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Equitable and efficient systems of water utility charges in the face of a changing water supply mix

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Equitable and efficient systems of water utility charges in the face of a changing water supply mix

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Abstract

In this research we argue that for jurisdictions where desalinated water has been introduced as a major supply source such that long run marginal cost is rising, marginal cost pricing is: (i) efficent; (ii) delivers revenue sufficency; and (iii) is more equitable than traditional pricing approaches. To illustrate our result we compare outcomes under different pricing structures in Western Australia, a jurisdiction where desalinated water is responsible for almost half total potable water supply. We also show that a pure volumetric charge for wastewater services is more equitable than property value based charges or a uniform tariff. The results are based on analysis of water charges for over 700,000 individual households.

Key Words: Regulated Industries, Water Utilities, Utilities, Monopoly Pricing
JEL Codes: K23, L95

1 Introduction

In the early 20th century utility pricing involved setting charges at average service cost. Such practices had notable pro-cyclical effects, and in response to what were seen as the negative economic impacts of average cost pricing, Hotelling (1938) developed the argument that social welfare would be maximized if charges were set at marginal cost, with the consequent revenue shortfall covered from consolidated revenue (income tax). Overtime, the idea of marginal cost pricing for utilities then became the consensus position in economics. The idea of multi-part tariffs for utilities with decreasing average cost was subsequently introduced in Coase (1946), but it was only decades later that multi-part pricing became popular (Coase, 1970).

In the specific case of water supply, as both the income elasticity and the own-price elasticity for residential water demand are close to zero -- see Worthington & Hoffman (2008) for a review -- policy makers have traditionally emphasized equity rather than efficiency considerations. For example, in the Australian water market, rather than marginal cost pricing or multi-part tariff pricing, water charging systems were historically linked to property values. As explained in Ng (1984) and Ng (1987), the way these charging systems worked was opaque, but the intent of the systems was for those living in higher value properties to subsidize those living in lower value properties: the system placed a priority on a particular view of equity, the 'ability to pay' principle, over efficiency. In 1994, however, a national agreement was reached to introduce two-part pricing for urban water services across Australia by 1998 (Hoffmann *et al.*, 2006). Today, most Australian water utilities use multi-part increasing block charging as the main cost recovery mechanism for water supply services (Sibly & Tooth, 2014).

The introduction of two-part or multi-part increasing block pricing for water supply in Australia was a significant economic reform, but in practice the link between property values and water charges was not always broken. For example, property values are still used to set the fixed charge in at least some States (Sibly, 2006). Further, water utilities typically provide a range of services in addition to potable water supply -- such as drainage services and wastewater services -- and in some jurisdictions these additional service charges are still directly linked to property values. For example, the main water utility service providers in both Western Australia and South Australia continue to use property value based charging for wastewater services, where the reason for this practice seems to be equity considerations (SA Water Corporation 2014).

Pricing practice for water supply and wastewater services in Australia is summarized in Table 1, and for water supply, all major Australian jurisdictions use either a fixed charge plus increasing block tariffs (IBT) or a fixed charge and a single volumetric tariff. Charges for wastewater services are more varied, with charges based on either property values, a combined fixed and variable charge, or a single fixed charge.

Table 1: The charging structure in Australia

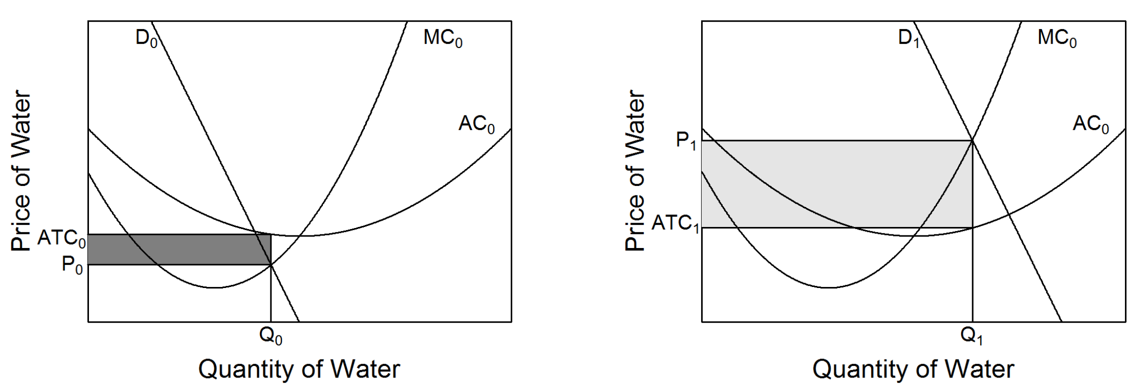
State	Utility	Water supply	Wastewater
ACT	Icon Water	Fixed + IBT	Fixed
NSW	Sydney Water	Fixed + Volume	Fixed
	Hunter Water	Fixed + Volume	Fixed
NT	Power and Water Corporation	Fixed + Volume	Fixed
Qld	Queensland Urban Utilities	Fixed + IBT	Fixed + Volume
SA	SA Water	Fixed + IBT	Property value
Tas	TasWater	Fixed + Volume	Fixed
Vic.	City West Water	Fixed + IBT	Fixed + Volume
	Yarra Valley Water	Fixed + IBT	Fixed + Volume
	South East Water	Fixed + IBT	Fixed + Volume
WA	Water Corporation	Fixed + IBT	Property value

Source: Relevant utility websites [accessed: 29 May 2017]

Recent supply augmentation decisions in Australia suggest that the classic characterization of the utility market, where average cost is falling over the relevant range, may no longer be appropriate. For example, in Western Australia, desalination is now responsible for almost half of the water flowing through the integrated water supply system (Water Corporation 2016); and as desalination supply has been integrated into the system, estimates of long-run marginal cost (LRMC) for water in Perth have approximately doubled (ERA, 2009, 2013).

In Figure 1, both the classic representation of the utility pricing problem -- where marginal cost pricing results in a revenue shortfall without a fixed charge -- and the characterization of circumstances in Western Australia -- where marginal cost pricing generates a surplus -- are shown. In Figure 1, when demand is D_0, marginal cost is P_0 and the revenue shortfall associated with marginal cost pricing is $Q_0 \times (ATC_0 - P_0)$. With demand D_1, marginal cost is P_1 and the surplus generated through marginal cost pricing is $Q_1 \times (P_1 - ATC_1)$.

Figure 1: Marginal cost pricing: past and present



Within Australia, no other jurisdiction is as reliant on desalination technology as Western Australia, but substantial desalination capacity exists in most major Australian population centres: Queensland (125 ML per day), South Australia (270 ML per day), New South Wales (250 ML per day), Victoria (410 ML per day). Desalination is also increasingly important in other jurisdictions. For example, in California, proposed new desalination plants have the potential to raise desalination capacity in the State to almost 1,500 ML per day (Badiuzzaman *et al.*, 2017). More generally, the International Desalination Association reports that the global capacity of commissioned desalination supply as of 30 June 2015 was 86.8 GL per day, and that desalinated water was part of the water supply mix for networks servicing more than 300 million people.[1] Considering the implications for water pricing policy of the introduction of desalination capacity into the supply network is therefore relevant to many global cities.

From the time multi-part pricing for water services began to emerge as a genuine policy option, concerns have been expressed that the use of a fixed charge results in a regressive pricing structure. One of the first attempts to balance the equity and efficiency concerns that flow from a two-part tariff is Feldstein (1972). The logic of Feldstein's model is that with a normal good consumption rises with income, and so by pricing above marginal cost those with higher incomes pay more, and this surplus can be used to reduce the fixed charge. The extent of the pricing above marginal cost is then subject to normative preferences that balance equity and efficiency.

In terms of the efficiency loss induced by IBT pricing, Sibly & Tooth (2014) show that the deadweight loss due to the use of IBT pricing is a function of the extent to which pricing in each tier deviates from the efficient price. As a way of improving efficiency, and at the same time meeting practical political implementation requirements, Sibly & Tooth (2014) propose a pricing structure that involves a fixed charge and an efficient volumetric charge, and a rebate for consumption below a predefined essential consumption level.

For property based water utility charges, Rajah & Smith (1993) find flat charges to be slightly more regressive than property based charges, while McMaster & Mackay (1998) find the opposite. Further complicating matters, Renzetti *et al.* (2015) show that the conclusions drawn about the impact of different pricing structures varies with the assumption made about the demand structure for water services. Empirical work on the impact of different charging structures, including structures that might intuitively seem regressive, such as uniform charges, is therefore valuable.

In this research we focus on water pricing in Western Australia, a jurisdiction where desalination is a large component of the total water supply system, and also the main future supply augmentation technology. As the efficiency case for marginal cost pricing is clear, our

[1] http://idadesal.org/ [accessed: 29 May 2017]

specific focus is on the equity implications of replacing the current increasing block tariff for water supply and the property value based charge for wastewater services with pure volumetric charges related to long run marginal cost. Specifically, we investigate whether: (i) water supply charges based on marginal cost, with a lump sum refund, are more equitable than the current multi-part pricing tariff structure; and (ii) volumetric wastewater charges are more equitable than property value based charges. To answer the research questions we use water consumption data for around 700,000 households to calculate the impact of alternative water pricing approaches and show that: (i) for water supply, marginal cost pricing (with lump sum transfers to consumers) is more equitable than the current increasing block plus fixed charge system; (ii) for wastewater services, volumetric charging is more equitable than property value charging; and (iii) basing charges on water use information only, rather than water use and property value information would generate substantial administrative cost savings.

2 Background

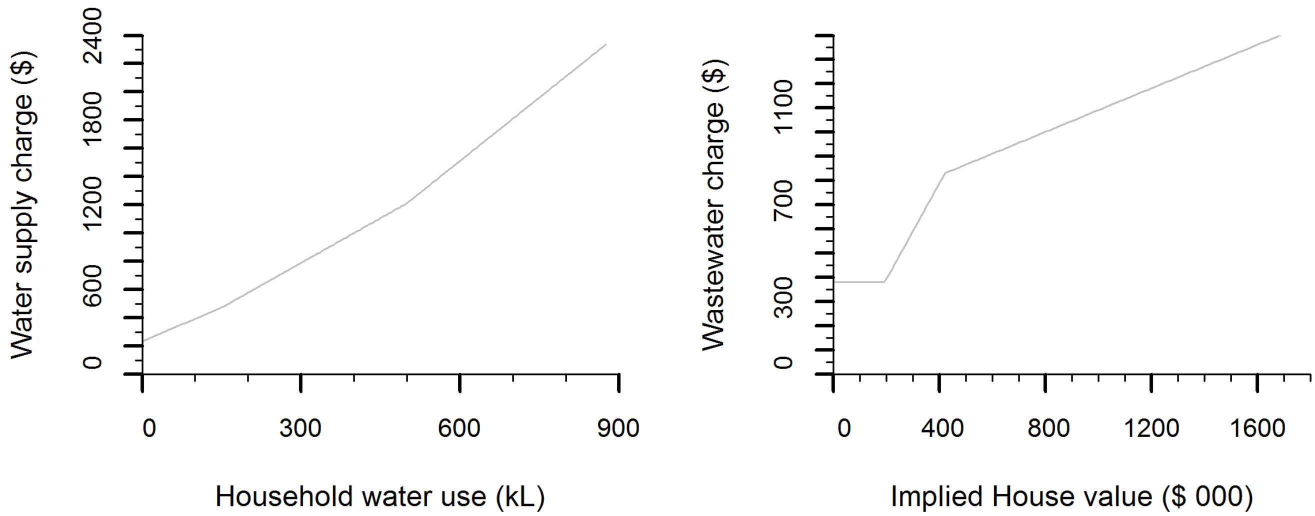
2.1 Water services in Western Australia

The principal supplier of water, wastewater, and drainage services in Western Australia is the government owned utility Water Corporation. Residential water supply charges are based on a multi-part tariff structure, with a fixed component for all households, and an increasing block charge for actual water usage. Wastewater charges are based on household property values. The specific property value metric used to determine wastewater charges is the property Gross Rental Value (GRV). The GRV of a property is the value "the land might reasonably be expected to realize if let on a tenancy from year to year upon condition that the landlord were liable for all rates, taxes and other charges thereon and the insurance and other outgoings necessary to maintain the value of the land".[2] One way to think about GRV information is that it provides an estimate of the amount of housing services consumed by each household in a given year, regardless of whether the home in question is rented or owned. Similar to wastewater charges, Water Corporation drainage charges, which apply to the subset of metropolitan properties serviced by main drains, are based on property values. Local drainage services are provided by local government. Across all Water Corporation service charges a range of concessions are available for low income and pensioner households.

In Figure 2, the plot on the left shows how the total water supply charge varies with water consumption, and the plot on the right shows how the total wastewater charge varies with

[2] Valuation of Land Act 1978

Figure 2: Current charging structures in Western Australia



property value.[3] For water supply, the fixed charge is currently $236, and the block prices are: $1.59 per kL for the first 150kL; $2.11 per kL for the next 350kL; and $2.99 for every kL above 500kL.

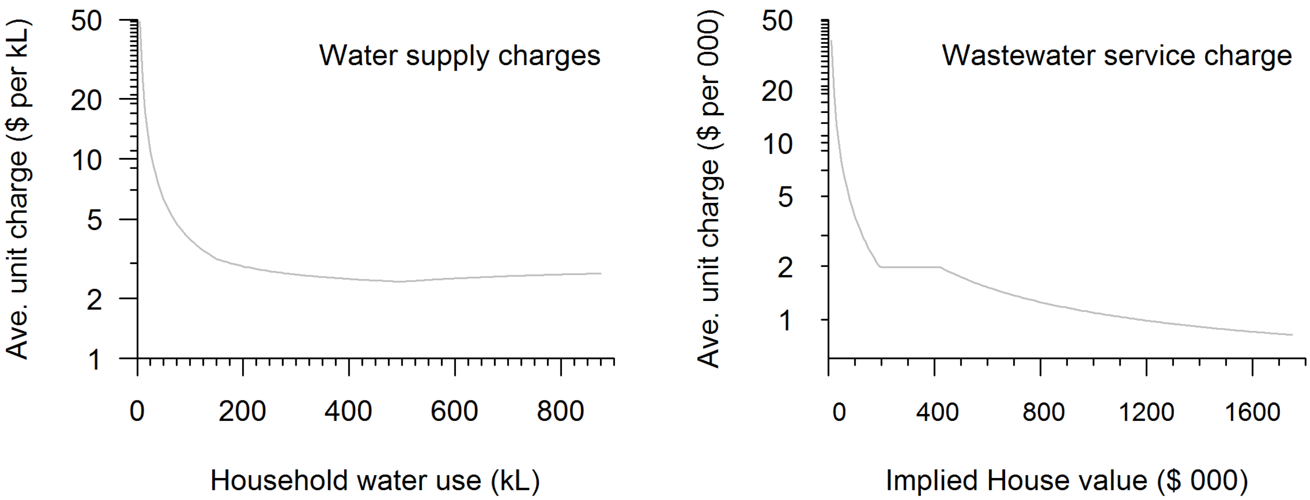
Assuming GRV is equal to five percent of the capital value of a property allows wastewater charges to be expressed in terms of house prices directly, and this way of reporting information is easier to understand. For wastewater charges, there is a minimum charge of $381, and this applies to houses where the value is $200,000 or less. For houses above $200,000 in value, the wastewater charge increases at a rate of $1.98 per $1,000 increase in property value, up to a value of $400,000. For properties above $400,000 in value, the marginal increase in the wastewater charge is $0.45 per $1,000 increase in property value.

In Figure 3, the plot on the left shows the average water supply charge for different levels of water use, and the plot on the right shows the wastewater charge for different property values. For water supply costs, the fixed charge means that those with low levels of consumption pay a high average price, but the increasing block tariff structure means that average cost starts to increase again once household consumption exceeds 500 kL. For the wastewater charge, the minimum charge means that those with very low value properties pay a relatively high charge per dollar of property value. Further, as there is a decreasing block tariff for wastewater charges, the total wastewater charge per dollar of property value is monotonically falling as property value increases.

A further complication with water utility pricing in Western Australia is that the State

[3] The implied house price has been derived from GRV using the assumption that the effective rental yield for a property is 5 percent. The dollar values are Australian dollars. Over the 10 years to June 2017 the average exchange rate was $1 AUD = $0.86 US.

Figure 3: Average cost to consumers



government is not bound to follow the water pricing recommendations of the independent Economic Regulation Authority (ERA), and this flexibility has implications for both the level of water charges and the way charges are levied. For example, Table 2 details the actual revenue collected by the State government for water services and the revenue that would have been collected by government had the ERA's recommended price structure been adopted for the five years to 2016. As can be seen, the cumulative difference over the five year period is an extra $910M return to State government.

Although there could be many reasons why the return to the Government of Western Australia from water services is higher than the return recommended by the regulator, the financial position of the State government is likely to be the dominate factor. Specifically, the State government has been running material budget deficits for a number of years and deficits are forecast for many years into the future (Government Government of Western Australia, 2016).

Table 2: Government return from water utility service provision ($M)

Item	2012	2013	2014	2015	2016
Dividend payments ERA	397	357	182	199	207
Tax equivalent payments ERA	223	204	124	126	136
Community service obligation payment ERA	-450	-428	-352	-370	-387
Net payment to government ERA	169	132	-46	-46	-44
Actual net payment to government	216	169	183	163	344
Net difference	47	37	229	209	388

Note: Financial years. Values may not add up exactly due to rounding.

Source: ERA (2013); Water Corporation Annual reports, various years

In addition to the level of water service charges being higher than recommended by the independent regulator, the way revenue is collected is also different. For example, ERA (2013) argues that linking wastewater charges to GRV (property values) is inappropriate because: (i) at the individual household level charges are not directly related to the cost of providing the service; (ii) customers with similar volumes of wastewater can pay significantly different service charges; (iii) the cost of maintaining a property GRV database is substantial; and (iv) there is no reliable evidence to suggest there is a strong correlation between property values and income. The ERA's preferred system is a: "fixed wastewater charge based on the average annual cost of service".

2.2 Supply sources

In Perth, scheme water is sourced from dams, groundwater sources, and desalination plants, and the relative importance of each water supply source has changed substantially over recent years. For example, over the past six years the proportion of Perth's water sourced from dam infrastructure has fallen from 45 percent to seven percent. The proportion of Perth's water that is sourced from groundwater resources has remained approximately constant over this period, with growth in desalination supply replacing dam supply. Specifically, between 2010 and 2016 the proportion of Perth's water supplied by desalination capacity has increased from 16 percent to 47 percent (Table 3).

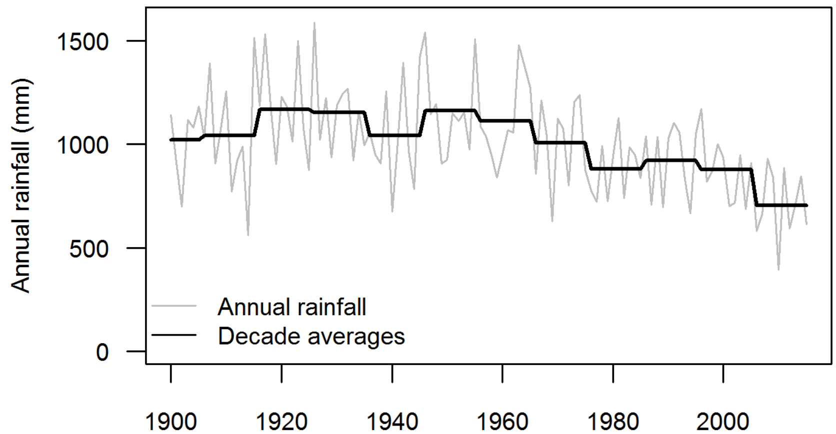
Table 3: Sources of scheme water

Source	2010	2011	2012	2013	2014	2015	2016
Total hills (dams) output (%)	45	35	26	17	17	17	7
Total groundwater output (%)	39	49	50	49	44	42	46
Total desalination output (%)	16	16	25	34	39	41	47
Total hills (dams) output (ML)	136,337	115,293	81,386	46,786	49,025	49,519	20,100
Total groundwater extraction(ML)	119,656	163,578	157,789	139,622	124,850	122,127	136,879
Total desalination output (ML)	47,693	52,010	78,847	95,770	113,060	119,457	138,645

Source: Water Corporation Annual Reports, Various Years

Although the proportion of water sourced from dams has fallen significantly over the past six years, and at the same time, the total water storage level in Perth's dam infrastructure has fallen from 35 percent to 24 percent; or in GL terms, the fall in storage has been from 216GL in 2010 to 138GL in 2016 (Water Corporation, various). That both the amount of water sourced from dams and dam storage levels have fallen is due to a sustained reduction in rainfall in the Perth region. There is significant variation in rainfall from year-to-year, but as can be seen from the decade-by-decade averages shown in Figure 4, which is for the weather station closest to one of Perth's main water supply dams, average rainfall today is much lower than it was in the past.

Figure 4: Rainfall at main metropolitan dam site



It is unlikely that the current low level of rainfall, and hence low dam inflows, will be reversed. Rather, there is a strong consensus in climate model projections that there will be a further substantial decline in rainfall in the south west of Western Australia, and the most likely scenario is that dam inflows will continue to fall (CSIRO, 2015). The decline in rainfall, in turn, is expected to have a substantial impact on the availability of drinking water from dams, and the publicly available water planning documents make it clear that surface water will continue to decline in importance as a water supply source for Perth (Water Corporation, 2009).

Going forward, the proportion of water supplied from groundwater supply sources is also expected to decline. Lower rainfall has meant less groundwater recharge, and current extraction rates are therefore depleting existing groundwater resources. For example, Iftekhar & Fogarty (2017) show that the Gnangara groundwater resource, which is the main groundwater supply source for metropolitan Perth, has fallen by over two metres over the past 35 years, and is continuing to decline. That current groundwater extraction levels are unsustainable is recognised in existing planning documents that imply water supply from existing groundwater sources in 2050 is expected to be half the level it is today (Water Corporation, 2009). The major new supply options proposed by the water utility to address the decline in existing resources and meet future demand are either new desalination plants or expansions at existing desalination plants (Murphy, 2016). The Economic Regulation Authority has acknowledged that future water sources for Perth will need to be climate independent, so objections to the expansion of desalination plant capacity on economic grounds are unlikely (ERA, 2013).

The financial implication of adding desalination supply sources can be seen in the financial reports of the Water Corporation, which are published as part of the utility's Annual Report. Specifically, between 2006 and 2016 Water Corporation's long-term debt increased from \$1.4

billion to $5.8 billion; operating costs per property increased from $479 to $796; and total Water Corporation costs per property serviced increased from $1,329 to $2,004 (Water Corporation, various). This evidence on costs, taken from audited financial statements, is consistent with the stylistic characterization of the market shown in the right-hand plot in Figure 1.

In summary, Perth's current water supply infrastructure delivers around 300GL of water to the greater Perth area, but is under stress. Around half the water supply is currently delivered via desalination technology. Going forward the existing supply infrastructure will deliver less water due to a combination of falling dam inflows and a reduction in extraction from existing groundwater resources. Under some realistic climate change scenarios Perth's existing dam infrastructure would actually cease to be a reliable part of the overall water supply infrastructure. Published Water Corporation projections suggest existing groundwater, surface water, and desalination resources will provide less than 200GL of supply by 2050, and only around 160GL by 2060. The main new supply sources will be high cost desalination and centralised water recycling projects, so LRMC is rising, and will continue to increase into the future.

3 Methods

We model the equity implications of different pricing structures for Perth, the capital of Western Australia, and Australia's 4th largest city, at the Level 1 Statistical Area (SA1). An SA1 is the smallest statistical unit in the Australian Census, and on average an SA1 block consists of around 200 households. Based on the 2011 Census, median household income in Perth at the SA1 level ranges from $20,000 per annum to $170,000 per annum, and median SA1 level GRV ranges from $4,000 to $95,000.

In the analysis all scenarios considered generate the same total revenue, which is set equal to current total revenue for each water service. Water consumption is held constant for each scenario, which based on the demand literature reviewed in Worthington & Hoffman (2008) is thought reasonable. Some customers, for example pensioners, are eligible for concessions on their water charges. Concession information was incorporated when calculating charges for individual households for each type of pricing.

For water supply charges the three pricing structures considered are: the current increasing block tariff structure used by the Water utility; a uniform tariff structure; and marginal cost pricing. The uniform charge is considered as if combined with a uniform wastewater service charge this approach to charging would generate significant administrative cost savings. For the marginal cost pricing structure we set the charge at the upper bound of the LRMC estimate in

ERA (2013). This approach generates $69M (18 percent) more revenue than the existing tariff structure, and to ensure the same amount of revenue is raised we provide all consumers with a lump sum refund, subject to the constraint that the minimum total water supply charge is non-negative.

For wastewater service charges the first charging structure considered is the current property value based charging structure used by the Water utility; the second is a uniform charge of the type advocated by the economic regulator; and the third is a pure volumetric charge.[4]

Subsequent to calculating the water and wastewater charges at the household level for each of the alternative pricing structures based on GRV and water consumption, household level data were aggregated to the SA1 level. The specific method used to create the SA1 database is explained in the appendix, but in brief, property specific information was matched to each SA1 location using details available from the Landgate Shared Land Information Platform. In total, 700,745 individual household records out of a total of 742,266 were matched to specific SA1 locations across Western Australia. Mean and median water supply and wastewater charges were then calculated for each SA1 and each pricing structure. These data were then combined with 2011 census data on SA1 level median incomes.

3.1 Comparison of water supply and wastewater service charges

To describe the overall relationship between income and charges for each pricing structure we fit a series of regression trend lines. The water supply charge regressions take the form:

$$S_{ij} = \alpha_j + \beta_j I_i + e_{ij}, \tag{1}$$

where, S_{ij} denotes the mean water supply bill for $SA1_i$ calculated using pricing method j; I_i denotes the median income level for $SA1_i$; and e_{ij} is a zero mean error term. The wastewater charge regressions take the form:

$$W_{ij} = \alpha_j + \beta_j I_i + e_{ij}, \tag{2}$$

[4] In practice, to implement volumetric pricing requires setting a discharge factor. However, in this application as we: (i) solve for a total revenue requirement, and (ii) consider household charges rather than unit charges it is not necessary to set a discharge factor. In a real world setting there are several approaches that could be used to set the discharge factor. One option would be to set a fixed discharge factor, such as 0.85, and apply this to total consumption. Another option would be to set the discharge factor based on winter water consumption data, as during winter outdoor water use is minimised. Alternatively, consideration could be given to setting a different discharge factor for apartments and stand alone properties to reflect the differences in outdoor water use.

where, W_{ij} denotes the mean wastewater service bill for $SA1_i$ calculated using pricing method j; and the remaining notation is as per equation 1. In each equation the β_j provide a measure of the rate of increase in the charge as income increases.

To describe the impacts of different pricing structures on different parts of the income distribution we calculate the proportion of total revenue collected from each income decile, under each charging structure, as well as the change in the average charge for each income decile.

3.2 Income-housing services relationship

Property value is a good predictor of capacity to pay if the proportion of income devoted to housing consumption is a constant proportion of income. However, if the poor spend a greater proportion of their income on housing, a property value based measure of capacity to pay will overestimate the capacity to pay of those on low incomes. To test whether the marginal propensity to consume housing services out of income is constant across different income deciles a quantile regression is estimated, and a joint test of whether the slope estimates at different quantiles are the same is the conducted. As the model we estimate has only one explanatory variable, we follow the notation of Koenker (2005) and write the quantile regression model as:

$$\min_{\beta} \sum_{GRV_i \geq \beta I_i} \theta \left| C_i - \beta^{\theta} I_i \right| + \sum_{GRV_i < \beta I_i} (1-\theta) \left| C_i - \beta^{\theta} I_i, \right| \tag{3}$$

where θ is the quantile and the remaining values are as previously denoted. Estimation of the quantile regression model relies on Koenker (2016), and we consider $\theta = 0.2$, 0.4, 0.6, 0.8.

To find the income levels where GRV based charging overestimates and underestimates capacity to pay we fit a least squares trend line to the data, forced through the origin, and compare this to a line fitted using a spline smoothing method. The proportional least squares regression equation is:

$$C_i = \beta I_i + e_i, \tag{4}$$

where C_i denotes the median property GRV for $SA1_i$, I_i denotes median household income for $SA1_i$, and e_i is a zero mean error term.

The relationship between the least squares trend line and the line fitted using the smoothing spline method can be seen from equation 5, which is the objective function that is minimised when using the smoothing spline method. In equation 5 the first term is the mean square error and the second term is a measure of curvature weighted by some factor λ. Higher values for λ imply a greater penalty for curvature, and as $\lambda \to \infty$ the second derivative terms are always zero, and so the solution converges to the least squares trend line. Conversely, as $\lambda \to 0$ there is no penalty for curvature and the fitted line traces the data exactly. The specific smoothing spline implementation is as explained in Venables & Ripley (2013, p. 230).

$$L\left(g, \lambda\right) = \frac{1}{n} \sum \left(C_i - g(I_i)\right)^2 + \lambda \int dI \left(g''(I)\right)^2 . \quad (5)$$

3.3 Implementation impacts

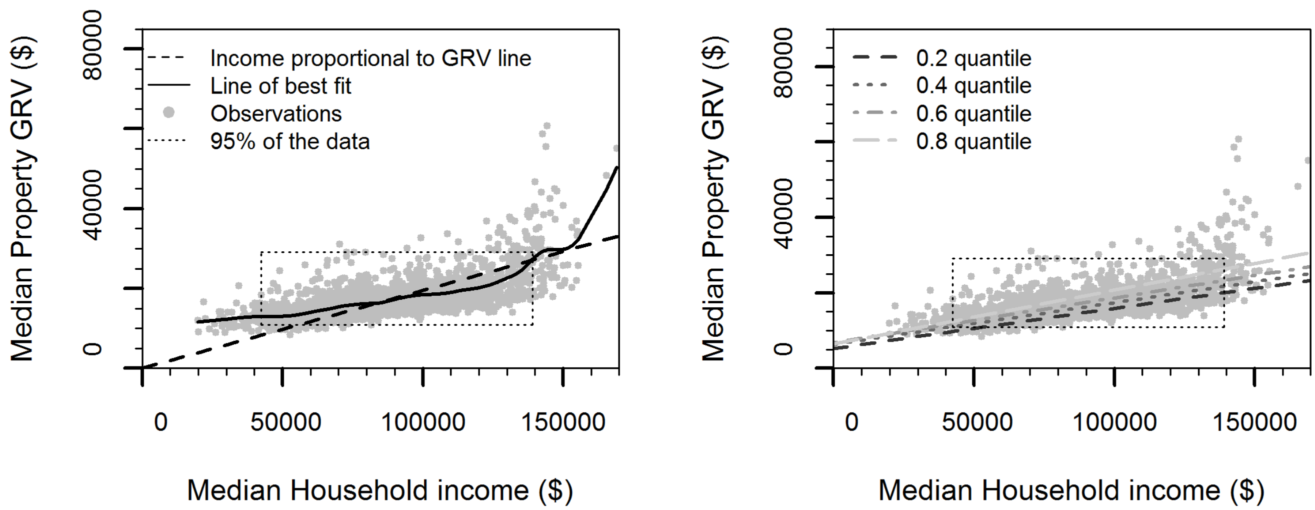
To investigate implementation impacts the following process was used. First, customers eligible for a concession were identified separately to other customers. For both concession and non-concession customers the lowest ten percent and highest ten percent of bills were then identified. For these customers the current wastewater and water supply charge was calculated and compared to what it would be under the alternative charging structures. For the water supply charge the comparison is between the current increasing block charge, a uniform charge, and marginal cost pricing. For the wastewater charge the comparison is between the current property value based charge, a pure volumetric charge, and a uniform charge.[5]

4 Results

The core findings are discussed in three sections. First, we present the findings of the investigation into the relationship between income and the proportion of income devoted to housing services. These results show that reliance on the GRV measure for assessing capacity to pay results in an overestimate of capacity to pay for those on low incomes. Second, we present information on the equity implications of different charging structures. These results show that for both water supply and wastewater services the use of volumetic charging results in more equitable outcomes than the current charging systems. Finally, we present estimates of the change in individual household charges following the implementation of different charging systems. These results show that at the individual household level the effect of shifting to volumetric based charging is generally modest.

[5] In addition to the results presented here, analysis was also conducted for non-metropolitan locations, where for each non-metropolitan region the revenue requirement was calculated separately. The results for regional customers and concession customers mirror the results for the main group of metropolitan non-concession customers, so for the discussion we focus on these results only.

Figure 5: Investigation of the relationship between income and property values



4.1 Income-housing services relationship

In Figure 5, the plot on the left shows the least squares trend line, assuming a fixed proportional relationship between property GRV and income, and the line of best fit to the data using the spline smoothing method. The rectangle traced by the dotted lines defines 95 percent of the data. The line fitted using the spline model becomes approximately horizontal at low income levels, which is consistent with the idea that there is a minimum level of expenditure required to access housing.[6] The plot on the right of Figure 5 shows the variation in the marginal propensity to consume housing services out of income across income groups, and an F-test strongly rejects the null of slope equality for the quantiles considered. This result can be interpreted as evidence that the marginal propensity to consume housing services is not proportional to income. Excluding the very upper tail of the distribution, a simple stylistic model of the relationship between income and the consumption of housing services would be to say that $C = \alpha + \beta I$ such that $^{c}/_{I} = ^{\alpha}/_{I} + \beta$, and so for $\alpha > 0$ the share of income devoted to housing falls as income increase.

Overall, from Figure 5 the following inferences can be drawn: (i) the relationship between income and GRV at the tails of the distribution is different to the relationship between income and GRV observed for the middle 95 percent of the data; (ii) the marginal propensity to consume housing services out of income falls as income increases; and (iii) for household incomes below around $85,000, a GRV based approach to setting wastewater charges overestimates capacity to pay.

To provide some context on the size of the differences in the proportion of income devoted

[6] The default λ value selected for the spline model was (8.49×10^{-5}), but this gave rise to a relatively noisy looking curve. Using a trial and error approach, and a visual inspection of the fitted curve, a value of $\lambda = 0.0002$ was selected for the final model.

to housing across different income groups we have divided the sample into deciles and conducted pair-wise comparisons. As the sample is large, this involves little cost in terms of estimate precision. Table 4 provides a summary of all comparisons and provides information of the mean difference in the share of income devoted to housing across deciles, and whether the difference is statistically significant. The most striking feature of the information in Table 4 is the difference between the share of income devoted to housing for the poorest 10 percent of households relative to all other income deciles. These differences can be seen by reading down the first column of Table 4, and the differences are both statistically significant and practically important. For example, the poorest income decile devotes, on average, six percentage points more of their income to housing services than the second poorest decile; and around ten percentage points more than households at or just above the median income level.

Table 4: Differences in the proportion of income devoted to housing by decile (mean difference)

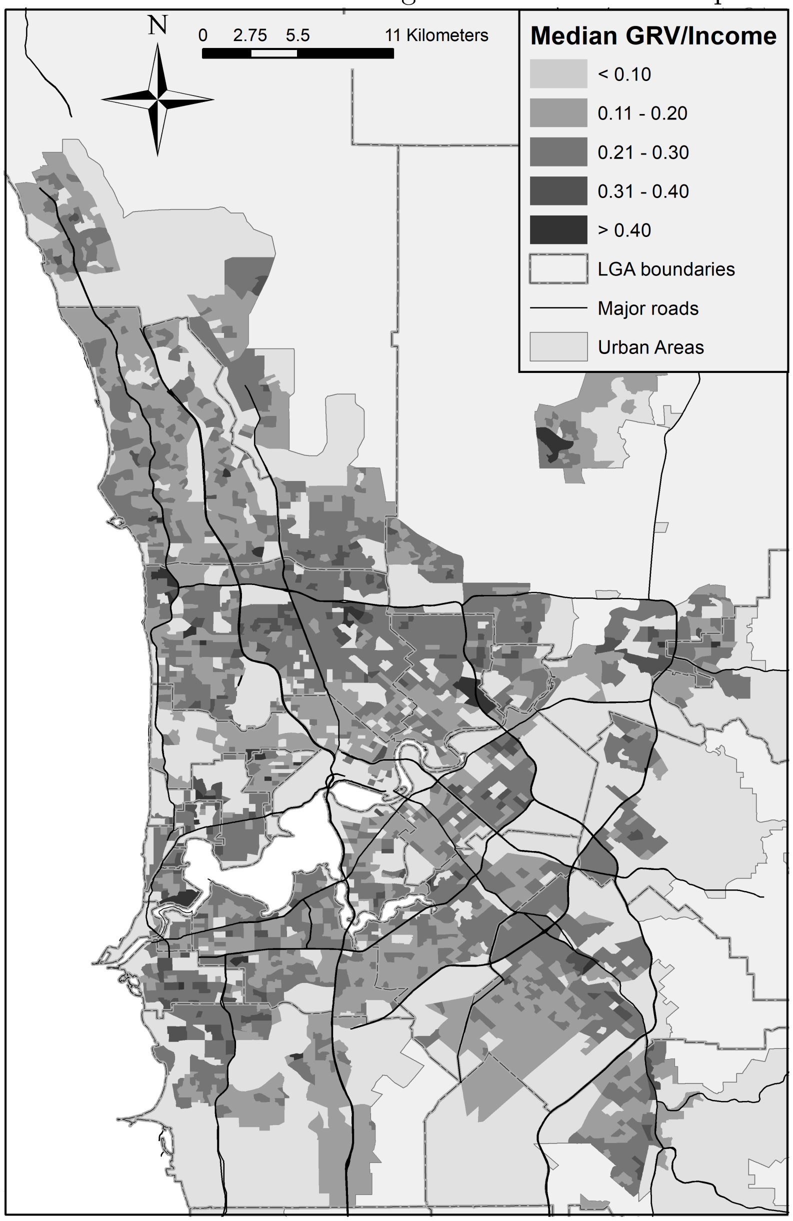
Decile	1tst	2nd	3rd	4th	5th	6th	7th	8th	9th
2nd	-0.06**	-	-	-	-	-	-	-	-
3rd	-0.07**	-0.01**	-	-	-	-	-	-	-
4th	-0.08**	-0.02**	-0.01*	-	-	-	-	-	-
5th	-0.09**	-0.03**	-0.02**	-0.01**	-	-	-	-	-
6th	-0.11**	-0.05**	-0.03**	-0.03**	-0.01**	-	-	-	-
7th	-0.11**	-0.05**	-0.04**	-0.03**	-0.02**	-0.01	-	-	-
8th	-0.12**	-0.06**	-0.05**	-0.04**	-0.03**	-0.01**	-0.01**	-	-
9th	-0.13**	-0.07**	-0.06**	-0.05**	-0.04**	-0.03**	-0.02**	-0.01**	-0.01**
10th	-0.12**	-0.06**	-0.05**	-0.04**	-0.03**	-0.01**	-0.01	0.00	0.01**

** * significant at the 1% and 5% level, respectively.
p-values have been adjusted to control the familywise type I error rate using the holm method and also allow for group-wise heteroskedasticty.

To more completely understand the spatial pattern of the variation in the proportion of income devoted to housing services, in Figure 6 we plot, at the SA1 level, the ratio of median GRV to Income for the Perth metropolitan region. As can be seen from the figure, across the metropolitan area there are pockets where the proportion of income devoted to housing services is high.

Aggregating the individual SA1 values to the suburb level, and taking the average of these values, we find that the five suburbs with the lowest GRV to income ratio are all suburbs where median household incomes are relatively high, between $98,000 and $112,000. This finding is consistent with the income range shown in Figure 5 where the non-parametric trend line is substantially below the proportional trend line. From Figure 5 we should also expect that the suburbs with highest GRV to income ratios will be drawn from both tails of the income distribution, and this is the case. Both Perth's most exclusive suburb (Peppermint Grove) and the suburb with the lowest median income (Midvale) feature in the top five suburbs for the GRV to income ratio.[7]

Figure 6: Share of income devoted to housing services: Main metropolitan area of Perth



That low income households are required to devote a disproportionate share of income is consistent with the idea that there is a minimum essential consumption level for housing services. There are many possible reasons for a high GRV to income ratio in exclusive high income suburbs. It is possible that a relatively high proportion of people in these suburbs have inherited the home

[7]The five suburbs with the lowest GRV/income ratio were: Wembley, Mount Hawthorn, West Leedervile, Leederville, and Kensington; and the five suburbs with the highest GRV/income ratio were: North Beach, Midvale, Mt Claremont, Pepermint Grove, and Midland

they live in so that their housing wealth, and hence consumption of housing services, is higher than expected given their level of income; true income in these areas may not be adequately captured in the data due, for example, to people in these suburbs deriving a relatively high proportion of income from capital gains; there could be a premium effect due to the exclusiveness of these suburbs such that people are willing to pay a much higher share of their income to live in these locations. It should also be noted that although the proportion of income devoted to housing in these suburbs is high, as income in these suburbs is high, the total dollar value of income available for non-housing consumption is still high, so allocating a relatively high proportion of income to housing services does not place undue demands on households in these suburbs. Alternatively, it could just be that GRV is simply not a good measure for very expensive houses.

4.2 Comparison of charging structures

4.2.1 Water supply charges

For water supply charges, the key estimation results are shown in Figure 7, Table 5, and Table 6. In Figure 7, the top left plot shows the relationship between household income and charges under the current increasing block charge. In the plot the solid black line represents the regression trend line and the black dotted lines represent 95 percent of the data points. The slope of the regression trend line says that, on average, for every \$1,000 increase in household income, water charges increase by \$3.70 (Table 5).

In Figure 7, the top right plot illustrates the relationship between household income and charges under marginal cost pricing (with a lump sum transfer to customers). Relative to the current increasing block tariff structure, there is more variation in water bills, but, on average, charges increase with income at a faster rate -- \$4.80 per \$1,000 of household income -- than under the current increasing block charging scheme (Table 5).

On average, the proportion of households eligible for a concession in low income SA1 areas is higher than in high income SA1 areas. As such, the results for the uniform charge, which are shown in the bottom left plot of Figure 7, show a slight increase in average SA1 level water charges as income increases. Specifically, at the SA1 level, as median income increases by \$1,000, charges, on average, increase by \$0.42 (Table 5).

For both the current charging structure, and the marginal cost pricing proposal, the proportion of variation in the data explained by the trend line is similar, with $R^2 = 0.41$ for the current IBT pricing model and $R^2 = 0.39$ for marginal cost pricing. With $R^2 = 0.24$, the proportion of the variation in the data explained by the uniform charging structure is noticeable lower.

A summary of the equity impacts of different charging structures can be seen in bottom right plot of Figure 7 and in Table 6. Specifically, to compare the equity impacts of different charging structure we have: (i) calculated the actual water supply charge for every household under each system; (ii) ranked properties by the median SA1 income level; (iii) calculated the cumulative proportion of the total water supply revenue collected at each income level; and (iv) calculated the change in the average charge for each income decile. The summary information shows that, relative to the current IBT approach to charging, marginal cost pricing places less financial burden on low income households. A uniform water charge, on the other hand, would result in low income households, on average, paying more than they currently pay.

As can be seen from Table 6, for the lowest income households, relative to the current IBT charging structure, with marginal cost pricing annual charges fall by around \$35, but would increase by over \$100 with a uniform charge. For the highest income households the impacts are reversed. With with marginal cost pricing annual charges increase by around \$60, but would fall by around \$190 with a uniform charge. Overall, with marginal cost pricing, the bottom 30 percent of households gain, there is no change for the next 20 percent of the income distribution, and charges rise for the top 50 percent of the income distribution. For a uniform charge, charges fall for the top 40 percent of the income distribution, there is no change for the next 10 percent of the income distribution and prices rise for the bottom 50 percent of the income distribution.

Marginal cost pricing is, by definition, efficient. Definitions of equity can be more varied. If equity is defined in terms of 'ability to pay' such that those on higher incomes pay proportionally more, then marginal cost pricing for water supply services in Western Australia is more equitable than current practice. Equity can also be taken to imply a 'beneficiaries pay' principle. Here, provided benefit is proportional to use, marginal cost pricing is also more equitable than the current IBT system, as those that use more water pay more. As such, relative to current practice, marginal cost pricing, in a system where desalination is the main supply augmentation option, appears to deliver both efficiency and equity gains.

Figure 7: Relationship between income and water supply charge: SA1 level

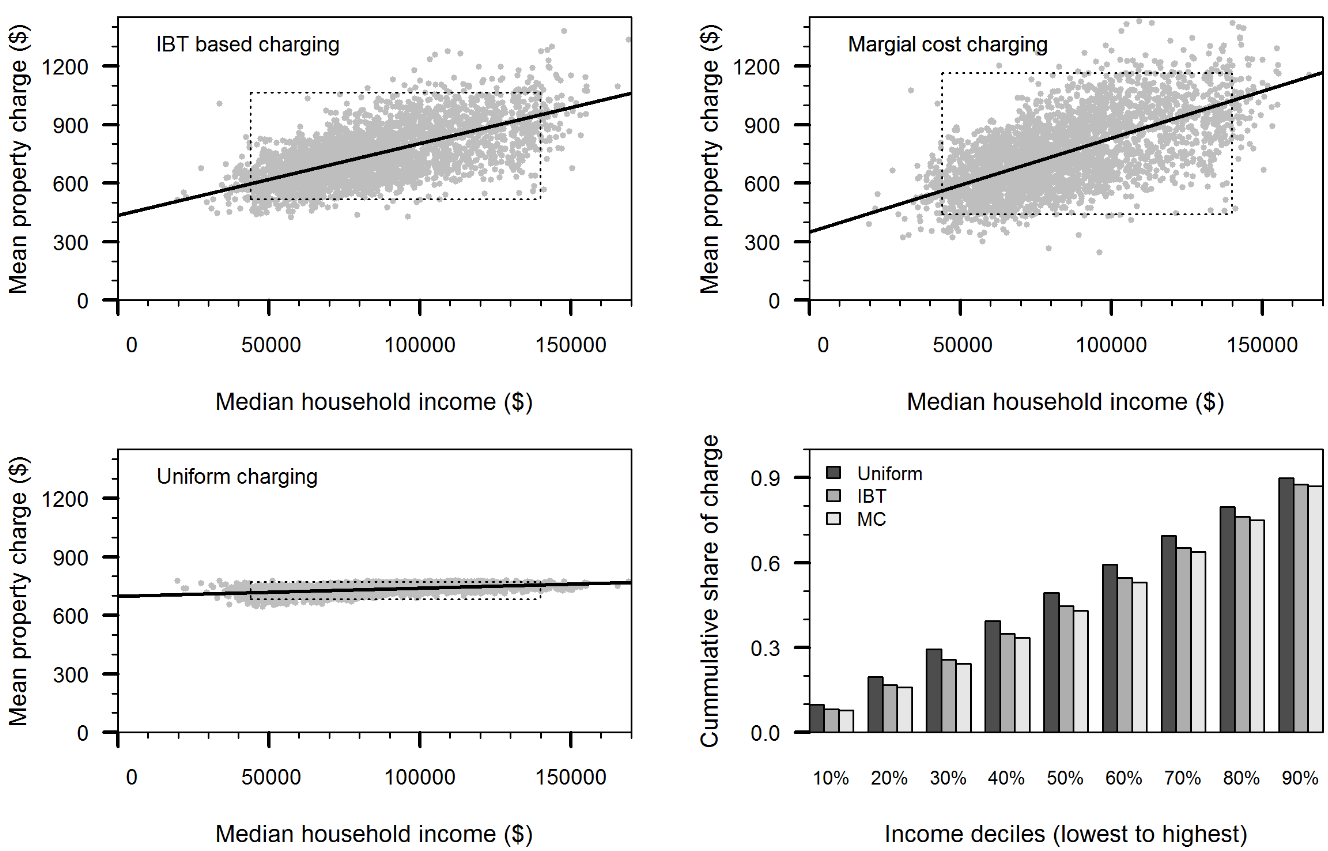


Table 5: Water supply regression model summary results

	IBT charges		Uniform charges		Marginal cost charges	
	Est.	S.E	Est.	S.E	Est.	S.E
Intercept	434	(7.69)	697	1.35	350	(10.0)
Slope×1,000	3.70	(.097)	.423	(.014)	4.80	(.014)
R^2	0.41		0.24		0.39	
Obs	2,857		2,857		2,857	

Note: Hetroskedastic robust standard errors.

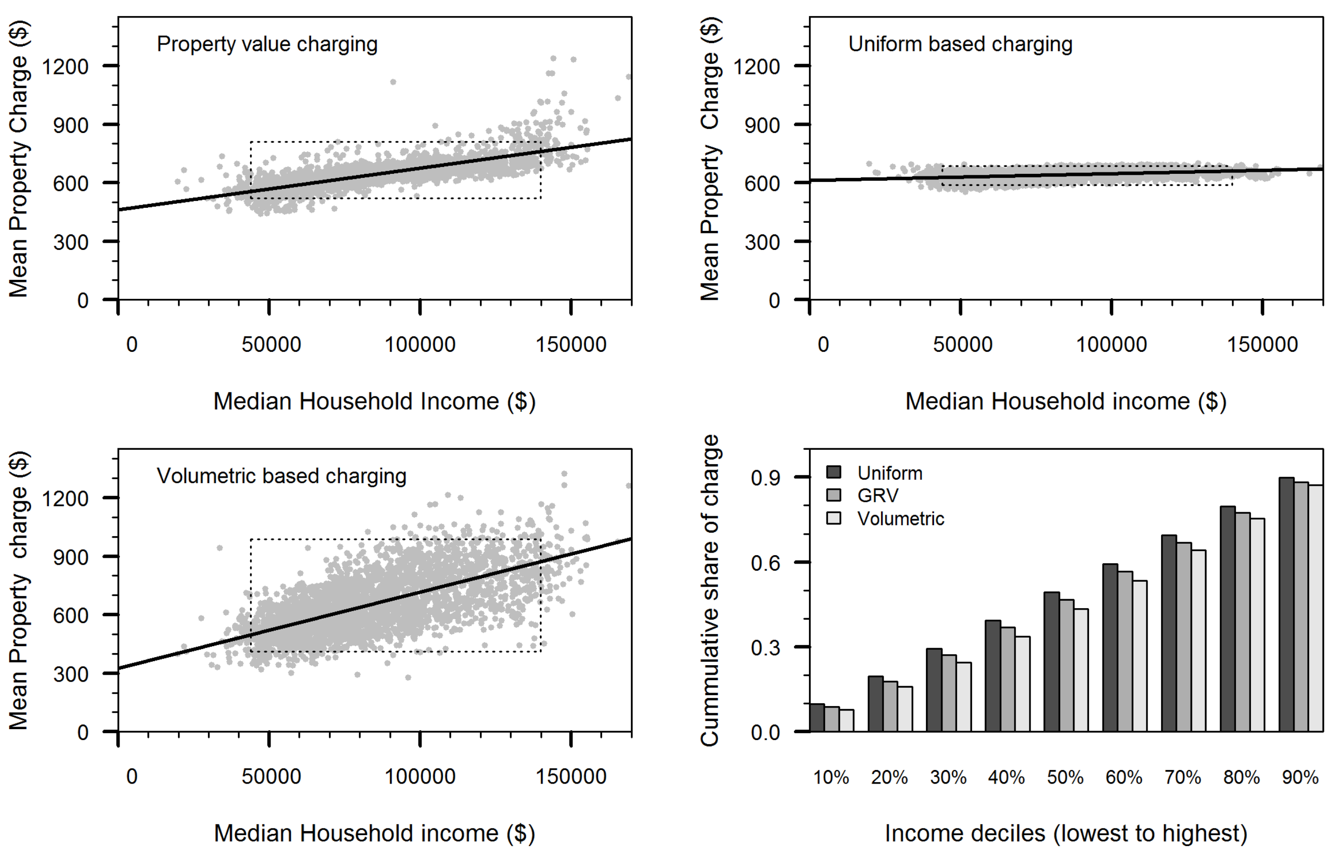
Table 6: Water supply charges: equity implications by income decile ($ per household)

Income decile	10	20	30	40	50	60	70	80	90	100
Change to MC	-34.55	-25.21	-19.85	-1.29	-0.35	8.73	19.00	29.92	39.46	59.36
SEM ($)	(2.45)	(2.07)	(2.46)	(2.41)	(3.04)	(2.75)	(2.55)	(2.97)	(2.40)	(2.77)
Change to Uni.	107.47	79.20	69.19	15.85	23.05	1.21	-23.92	-60.03	-96.63	-189.43
SEM ($)	(4.02)	(3.88)	(4.90)	(5.66)	(5.15)	(6.08)	(5.94)	(7.36)	(6.67)	(11.11)

4.2.2 Wastewater charge relationship

A summary of the results for the analysis of wastewater charges is presented in Figure 8, Table 7, and Table 8. Similar to the water supply charge plots, in Figure 8 a rectangle has been added to each regression plot to identify 95 percent of the observations. The slope information for each model (see Table 7) provides a measure of the rate of increase in wastewater service charges as income increases. For the property value based approach to charging for wastewater services, for every $1,000 increase in income, on average, wastewater service charges increase by $2.13; for the uniform charge, due to the effect of concessions for some households, on average, for every $1,000 increase in income, wastewater service charges increase by $0.34; and for the volumetric charge, on average, for every $1,000 increase in income, wastewater service charges increase by $3.91. The pattern of results for wastewater charges therefore follows the same pattern as found for water supply charges. For GRV (property value) based charges, the regression R^2 is 0.58; for the uniform charge R^2 is 0.14; and for volumetric charging R^2 is 0.42.

Figure 8: Relationship between income and wastewater charge: SA1 level



In Figure 8, the plot on the bottom right shows that for volumetric charging low income households pay less than under current arrangements and pay more with a uniform charge. In

Table 7: Regression model summary results

	Property value		Flat charge		Volumetric charge	
	Est.	S.E	Est.	S.E	Est.	S.E
Intercept	462.4	(2.97)	612.3	(1.49)	325.2	(7.62)
Slope×1,000	2.14	(.053)	.342	(.016)	3.91	(.010)
R^2	0.58		0.14		0.42	
Obs	2,875		2,875		2,875	

Note: Hetroskedastic robust standard errors.

Table 8: Wastewater charges: equity implications by income decile ($ per household)

Income decile	10	20	30	40	50	60	70	80	90	100
Change to Vol.	-53.10	-41.13	-40.27	-17.67	2.70	20.63	39.83	67.81	85.48	73.64
SEM ($)	(4.93)	(4.72)	(5.25)	(5.76)	(6.20)	(6.59)	(7.15)	(7.93)	(7.74)	(8.86)
Change to Uni.	62.49	44.38	29.95	14.71	7.70	2.88	-14.01	-23.18	-39.49	-112.10
SEM ($)	(2.40)	(1.91)	(1.99)	(1.96)	(1.84)	(1.59)	(2.21)	(2.17)	(2.51)	(5.95)

Table 8 the size of the average change in the wastewater bill is shown for each income decile, and the results make it clear that a shift to volumetric pricing would result in lower charges for those on low incomes, while a shift to the position favored by the Economic Regulation Authority would result in low income households paying more. Overall, with volumetric charges, wastewater charges fall for households in the bottom 40 percent of the income distribution, are unchanged for the next ten percent of the income distribution, and increase for the 50 percent of the income distribution. Conversely, with a uniform charge, charges fall for the top 40 percent of the income distribution, are unchanged for the next the percent of the income distribution, and increase for the bottom 50 poercent of the income distribution.

In terms of specific dollar amounts, for the bottom ten percent of the income distribution, the annual wastewater charge would, on average, increase by around $62 following the introduction of a uniform charge, and fall by around $53 following a change to volumetric pricing. For the top ten percent of the income distribution, on average, wastewater charges would increase by around $74 following the introduction of volumetric charges and decrease by around $112 if a uniform charge was levied.

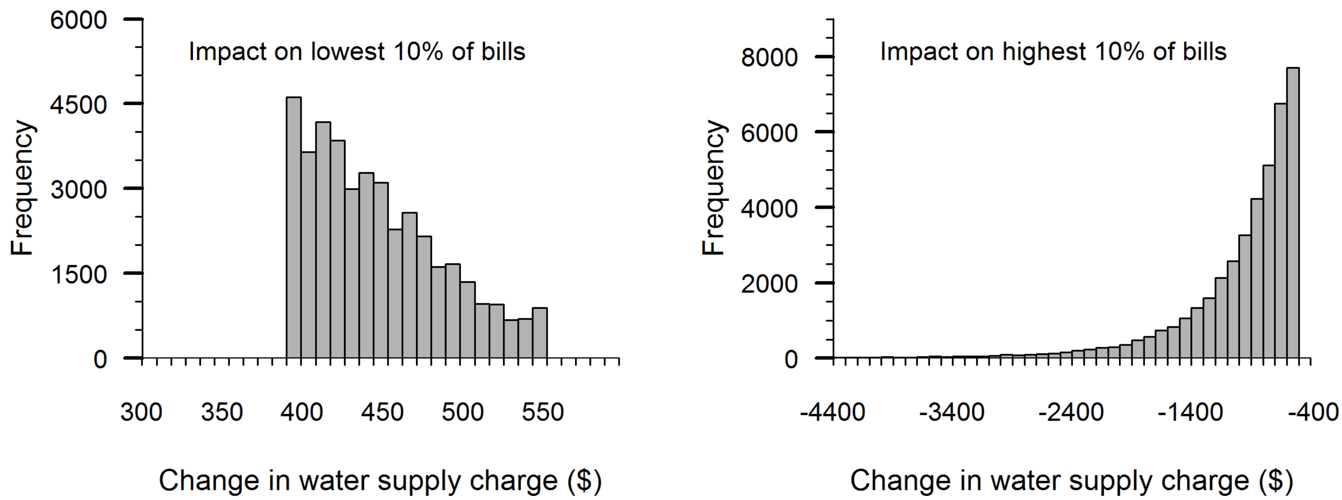
4.3 Implementation impacts

The investigation of the relationship between income and charges relied on the aggregation of data to the SA1 level. To understand the implementation effects, we consider impacts at the individual household level, both for the changes to the water service charge and the changes to the wastewater charge.

4.3.1 Water supply charges

Figure 9 plots the distribution of impacts for metropolitan customers that currently face high (top ten percent) and low (bottom ten percent) water supply service charges, following the introduction of a uniform water supply charge. With a fixed uniform charge, the households that currently have the lowest annual water supply charges would face increases of between $400 and $550. Conversely, those households that currently face large water supply charges would see substantial falls in their water supply charge. Specifically, across the households that currently represent the top ten percent of water users, the mean reduction in their water supply bill would be $990 per year.

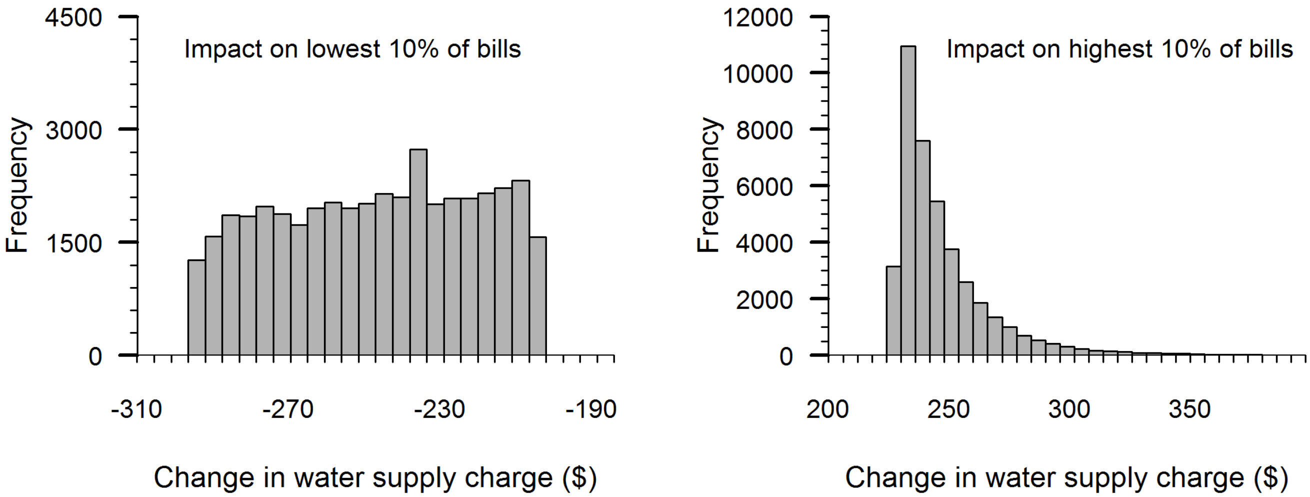
Figure 9: Impact of uniform charge: water supply



The impact of the introduction of marginal cost pricing is shown in Figure 10. With marginal cost pricing the average decrease in the water supply charge for those that currently have the lowest water supply bills would be $248 per year. The primary reason for the reduction in the water supply charge for these households is the removal of the fixed access charge. For those households that currently use a large amount of water, and hence have a high current water supply charge, the average increase in the water supply charge following the introduction of marginal cost pricing would be $249 per year.

Overall the results are clear. If you face a low water supply bill today, it would increase following the introduction of a uniform tariff, and fall following the introduction of marginal cost pricing. The opposite is then true for those that currently face large water supply charges: charges fall with the introduction of a uniform charge and increase with the introduction of marginal cost pricing.

Figure 10: Impact of marginal cost pricing: water supply



4.3.2 Wastewater charges

The impacts on individual customers at each end of the current wastewater service charge distribution following a change to a uniform tariff are shown in Figure 11. The plot on the left shows the impact on those customers that currently have relatively low wastewater service charges and the plot on the right shows the impact on those customers that currently have relatively high wastewater service charges. As can be seen, application of a revenue neutral uniform tariff results in higher charges for all customers that currently face low wastewater service charges and lower charges for all customers that currently face high wastewater service charges. Across metropolitan locations the mean increase in the annual charge for the bottom ten percent of customers is \$135. For 75 percent of the relevant cohort, the increase is less than \$164, and 95 percent of the increases are between \$78 and \$262. For those customers that currently face a large wastewater service charge, the mean decrease in their wastewater service charge is \$180, with 95 percent of the falls in wastewater service charges between \$82 and \$507.

Figure 11: The impact of a uniform wastewater charge

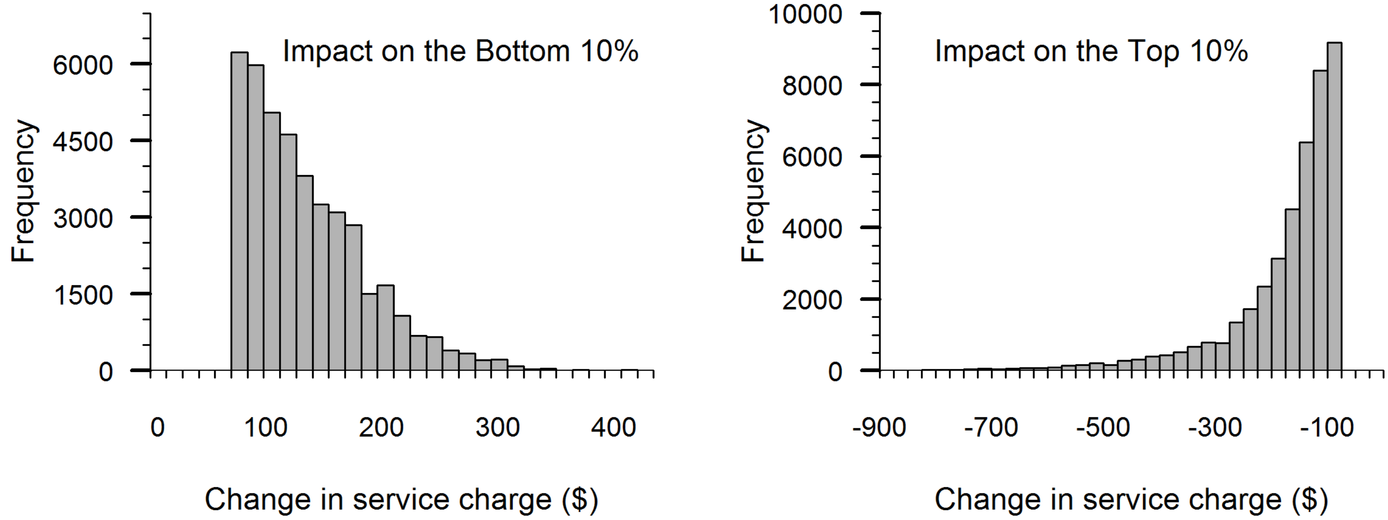
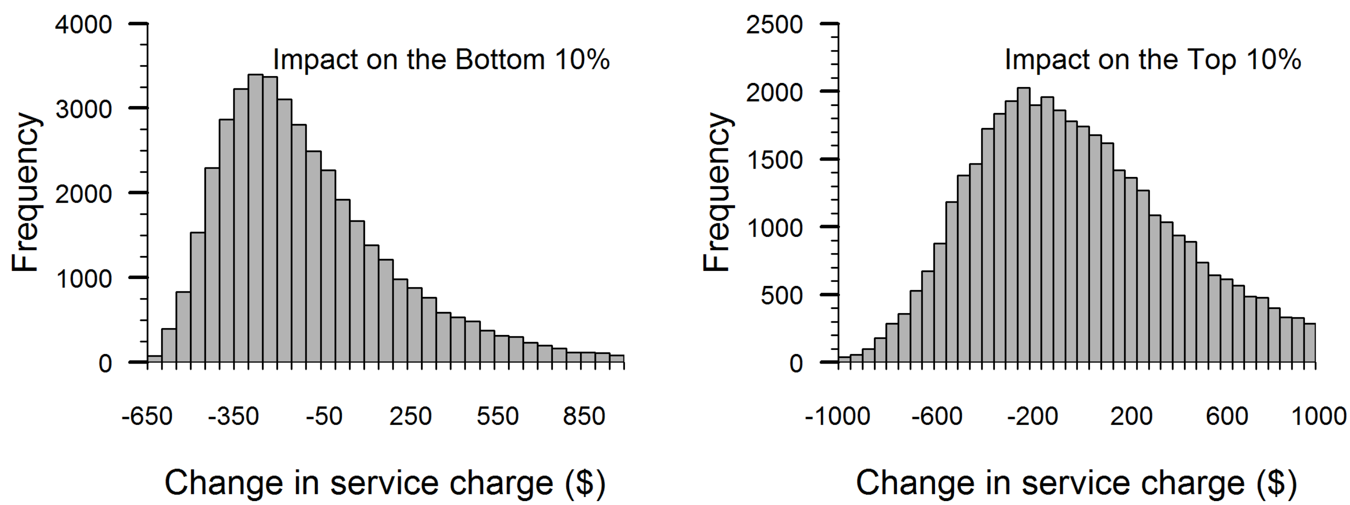


Figure 12 shows the impact on individual customers at each end of the current charge distribution following a change to a pure volumetric wastewater service charge, and as can be seen, these impacts are more variable than under the change to a uniform charge. Those customers that currently have the lowest wastewater service charges, would, on average, face a decrease in their wastewater service charge of $66. There is, however, significant variation across households, and the range that captures 95 percent of service charge changes extends from a decrease of $512 through to an increase of $856. For those customers that currently face relatively large wastewater service charges, the mean increase in their wastewater service charge would be $73, with the range that captures 95 percent of the changes in wastewater service charges extending from a $703 decrease to a $1,421 increase.

Figure 12: Impact of a volumetric wastewater charge



5 Discussion

The empirical work presented here focuses specifically on Western Australia, but the issues addressed are relevant for all jurisdictions where new supply augmentation relies on high cost energy intensive options such as desalination or wastewater recycling.

In jurisdictions where water supply augmentation involves adding high cost supply sources such as desalination to existing dam and groundwater infrastructure there is no longer any reason to use two-part or increasingly block tariffs to price water services. LRMC pricing results in revenue more than sufficient to cover utility costs. Further, and most importantly for the issues considered in this research, LRMC pricing results in both improvements in efficiency and equity.

The model presented here involves LRMC pricing, plus a lump sum transfer back to households. In practical terms the pricing structure we model is not dissimilar to the 'politically aware' efficient IBT model of Sibly & Tooth (2014), where households receive a refund based on water saved below a threshold essential amount. However, the essential consumption requirement for a household is a function of both household size and environmental factors (Barberán & Arbués, 2009), and as such, defining the essential consumption level for each household would be difficult without the introduction of new detailed data collection mechanisms. In contrast, the pricing system evaluated in this research requires no new administrative infrastructure. So, while the Sibly & Tooth (2014) model could deliver an efficient outcome, due to differences in the administrative burden, we prefer the simple lump sum refund approach considered here.

Rather than recycling revenue to consumers, Freebairn (2008) considers the surplus available in a world with rising LRMC in water supply to be available for taxation via a resource rent tax. It is difficult to understand the equity implications of using LRMC pricing combined with a resource rent tax. However, in most jurisdictions there are many existing inefficient taxes. In the specific case of Australia, for example, the marginal excess burden of conveyance stamp duties is generally found to be around \$0.75 to \$0.80 per dollar of revenue raised (Cao *et al.*, 2015, p. 54). Similar inefficiencies are likely in all major jurisdictions. The use of a resource rent tax, in conjunction with LRMC pricing, to capture the surplus revenue could, therefore, generate material improvements in the efficiency of the tax system as a whole, but the equity implications of such an approach are unclear.

The case against a property value based system for wastewater service charges is strong. Such systems are not simple to implement, charges are not transparent to customers, and it is costly to maintain a property value database. For example, in the specific case of Western Australia, the annual fee charged for property value information is approximately \$4 million.

The perceived strength of property based charging systems is that they result in lower charges for those on low incomes. However, as shown in this research, volumetric pricing performs better in terms of lowering the cost to those on low incomes than property value based charging, at least in the Australian context.

A uniform charge for wastewater services, which is the approach used in some Australian jurisdictions, is administratively simple to implement. A regulated total revenue requirement is determined and an appropriate charge is set for a pre-determined period. However, with this approach, those on low incomes pay more than under a property value based charging system. So, on equity grounds volumetric charges seem more appropriate than a fixed charge.

6 Conclusions

The 1994 Australian National Water Initiative (NWI) pricing principles aimed to: (i) to ensure the efficient and sustainable use of water resources and water infrastructure; (ii) ensure sufficient revenue generation to efficiently deliver water services; and (iii) enable efficient water markets to function and give effect to the user-pays principle. In jurisdictions such as Western Australia, where desalination is a major part of the supply network, pure volumetric tariffs for wastewater services and water supply services based on LRMC are consistent the NWI principles. Further, regardless of whether equity is defined in terms of a user benefit principle or a capacity to pay principle, these approaches to pricing appear to be more equitable than the current approach to setting charges. Marginal cost volumetric pricing also has low administrative cost and charges are easy for consumers to understand. As such, the approach appears to strictly dominate current practice: administrative costs would be lower, and there would be improvements in both equity and efficiency.

A Appendix

To conduct the analysis required the creation of a unique GRV and income database. The database was developed using the following steps:

1. Download the cadastral layer “LGATE-002 Cadastre (Address)” from the Landgate Shared Land Information Platform (SLIP).

2. Calculate a centroid point for each property.

3. Download spatial and tabular data from the 2011 Census to obtain information on household income at the SA1 level.

4. Match each property to its SA1 unit using property centroids and SA1 polygons.

5. Create a tabular dataset matching property address and SA1 code.

6. Join the GRV and water consumption records database with the income database using suburb, street, and street number. Cases that were not automatically matched were manually checked. GRV and water consumption records that still did not match were then joined to the database using address, suburb, and street, if the street was completely within an SA1 polygon. This process resulted in matching 700,745 of the 742,266 records.

7. For each household, calculate water supply charges and wastewater charges using each pricing method.

8. For each SA1, calculate the mean and median: GRV, water consumption, water supply charges, and wastewater charge.

One of the issues found in terms of failing to generate property matches was that for some areas there are a number of housing lots that are not sewered (see Figure 13). SA1 areas where the number of matched households deviated from the total number of households by more than 20 percent were removed from the database.

Figure 13: Sewer network property overlap

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