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Modelling residential water demand with fixed volumetric charging in a large urban municipality: The case of Brisbane, Australia

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Abstract

This paper uses household level data to model residential water demand in Brisbane, Australia from 1998 to 2004. In this system, residential consumption is charged using a fixed annual service fee with no free entitlement and a fixed volumetric charge per kilolitre. Water demand is specified as quarterly household water consumption and demand characteristics include the marginal price of water, household income and size, and the number of rainy (with at least some precipitation) and warm (greater than 19.5°C) days. The findings not only confirm residential water as price and income inelastic, but also that the price and income elasticity of demand in owner-occupied households is higher than in renter households. However, the results also show that weather, especially the number of warm days, is likely to exert a much greater influence on residential water consumption than any factors subject to the usual demand management strategies.

JEL classification: C23, D12, Q25

Keywords: Residential water demand, two-part tariffs, fixed volumetric charge, demand management strategies

1. Introduction

Water supply efficiency and demand management are increasingly important issues for residential water supply authorities throughout the world. Population growth, coupled with the reduction in available fresh water supplies, has prompted suppliers to place renewed emphasis on demand management through pricing structures and other strategies. In the United States, for example, Ipe and Bhagwat (2002) found that water sources in Chicago are reaching exhaustion while population and per-capita water use is increasing. On this basis, Ipe and Bhagwat (2002) recommended that scarcity rents be incorporated into water prices to help promote the more sustainable use of available water.

Similarly in Israel, Klawitter (2000) concluded that the Tel Aviv water utility is economically unsustainable because water is over-consumed as the price does not send appropriate welfare signals to users. Klawitter (2000) proposes that sustainable water pricing must then be designed to meet the needs of current and future generations, resource use efficiency, full cost

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recovery, the economic viability of the water utility, and equity and fairness for different users. Dalhuisen, de Groot and Nijkamp (2001) agree that the pricing structure should cover costs, be fair, induce economically efficient usage, and be administratively feasible. They observe that the trend for most OECD economies is for increased metering, increasing block prices and reduced subsidies. These trends in residential water demand management have been reflected elsewhere in the world, particularly in a number of World Bank reports. Yepes and Dianderas (1996) conclude that per capita consumption falls as metering penetration increases and that residential customer account for the vast majority of connections and consumption in both developed and developing economies.

In Australia too, there have been longstanding efforts to improve residential water demand management, notwithstanding broader concerns about agricultural and industrial usage and pricing, and the sustainability of water supplies more generally. These have received renewed emphasis with the sustained drought in the eastern states (especially New South Wales) and the critical level of water reservoirs supplying large urban centres. As far back as 1994, The Strategic Framework for the Efficient and Sustainable Reform of the Australian Water Industry was endorsed at the meeting of the Council of Australian Governments (COAG). This framework required councils to: (i) introduce two-part tariffs for water pricing where it is cost-effective to do so, with fully transparent community subsidy schemes (if any) and the minimal free allocation of water; and (ii) ensure that the pricing regime achieves full cost recovery, including the long-term cost of asset maintenance and resource replenishment.

Clearly, the introduction of two-part tariffs throughout Australia has affected residential water consumption. In Tasmania, the Government Prices Oversight Commission (2003a) suggested that a fifteen percent fall in consumption could be anticipated following the introduction of two-part tariffs; but that this would be smaller if the volumetric component was set at a low level, or a free allowance was provided, or if an abnormally hot and dry summer occurred following the rate structure change. And in Queensland, Marsden Jacob Associates (1997) found anecdotal evidence of a twenty percent reduction in per capita consumption in the first year of implementing two-part tariffs. Work of a similar nature in other states includes IPART (2003), Essential Services Commission of Victoria (2004) and Government Prices Oversight Commission Tasmania (2003a; 2003b). But apart from these, remarkably little empirical effort has been directed at the explicit modelling of residential water demand in Australia [for exceptions, see Barkatullah (1996), Creedy (1998) and Higgs and Worthington (2001)].

This is important, because not only does such work throw light on the price and income elasticities of water demand, but also on the many other factors posited to affect water consumption, thereby allowing the construction of more effective demand management policies. The purpose of this paper, part of a wider joint project conducted by the Queensland Department of Natural Resources & Mines and the Queensland University of Technology, is to address this imbalance. The paper itself is organised as follows. The second section discusses the environmental and institutional context of the empirical analysis. The third section presents the model for estimation of the water demand and the set of independent variables to be included. A descriptive analysis is provided in the fourth section. The fifth section presents the results of the estimation. The paper ends with brief concluding remarks

2. Data context

The information for the demand estimation is obtained from the Brisbane City Council, Australia's largest local government. Brisbane, the capital city of the state of Queensland, is a moderately-sized city covering an area of 1,367 square kilometres with approximately 950,000 residents. The city has a subtropical climate, lying as it does 27.5° south of the equator. Centred on the Brisbane River, fifteen kilometres inland from the Pacific Ocean, Brisbane has mild dry winters and hot wet summers: the average daily maximum temperature is 26.3°C, the average daily minimum temperature is 15.3°C and average daily rainfall is 2.69 mm. In line with high population growth in the rest of south-eastern Queensland, the city has grown steadily since the mid-1990s, with population increasing by 9.4 percent and residential dwellings by 12.3 percent. As a result, the average household size, currently 2.57 persons, has fallen by 2.6 percent.

Brisbane's water has historically been supplied under a fixed access charge until 1993, when water meters and optional volumetric pricing were introduced in 1995/96 [see Higgs and Worthington (2001) for an analysis of this policy change]. Compulsory two-part tariffs were introduced in July 1997. Since then, all residential consumption has been charged using a fixed annual service fee with no free entitlement and a fixed volumetric charge per kilolitre. Over the period 1997/98 to 2003/04 residential water has been billed quarterly with an annual access charge of $100 and a volumetric rate rising from $0.60 per kilolitre in 1997/98, $0.70 from 1998/99 to 1999/00, $0.80 from 2000/01 to 2001/02, and $0.82 in 2002/03 and $0.84 in 2003/04. In addition, the council has imposed outdoor water use restrictions in the form of alternate fixed sprinkling days for more than twenty years, as well as a high publicity 'Water Wise' education campaign. Brisbane, however, has generally less severe water restrictions than most other Australian state capitals. For example, Sydney Water (responsible for the greater Sydney metropolitan, suburban and satellite area) has standing prohibitions on fixed garden irrigation systems and hosing of 'hard surfaces' (including cars, footpaths, paving and buildings).

3. Demand estimation

The increased reliance on demand side management policies as an urban water consumption management tool has stimulated considerable debate among economists, water utility managers and policymakers. While it is generally agreed that urban water prices should reflect marginal costs is a means of reducing demand during periods of limited water supply availability, it is also argued that urban water demand is relatively price inelastic, and therefore price is an ineffective tool for regulating demand and consumption. Supporters of this viewpoint then suggest that more appropriate mechanisms for regulating water consumption are non-price strategies, encompassing public education campaigns, rationing, water use restrictions and subsidisation of programs aimed at adopting more water efficient technologies. Within this, water demand equations generally take a form where the quantity of water demanded or consumed is expressed as a function of the price of water, income and other independent variables posited to influence demand other than price and income.

The specification actually employed depends heavily on the data available and whether this is available at the household level or higher. Unfortunately, and in common with most previous studies of water demand, there is limited data available at the micro level [see Arbués et al (2003) for a useful survey of water demand estimation]. Accordingly, in this study a suburb-level model is specified where the quantity of water consumed per quarter is specified as the dependent variable in a regression (expected sign of the estimated coefficient in brackets) against the marginal price of water per kilolitre (-), household income in dollars (+), the size of the household (+), the number of rainy (-) and warm (+) days per quarter and whether the quarter is in summer (+) or otherwise.

To start with, the dependent variable, water demand, can be measured either at the household level via user metering, or at the main line meter at the water substation. If measurement is at the bulk meter, system losses and other consumption such as industrial, commercial, community and rural use must be accounted for prior to estimation. The Queensland Department of Natural Resources and Mines provided quarterly residential water consumption data by postcode area. The data comprises two separate records: 'Tariff 02' records which pertain to water supplied to all residential premises rated as owner occupied, and 'Tariff 70' records which relate to water supplied to all residential premises rated as non-owner occupied (tenanted or rented). Under the Queensland *Residential Tenancies Act 1994*, tenants are entitled to a free allocation of a 'reasonable' amount of water by their landlords so it can be expected that renting household may be less price-sensitive than owner-occupier households. Data for both renting and owner-occupied households is collected quarterly from September quarter 1998 to June quarter 2003 and includes the total number of bills and total billed water consumption for Brisbane suburbs by postcode. With this information in hand, average household water consumption for owner-occupied and rental housing in fifty-three postcode areas is calculated for the sample period of twenty quarters.

The first independent variable specified is the marginal price of water in Brisbane. A key feature of demand side management policies is clearly the pricing structure and a variety of alternative forms have been employed in Australia and elsewhere (Dinar and Subramanian, 1998; Bartoszczuk and Nakamori, 2004). These include: a fixed charge invariant to the level of consumption; a fixed charge with a free allowance followed by some excess charge for consumption over a particular level; a two-part tariff consisting of a fixed access charge and a cost per unit based on the volume of water consumed (as in Brisbane) or cost per unit that varies when consumption reaches certain thresholds, in such a way that the tariff consists of sequence of marginal prices for different consumption blocks. These block prices could be increasing with each successive block of water use (increasing block), or decreasing with each successive block of water use (decreasing block).

While these different structures can complicate the calculation of a marginal price [see Nieswiadomy (1992) and Garcia and Reynaud (2003) for approaches using marginal prices, Barkatullah (1996) and Renwick et al. (1998) for the marginal price less Nordin's difference, Gaudin et al. (2001) for the average price, Pashardes and Hajispyrou (2002) for the marginal price in the highest tariff block and Martínez-Espiñeira (2003) for the average marginal price], in Brisbane the single block volumetric pricing means that the average price is equal to marginal price (ignoring the zero allowance access charge) at all levels of consumption. Water pricing information is provided directly by the Brisbane City Council.

It is evident that some external influences are present yet unobservable, namely increasing community awareness of water pricing and possible adoption of water saving technologies. An alternative to expressly including these unmeasurable elements is to include an appropriate lagged term into the equation. In the case of water consumption, it is feasible to assume that a household's current period water use will be similar, or related to, their previous period's use. Therefore, the inclusion of the previous quarter's consumption should capture unobservable determinants. By including the lagged term for consumption, the model is effectively estimating the long-run price elasticity (Dandy et al, 1997).

The third independent variable is household income. The first consideration is that water consumption, as a normal good, should be positively related to income. This is especially the case since income is also positively related to many other water-using goods, including swimming pools, in-ground irrigation systems and dishwashing machines. A second consideration, however, is that income through its positive relationship with education may be reflective of water conservation measures taken by the household through the purchase of water-conserving appliances and planting of drought-tolerant garden vegetation. Regardless, most studies have found that income elasticity of demand is positive (Agthe and Billings, 1987; Thomas and Syme 1988; Renwick and Archibald, 1998; Rietveld et al 2000). The data on household income in this study is sourced from the Australian Taxation Office, which provides mean and total individual incomes by postcode area for Australia. Of course, there is inevitably some bias with this information - individuals without group certificates are not obliged to lodge returns, taxable income is less than total incomes because of tax deductions – but is nonetheless generally acceptable.

The fourth independent variable is the size of the household. The basic argument is water consumption is positively related to the number of household members. But Arbués et al. (2001), for example, found that water use is less than proportional to the increase in household size or population because of economies of scale in discretionary and nondiscretionary water usage, including cooking, cleaning, car washing and gardening. The average size of households is taken from the Australian Bureau of Statistics (ABS) 2001 Census. This information is grouped by Statistical Local Area (SLA), which roughly corresponds to suburbs with some minor variation.

The next three independent variables concern weather and temperature-related effects. These have been shown to influence residential water use in a number of ways. The amount of rainfall, for example, has an influence on garden watering, and also on other activities such as washing cars, laundry and topping up swimming pools. Temperature has also been shown to influence water consumption, with hotter days inferring higher consumption through increased garden watering and topping up of swimming pools. Daily weather information is sourced from the Australian Bureau of Meteorology. To include weather and temperature factors, dummy variables are specified for the number of rainy days (where rainfall exceeds zero millimetres) and the number of warm days (where temperature exceeds 19.5°C). The final variable specified is also a dummy variable which takes a value of one for summer months; otherwise zero.

4. Descriptive statistics

Table 1 presents a summary of descriptive statistics across the fifty-three Brisbane post code areas from the September quarter 1998 to June quarter 2003. Sample means, maximums, minimums, standard deviations, skewness, kurtosis and Jacque-Bera statistics and *p*-values are reported. Also included are decompositions of these variables into their mean, seasonal and time series components. As shown, household quarterly water consumption averaged 73.11 kilolitres with owner-occupied households averaging 75.36 kilolitres and renter households averaging 65.45 kilolitres. There is clearly a strong seasonal component with household water consumption being 17.91 kilolitres higher in the December quarter and 4.49 kilolitres lower in the June quarter. Consumption has also trended upwards over the period by 0.58 kilolitres across all households: 0.35 kilolitres in renter households and 0.67 kilolitres in owner-occupied households. Across all postcode areas and quarter, the marginal water price averages 76 cents per kilolitre, the average household income if $12,495 and the average number of rainy and warm days are 34 and 89 per quarter respectively.

<TABLE 1 HERE>

By and large, the distributional properties of all seven variables appear non-normal. Given that the sampling distribution of skewness is normal with mean 0 and standard deviation of $\sqrt{6/T}$ where T is the sample size, all of the series, are significantly skewed. Water consumption per household for both renters and owner-occupied households are positively skewed signifying the greater likelihood of observations lying above the mean than below. The kurtosis, or degree of excess, across all variables is also large, indicating leptokurtic distributions with many extreme observations. Given the sampling distribution of kurtosis is normal with mean 0 and standard deviation of $\sqrt{24/T}$ where T is the sample size, then all estimates are once again statistically significant at any conventional level. None of these variables are then well approximated by the normal distribution.

5. Empirical results

Table 2 provides the estimated coefficients, standard errors and p-values and the elasticities (at the means) of the parameters detailed. The results of six separate regressions are presented.

The upper panel includes the estimated results of a linear form and the lower panel are a non-linear form with log-log transformation. The three sets of estimated results for the linear and non-linear forms are for all households, owner-occupied household and rental households, respectively. The standard errors and *p*-values all employ White's corrections for heteroskedasticity of an unknown form.

Also included in Table 2 are statistics for R^2 and adjusted R^2 and F-statistics and p-values for the joint hypothesis test that all slope coefficients are zero. Panel data estimation is used specifying common effects: a reasonable *a priori* assumption given that all cross-sections are drawn from a small geographic region with many interrelated economic and social commonalities. To test for multicollinearity, variance inflation factors (VIF) are calculated. As a rule of thumb, a VIF greater than ten indicates the presence of harmful collinearity. Amongst the independent variables the highest VIFs are for household size (1.173), water price (2.623), and warm days (8.738). This suggests that multicollinearity, while present, is not too much of a problem. Somewhat typically for pooled time-series, cross-sectional data, the R^2 of all six regressions are fairly large, ranging from 0.598 to 0.768 for the linear models and 0.704 and 0.781 for the non-linear models.

<TABLE 2 HERE>

The models first discussed are those employing a linear specification. For all households, the estimated coefficients for all parameters are significant at the 1 percent level of significance or lower and conform to *a priori* expectations. Using the F-statistic the null hypothesis that all slope coefficients are jointly zero is also rejected at the 1 percent level. The largest effects on water consumption are clearly the number of warm days and the water price. The price elasticity of demand is -0.667 (inelastic) indicating that a ten percent increase in the price of water is associated with a 6.67 percent decrease in the quantity demanded. The income elasticity of 0.269 (inelastic) suggests that a ten percent increase in income is associated with a 2.69 percent increase in the quantity of water demanded.

By way of comparison, Agthe and Billings (1987) calculated a price elasticity of -0.56 and an income elasticity of 0.46, Barkatullah (1996) -0.21 and 0.07, Dandy (1997) -0.78 and 0.38, Garcia and Renaud (2003) -0.25 and 0.00 and Gaudin et al. (2001) -0.47 and 0.19. A one day change in the number of rainy and warm days is equal to approximately 2.97 per cent and 1.13 per cent at their respective means. Therefore, the elasticities for the rainy day and warm day parameters indicate that a rainy day (at least some precipitation) is associated with a 0.81 percent *fall* in water consumption for the quarter; while a warm day (more than 19.5°C) is associated with a 0.87 percent *increase* in water consumption for the quarter. There is broad agreement between this regression and those for owner-occupier and rental households with the exception that the price elasticity of demand is higher (-0.681 compared to -0.509) and the income elasticity of demand lower (0.267 compared to 0.290) for the owner occupied residences.

The lower panel in Table 2 presented the estimated coefficients, standard errors and p-values and elasticities for the non-linear model. On the basis of adjusted R^2 the non-linear models are preferred, accounting for up to 78 percent of the variation in the quantity of water demanded. All of the estimated coefficients are significant at the 1 percent level of significance or lower and conform to *a priori* expectations. The price elasticity of demand across all households is -0.548 indicating that a ten percent increase in the price of water is associated with a 5.48 percent decrease in the quantity of water demanded. The income elasticity of demand of 0.242 suggests that a ten percent increase in income is associated with a 2.42 percent increase in the quantity of water demanded. But the price and income elasticities of demand are lower for renter households when compared to owner-occupied households. The difference in price elasticity between owner-occupied and renter households especially is not surprising. Under the Queensland *Residential Tenancies Act 1994*, tenants are entitled to a free allocation of a 'reasonable' amount of water by their landlords, after which negotiations are necessary to resolve payment. Since the transaction and enforcement costs of such negotiations are likely to be large relative to the benefits (the variable component of water bills for rental households in the sample averaged just $49.74), reimbursement of 'unreasonable' expense is unlikely.

6. Concluding remarks and policy recommendations

The present study uses linear and non-linear regression techniques to model household residential water demand. The data is drawn from the Brisbane City Council, Australia's largest local government area, where two-part tariffs consisting of a fixed access charge with no free entitlement of water and a constant volumetric charge per kilolitre. As far as the authors are aware, this is the first attempt to derive models of household water demand in Queensland, and one of few conducted in Australia. This represents a sizeable advance over projects of a similar nature conducted in Australia, including IPART (2003), Essential Services Commission of Victoria (2004), and Government Prices Oversight Commission Tasmania (2003), which have tended to rely on relatively simple comparisons between changes in water pricing structures and charges and changes in water consumption to formulate policy.

The most important finding is that the price elasticity of demand, though inelastic, is larger than previously thought. This implies that the price mechanism can be an effective tool for managing the demand and consumption of residential water. Depending upon the model specified a ten percent increase in the price of water is associated with a five and a half percent reduction in the quantity demanded. In other terms, a price rise of just $0.0157 per kilolitre would have prevented Brisbane household water consumption trending upwards by 580 litres per household per quarter over the period 1998-2004. This would amount to a saving of 789 thousand kilolitres per year across Brisbane.

Unfortunately, it is not possible in the current study to comment on the effectiveness of price relative to non-price controls, including public education campaigns and water use restrictions, as most programs have been in place and relatively unchanged during the period under consideration. However, evidence elsewhere suggests that constraints placed on discretionary water use (gardening, car washing, filling/topping up of swimming pools) can have an equal, if not more sizeable, impact on water demand. A second finding is that the price elasticity of demand is lower for renter households than owner-occupier households. One likely reason is that under tenancy legislation renter households in Queensland are only obliged to pay for 'excess' water usage and this obscures, contrary to all economic principles regarding pricing transparency, the marginal cost of water consumption in these households. This is a clear omission in the legislation.

The final finding is that factors beyond the control of water authorities also have an influence on residential water demand. That is, there is a significant increase in water demand in summer months and on warm days, and this is only partially moderated by a fall on rainy days. When combined with strong population growth and the continuing fall in average household size in south-eastern Queensland, the (in-sample) trending upwards of warm days (by one approximately every seven years) and downwards in rainy days (by one every sixteen months) suggests that residential water demand in Brisbane will continue to grow.

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TABLE 1. Variable definitions and descriptive statistics

		Combined consumption (kL)	Owner-occupied consumption (kL)	Rental consumption (kL)	Water price ($/kL)	Household income ($)	Rainy days (n)	Warm days (n)
Central tendency and distribution	Mean	73.11	75.36	65.45	0.76	12495.00	33.70	88.70
	Std. dev.	21.46	22.41	18.68	0.05	3242.00	9.98	3.76
	Minimum	23.31	7.75	13.75	0.70	7531.00	15.00	81.00
	Maximum	211.91	214.47	302.36	0.82	24992.00	51.00	92.00
	Kurtosis	6.95	6.39	30.65	-1.80	1.38	-0.72	-0.91
	Skewness	1.99	1.84	3.70	-0.35	1.18	-0.40	-0.68
Seasonal and time decomposition	Intercept	67.06	68.36	61.79	0.68	11191.00	41.50	87.23
	Time trend	0.58	0.67	0.35	0.01	124.00	-0.74	0.14
	March quarter	2.90	3.57	1.72	0.09	1379.00	-2.70	4.77
	June quarter	-4.49	-4.23	-4.46	0.09	1528.00	-4.90	-2.03
	September	7.88	9.22	3.94	0.09	1081.00	-15.70	-1.63
	December quarter	17.91	19.41	13.44	0.09	1230.00	-7.90	4.77

TABLE 2. Estimated linear and non-linear regression models

		All households				Owner-occupier households				Renter households			
	Variable	Coefficient	Std. error	p-value	Elasticity	Coefficient	Std. error	p-value	Elasticity	Coefficient	Std. error	p-value	Elasticity
Linear demand equation	Constant	1.553	13.210	0.906	–	9.081	12.838	0.480	–	-40.471	24.754	0.102	–
	Water price ($/kL)	-64.124	9.088	0.000	-0.667	-67.458	7.994	0.000	-0.681	-43.779	16.923	0.010	-0.509
	Lagged demand (kL)	0.547	0.056	0.000	–	0.568	0.052	0.000	–	0.370	0.134	0.006	–
	Household income ($)	0.002	0.000	0.000	0.269	0.002	0.000	0.000	0.267	0.002	0.000	0.000	0.290
	Household size (n)	6.813	1.494	0.000	0.236	5.670	1.301	0.000	0.191	11.071	3.251	0.001	0.429
	Rainy days (n)	-0.596	0.046	0.000	-0.273	-0.645	0.047	0.000	-0.287	-0.387	0.064	0.000	-0.199
	Warm days (n)	0.637	0.131	0.000	0.769	0.616	0.136	0.000	0.722	0.856	0.195	0.000	1.155
	Summer {1, 0}	14.412	0.773	0.000	–	15.335	0.816	0.000	–	10.435	1.069	0.000	–
	R-squared	0.768	–	–	–	0.778	–	–	–	0.598	–	–	–
	Adjusted R-squared	0.766	–	–	–	0.776	–	–	–	0.596	–	–	–
	F-statistic	472.160	–	0.000	–	498.726	–	0.000	–	212.731	–	0.000	–
Non-linear demand equation	Constant	-4.000	0.722	0.000	–	-5.332	1.183	0.000	–	-4.228	0.847	0.000	–
	Water price ($/kL)	-0.548	0.077	0.000	-0.548	-0.510	0.084	0.000	-0.510	-0.435	0.101	0.000	-0.435
	Lagged demand (kL)	0.557	0.045	0.000	–	0.480	0.077	0.000	–	0.499	0.076	0.000	–
	Household income ($)	0.242	0.028	0.000	0.242	0.303	0.046	0.000	0.303	0.194	0.033	0.000	0.194
	Household size (n)	0.215	0.044	0.000	0.215	0.212	0.051	0.000	0.212	0.327	0.073	0.000	0.327
	Rainy days (n)	-0.212	0.014	0.000	-0.212	-0.225	0.019	0.000	-0.225	-0.159	0.016	0.000	-0.159
	Warm days (n)	0.872	0.148	0.000	0.872	1.129	0.242	0.000	1.129	1.012	0.181	0.000	1.012
	Summer {1, 0}	0.185	0.010	0.000	–	0.178	0.014	0.000	–	0.153	0.012	0.000	–
	R-squared	0.781	–	–	–	0.727	–	–	–	0.704	–	–	–
	Adjusted R-squared	0.780	–	–	–	0.725	–	–	–	0.702	–	–	–
	F-statistic	509.579	–	0.000	–	379.785	–	0.000	–	338.976	–	0.000	–