it does not really fit into the explanatory framework (comprising factors such as functional form and estimator). The income elasticity sample contains 161 observations. The adjusted samples are shown in the bottom graph of Figure 1.

IV. META-REGRESSION

In order to attain a rigorous insight into the causes for structural differences in estimated price and income variability of residential water demand, a multivariate analysis is needed. Espey, Espey, and Shaw (1997) use a framework in which price elasticities are explained as a function of the demand specification (including functional form and the specification of the conditioning variables), data characteristics, environmental characteristics, and the econometric estimation technique. Positive estimates for price elasticities are excluded, yielding a sample of 124 observations, with a mean price elasticity of $-.51$ and approximately 90% of the estimates between $-.75$ and 0. They estimate a linear, a loglinear, and a Box-Cox specification.⁴

A χ^2 -test indicates that the nonlinear Box-Cox specification achieves the highest explanatory power, and the results are more or less robust comparing signs and significance across specifications. In the nonlinear Box-Cox version of the model Espey, Espey, and Shaw find that primary studies in which the demand specification includes evapotranspiration and rainfall variables, and are based on winter data (instead of summer or year-round data), reveal significantly lower elasticity estimates. Significantly higher values for the price elasticity are obtained when using average or Shin prices and when a difference variable is included in the demand equation.⁵ Elasticities under increasing block rates as well as long run elasticities are significantly higher. Finally, estimates referring to commercial water use and the summer season are significantly greater. In terms of magnitude, evapotranspiration, the use of a difference

variable, and summer data have the greatest impact.

Following up on the work of Espey, Espey, and Shaw, we provide additional results in this article. The first subsection deals with a re-analysis of the Espey, Espey, and Shaw sample and our extended sample, in order to judge the robustness of results across studies. Subsequent subsections are confined to the use of our extended sample. First, we use a somewhat different specification for the meta-regression and derive results for both price and income elasticities. Second, we present a more accurate way of investigating the impact of tariff systems. Finally, we succinctly investigate the implications of different microeconomic behavioral models for the estimated elasticity values.

Robustness of Results for Price Elasticities across Different Meta-Samples

The Espey, Espey, and Shaw sample contains 124 estimated price elasticities from 24 journal articles published between 1967 and 1993. Our extended sample comprises 296 estimates from 64 studies that appeared between 1963 and 2001. In order to investigate the robustness of the results across studies and the relevance of sample selection bias, we compare the results of our sample to the Espey, Espey, and Shaw results, using their specification. The results are presented in Table 1 for the linear and Box-Cox specifications. The first four columns refer to the Es-

⁴ The Box-Cox transformation applies to the dependent variable y only, which is transformed to $(y^\lambda - 1)/\lambda$. We use maximum likelihood techniques as opposed to the grid search procedure used in Espey, Espey, and Shaw (1997), which is not necessarily maximum likelihood (Greene 2000). We follow Espey, Espey, and Shaw in multiplying the elasticities with -1 , because the argument of the natural logarithm is strictly positive, but only do this in Table 1.

⁵ Espey, Espey, and Shaw (1997, 1371) refer to this as the difference price, indicating the difference between what the consumer would pay for water if all water were purchased at the marginal rate and what is actually paid (Agthe and Billings 1980). Because the difference price is strictly speaking not a price variable, but rather a correction factor accounting for lump sum transfers in case of block rate tariffs, we prefer the label "difference variable."

TABLE 1

ESTIMATION RESULTS FOR THE REPLICATION OF THE ESPEY, ESPEY, AND SHAW (1997) ANALYSIS FOR THE ORIGINAL AND THE EXTENDED SAMPLE^a

Dependent Variable: Absolute Value Price Elasticity	Espey, Espey, and Shaw Sample				Extended Sample	
	Original		Adjusted		Linear	Box-Cox
	Linear	Box-Cox	Linear	Box-Cox		
Constant	.68** (2.60)	-1.05** (-3.01)	.48 (1.16)	-1.07** (-2.45)	.13 (0.72)	-1.80*** (-7.43)
Increasing block rate	0.18 (1.57)	.39*** (2.67)	0.23 (1.61)	.44*** (2.89)	.35*** (3.21)	.54*** (3.90)
Decreasing block rate	.07 (.58)	.23 (1.61)	.06 (.67)	.32** (2.05)	.14 (1.09)	.32* (1.92)
Average price	.59 (.96)	.18** (2.26)	.18 (1.60)	.43*** (3.48)	-.09 (-1.09)	.04 (.41)
Shin price	0.13 (1.36)	.30** (2.41)	0.20 (1.20)	.53*** (2.93)	-.08 (-.52)	.04 (.19)
Income included	-.48* (-1.87)	-.15 (-.47)	0.08 (0.19)	-.75 (-1.51)	-.19 (-1.42)	-.58*** (-3.25)
Difference variable included	1.29*** (6.91)	1.18*** (5.18)	.13 (.45)	-.47 (-1.50)	-.20 (-1.54)	-.20 (-1.25)
Long run	.34** (2.28)	.39** (2.14)	.56*** (3.12)	.45** (2.38)	.23** (2.30)	.45*** (3.44)
West United States	.03 (.27)	.20 (1.33)	.09 (.62)	.33** (2.05)	.19* (1.87)	.38*** (2.86)
East United States	.06 (.57)	.15 (1.25)	-.05 (-0.39)	.05 (.38)	.06 (.62)	.19 (1.44)
Loglinear specification	.04 (.45)	.08 (.86)	.13 (1.04)	.18 (1.45)	.28*** (3.80)	.48*** (4.97)
Population density included	.35** (2.06)	.42** (2.02)	-.05 (-.17)	-.10 (-.34)	.18 (1.18)	.38* (1.90)
Household size included	.01 (.10)	.07 (.48)	-.04 (-.28)	-.16 (-1.15)	-.12 (-1.04)	-.05 (-.33)
Seasonal dummy included	-.20 (-1.22)	0.05 (.23)	.53** (2.33)	.57** (2.38)	.23* (1.73)	.30* (1.75)
Evapotranspiration included	-1.83*** (-9.31)	-1.52*** (-6.28)	-.75** (-2.10)	-.19 (-.49)	-.21 (-1.42)	-.08 (-.44)
Rainfall included	-.62*** (-5.41)	-.43*** (-3.04)	.56** (2.13)	.76*** (2.74)	-.17* (-1.93)	-.15 (-1.27)
Temperature included	.17* (1.85)	-.22 (-1.19)	-.67* (-2.61)	-1.00*** (-3.67)	-.02 (-.22)	-.07 (-.69)
Lagged dependent variable	.02 (.16)	.05 (.32)	-.07 (-.30)	.01 (.04)	.23** (2.36)	.05 (.44)
Commercial use	.43*** (2.69)	.58*** (2.95)	-.86* (-1.82)	-1.13** (-2.28)	.17 (.83)	.31 (1.18)
Other estimation techniques	.04 (.64)	0.03 (0.42)	-.01 (-.08)	.11 (1.02)	-.03 (-.51)	-.09 (-1.04)
Daily data	-.14 (-.83)	-.91 (-4.44)	-.62* (-1.71)	-.52 (-1.36)	.33* (1.87)	.77*** (3.35)
Monthly data	.49*** (2.87)	.48** (2.33)	-.35 (-.93)	.47 (1.14)	.29** (2.33)	.81*** (4.84)
Household level data	-.06 (-.47)	-.18 (-1.22)	-.37** (-2.08)	-.54*** (-2.87)	.18 (2.01)	.18 (1.60)
Cross section data	.08 (.84)	.52 (.46)	-.27 (-.73)	.49 (1.17)	.15 (1.09)	.53*** (2.85)
Winter data	-0.59*** (-4.90)	-.34** (-2.23)	-.03 (-.09)	.07 (.26)	-.18* (-1.65)	-.25* (-1.78)
Summer data	1.67*** (14.67)	1.44*** (10.35)	1.22*** (5.37)	1.07*** (4.48)	.15 (1.43)	.13 (.99)
R ² -adj.	.81		.46		.22	
F-test	21.83***		5.24***		4.42***	
λ		0.49*** (5.93)		0.12* (1.93)		0.23*** (6.65)
LR test		41.06***		162.43***		336.42***
Log Likelihood	23.62	-15.05	-40.49	-60.70	-163.86	-252.08
Akaike Info. Cr.	.04	.66	1.07	1.40	1.28	1.88
Log Amemiya Prob. Cr.	-2.80	-2.41	-1.76	-1.67	-1.56	-1.05
N	124	124	124	124	296	296

^a Significance is based on a two-sided *t*-test (with *t*-values in parentheses), and indicated by ***, **, and * for the 1, 5, and 10% level, respectively. Note that these results are generated using the absolute value of the (negative) price elasticities as the dependent variable in order for the Box-Cox transformation to be feasible. The Box-Cox estimator is maximum likelihood.

pey, Espey, and Shaw sample,⁶ the last two to the extended sample. The estimations are based on a full maximum likelihood procedure for all parameters including the transformation parameter λ . The Likelihood Ratio test reported in Table 1 concerns the test of the Box-Cox model as unrestricted model against the linear model containing the (implicit) restriction of λ being equal to one.

The third and fourth column (labeled "Adjusted") show the results for the Espey, Espey, and Shaw sample with some additional adjustments to the coding of the data in order to make the data fully comparable to the data set for the extended sample. We increased the number of observations for which the type of tariff system is known (from 11 in the original Espey, Espey, and Shaw sample to 53 in the adjusted sample), using information regarding the estimated parameter value of the difference variable.⁷ These changes affect the original Espey, Espey, and Shaw results by reducing the explanatory power: the adjusted R^2 drops from .81 to .46. The significance of almost half the variables changes as well (from significant to insignificant, or vice versa). Regarding the microeconomic variables, decreasing block rates is now significantly different from zero in the Box-Cox specification, but the difference variable loses its significance in both specifications.

The comparison of the last two columns of Table 2 with the middle two columns gives an indication of the robustness of the results across different meta-samples. The extended meta-sample is twice as large as the Espey, Espey, and Shaw sample. In terms of sign, some noteworthy changes can be observed. For instance, the effect of the data type (daily data and household level data) is reversed in the extended sample. Furthermore, with respect to the important microeconomic variables, specifically average price and Shin price, we observe a reverse effect in terms of significance. The adjusted R^2 drops even further to .22. These changes reinforce the conclusion that the literature retrieval process is of paramount importance, and show as well that the estimation results are not overly robust. This is even more relevant as the fixed effects approach that characterizes many meta-regressions, is par-

ticularly sensitive to the number of degrees of freedom available—in terms of statistical significance as well as with regard to the variation available and the degree of multicollinearity.

It should, however, also be noticed that there are some "peculiarities" in these specifications. For instance, the omitted category for tariff systems includes cases for which no information can be retrieved from the underlying studies as well as those that have a flat rate system. Following Section 2, we also expect differences among studies to be related to diverging income levels for the respective study areas. Finally, no formal distinction is made for the relatively new studies using the two-error model approach, because they were not included in the Espey, Espey, and Shaw analysis. In the remainder of this section, we will remedy these issues by means of alternative specifications.

Alternative Meta-Specifications for Price and Income Elasticities

In this section, we introduce various adaptations to the econometric specification, and we extend the analysis to income elasticities of residential water demand. The specification of the design matrix used in the meta-regressions includes variables from five different categories.

⁶ The Espey, Espey, and Shaw results presented in the first two columns of Table 1 (labeled "Original") are slightly different from those published in Espey, Espey, and Shaw (1997). Apparently, there has been some confusion in their coding of the variable referring to household level data. In Table 2 of the Espey, Espey, and Shaw study (1997, 1372) it is indicated that 28 observations refer to household data and 96 to aggregate data. This is, however, not in accordance with their database, which gives 81 and 43 observations for household and aggregate data, respectively. As the latter is equivalent to our own coding we have used an accordingly coded dummy variable in replicating the Espey, Espey, and Shaw analysis. The correction does not significantly alter their results. There also seems to be a slight mistake in Table 1 with respect to the numbers of studies using "long run demand" and "lagged dependent variable," 17 and 22, respectively, which should be reversed. This is, however, most likely a typographical error.

⁷ A negative (positive) sign implies increasing (decreasing) block rates. We also split the observations of Lyman (1992) more precisely according to season considered (summer, winter, or year-round).

TABLE 2
ESTIMATION RESULTS FOR PRICE AND INCOME ELASTICITIES BASED
ON A LINEAR SPECIFICATION WITH HETEROSCEDASTICITY
CORRECTED STANDARD ERRORS

Dependent Variable: Price and Income Elasticity	Price Elasticity		Income Elasticity	
	Full	Restricted	Full	Restricted
Constant	-.12 (-.38)	-.40** (-2.22)	.20 (.38)	.06 (.21)
Increasing block rate	.05 (.34)	.11 (1.05)	.02 (.03)	.24 (.81)
Decreasing block rate	.003 (.02)	.06 (.55)	.96 (1.14)	1.09** (2.00)
No block rate info available	.01 (.09)	.04 (.64)	-.44* (-1.87)	-.33* (-1.85)
Average price	-.25 (-.44)	-.0004 (-.007)	-.04 (-.46)	-.05 (-.51)
Shin price	-.03 (-.34)	-.06 (-.075)	.14 (.36)	.20 (.44)
Income included	-.12 (-.65)	-.12 (-.86)	—	—
Difference variable included	.08 (.65)	.18** (2.07)	-.59 (-1.29)	-.53 (-1.21)
Discrete-continuous model	-1.07*** (-6.24)	-1.25*** (-8.79)	-1.14*** (-3.74)	-1.19*** (-5.10)
Long run	-.26* (-1.65)	-.28** (-2.43)	-.06 (-.32)	-.08 (-.71)
Segment elasticity	-.67** (-2.04)	-.67*** (-2.60)	—	—
GDP per capita (× 1,000)	.01 (.66)	.02* (1.89)	.01 (.40)	.04* (1.87)
West United States	-.17** (-2.03)	-.21*** (-3.64)	.01 (.08)	—
East United States	-.005 (-.06)	—	-.08 (-.42)	—
Europe	.28* (1.73)	.29*** (3.02)	-1.08* (-1.83)	-.77*** (-2.71)
Other locations	-.20 (-1.07)	-.29** (-2.00)	.24 (.74)	.60*** (4.32)
Midpoint time trend	-.005 (-.74)	—	.03 (1.44)	—
Loglinear specification	-.15** (-2.48)	—	.08 (.62)	—
Population density included	-.18** (-2.02)	-.17** (-2.48)	.27 (1.21)	.22* (1.77)
Household size included	-.07 (-1.02)	—	-.33 (-1.39)	—
Seasonal dummy included	-.38 (-1.48)	-.48** (-2.36)	-1.23 (-1.60)	-1.30** (-2.04)
Evapotranspiration included	.11 (.84)	—	.74*** (2.88)	.82** (2.55)
Rainfall included	.06 (.71)	—	-.08 (-.33)	—
Temperature included	-.04 (-.63)	—	.03 (.23)	—
Lagged dependent variable	-.17 (-1.37)	—	.02 (.14)	—
Commercial use	-.19 (-1.13)	—	-.56** (-2.40)	-.30*** (-2.69)
Other estimation techniques	.01 (.16)	—	-.21 (-.86)	—

TABLE 2 (CONTINUED)

Dependent Variable: Price and Income Elasticity	Price Elasticity		Income Elasticity	
	Full	Restricted	Full	Restricted
Daily data	-.08 (-.64)		-1.44** (-2.40)	-.93*** (-4.09)
Monthly data	-.22** (-2.08)	-.22*** (-2.66)	-.95* (-1.79)	-.79*** (-3.22)
Household level data	-.09 (-1.16)		.16 (.92)	
Cross section data	.04 (.33)		.04 (.13)	
Panel data	.30** (2.51)	.27*** (3.13)	.79*** (3.12)	.84*** (2.84)
Winter data	.13** (2.39)	.10*** (2.65)	.24* (2.06)	
Summer data	-.25** (-2.24)	-.28** (-2.37)	.23 (1.46)	.30* (1.97)
Unpublished studies	.27* (1.93)	.28*** (3.68)	.59* (1.86)	.78*** (3.40)
R^2 -adj.	.32	.33	.39	.42
F test	5.03***	7.61***	4.14***	6.74***
Log Likelihood	-140.12	-143.85	-130.87	-133.75
Akaike Info. Crt.	1.18	1.13	2.04	1.92
Log Amemiya Prob. Crt.	-1.65	-1.71	-.80	-.91
N	296	296	161	161

- Following the discussion in Section 2, we include variables reflecting differences in *microeconomic theory* and *econometric methods*. Specifically, we include variables relating to the type of tariff system (increasing and decreasing block rates, and a flat rate system vs. those for which no information is available), the price variable (fixed, average, marginal, or Shin), whether or not the price elasticity is conditioned on income, and the modeling approach (inclusion of a difference variable, and application of the discrete-continuous choice approach). GDP per capita is used to account for income differences across studies. Finally, short and long term, and point and segment elasticities are distinguished.
- Spatio-temporal dynamics* are represented by means of dummy variables related to location (West United States, East United States, Europe and other countries vs. the United States as the omitted category), and a linear time-trend referring to the mid-point of the first and last year to which the data pertain.
- Estimation characteristics* of the primary studies are represented by means of information about the functional form (loglinear vs. other functional forms), the conditioning variables used in the underlying studies (population density, household size, seasonal dummy, evapotranspiration, rainfall, temperature, the lagged dependent variable, and commercial use), and a variable indicating whether an estimator different from OLS is used.
- The potential influence of the *type of data* is operationalized by means of the frequency of observation (daily or monthly data vs. yearly data as the omitted category), the aggregation level (individual or household data vs. aggregate data as the omitted category), and the type data series (cross section or panel data vs. time series data as the omitted category).

5. Differences in terms of *publication status* are included by means of a dummy variable for unpublished studies.

With respect to the functional form of the meta-regression, we believe that the use of a Box-Cox transformation accounting for non-linearities is not the appropriate solution. The main reason for what looks like a non-linear pattern is the statistical principle that estimates based on fewer observations are less efficient. Consequently, a Box-Cox transformation is likely to provide a good fit, but no substantive explanatory power can be attached to it. It merely replicates a statistical principle, and all estimates, regardless of how precise they are, are given the same weight. The real problem is that meta-regressions are inherently heteroscedastic, because the effect sizes of different primary studies are estimated with differing numbers of observations. We therefore use a linear specification, and correct for heteroscedasticity by using White-adjusted standard errors.⁸

The estimation results for both price and income elasticities, with the variables grouped according to the above categories, are presented in Table 2. Since we do not use a Box-Cox transformation the price elasticities have been defined on the usual interval $[-\infty, 0]$. Table 2 contains the results for the "Full Model" and for a "Restricted Model" in which conditioning variables from categories 2–5 that are not significantly different from zero are excluded using Theil's (1971) backward stepwise elimination strategy.

It is remarkable that elasticities under block rate pricing are not significantly different from those under a flat rate system, except for income elasticities under decreasing block rates in the restricted model. From the other microeconomic variables, it is only the inclusion of the difference variable on price elasticities in the restricted model that is significantly different from zero. Most pronounced, however, is the effect of the two-error model. The effect of long vs. short run values conforms to expectations, although the difference is only significant for price-elasticities. The income elasticity sample does not contain segment elasticities, but for the price elasticity sample, they are signifi-

cantly higher. The effect of GDP per capita across studies is interesting: it is significantly positive for price and income elasticities in the restricted model, indicating that price elasticities are generally smaller in absolute value (i.e., more inelastic) and income elasticities are higher in richer countries.

Table 2 also shows that elasticities tend to be smaller in Europe as compared to the United States, and within the United States, price elasticities are greater in absolute value in the arid West. The latter may be the result of water use for purposes that are more elastic, such as irrigation (Espey, Espey, and Shaw 1997). From the estimation characteristics, the climate-related variables have a systematic influence on the magnitude of the elasticities. Some of the data characteristics are significantly different from zero as well. A final interesting result is that unpublished studies tend to report smaller absolute values of the price elasticity, and greater income elasticity values. The result with respect to price elasticities contradicts the typical feature of publication bias: "exaggerated" effects, in this case high absolute values of the elasticities, have a lower probability of being published (Card and Krueger 1995; Ashenfelter, Harmon, and Oosterbeek 1999).

The Impact of Differing Tariff Systems

We re-estimate the specification developed in the preceding section on a subset of the sample for which information on the tariff structure is available, in order to assess the impact of differing tariff systems more accurately. The results are reported in Table 3. For price elasticities, we again use the backward stepwise elimination strategy. For income elasticities, this is not feasible because of the limited number of observations for which we have conclusive information about the rate structure. With the number of observations be-

⁸ The results of a Box-Cox specification do not alter the main conclusions of our analysis. A comparison of the linear and the Box-Cox results is available from the website mentioned in footnote 2. We present the linear results in this article in order to avoid having to omit negative income elasticities from the meta-sample, and because the interpretation of the coefficients of the linear model is more straightforward.

TABLE 3

ESTIMATION RESULTS FOR PRICE AND INCOME ELASTICITIES BASED ON A LINEAR SPECIFICATION WITH HETEROSCEDASTICITY CORRECTED STANDARD ERRORS FOR A SUBSAMPLE FOR WHICH INFORMATION ON THE TARIFF STRUCTURE IS AVAILABLE

Dependent Variable: Price and Income Elasticity	Price Elasticity		Income Elasticity
	Full	Restricted	Restricted
Constant	2.24*** (2.70)	.40 (1.60)	-.97*** (-2.87)
Increasing block rate	-.16 (-1.60)	-.14* (-1.77)	-.41** (-2.50)
Decreasing block rate	-.13 (-1.11)	-.07 (-.87)	.61* (1.89)
Average price	-.23*** (-3.40)	-.19*** (-3.42)	.48* (1.75)
Shin price	-.11 (-1.28)	-.13 (-1.55)	2.98** (2.33)
Income included	-1.17* (-1.97)	-.03 (-.18)	—
Difference variable included	-.07 (-.61)	-.08 (-1.23)	.93*** (3.22)
Discrete-continuous model	-1.09*** (-4.99)	-1.04*** (-12.39)	.05 (.21)
Long run	-.01 (-.07)	-.10 (-1.30)	-.08 (-.53)
Segment elasticity	-2.60*** (-3.58)	-1.28*** (-3.32)	—
GDP per capita ($\times 1,000$)	-.14*** (-3.13)	-.04*** (-3.82)	.06*** (3.53)
West United States	.75** (2.59)	.24*** (3.77)	—
East United States	.21 (1.34)	—	—
Europe	-.69*** (-2.74)	—	—
Other locations	-.38* (-1.82)	—	—
Midpoint time trend	.05*** (2.76)	.009*** (2.83)	—
Loglinear specification	.08 (1.03)	—	—
Population density included	.43 (1.63)	—	—
Household size included	-.33 (-1.02)	-.19*** (-2.85)	—
Seasonal dummy included	-.50*** (-3.61)	-.29*** (-4.97)	—
Evapotranspiration included	-.18 (-1.43)	—	—
Rainfall included	-.07 (-.42)	—	—
Temperature included	.03 (.40)	—	—
Lagged dependent variable	-.06 (-.34)	—	—
Commercial use	.26 (1.26)	—	—
Other estimation techniques	-.12 (-1.25)	—	—
Daily data	.47	—	—

TABLE 3 (CONTINUED)

Dependent Variable: Price and Income Elasticity	Price Elasticity		Income Elasticity
	Full	Restricted	Restricted
Monthly data	(1.47) -1.27***	- .57***	—
Household level data	(-3.30) -.09	(-4.14)	—
Cross section data	(-.52) -.38***		—
Panel data	(-2.64) 1.15**	.58***	—
Winter data	(2.61) .16	(4.01)	—
Summer data	(1.14) -.42***	-.41***	—
Unpublished studies	(-3.29) -.10 (-.60)	(-6.78)	—
R^2 -adj.	.23	.32	.43
F test	2.10***	4.33***	7.28***
Log Likelihood	-52.10	-54.78	-78.35
Akaike Info. Crt.	1.40	1.18	2.61
LogAmemiya Prob. Crt.	-1.42	-1.65	-.23
N	123	123	67

ing as low as 67, serious multi-collinearity inflates standard error estimates, and we therefore report a “base case” model in which only the microeconomic variables are included.

The results show that the effects of the microeconomic variables are now much more pronounced. Increasing block rate pricing makes the demand for water more elastic, but the income elasticity tends to be lower. Decreasing block rate systems do not have a significant effect on price elasticities, but the income elasticities are significantly higher. The nexus of average and Shin prices increases the absolute value of the elasticities as compared to marginal prices, the latter in particular for income elasticities. Inclusion of a difference variable and the specification of the demand for water as a discrete-continuous choice problem both have an effect, but the former only on income elasticities and the latter on price elasticities. The significant difference between short and long run elasticities disappears, but GDP per capita is now significantly different from zero for both price and income elasticities. Higher income areas tend to have higher price and income elasticities (in absolute terms).

Except for an occasional case, the sign and significance of the control variables is similar to those reported for the full sample. The spatial variables are an exception: the sign for the arid West of the United States is now positive, and the price elasticities for Europe are greater than in the United States.

The Impact of Differing Microeconomic Behavioral Approaches

Some of the microeconomic variables always appear in specific combinations, and can be categorized as different microeconomic behavioral approaches to modeling residential water demand. We distinguish the following approaches.

1. The *naïve approach* uses average or fixed prices, without conditioning on income (except for income elasticities), and models demand as a continuous choice.
2. The *conditional approach* conditions for income differentials, uses either average or fixed prices, or marginal or Shin prices, and models demand as a continuous choice.

TABLE 4

(PARTIAL) ESTIMATION RESULTS FOR PRICE AND INCOME ELASTICITIES BASED ON FOUR DIFFERENT BEHAVIORAL APPROACHES AND A LINEAR SPECIFICATION WITH HETEROSCEDASTICITY CORRECTED STANDARD ERRORS, FOR A SUBSAMPLE FOR WHICH INFORMATION ON THE TARIFF STRUCTURE IS AVAILABLE

Dependent Variable: Price and Income Elasticity	Price Elasticity		Income Elasticity
	Full	Restricted	Restricted
Constant	2.02** (2.42)	.16 (.63)	-.91** (-2.37)
Increasing block rate	-.17* (-1.77)	-.26*** (-3.65)	-.36** (-2.09)
Decreasing block rate	-.15 (-1.31)	-.17** (-2.46)	.57 (1.62)
Conditional income approach with average/fixed price	-1.16* (-1.93)	.06 (.31)	— ^b
Conditional income approach with marginal/Shin price	-.99* (-1.67)	.18 (.98)	.79 (1.20)
Corrected conditional income approach	-.99* (-1.69)	.13 (.64)	.41** (2.41)
Discrete-continuous choice approach	-2.06*** (-3.30)	-.77*** (-3.99)	.39 (1.61)
Long run	-.007 (-.05)	-.08 (-.96)	-.31 (-1.18)
Segment elasticity	-2.57*** (-3.47)	-1.48*** (-3.55)	—
GDP per capita ($\times 1,000$)	-.14*** (-3.15)	-.04*** (-3.26)	.09*** (3.44)
...	—
R^2 -adj.	.24	.31	.18
F test	2.17***	4.08***	3.05***
Log Likelihood	-52.25	-54.61	-91.30
Akaike Info. Crt.	1.39	1.20	2.96
LogAmemiya Prob. Crt.	-1.44	-1.64	.13
N	123	123	67

^a The specifications for price elasticities also contain several control variables. Because the coefficients are virtually identical to those presented in Table 3, they are not reported here.

^b For income elasticities the conditional income approach with average/fixed price is identical to the naïve approach, which is the omitted category.

3. The *sophisticated conditional approach* conditions for income differentials, uses marginal or Shin prices, includes a difference variable, and models demand as a continuous choice.
4. The *discrete-continuous choice approach* conditions for income differentials, uses marginal prices, includes a difference variable, and models demand as a discrete-continuous choice.

For income elasticities, the naïve approach and the conditional income approach

with average or fixed prices coincide, because income elasticities are by definition conditioned on income. As the specification of the above approaches is merely a regrouping of dummy variables used earlier, the estimation results are very similar for all variables except for the behavioral model variables. The results are presented in Table 4.

The results for block rate pricing, GDP per capita, and long vs. short run and segment vs. point elasticities conform to those reported in Table 3, with the results for block

rate pricing being slightly more significant. Table 4 shows that the more sophisticated behavioral approaches, such as the (sophisticated) conditional approaches and the discrete-continuous approach, increase the absolute value of both price and income elasticities. This is not the case for the restricted model referring to price elasticities, and for the conditional income approach with marginal or Shin prices in the case of income elasticities. Subsequent F -tests on the restriction that the estimated coefficients of the different approaches are the same (in the so-called restricted models), is rejected for price elasticities ($F = 6.97$, $p = .00$), but not rejected for income elasticities ($F = .57$, $p = .64$). In the case of price elasticities F -tests on the behavioral approaches having the same effect are accepted for all pairwise comparisons, except for those with the discrete-continuous approach (all p -levels $< .10$). In sum, the discrete-continuous approach constitutes a noticeably different behavioral modeling approach resulting in substantially greater price elasticities, but income elasticities based on this approach cannot be discerned from those based on other modeling approaches.

V. CONCLUSION

In reviewing the literature on water demand modeling, Hewitt and Hanemann (1995) provide a "history" of residential water demand modeling, and they point out that studies differ along many dimensions. The meta-analysis reported in this article gives a systematic statistical account of these differences, in a multivariate framework. The analysis goes beyond the Espey, Espey, and Shaw (1997) analysis, because the current analysis is concerned with a larger sample of studies, includes income elasticities, contains three studies using the discrete-continuous approach, and accounts for differences in income levels across studies through GDP per capita levels.

We have taken special care to assess the impact of differing microeconomic characteristics of the primary studies. In sum, we find that residential water demand is relatively price-elastic, but income elasticities

are relatively inelastic, under increasing block rate pricing. In studies using sophisticated modeling approaches (such as marginal or Shin prices, income differential controls, a difference variable, and a discrete-continuous choice setup), price and income elasticities are relatively high. There is, however an important proviso: the use of the discrete-continuous model does not have a significant impact on income elasticities. Phrased in terms of the four behavioral models distinguished above, the discrete-continuous model is characterized by significantly higher price elasticities of demand, whereas for income elasticities no significant differences between the four approaches can be discerned. Segment price elasticities are substantially greater, and there is some (although not very robust) evidence that long run elasticities are larger in magnitude. Finally, it is crucial to account for income differences among studies. We include GDP per capita as a proxy, and find that the absolute magnitude of price and income elasticities is significantly greater for areas with higher incomes.

Although the attention for water scarcity issues would lead one to expect that elasticities have increased over time, this is not the case: there is no significant time trend in the elasticity values. The geographical dimensions of variation are less clear. In the United States, elasticity values are rather homogeneous, except for the arid West. The elasticities in Europe and in other locations are distinctly different from those in the United States. For both Europe and the West United States, the results are however not robust across different meta-samples. It is therefore still unclear where (absolute) elasticity values are highest.

The qualitative analysis of Hewitt and Hanemann (1995) and the meta-analysis of Espey, Espey, and Shaw (1997) as well as the current meta-analysis show that functional specification, aggregation level, data characteristics, and estimation issues are associated with different elasticity values. The direction and significance of these effects is, however, not yet robust. This clearly shows that additional primary research is needed. Future primary research is also called for to settle the

issue of the appropriateness of the discrete-continuous choice approach to modeling residential water demand.

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