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Water markets and demand in Central American cities

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ABSTRACT. We analyse data from sample surveys of water use and prices for households in 17 cities in Central America and Venezuela. In some of the cities, almost all sampled households have tap water, but in others many rely on nontap ('coping') sources. Coping households use less than one-fifth as much water as metered tap households do, face average water prices ten times as high, are much poorer, and face substantial water hauling costs. Water demand functions are estimated for metered tap households and coping households separately and jointly. Increasing block rates complicate estimation on metered tap households. Using 2SLS, we find price elasticities of water demand, with respect to both average and marginal water price, of about –0.3, with average price giving the greater partial effect. Coping demand has price elasticity closer to –0.1, and is also negatively affected by increased hauling costs. Estimations on the joint data indicate that the water connection itself explains most of the difference between tap and coping consumption and indicate serious problems in such data pooling.

1. Introduction

This paper studies water demand in 17 Central American cities based on household sample surveys. The paper has two main aims. One is to estimate water demand functions for two different household groups in these cities, namely those with tap water and meters, and those without

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tap water access. Such estimates are important for many purposes of policy. Water demand analysis gives crucial information on the relationship between household water consumption and prices and other socio-economic variables. It also tells us how water demand would change when water prices change, when rationing of connected households becomes less severe, and when additional households are provided with tap water connections, and gives a basis for calculating welfare effects of such changes. Information on such welfare effects is in turn crucial for evaluating programs to expand urban water coverage and supply. Our data set, based on surveys from 17 cities, is unusually detailed. It provides exact consumption and prices of water for more than 1,000 households with metered tap connections, and more than 2,600 households without tap access. To our knowledge, this is the first detailed, empirical, and econometric study of developing-country water demand, based on household-level data, covering different types of households, cities, and water service modes.

A second objective is to study various socio-economic aspects of water use for connected and non-connected households. Some of the cities in our sample, we argue, are caught in a 'low-level equilibrium trap' with low levels of water service, low prices and water utility revenue, and little incentive for change.[1] While most households in these cities have tap connections, in some cities many poor households are not connected to the water system and must rely on other water sources. Non-connected households consume on average less than one-fifth of the amount of water consumed by connected households, at water prices that are about ten times as high on average. They also face additional disadvantages such as considerable water hauling, poor water quality, and great difficulties in using water in many 'normal' ways (such as taking showers or using washers). As a consequence, the welfare effect of providing connections to these households is likely to be very large.[2]

In section 2, we present the key features of our data, and in sections 3–5 we estimate water demand functions based on these data. Section 3 considers water demand for metered tap households, using instrumental variables techniques, that serve to reduce or eliminate the biases in water demand estimation that would otherwise arise when water quantities and (marginal and average) prices are simultaneously determined under the city

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[1] For elaborations on this topic see, e.g., the detailed analysis of Walker *et al*. (1999) for Tegucigalpa, and similar analyses by Altaf *et al*. (1993) for Pakistan and Singh *et al*. (1993) for India. Dinar (2000) and Shirley (2002) summarize several studies from different regions of the developing world, pertaining to water pricing and inefficiency in local water systems. See also Strand and Walker (2000), who explore the theoretical possible existence of several different water-market equilibria.

[2] See, in this connection, two other reports based on the same material, namely Walker *et al*. (2000) and Strand and Walker (2003b), where several such issues, in particular income distribution effects of differential water pricing policies, are studied in more depth; see also the discussion in footnote 17 below. We also refer to the related political economy analysis in Walker *et al*. (1999) for Honduras.

block-rate price structures.[3] In section 4, we estimate water demand functions for households that do not have tap water access, and instead rely on other ('coping') sources. In section 5, we present tentative estimations on a merged data sets including both metered tap and coping households. The final section 6 sums up some of the main conclusions, and indicates some implications for policy and future research.

2. The water demand situation in Central American cities

Our data have been collected by the consulting firm ESA Consultores in Tegucigalpa, Honduras, and contain household data on water demand and other socio-economic and background variables for 17 cities (with the years in which the studies were undertaken in parentheses): Tegucigalpa (1995), San Pedro Sula (1995), Santa Rosa de Copán (1995), Choluteca (1995), and Comayagua (1995) – all Honduras; Managua, Nicaragua (1996); Santa Ana (1996), Sonsonate (1996), and San Miguel (1996) – all El Salvador; Barquisimeto (1996) and Merida (1996) – Venezuela; Guatemala City, Villa Nueva, Chinautla, and Mixco (1997) – Guatemala; and Panamá City (1998) and Colón (1998) – Panama. The data were collected in separate personal interview studies (where one household member was questioned), dealing with a range of issues, such as current water service and consumption and willingness to pay for proposed service improvements. The sample sizes in individual surveys range from 750 to 2,400.[4] This aggregate data set is unique in providing comparable and detailed household information on a wide range of issues, for large individual samples from cities in six different countries in Central America. The questions posed in the surveys were in most cases almost identical, making estimations on the entire pooled data or subsets of it possible. This set is probably unique in its detail and the fact that it covers a large number of cities, in several countries.

Overall, about 3,700 household observations are useful for the estimation of water demand functions. They fall into two main categories. First, we have exact (metered) consumption and (average and marginal) water prices for 1,035 households with tap connections and meters, for the last billing month before the survey, as interviewees were asked to show their last monthly water bill.[5] Most of these households are from five cities, namely

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[3] Essentially, the instrumental variable technique implies that the (marginal and/or average) water price variable is replaced by a new constructed variable that is correlated with the water price, but uncorrelated with the error term in the water demand relationship. In practice, the way to do this is to regress the water price on a set of explanatory (background) variables, and use predicted water price values from this relationship instead of the actual water price, in the demand relationship.

[4] Note that the original data are not fully representative of the entire populations in the different cities. The main reason for this is that a good part of the data were collected largely for the reason of gaining information on particular subsets of these populations, in many cases (as in many of the Honduran cities) those segments of the populations without piped water access. This, however, does not seriously affect the quality of the data when it comes to demand estimation, as correction for relevant background variables can easily be done here.

[5] Each survey was done for one particular month of the year in question, and thus generally in different months for different cities. Since there is some seasonality

Table 1. *Average water consumption (m^3 per household during the month surveyed) and average water prices for households with metered tap connections, and unconnected households (excluding bottled water), by city (USD pr. m^3 at PPP rates. Numbers of households in parentheses)*

City	*Tap consumption*	*Tap prices*	*Non-tap consumption*	*Non-tap prices*
Managua	26.7	0.784 (366)		
Santa Ana	30.5	0.263 (153)	8.6	2.08 (141)
Sonsonate	31.1	0.257 (143)	5.1	2.76 (222)
San Miguel	30.1	0.260 (111)	11.4	0.61 (191)
Panama	31.1	0.554 (218)		
Colón	34.8	0.526 (37)		
Tegucigalpa			3.7	8.43 (826)
San Pedro Sula			4.8	1.34 (175)
Choluteca			3.8	2.47 (24)
Guatemala			5.2	5.73 (206)
Villa Nueva			7.1	5.27 (192)
Chinautla			3.1	3.23 (55)
Mixco			8.3	5.68 (121)
Total average	29.3	0.515 (1035)	5.5	5.12 (2217)

Managua (Nicaragua), Santa Ana, Sonsonate, and San Miguel (El Salvador), and Panama City (Panama), with the largest number of observations (366) from Managua. Secondly, almost 2,700 of our sampled households are not connected to any water system, and rely on a variety of water sources, with greatly varying water prices, and water-related costs, such as water hauling times, as documented in more detail in section 4 below. Those interviewed are here asked to state their water consumption and expenses during the last month before the survey, from each of a number of different sources. Tegucigalpa has the most household observations in this category (839), and Guatemala City and Villa Nueva also have relatively many observations. An important subgroup, about 720 households, have part of their consumption of water sold from tank trucks, where the average purchase price of water provides a reasonable proxy for marginal water cost. The rest of our households, almost 8,000 in number, have tap connections but no meters; their consumption levels are not observed and cannot be used for estimation purposes here.[6]

Table 1 describes average water consumption during the last month, and average prices paid for this water, for households with metered tap water,

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in regional water consumption (with somewhat higher consumption in the dry season which runs from late fall until May), the data may contain some slight biases in relative consumption levels across cities.

[6] The data sets are not in all cases fully representative of the underlying populations. In some cities, such as Tegucigalpa, surveys were done only in 'barrios marginales' where water service levels are relatively poor. The data can thus not generally be taken to indicate average levels for the respective cities. Within the groups of metered tap and non-tap households, however, our data are likely to be largely representative.

and for unconnected households. Bottled drinking water is excluded from the analysis. On average, household water consumption is around 29 m^3 per month for metered tap households, and about 5.5 m^3 per month for coping households. The average tap water price, in US dollars (US$) converted to comparable local values using the World Bank's purchasing power parity (PPP) conversion factor for the respective years of each survey, is US$ 0.51.[7] The average marginal tap water price varies little between cities (with 'substantial' numbers of households in the respective categories), from a low of US$ 0.18 in Panama City, to a high of US$0.62 in Managua (this high figure is moreover related to the high PPP conversion factor for Nicaragua). For non-tap water average prices are dramatically higher, more than US$5, or about ten times the prices paid by metered tap consumers.[8] The main reason for this discrepancy in prices is the extremely high expense involved in much non-tap water service (in particular that involving truck delivery), typical also for many developing countries in other parts of the world. As documented more carefully in section 4 below, these prices also show much more variation across cities, for households in a given city, and for different sources for a given household.

Not surprisingly, average incomes are found to be relatively high in the group of metered tap households, and low in the group relying on coping sources.[9] This implies that water service has important distributional implications as the lack of tap water puts additional burdens on many low-income households. There is no strong connection between average household size and type of water service. Note that many households with tap water also experience poor service. Among the approximately 9,000 households with tap connections in our sample, less than half (about 4,200) have continuous service, and about 2,400 are not served every day.

A striking feature of these data is the extreme disparities in prices and consumption between those with and those without access to tap water. While not previously documented on such a large scale for Central American cities, this pattern is well-known also from other developing-country cities with poor tap water coverage and where water vending is the leading alternative for a majority of households; see, for example, Whittington *et al.* (1989, 1990) for similar examples from Africa.

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[7] For connected households, the average water price here includes the cost of a fixed connection charge.

[8] The main reason for this enormous discrepancy of water prices, between tap and non-tap sources, is the great inefficiency in water delivery from non-tap sources, as compared with delivery by tap. In particular, delivery by tank trucks involves great transportation and distribution costs, and only a small share of the tank truck revenue is typically appropriated as net rent for truck operators.

[9] When correcting for city, we find (with metered tap households as reference group) that average monthly incomes are US$190 lower for non-metered tap households, and US$380 lower for non-connected households, both PPP corrected. For comparison, the average monthly household income for the entire set of households is approximately US$800 month, PPP corrected.

3. Estimation of water demand functions for metered tap households

In estimating water demand functions for households with tap water and installed meters, several problems need consideration. First, the block-rate structure of water prices makes (marginal and average) water prices depend on the amount of water consumed by the household, implying that OLS regression is likely to yield biased estimates (often with wrong sign). Several studies, for example Billings and Agthe (1980), Griffin and Williams (1981), Foster and Beattie (1981), Opaluch (1982), Nieswiadomy and Molina (1989), and Bachrach and Vaughan (1994), address this problem using instrumental variable techniques such as two-stage least squares (2SLS) regression, where the water price is explained by instruments uncorrelated with the error term of the water demand equation.[10] Under block rates, when consumers are full optimisers, maximum-likelihood estimation techniques (originally developed for the labor market by Burtless and Hausman (1978); see also Moffitt (1990)) may instead be used. Here one assumes that households adjust their water consumption continuously and rationally to changes in marginal water prices (and where average price changes only have standard income effects), and are fully aware of the point(s) at which the marginal price jumps. This 'combined discrete-continuous approach' has been applied by Hewitt and Hanemann (1995), Hewitt (1998), Corrall *et al.* (1998), Pint (1999), and Cavanagh *et al.* (2002) for the US, and Rietveld *et al.* (1997) for Indonesia. Some studies (Hewitt and Hanemann, 1995; Rietveld *et al.*, 1997) find rather high (absolute valued) long-run elasticities of water demand with respect to marginal price (around –1). Others (Höglund, 1999; Cavanagh *et al.*, 2002) find lower values, Höglund as low as -0.1 to -0.2, for Sweden.

A second and related problem is that water demand instead may be motivated also by average prices, far in excess of standard income effects. This issue was first considered for the electricity market by Taylor (1975) and Nordin (1976), and in later work for the water market by Opaluch (1982, 1984), Shin (1985), Chicoine and Ramamurthy (1986), and Bachrach and Vaughan (1994). More recent applications include Nieswiadomy (1992), Nieswiadomy and Cobb (1993), Nauges and Thomas (2000), Renwick and Archibald (1998), and Renwick and Green (2000). In these studies, the elasticity of water demand with respect to average price is typically far (and significantly) higher in absolute value than the elasticity with respect to marginal price, often twice as high or more.[11] Moreover, average price is often a better predictor than marginal price of household water

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[10] Bachrach and Vaughan (1994) also apply a Heckman sample selection correction procedure to correct for possible selection effects to the different blocks, in addition to using 2SLS, in estimating water demand functions for Argentina. The two approaches are shown to yield similar price demand elasticities.

[11] Note that, with low regular income elasticities (often as here around 0.1) and water budget shares (typically 1–4 %), this implies that the effect of average price changes on water demand, when also marginal price is included in the estimated demand relationship, is about two orders of magnitude greater than that represented by the income effect alone. This strongly indicates that households largely substitute the average for the marginal price in their decision making.

consumption. Recent surveys of water demand estimation, Espey *et al.* (1997), Arbués *et al.* (2003), and Dalhuisen *et al.* (2003), tend to support these results more generally, when reviewing a large number of studies from both developed and developing countries. Overall, the empirical evidence supports the idea that households tend to use rules of thumb in adjusting their demand to price changes, and are often unaware of the particular kinks in the block-rate schedules, or have difficulty taking these optimally into consideration in determining their water demand. We take these results to indicate that it is appropriate to model water demand as depending on both marginal and average price, applying 2SLS estimation.[12] Note finally that more recently other econometric approaches have been utilized, for example Nauges and Blundell (2002) who apply nonparametric methods (developed by Blomquist and Newey, 2002) to the estimation of water demand in Cyprus. They find higher-valued demand elasticities, with respect to marginal price, than those found when using 2SLS on the same data set.

Some further problems make water demand estimation difficult here. First, as already noted, almost 40 per cent of metered tap households do not have continuous water service. This implies that their actual water consumption may be less than their potential (un-rationed) demand, for given water prices. Secondly, household water is a heterogeneous good: its quality varies in several respects, such as its pressure and whether or not it is clean, and we do not have full information on these variables.

Our (linear or log-linear) demand relationships are assumed to take the form

$$W = a + bP + cA + dQ + \varepsilon \tag{1}$$

or

$$\log W = \alpha + \beta \log P + \gamma \log A + \delta \log Q + \mu \tag{2}$$

where W is household water demand, P the marginal water price facing the household, A the average water price, and Q a set of background variables. a, b, c, d, α, β, γ, and δ are coefficients to be estimated, and ε and μ are error terms, assumed independent, and identically and normally distributed, in the respective cases. We concentrate on the linear and log-linear relationships mainly for ease of interpretation. (2) yields demand elasticities (for example β is the price elasticity of demand with respect to marginal price). (1) is a linear specification, where coefficients are interpreted as derivatives and the underlying assumption is that these are constants. The demand elasticities will then generally vary and be greater for low demand levels than for high.

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[12] The recent study closest in spirit to ours is probably Hajispyrou *et al.* (2002), who estimate water demand functions for households from different regions of Cyprus, who also face rising block-rate tariffs, using 2SLS. Other recent related analyses using the same econometric technique, based not on household data but rather on regional (panel-type) data, from respectively California and Spain, are Renwick and Green (2000) and Martinez- Espiñera (2002).

Separate relationships for P and A are estimated using 'instrumental variables', that are constructed to be uncorrelated with the error terms ε or μ, and that are included in the data set. In the linear case, we specify

$$P = a_1 + b_1 V + \eta \tag{3}$$

$$A = a_2 + b_2 Z + \kappa \tag{4}$$

where η and κ are i.i.d. error terms, V and Z are sets of instrumental variables, a_i and b_i determined by the relationships, with equivalent relationships estimated in the log-linear cases. Provided that V and Z are uncorrelated with the respective error terms, (3) and (4) can be used to derive predictions for P and A, which will generally be uncorrelated with the errors ε and μ. These sets of values can then in turn be used as explanatory variables in the original relationships (1) and (2), resulting in asymptotically unbiased estimates of these relationships. Note that in several of the empirical applications mentioned above, one includes a variable $D = W(R - A)$ (called the Taylor–Nordin difference variable – from Taylor (1975) and Nordin (1976) – representing the implicit positive or negative subsidy following from the block-rate schedule). A similar variable, often called the Shin variable, is used in the log-linear case, see Shin (1985) and Nieswiadomi (1992) for applications. Opaluch (1984) and Chicoine and Ramaurthy (1986) used the specification (1) to test for effects of the marginal versus average price on water demand; see also Bachrach and Vaughan (1994). The following hypotheses can be tested:

1. Marginal price model: null hypothesis implies $b < 0$, $c = 0$.
2. Average price model: null hypothesis implies $b = 0$, $c < 0$.

Table 2 sums up our main estimations on this data set. The first three columns of the table include one linear and two log-linear estimations on the pooled set of metered households. All include marginal water price as one explanatory variable. In the first and third, an average price variable is included in addition. In the second estimation, we correct for city by introducing city dummies. We find no strong systematic relative differences between the linear and log-linear relationships in overall fit as measured by adjusted multiple R-squared, and significance of price variables.

Our first regression involves a direct (Taylor–Nordin) linear test of the marginal versus average price model. We find that P and A both have negative effects on water demand, but that only A has significant effect, which is much greater in absolute value than that of P under this specification. We can then reject hypothesis 1, and conclude that average price has an effect on water demand separate from marginal price. However, we do not reject hypothesis 2. These results imply that, at average consumption values (approximately 29 m^3/month), the partial elasticity of water demand with respect to marginal water price is only approximately -0.05, while the partial elasticity with respect to average price is close to -0.14. When marginal and average water prices are both increased by 1 per cent (as when water charges are kept proportional to consumption), demand then falls by about 0.2 per cent under the linear model.

Table 2. *Estimated water demand functions for metered tap households based on 2SLS regressions, where instruments are used both for marginal price and difference variable/average price (t statistics in parentheses)*

Variable	*Linear, including both marg and average price*	*Log-linear, only marg price variable*	*Log-linear, incl. average price and rationing dummies*	*Log-linear, incl. difference variable, Managua*
Marginal water price	−4.3 (−1.10)	−0.172 (−2.22)	−0.085 (−1.56)	−0.268 (−1.45)
Difference variable				0.36 (3.64)
Average water price	−10.42 (−3.55)		− 0.221 (−3.26)	
Household income	0.0016 (3.28)	0.024 (2.94	0.022 (1.57)	
Children	1.48 (4.02)	0.065 (5.09)	0.053 (4.15)	0.053 (1.2)
Adults	1.85 (5.39)	0.088 (7.28)	0.085 (7.13)	0.100 (2.55)
Have telephone	2.94 (2.86)	0.099 (2.98)	0.109 (2.93)	0.069 (0.96)
Value of house	0.000036 (2.67)	1.11e-06 (1.39)	6.93e-07 (1.39)	5.32 e-07 (0.47)
Santa Ana dummy		0.123 (2.00)		
Sonsonate dummy		0.187 (3.19)		
San Miguel dummy		0.164 (2.62)		
Service >16 h/d dummy			0.319 (3.24)	
Service 8–16 h/d dummy			0.307 (3.07)	
Service < 8 h/d dummy			0.345 (3.35)	
Constant	23.7 (13.5)	2.48 (26.4)	2.16 (13.81)	
Adjusted multiple R squared	0.184	0.177	0.162	0.184
Number of cases	1,035	1,035	1,035	1,035

The log-linear specification in column 3 implies a test of the Shin (1985) model. We also here reject hypothesis 1 but not hypothesis 2. Again only A has a partial significant effect, which is greater in absolute value than that of P (−0.22 versus −0.085). The total effect on water demand of a simultaneous increase in average and marginal prices is now about −0.3, somewhat greater in absolute value than the effect from the linear estimation (when calculated near the average for the observations).

When only P is included, in column 2, its elasticity is –0.17, higher than that for P when both P and A are included, but lower than the sum of elasticities for P and A.

We find rather small income effects (elasticities are below 0.1). On average, adding one child to the household adds $1.5\,\mathrm{m}^3$ (5 per cent) to household consumption in the linear (log-linear) case, while adding one adult adds about $2\,\mathrm{m}^3$ (8 per cent) per month.[13] Rationing affects water consumption significantly, but only for households who are not served every day. For those serviced daily, average consumption is about 30–40 per cent higher than for those served less frequently (the reference group). There is no measurable effect on water consumption of average daily service time, given daily service. This may appear surprising, but may be due to the presence of private water tanks that are filled up when water is available for use during the rest of the day. Our results here indicate that attempts to ration household water consumption by making it available only during part of the day have no effect on total water consumption, but rather only imposes costs on households by making them install expensive water tank systems. Note also that the adjusted multiple R-squared values are rather small (the model explains relatively little of the cross-family variation in water demand) but similar to those in other similar studies, such as Bachrach and Vaughan (1994).

Our data set is too small to yield good demand estimates at the city level, except possibly for the case of Managua, which has the largest number of households in this category (366). In the right-hand column of table 2, we include estimation results from one 2SLS regression for Managua, where instruments are used for both the marginal price and the difference variable D. We here find a somewhat larger absolute value of the marginal price elasticity of demand, −0.27 (versus −0.2 in the corresponding case using the whole data set).

4. Estimations for coping-source households

'Coping' households are not connected to any water system, and rely on a variety of water sources, with different water prices and where the value of the water may depend on the source (see Whittington and Swarna (1994) for a detailed discussion). In table 3, total consumption of coping-source

[13] We have also attempted to use more complicated specifications of these effects (such as numbers of adults and children entering with quadratic terms), without this essentially changing our results (such additional terms are all insignificant). We have also calculated elasticities of water demand with respect to family size, not reproduced here: these are in all cases between 0.35 and 0.40, implying that doubling family size increases water demand by a little more than one-third.

Table 3. *Distribution of coping-source water use, as averages for unconnected households in each city.* m^3 *per month, and average water prices, in USD per* m^3 *at PPP rates, by city and types of use*

City	*Bottle*	*Private tap*	*Public tap*	*Truck*	*Private well*	*Other well*	*Lakes, rivers*	*Other*	*Total*	*Number of hhs*
Santa Ana	0.06	0.98	0.34	2.35	0.90	1.60	0	2.34	8.51	143
Sonsonate	0.00	0.78	2.43	0	1.04	0.07	0.13	0.65	5.09	225
San Miguel	0.02	1.00	0.69	0.17	8.08	1.30	0.02	0.10	11.4	195
Panama	0	1.00	0	0	0	0	0.14	0	1.14	19
Colón	0.25	2.21	0.17	0	0	1.04	0	0.21	3.63	10
Tegucigalpa	0.01	0.69	1.26	1.62	0.01	0.07	0.02	0.13	3.67	839
San Pedro Sula	0.04	1.07	1.77	0.34	0.73	0.79	0.02	0.09	4.80	181
Choluteca	0.00	0.78	0	0.83	0.44	1.78	0.01	0	3.84	28
Santa Rosa	0	0.76	0	0	0.94	0.07	0	0.11	1.87	22
Comayagua	0	2.76	0	0	0	0.02	0.05	0	2.83	31
Guatemala City	0.03	0.73	0.64	3.64	0.06	0.10	0.03	0	5.20	233
Villa Nueva	0.03	0.88	1.54	4.47	0.01	0.01	0	0.13	7.05	206
Chinautla	0.01	2.30	0.60	0.13	0	0	0.02	0.04	3.08	68
Mixco	0.02	0.71	0	7.32	0.00	0.24	0	0.03	8.30	130
Average consumption	0.02	0.88	1.12	1.69	0.91	0.35	0.03	0.24	5.48	2,330
Average cost	150.1	6.01	3.18	9.47	0.25	3.20	0.35	1.73	5.12	

Table 4. *Average hauling times for coping households, hours per household per month*

City	*Truck water*	*Water from other coping sources*	*Total coping water use*	*Numbers of households affected*
Santa Ana	0.02	2.93	2.95	143
Sonsonate	0	8.15	8.15	225
San Miguel	0	3.72	3.72	195
Panama	0	7.57	7.57	19
Colon	0	16.58	16.58	10
Tegucigalpa	0.95	7.21	8.16	839
San Pedro Sula	0.04	18.53	18.57	181
Choluteca	0	3.01	3.01	28
Santa Rosa	0	4.71	4.71	22
Comayagua	0	4.31	4.331	31
Guatemala City	10.83	13.39	24.22	233
Villa Nueva	4.96	10.13	15.09	206
Chinautla	0.10	8.39	8.48	68
Mixco	8.03	3.55	11.59	130
Average	2 h 20 min	8 h 16 min	10 h 40 min	2,330
Average hauling time per m^3 consumed	1 h 20 min	2 h 15 min	1 h 55 min	2,330

water is split up into eight different categories: bottled water, private tap water, public tap water, water vended from tank trucks, water from private wells, water from other wells, water hauled from rivers and lakes, and water stemming from other unspecified sources. Among the cities with at least 100 coping households in our sample, average total coping water consumption varies from a low of 3.7 m^3/month in Tegucigalpa, to a high of 11.4 m^3/month in San Miguel, with an average of 5.5 m^3. The types of coping sources used vary widely across cities. Vended truck water is the most important overall single source (and particularly important in Tegucigalpa, Guatemala City, Villa Nueva and Mixco), followed by water from public taps, private wells, and private taps respectively.

The last line of table 3 shows average costs per m^3 of coping water for the different sources. Apart from bottled water, water vended from trucks is generally most expensive (with average price of about US\$9.50/m^3), followed by private tap water, and then by water from public taps and external wells, while water from private wells and hauled from lakes and rivers bear low monetary costs.

Much water from coping sources must be hauled by household members, imposing both time costs and effort costs on households. Table 4 shows average household hauling times during the month for which we have data. We distinguish between time used in hauling water, as delivered by trucks and from other sources separately, in the first two columns of the table. The third column shows total monthly hauling cost per household, on average almost 11 hours. Not surprisingly, water bought from trucks implies comparatively low hauling costs, about 1 hour 20 minutes per m^3 against 2 hours 15 minutes as the average for other water.

Consuming water from non-tap sources implies several disadvantages relative to direct tap consumption. Two of these are higher pecuniary cost and substantial hauling costs for non-tap water. A third disadvantage, not directly measurable from our data, is inconvenience of consuming water which is not delivered by tap. Non-tap water cannot easily be pressurized and is not readily applied, for example for taking showers or for use in washers. A fourth disadvantage is that tap water often is cleaner than non-tap water.

In our empirical analysis we tried out, among others, the following model specifications:

(a) Using only the truck water price, which is then taken to represent the marginal price of water from all sources. This allows for the inclusion of only households with some truck purchased water in the calculations.
(b) Using both the truck vending price as the relevant water price for those with positive truck purchases, and the average coping water price for those without truck purchases, and one common water consumption variable, namely overall coping water use. This permits all households with some purchases of coping water to be included in one estimation, but the included water price will have a different interpretation for those with and without truck purchases.
(c) Using the truck price and the average price of other coping water as two independent explanatory variables, and using one aggregate variable for coping-source water consumption.
(d) Using the truck price and the different prices of coping-source water, by source, as simultaneous independent explanatory variables, for overall coping water consumption.

Only (a) and (b) were found to yield meaningful empirical results and are discussed here. A separate difficulty is how to include the time cost of hauling, as no direct money measure of this cost is available to us. We have chosen to use average hauling time per unit of water consumed, from trucks and other sources separately, as independent explanatory variables.

Problems of simultaneity could arise, for example, if households with high coping-source water consumption systematically pay either higher water prices than others (because they may need to rely on more remote and expensive sources at the margin when demand is high), or lower prices (because high-consumption households have better supplies of such water, for example own wells or get rebates from vendors). We have tested for such simultaneity, and found none. We have also run 2SLS regressions using instruments for the coping water price, but find no major differences from using OLS, so we have stuck with the latter.

Table 5 shows results from one linear and two separate log-linear OLS estimations of total water demand for coping households. We tested several specifications and ended up with a common model with only one water price variable, using two varieties corresponding to alternative (a) and (b) discussed above. The first two columns describe results from calculations where only households who purchase at least some water from tank trucks are included, and where the average tank truck price is included. Here time hauling cost is defined as hauling time per m^3 of water provided for each

Table 5. *Estimated water demand functions for coping households (In linear relationship, effects in m^3/month, prices/incomes in USD at PPP rates. T statistics in parentheses)*

Variable	*Linear, truck price only*	*Log-linear, truck price only*	*Log-linear, all prices*
Water price	−0.11 (−2.76)	−0.12 (−2.40)	−0.10 (−7.17)
Truck water time Hauling cost	−0.19 (−2.13)	−0.22 (−8.52)	−0.097 (−27.9)
Other water time Hauling cost	−0.06 (−1.71)	−0.093 (−2.67)	−0.36 (−3.70)
Household size	0.40 (3.36)	0.056 (5.88)	0.063 (10.1)
Household income	0.0029 (4.81)	0.077 (4.84)	0.041 (3.80)
Tegucigalpa dummy	−3.10 (−4.02)	−0.59 (−8.69)	−0.268 (−7.72)
Guatemala dummy	−2.50 (−2.55)	0.015 (0.18)	0.23 (4.09)
Villa Nueva dummy	−2.03 (−2.01)	−0.021 (−0.26)	0.25 (4.65)
Owner w. title	1.58 (1.86)	0.19 (2.78)	0.12 (3.53)
Owner wo. title	1.81 (1.95)	0.096 (1.29)	0.034 (0.90)
Constant	5.74	1.72	1.55
Adjusted multiple R squared	0.156	0.411	0.371
Number of observations	722	722	2,248

of the water categories (truck water and other water).[14] The estimation in the right-hand column includes also households who purchase no truck water, in which case the average price paid for water from other sources is used as the relevant water price variable. The set of households included is then expanded from 722 to 2,248. Overall, log-linear relationships here give much better general fit than linear, and more significant coefficients, and should thus be emphasized.

The tank truck price has a significant, but relatively small, negative effect on total coping water demand. In the linear relationship, an increase in this price by one (PPP converted) US$ reduces overall coping demand by about 110 liters per month, which corresponds to a price elasticity of about −0.15. In the log-linear relationship the price elasticity is around – 0.10. It is slightly higher in absolute value when only the truck price is included, than when other coping water prices are also included. This appears reasonable in particular as water supply from tank trucks is likely to be rationed less than water from other sources.

In all estimations, hauling costs are shown to have substantial impacts on coping water demand. A 1 per cent increase in (truck or other) hauling costs reduces overall coping water demand by 0.1–0.35 per cent. All effects are significant, and the truck water hauling cost variable highly so. Among

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[14] An obvious alternative would be to include a monetized hauling cost, for example as a fraction of wage costs for the respective households. We have tested out such specifications, without much success. A problem with this is that much hauling is done by women and children in their otherwise spare time, and links to (male) wages are not relevant in this context.

Table 6. *Estimated water demand functions for coping households, Tegucigalpa. m^3 per month in linear relationships, USD at PPP rates (T statistics in parentheses)*

Variable	*Linear, truck price only*	*Log-linear, truck price only*	*Log-linear, all prices*
Truck water price	−0.129 (−3.33)	−0.475 (−5.61)	−0.353 (−5.20)
Other water prices			−0.033 (−1.97)
Truck hauling time cost	−0.062 (−1.80)	−0.254 (−7.58)	−0.248 (−7.45)
Other hauling time cost	−0.059 (−3.54)	−0.018 (−0.39)	−0.217 (−11.96)
Household size	0.344 (3.77)	0.058 (4.52)	0.068 (7.93)
Household income	0.0018 (3.56)	0.125 (4.27)	0.075 (4.33)
Constant	3.04	1.77	1.70
Adjusted multiple R squared	0.075	0.341	0.313
Number of observations	839	375	836

the cities, we find that Tegucigalpa has significantly lower water demand than the others (with a dummy of – exp(0.55) corresponding to about 60 per cent of the average for the reference cities). Adding one household member increases demand by 400 liters per month from the linear relationship, and about 6 per cent (or about 330 liters for an average household) from the log-linear ones. Adding US$100 (PPP adjusted) to monthly household income increases water consumption by 290 liters per month in the linear relationship. The corresponding income elasticity is about 0.08, or 140 liters of increased water consumption per US$100 of additional income, at average PPP-corrected household income of US$515.

Tegucigalpa has almost half of all our observations of water demand from tank trucks. Table 6 shows results from separate linear and log-linear regressions for Tegucigalpa, similar to those in table 5. The fit of log-linear relationships, relative to the linear one, is here even better (with r-squared of more than 0.3 in the former cases and only 0.075 in the latter). In the first log-linear relationship (where only the truck price is considered), the price elasticity of demand is now −0.47, that is considerably higher in absolute value than for the pooled sample. In the second log-linear case (where both price variables are included) this elasticity is smaller but still quite high (−0.35, and almost −0.4 when considering simultaneous increases in all water prices). Estimated hauling time elasticities are now particularly high for the truck water (−0.25 and highly significant). The elasticity with respect to other water prices is low and insignificant. Household size has similar effects for Tegucigalpa as in the pooled data set, while household income effects in the log-linear relationships are somewhat greater for Tegucigalpa.

The price elasticity of demand for the pooled sample of coping households is around –0.1, smaller in absolute value than for metered tap households, which is not surprising. Most coping households' water consumption is initially very low, and increasing the water price may not reduce consumption much further. Nor would a reduction in the coping water price necessarily increase consumption by much unless the household gets a tap connection, since few extra uses become worthwhile in the absence of tap water access.

Table 7. *Estimated, linear and log-linear, water demand relationships on pooled data for metered tap and coping households (t statistics in parentheses)*

Variable	*Linear, all obs.*	*Log-linear, all obs.*	*Log-linear, El Salvador cities only*
Water price	−0.036 (−2.42)	−0.040 (−2.64)	−0.198 (−5.84)
Household size	0.739 (8.95)	0.069 (13.42)	0.060 (3.70)
Household income	0.0022 (8.51)	0.061 (6.83)	0.055 (3.15)
Have water connection	20.38 (19.4)	1.27 (19.5)	0.857 (2.67)
Owner with title	0.59 (1.23)	0.042 (1.42)	0.122 (2.44)
Owner without title	−0.079 (−0.14)	−0.0083 (−0.24)	−0.009 (−0.16)
Service daily >16 h	1.99 (1.90)	0.284 (4.35)	0.605 (2.67)
Service daily 8–16 h	0.83 (0.82)	0.173 (2.73)	0.444 (1.87)
Service daily <8 h	1.90 (1.91)	0.188 (3.00)	0.475 (1.45)
Constant	3.48	1.48	1.42
Multiple r-squared	0.581	0.667	0.592
Number of observations	3,282	3,282	963

5. Estimations on combined data for metered tap and coping consumers

This section presents some tentative results based on merged data for metered tap and coping-source consumers, using a common water price variable. For metered households, this is the marginal water price (replaced by imputed values due to the simultaneity problem discussed above). For coping households, we use the truck price whenever observed, and the average coping price otherwise. The overall data set is, therefore, somewhat of a hybrid, perhaps making such an analysis questionable (and the data in addition fail in simple poolability tests). Such calculations may still be of interest for at least three reasons. First, many researchers in the area (such as Whittington and Swarna, 1994) presume that a common demand function holds for both groups, an issue we can investigate here. Secondly, whenever such data pooling is meaningful (as when the common demand function hypothesis holds) the set of observations is increased. Thirdly, the range for observed water prices and demand is expanded substantially, which would permit more precise estimation of demand response when water prices change.

The two first columns in table 7 show one linear and one log-linear OLS regression on this data set. We include dummies for all cities, two categories of house ownership (owner with title, and owner without title,[15] with non-owners as reference group), and four rationing categories (service more than 16 h/day, service 8–16 h/day, service less than 8 h/day, and service 15–29 days/month, where those served less than 15 days/month are reference group). The log-linear relationship is found to give a particularly good fit to these data (r squared is almost 0.67). The fit is somewhat inferior (with r

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[15] 'Ownership without title' implies that the resident in the interview states that he or she perceives of the property as being owned, but with no formal document to prove this.

squared of 0.58) for the linear relationship. This seemingly extraordinary fit to individual data is strongly related to the high explanatory power of the binary variable representing the metered tap versus coping category (in the table, the variable 'have a connection'). In the linear relationship, the water connection itself 'explains' more than 20 m^3 of water consumption, that is more than two-thirds of average total water consumption for connected households. Thus, providing water access to a household raises its water consumption tremendously, regardless of prices charged for water before or after the access change. From the log-linear relationship, connecting a household to the water system raises its water consumption by a factor of more than 3, at given prices. The estimated price elasticity on the merged data is only around −0.04 (but significant), smaller in absolute value than estimated elasticities for the two separate (now merged) data sets. Income and family size elasticities are all in the range 0.06–0.07, that is similar to those for the two separate relationships.

We also now find strong effects of rationing on overall water demand among metered tap households. Using households with water tap service fewer than 15 days a month as reference group, non-rationed households' water consumption is 28 per cent higher on average. This difference is highly significant but smaller than for metered households alone. The estimations include estimated dummy variables for all cities, not reproduced in the table. Many of these are large and highly significant and in line with city dummies estimated for each of the two separate data sets in previous sections.

Our results here indicate that there are serious problems with estimating a common water demand function based on these two types of water demand data sets. First, most of the difference in water consumption between the two groups is explained by a dummy variable for the connection, a highly unsatisfactory result. This, and the property that demand function coefficients are different in the pooled as compared to the separate data, and the problems of defining a common water price variable, make it highly likely that this model is misspecified. In fact we have conducted a simple poolability test where the null hypothesis is a common water demand coefficient with respect to price for the two data sets. This test fails badly; in the log-linear relationship the partial elasticity with respect to price becomes significantly positive for the metered tap, and significantly negative (and greater than one in absolute value) for the coping data. While further investigation into this issue is clearly warranted, our analysis here gives a strong message that merging two such diverse data sets in a common analysis is difficult, or even perhaps hopeless.

The right-hand column of table 7 gives separate results for the three cities in El Salvador, Santa Ana, Sonsonate, and San Miguel, the only cities in our sample with substantial numbers of both metered tap and coping households. This (together with the fact that they are in the same country) may tend to make this group relatively more homogeneous than the overall set of cities. Here, the overall price demand elasticity is higher in absolute value, about –0.2 (and highly significant) and thus more in line with estimated elasticities for the two data sets separately, for the entire data set. The effect of a water connection is lower and barely significant, but still high (about 0.85). This coefficient implies that having tap water access increases water consumption by a factor of almost 2.5 in these three cities. The effect on water consumption of rationing is now greater than for the entire pooled sample, with a coefficient of 0.6 on nonrationing (where reference group as before is households without daily access), but again little difference between nonrationed households and others with daily water access. Otherwise results are similar to those for the entire data set. We also note that, also in this case, a simple poolability test fails badly (although somewhat less badly than for the common data for all cities).

To our knowledge, this is the first analysis in the literature using two such merged data sets. The most important new result from this analysis is probably our documentation of the enormous effect on water consumption of the connection itself, apart from other observable variables such as water prices and income. It renders highly questionable the procedure of estimating social benefits from increased water access, based on a commonly estimated water demand function, based on average observed water consumption and prices for both the metered and coping households, as proposed by e.g. Whittington and Swarna (1994). Our results indicate that this may lead to serious misspecification, since tap and nontap water demand functions turn out to be radically different.[16]

We also need to point out other problems with merging the data in the way done here. First, water consumed in the household is likely to be a quite different commodity for connected as opposed to unconnected households. Secondly, there are technical problems with merging the two data sets. The metered data embed problems of consistency of estimates, while the coping data set can be used directly but is much more diverse in terms of water sources, prices, availability, and possible rationing. Finally, we may have sample selection problems, whereby households relying on coping sources are a self-selected group with a different water demand structure. The estimates presented here should thus be considered as quite tentative.

6. Conclusions and final comments

From the results presented above, we emphasize the following 9 points.

1. The 'most reasonable' estimate on the price elasticity of water demand for metered tap households is only between –0.1 and –0.2 for marginal price alone, but higher (around –0.3) for a simultaneous change in marginal and average water prices. These are similar to results found from other studies on Latin American data, such as Gomez (1987) and Bachrach and Vaughan (1994), who typically find marginal price elasticities of demand in the range −0.1 to −0.5, but in most cases

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[16] We have also fitted water demand function on the entire pooled data using a 'stripped-down' model where only one water price variable, household income and household size are used as explanatory variables. While not presented here, the estimated elasticity of water demand is now much higher in absolute value, namely about −0.4 for the entire data set, and about −0.5 for in El Salvador. This indicates that demand elasticities estimated on such pooled data without making the proper corrections may be too high in absolute value.

average water price is not found to yield significant individual effects.[17] Here, in contrast, average price explains water demand in a stronger and more significant way than marginal price, corresponding to results from several other recent studies, most from developed countries, by Nieswiadomy (1992), Nieswiadomy and Cobb (1993), Nauges and Thomas (2000), Renwick and Archibald (1998), and Renwick and Green (2000). This seems to be the first documentation of such effects for developing countries.

2. The price elasticity estimated on the common data for all 'coping' households is close to −0.1, that is lower in absolute value than for metered tap consumers. This is a new result as no similar demand elasticity estimates seem to exist in the literature. It is not surprising in view of the marginalized water consumption of coping households.
3. We have estimated price elasticities for individual cities, Managua for metered tap households, and Tegucigalpa for coping households. For Managua, we find a price elasticity of about −0.25 for marginal price alone, and close to –0.6 when considering both marginal and average price. For Tegucigalpa, the price elasticity is close to −0.4. In both cases, individual city elasticities are greater in absolute value than common elasticities. It must be underlined that these results are far more uncertain than those obtained from the pooled data, as the data sets are far smaller', the Managua results are derived from just one block-rate schedule, and the Tegucigapla results imply far less variation in water sources and prices than the entire data set for coping households.
4. Among 'coping' consumers, demand elasticities with respect to all relevant hauling cost variables are found to be rather substantial, around −0.3 to −0.4. This also appears to be a novel result in the literature.
5. Average water consumption is more than five times as high for connected and metered households as for unconnected ones. Still, unconnected households have greater overall water costs, since the prices they pay for water is on average about ten times as high. Both consumption and prices vary more for non-tap households than for those with tap. Non-tap households also spend an average of 11 hours per month in hauling water to their homes, and are substantially (about 25 per cent) poorer than tap households. The households that rely on 'coping' sources are largely concentrated to Honduras, Guatemala, and El Salvador.
6. Income elasticities of water demand are small, mostly below 0.1, which is a standard result also from developed countries. One additional household member typically increases water demand by 5–10 per cent, somewhat more for adults than for children. This elasticity effect is similar for metered tap and for coping households.
7. Rationing has notable effects on water consumption, but only for households without daily water access (which lowers average water

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[17] See also the meta analysis by Espey *et al.* (1997) which shows that most available price elasticity estimates are in the range −0.1 to −0.6, with no significant difference between developed and developing countries.

consumption by about 40 per cent). Households that are rationed only within a given day seem not to be affected by rationing, perhaps due to sufficient water storage facilities. As a consequence, within-day rationing is likely to have little impact on overall water consumption; it only imposes hardships on households by forcing them to install storage tanks or to consume water at inconvenient times.

8. Our calculations confirm that sensible estimation on metered data under block-rate pricing schedules requires corrections for simultaneity of water consumption and price. Tentative OLS estimations on our data for metered tap households give in all cases wrong (positive) signs for the estimated price elasticity of demand. In our case, this problem is dealt with by using 2SLS instrumented for both the marginal and average price. In future work, other methods (such as maximum likelihood and nonparametric methods) should be applied. For coping-source data, OLS appears to give consistent estimates.
9. When estimating water demand functions on a merged data set consisting of both metered tap and coping demand, the connection itself explains a large fraction (about two-thirds) of the overall consumption of connected households. A simple test of poolability of the two data sets also fails. This indicates a lack of common structure in the water demand functions for these two groups, something that has not been properly recognized in the literature.

We draw two main overall conclusions from our study. First, household water demand in Central American cities is rather inelastic to price changes, and particularly so for non-tap households. Secondly, water prices are at least one order of magnitude higher for non-tap households, and consumption less than one-fifth, when compared with tap households. One implication of these conclusions is that extending connections to unconnected households may lead to enormous welfare gains.[18] It is not the purpose of this paper to elaborate on how such gains can be realized. One obvious approach may, however, be mentioned, namely to charge somewhat higher water prices to connected households (who today largely pay only one-third of the long-run marginal cost of water provision), and use the revenues to subsidize the construction of new connections.[19]

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[18] In a separate paper based on the same data source, Strand and Walker (2003b), we estimate the value of adding a water connection to an non-connected household, at the terms currently enjoyed by connected households. We find that adding a water connection eliminates about 12 percentage points of the (38 per cent) average real income difference between connected and non-connected households. The positive welfare effects of more equitable distribution of water resources in Central America are thus likely to be very significant.

[19] One may here of course fear that connected households who today pay very low water prices, will strongly oppose such price increases something that may make them politically infeasible. Note, however, that many of the surveys included here asked respondents about their attitudes toward such changes. A clear majority of respondents stated that payments for water should be determined according to actual water consumption and cost of provision and not other criteria (such as income or custom). See Walker *et al.* (2000) for elaboration of these points.

We also find that within-day water rationing is rather ineffective in reducing overall water consumption. Households apparently fill up their water tanks during hours with tap water, and use stored water during the rest of the day, thus leaving overall consumption unaffected. Denying some households daily access has larger effects on consumption, but this is hardly advisable policy. A much better alternative seems to be to raise (marginal, and to some degree average) water prices, and instead limit rationing.

Our study provides tentative answers to several interesting economic and political questions regarding the water sector in Central American cities. Still many questions are left unanswered. First, our study cannot be said to go very far methodologically; alternative models could be applied to these, or similar data. Secondly, we do not directly address the distribution issues implied by the severe inequity in water service provision in this and many other regions; see, however, Strand and Walker (2003b) for an analysis of such issues on the present data set. Finally, costs and benefits of system expansion (in terms of adding connections and supply capacity) are not studied, and neither are the political constraints placed on possible policy changes. Our intention is to address such issues in later related work.

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