Optimal Water Metering and Pricing

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Abstract

Marginal cost pricing of running water and sewerage services has long been the default recommendation of economists and natural resource specialists to firms and local governments. However, water pricing has never been studied simultaneously with the water metering problem before. The socially optimal number of meters crucially depends on the price of water charged by the Water Company because depending on this will be the fall in consumption and therefore in water production costs and vice versa. This paper breaks the inertia as it combines both issues in one optimization problem. Both in a centralized and in a decentralized way, the optimal number of meters is determined simultaneously with the optimal per unit water rate. The Rateable Value System (RV) (i.e. the "Status Quo" or benchmark regime) is confronted with Universal Metering (UM), Optimal Metering (OM) and Decentralized Metering (DM) in terms of optimal water rates and the socially optimal number of meters. Except for RV, the results of (UM), (OM) and (DM) all recommend setting price equal to marginal cost and the optimal number of meters is hereby endogenously determined by a functional form relating water and metering costs and water demand characteristics. Conclusions and policy recommendations are drawn from the theoretical analysis.

Keywords: water pricing, water metering, water rates, rateable value system, water services, incentive mechanism

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1. Introduction

Nowadays there seems to be wide agreement among natural resource economists that the optimal price for running water and wastewater services should be some version of marginal cost pricing. Be it short or long run, marginal cost pricing has been widely endorsed by Governments, Water Authorities and Companies around the world[1]. Ever since Turvey's 1976 seminal paper on the marginal costs of water supply, there has been a steady push for adopting this pricing methodology. Correctly defined, marginal cost pricing of water services assures the optimal allocation of scarce resources as it sends the right signal to both investors and consumers.

Marginal cost is the price reflecting the resources that must be committed by society for the production of one additional unit of water. Only in the event that society is willing to pay the cost of producing, distributing and treating the last cubic meter of water, must it be produced. Warford (1997) defines marginal opportunity cost of water as the sum of marginal water production costs (including extraction, transport, distribution, effluent treatment and disposal), marginal user costs (opportunity cost of resource depletion) and marginal environment costs (i.e. positive or negative environmental and health externalities created by water consumption). This definition however, does not take into account the fact that to be able to price water services at marginal cost, actual consumption has to be metered. But since metering costs do not enter the above definition of marginal costs, total water costs after metering can well end up being above total water costs before metering.

Nevertheless and although there seems to be wide agreement on the convenience of marginal cost pricing of water services, there does not appear to be the same consensus around the optimal water metering policy. The traditional recipe for countries with water shortages in summer months or with high water production and treatment costs was to follow Universal Metering (UM) policies. This policy recommends installing water meters in all dwellings, adopting a two – part - pricing scheme with a fixed or entry fee that proxies contribution to water capacity demand and a volumetric charge equal to (short or long run) marginal cost. This is an appealing approach as one should expect an important reduction in water consumption and hence in water production and treatment costs. This reduction in consumption would in turn curtail drastically the probability of shortages and non – price demand rationing such as outright service interruptions.

[1] OECD (1987, pp.15 -16) recommends water management authorities in Member countries to adopt marginal cost pricing of water services

The problem with this mechanism is that water metering is expensive and if it is not the result of a careful cost – benefit analysis it should not take place as the medicine could turn out to be worse than the illness. Several studies recommend adopting a selective metering policy, IBRD (1977[a,b]), OECD (1987) and OFWAT (2001) suggesting that consumption should me metered only if the savings in water production and treatment costs (and eventually wastewater treatment costs too) are high enough to compensate for incremental metering costs[2].

In a recent paper, Chambouleyron (2003) presents an incentive mechanism that induces Water Companies to install the socially optimal amount of meters in a decentralized way. The paper shows that a Social Planner will install meters in those dwellings where metering will bring about an increase in welfare. This is, where savings in water costs more than offset the fall in consumer surplus (due to the increase in the volumetric charge) plus metering costs. Obviously and as the paper shows, this condition will not necessarily hold for all dwellings as the reduction in consumption will depend on the demand characteristics of each dwelling (number of dwellers, existence of a garden or pool etc.). However, if the decision to install meters is given to the Water Company, this will install meters in those dwellings that bring about an increase in marginal profits (not welfare) without taking into account the impact of this decision on consumer surplus. And if, on the other hand the metering decision is given to the user, this will install a meter in his dwelling only if he feels that he will experience an increase in consumer surplus (not welfare) without caring much about water production costs, wastewater generated let alone environmental costs. It is clear from this analysis that any decentralized metering decision will lead to a sub optimal number of meters because neither the Company nor the user internalizes the cost he imposes on the other party or on society as a whole through environmental damage.

To solve this externality problem and make the decentralized decision optimal, Chambouleyron (2003) proposes and incentive mechanism whereby the Social Planner imposes a sort of Pigouvian Tax on the party creating the externality letting both parties reach the efficient solution through bargaining over welfare gains. The paper also shows that the incentive mechanism can be materialized in practice assigning the user the property right over the pricing regime, i.e the Water Company has to "buy the right to meter" from the user compensating him for the fall in consumer surplus thus reaching the efficient solution. However, this mechanism is defined for a given

[2] OFWAT (2001) recommends metering only "…when it is cheap or economic to do so..." for example in new houses with discretionary use of water (i.e, watering gardens or swimming pools) or where the resource is limited or scarce. OFWAT does not advocate universal metering (2001, pp.40)

water rate that is not determined in the paper. It is obvious that the socially optimal number of meters will depend on the marginal water rate as the fall in consumption following metering will be proportional to the water rate set by the Social Planner (i.e the higher the water rate the higher the reduction in consumption after metering)

This paper builds upon Chambouleyron (2003) in a very important way: It determines the optimal water rate simultaneously with the socially optimal number of meters. It does so within the framework of four revenue collecting regimes: The Rateable Value System (RV) (i.e. the "Status Quo" or Benchmark regime), the Universal Metering (UM) system, the Optimal Metering (OM) system and finally, the Decentralized Metering (DM) scheme designed by Chambouleyron (2003). The results indicate that regardless of the rate regime adopted marginal cost pricing of the volumetric charge is the recommended policy with the socially optimal number of meters determined endogenously by a function of water and metering costs and the unitary water demand function.

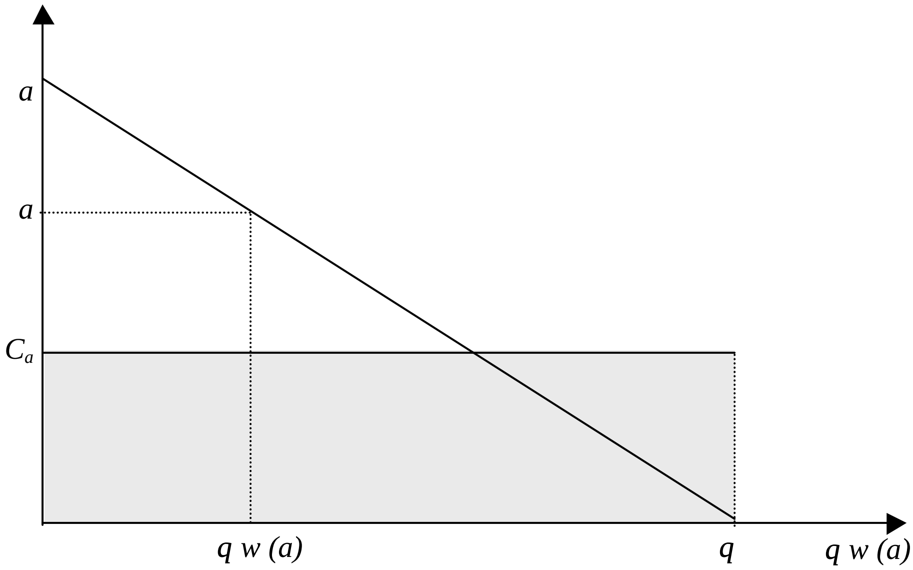
The paper proceeds as follows: Section 2 lays out the basic microeconomics of the metering problem. Section 3 introduces the Status Quo or Benchmark regime: The Rateable Value system and computes aggregate welfare and producer and consumer surpluses. Sections 4, 5, 6 and 7 present the Universal Metering (UM), Optimal Metering (OM) and Decentralized Metering (DM) regimes. In all cases the optimal water rate is calculated maximizing aggregate consumer surplus subject to a profit constraint setting this way also the optimal number of meters. Section 8 concludes drawing on the theoretical analysis and making recommendations to policy makers.

2.The Basic Setting

Borrowing from Chambouleyron (2003), there is a firm that provides water services to a city with N dwellings (normalized to one for simplicity), each of which has a water demand function of $q\ w(a)$ where q is a demand parameter (say, the number of dwellers per dwelling) and $w(a)$ £ 1 is the unitary water demand function (i.e. per dweller). The Water Company provides services both on a metered and unmetered basis. For unmetered water services it collects a fixed rateable monthly fee h per dwelling calculated following its physical features (i.e. area, covered area, property age etc). For the metered service, the Company collects a different monthly fee φh (with φ presumably < 1) and a volumetric charge of a [\$ / m^3] for water consumption (and eventually sewage generated and treated too) in excess of an allowed free threshold $q\ w^*$. If the dwellers consume less than $q\ w^*$, they will pay the fixed fee φh. If they consume more than the allowed threshold, they will be charged for consumption in excess of the threshold, T(*a*) = *j h* + *q a* (max [0, (*w(a)* - *w**)]). Metering cost C_m is a monthly cost incurred by the Company on a per dwelling basis that includes meter purchase and installation, meter reading and maintenance costs.

When the Company does not meter actual consumption, the marginal water rate faced by the consumer is zero and demand per dwelling is maximal at θ (as $\lim_{a \to 0} w(a) \to 1$). After the meter is installed and actual consumption charged, demand falls to θ *w(a)* < θ. C_a is the per unit (marginal) water production cost that includes all relevant water and wastewater costs and is assumed constant for simplicity. Before metering, dwellers reach their satiation levels θ as marginal consumption is free. When the meter is installed, dwelling consumption falls to *q w(a)*. The shaded rectangle in Figure 1 shows pre metering water production costs θ C_a per dwelling.

Figure 1: Change in demand with metering



Again, and as in Chambouleyron (2003), the fixed rateable monthly fee h $\in \left[\underline{h}, \overline{h} \right]$ is distributed with density g(h) and cumulative density G(h). Demand parameter θ $\in \left[0, \overline{q} \right]$ is distributed following a conditional density function f (θ / h) and cumulative density function F(θ / h). No a priori specific form is assumed for these distribution functions as the analysis is general enough to accommodate a wide range of functional forms. The total number of water connections the Company has (both metered and unmetered) will be given by (1):

$$N_T = \int_{\underline{h}}^{\bar{h}} \left\{ \int_0^{\bar{q}} dF(q \ / h) \right\} dG(h) = 1 \quad (1)$$

This is, for each h there will be dwellings with demand parameters θ ranging from zero (empty lots) all the way up to $\bar{q}$. For the sake of simplicity and from now on it will be assumed that the demand parameter θ will no longer depend on the rateable fee h. In other words, the distribution of θ's will be independent of the value of h and therefore of the physical features of the dwelling.

3. Water pricing under the Rateable Value System (RV)

This regime will be dubbed the Status Quo or the Benchmark regime as it will serve the purpose of comparison with metered regimes in terms of consumer surplus and welfare generated. As its name indicates, this regime charges water users a fixed monthly fee following a formula that takes into account the physical features of each dwelling such as area, covered area, land price etc. Total revenues collected by the Water Company in this regime are given by

$$H = \int_{\underline{h}}^{\bar{h}} h \ dG(h) \quad (2)$$

Since consumers face a marginal water rate of zero, they consume until they are satiated at θ. Total operating costs incurred by the Company will be the sum of total water production costs (and eventually wastewater treatment costs too) plus an overhead cost *F*.

$$C_A = C_a \int_0^{\bar{q}} q \ dF(q) \int_{\underline{h}}^{\bar{h}} dG(h) + F = C_a \int_0^{\bar{q}} q \ dF(q) + F \quad (3)$$

Aggregate Company's profits will be then

$$\Pi_{RV} = H - C_A = \int_{\underline{h}}^{\bar{h}} h dG(h) - C_a \int_0^{\bar{q}} q \ dF(q) - F = 0 \quad (4)$$

Assuming that the Company is either owned by the government or regulated by the Water Authority profits have to add up to zero. Aggregate consumer surplus is given by (5)

$$CS_{RV} = \int_0^{\infty} w(x)\,dx \int_0^{\bar{q}} q \;\; dF(q) - \int_{\underline{h}}^{\bar{h}} h \;\; dG(h) \tag{5}$$

And aggregate welfare

$$W_{RV} = \int_0^{\bar{q}} q \;\; dF(q) \; \left\{ \int_0^{\infty} w(x)\,dx - C_a \right\} - F \tag{6}$$

In sum, the benchmark or Status Quo regime is a system where consumers satiate themselves and the Water Company collects no variable revenue but has a fixed income similar to that generated by a tax on real estate property. Costs are also inflexible as water consumption in this model is fixed at θ.

4. Water pricing under Universal Metering (UM)

Under (UM) water meters are installed in all dwellings. The user whose consumption is about to be metered stops paying the fixed rateable fee h and starts paying a fixed monthly fee equal to φh + m. In this case φ represents a discount on the rateable fee h and m represents a metering fee that helps the Company recover metering costs. This new monthly fee gives the consumer the right to consume *qw** units of water per month. If dwellers consume in excess of the threshold they start paying a volumetric charge *a* per unit of water in excess of the threshold. Aggregate Company's revenues are now

$$R_{um} = a\; max\left\{0, \left[w(a) - w^{*} \right] \right\} \int_0^{\bar{q}} q \;\; dF(q) \; + j\,H + m \tag{7}$$

Aggregate Company's costs are given by

$$C_{um} = C_a \;\; w(a) \int_0^{\bar{q}} q \;\; dF(q) \;\; + C_m \int_0^{\bar{q}} dF(q) + F \tag{8}$$

Where C_m represents per dwelling (monthly) metering costs. Assuming that actual water consumption falls above the threshold (i.e $w(a) > w^*$), aggregate Company's profits are then

$$\Pi_{um} = \left[(a - C_a)w(a) - aw^*\right]\int_0^{\bar{q}} q \;\; dF(q) \; + j\,H + (m - C_m) - F \qquad (9)$$

Aggregate consumer surplus and welfare are given by (10) and (11)

$$CS_{um} = \left[aw^* + \int_a^{\infty} w(x)dx\right]\int_0^{\bar{q}} q \;\; dF(q) \; - j\,H - m \qquad (10)$$

$$W_{um} = \left[(a - C_a)w(a) + \int_a^{\infty} w(x)dx\right]\int_0^{\bar{q}} q \;\; dF(q) \; - C_m - F \qquad (11)$$

The Social Planner's problem will be then to find a volumetric charge a_{um} that maximizes consumer surplus subject to the Water Company breaking even[3],

$$a_{um} = \underset{a}{arg\ max}\left\{L = CS_{um} + l\ \Pi_{um}\right\} \qquad (12)$$

The first order conditions for a and m (or H) are

$$a : \left[-w(a) + w^*\right]\int_0^{\bar{q}} q\ dF(q) + l\left\{w(a) + (a - C_a)w'(a) - w^*\right\}\int_0^{\bar{q}} q\ dF(q) = 0 \quad (13)$$

$$m, H: \quad -1 + \ l = 0 \quad then \quad l = 1$$

Replacing in (13) $(a - C_a)\ w'(a) = 0$ and $a_{um} = C_a$ (14)

This result is indicating that marginal cost pricing of the volumetric charge is optimal regardless of the size of the consumption threshold. This was expected as the

[3] Notice that common sense would recommend including a consumer participation constraint. This would prevent the Regulator from setting a rate structure that could cause any dweller to end up having a negative consumer surplus. In reality and unfortunately however this could well happen as water and wastewater service disconnection is normally not allowed once installed.

threshold does not affect welfare (See equation (11)). It is simply a transfer from the Company to the user.

Since the Lagrange multiplier of (12) is grater then zero (λ = 1), (9) is binding then

$$\Pi_{um} = -C_a w^* \int_0^{\bar{q}} q \ \ dF(q) \ + j\,H + (m - C_m) - F = 0 \tag{15}$$

Setting the metering fee m equal to metering costs, $m = C_m$ and equating the Company's profit constraint under (RV) (4) with (15) above, the optimal discount on h (1 - j_{um}) obtains

$$1 - j_{um} = \frac{(1 - w^*)\, C_a \int_0^{\bar{q}} q \ \ dF(q)}{H} > 0 \tag{16}$$

If metering is to be effective $w^* < 1$ and from (16) it is clear that with Universal Metering 1 - $j_{um} > 0$, i.e. once actual consumption is charged, all fixed rateable monthly fees should fall by 1 - j_{um}. In sum, with Universal Metering all users will end up paying a fixed fee $jh + m$ with the right to consume up to w^* of water per month. Any consumption in excess of the basic threshold will be charged a per unit.

5. Water pricing under Optimal Metering (OM)

As opposed to UM, under Optimal Metering (OM) the Social Planner installs meters only in those dwellings where he / she deems there will be an increase in welfare. Again, and borrowing from Chambouleyron (2003), welfare before metering and for a generic dwelling with rateable fixed fee h and demand parameter θ, is given by

$$W_{before} = q \int_0^{\infty} w(x)\ dx - h + (0 - C_a)q \ + h = q \left[\int_0^{\infty} w(x)\ dx - C_a \right] \tag{17}$$

After the meter is installed and metering costs are borne by the company, the consumer starts paying a per unit of water beyond the threshold qw^*. The welfare function becomes

$$W_{after} = q \left\{ aw^* + \int_a^{\infty} w(x)dx \right\} + q\left\{(0-C_a)w^* + (a-C_a)\left[w(a) - w^*\right]\right\} - C_m \quad (18)$$

The change in welfare will be given by

$$\Delta W = q_R^* \left\{ \int_a^0 w(x)\;\; dx + (a-C_a)w(a) - (0-C_a) \right\} - C_m \quad (19)$$

This is, charging the consumer based on actual consumption will bring about an increase in welfare ($\Delta W > 0$), only if the term within brackets is positive and greater in absolute value than the second term on the right hand side of (19). Metering will be welfare enhancing only if the change in the Company's profits more than offset the fall in consumer surplus and metering costs. Of course, this condition will not hold for all dwellings. For a given volumetric charge *a*, metering will make sense in those dwellings where θ is high (many dwellers, garden or pool), whenever water production costs C_a are high, or when metering costs C_m are low. Equating (19) to zero, the cutoff demand parameter θ will be

$$q_R^* = \frac{C_m}{\int_a^0 w(x)\; dx + \left[(a-C_a)\; w(a) - (0-C_a)\right]} \quad (20)$$

This is, the regulator will install meters in those dwellings with demand parameters $\theta > \theta^*_R$. This is, with selective (optimal) metering some dwellings will be metered and some will not. Aggregate water demand with selective metering will be given by

$$w_{om} = \int_0^{q_R^*} q\; dF(q) + w(a)\int_{q_R^*}^{\bar{q}} q\; dF(q) \quad (21)$$

Water demand (and production) will involve serving both kinds of dwellings, those metered and those not metered. Similarly, aggregate water costs will be

$$C_{om} = C_a \left\{ \int_0^{q_R^*} q \; dF(q) + w(a) \int_{q_R^*}^{\bar{q}} q \; dF(q) \right\} + C_m \int_{q_R^*}^{\bar{q}} dF(q) + F \tag{22}$$

Unmetered consumers will pay the rateable fixed fee h and metered consumers will pay φh + m plus *a* per unit of water beyond the threshold. Aggregate revenue will then be given by

$$R_{om} = a\left[w(a) - w^*\right] \int_0^{q_R^*} q \; dF(q) + (j\,H + m) \int_{q_R^*}^{\bar{q}} dF(q) + H \int_0^{\bar{q}} dF(q) \tag{23}$$

Aggregate Company's benefits

$$\begin{aligned} \Pi_{om} = {} & \left[(a - C_a) w(a) - a w^*\right] \int_{q_R^*}^{\bar{q}} q \; dF(q) - C_a \int_0^{q_R^*} q \; dF(q) + \\ & + (m - C_m + j\,H) \int_{q_R^*}^{\bar{q}} dF(q) + H \int_0^{q_R^*} dF(q) - F \end{aligned} \tag{24}$$

Aggregate Consumer surplus

$$\begin{aligned} CS_{om} = {} & \left[a w^* + \int_a^{\infty} w(x) dx \right] \int_{q_R^*}^{\bar{q}} q \;\; dF(q) - \left[j\,H + m\right] \int_{q_R^*}^{\bar{q}} dF(q) + \\ & + \int_0^{\infty} w(x) dx \int_0^{q_R^*} q \;\; dF(q) - H \int_0^{q_R^*} dF(q) \end{aligned} \tag{25}$$

Aggregate welfare will then be given by the sum of (24) and (25)

$$W_{om} = \left[(a - C_a) w(a) + \int_a^{\infty} w(x) dx \right] \int_{q_R^*}^{\bar{q}} q \; dF(q) + \left[\int_0^{\infty} w(x) dx - C_a \right] \int_0^{q_R^*} q \; dF(q) \qquad (26)$$

$$- C_m \int_{q_R^*}^{\bar{q}} dF(q) - F$$

The Social Planner's problem now is to find the volumetric charge, the fixed rateable aggregate fee H (the metering fee m) and the optimal number of meters so that aggregate consumer surplus is maximized subject to the Water Company breaking even.

$$a_{om} = arg \max_a \{ L = CS_{om} + l \; \Pi_{om} \} \qquad (27)$$

The first order conditions with respect to m and a lead to the following expressions:

$$m : - \int_{q_R^*}^{\bar{q}} dF(q) \; + \; l \int_{q_R^*}^{\bar{q}} dF(q) = 0 \quad then \quad l = 1 \qquad (28)$$

$$a : \left\{ \int_0^a w(x) dx - \left[(a - C_a) w(a) + C_a \right] \right\} q_R^* \; f(q_R^*) \frac{\partial q_R^*}{\partial a} + (a - C_a) w'(a) \int_{q_R^*}^{\bar{q}} q \; dF(q) \qquad (29)$$

$$+ C_m \; f(q_R^*) \frac{\partial q_R^*}{\partial a} = 0$$

Besides, and given that

$$q_R^* = \frac{C_m}{\int_a^0 w(x) \; dx + \left[(a - C_a) \; w(a) - (0 - C_a) \right]} \qquad (20)$$

And that[4]

[4] As the volumetric charge a increases (falls) so does the threshold θ meaning that the optimal number of meters is lower (greater). This is easily explained: as a increases (falls), so does the deadweight loss created by the increase in the volumetric charge and metering is (more) less socially desirable

$$\frac{\partial q_R^*}{\partial a} = \frac{-C_m(a-C_a)\ w'(a)}{\left[\int_a^0 w(x)\ dx + \left[(a-C_a)\ w(a) - (0-C_a)\right]\right]^2} > 0 \tag{30}$$

Replace (20) into (29) to get

$$a : (a - C_a) w'(a) \int_{q_R^*}^{\bar{q}} q\ dF(q) - C_m\ f(q_R^*) \frac{\partial q_R^*}{\partial a} + C_m\ f(q_R^*) \frac{\partial q_R^*}{\partial a} = 0 \tag{31}$$

$$a : (a - C_a) w'(a) \int_{q_R^*}^{\bar{q}} q\ dF(q) = 0 \qquad \text{therefore} \qquad a_{om} = C_a \tag{32}$$

Again, the optimal volumetric charge *a* coincides with marginal social cost. The optimal *q* and hence the optimal number of meters under (OM) are shown in Lemma 1.

Lemma 1: Unless $C_m = 0$*, the optimal q under (OM) is strictly greater than zero*

Proof: Replace *a* by C_a in (20) to get

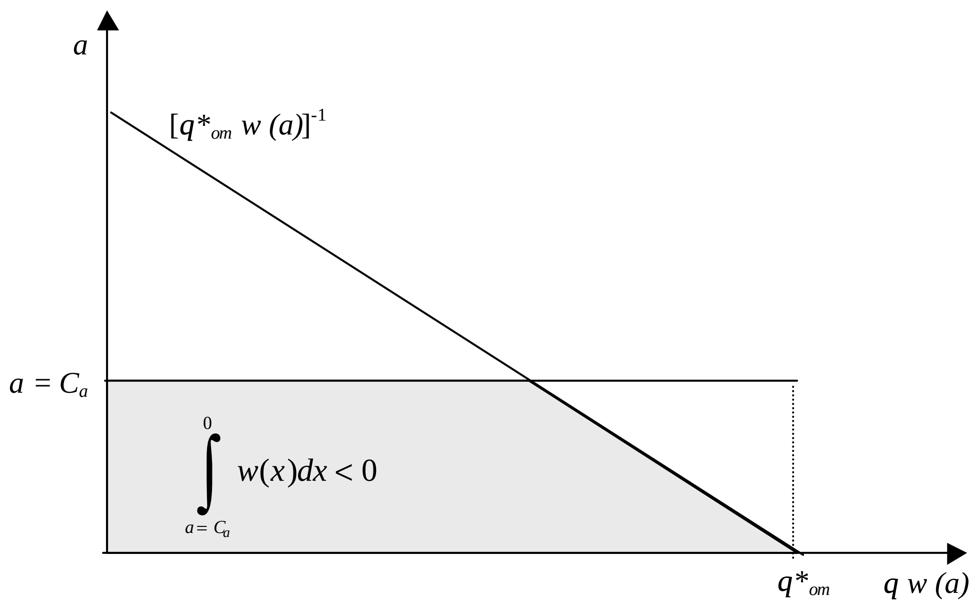
$$q_{om}^* = \frac{C_m}{\int_{a=C_a}^0 w(x) dx + C_a} \tag{33}$$

Rearranging (33) and by definition of q_{om}

$$q_{om}^* \left[\int_{a=C_a}^0 w(x) dx + C_a \right] - C_m = 0 \tag{34}$$

Then unless $C_m = 0$, q_{om} is strictly greater than zero (See Figure 2) Q.E.D

Figure 2: The optimal q under (OM)



Since the Lagrange multiplier in (28) is greater than zero (λ = 1), the profit constraint under (OM) (24) binds. Equating (24) with that under (RV) (15) and assuming that m = C_m, the optimal discount under (OM) 1 - φ_{om} obtains

$$1 - j_{om} = \frac{(1-w^*)\, C_a \int_{q^*}^{\bar{q}} q \; dF(q)}{H \int_{q^*}^{\bar{q}} dF(q)} > 0 \qquad (35)$$

Under (OM) all metered connection will receive a discount of 1 - j_{om} on their rateable fixed fee h.

6. Universal (UM) vs. optimal metering (OM)

Subtracting (11) from (26) and keeping in mind that in both models a = C_a

$$\Delta W = \int_0^{C_a} w(x)dx \int_0^{q_R^*} q \; dF(q) - C_a \int_0^{q_R^*} q \; dF(q) + C_m \int_0^{q_R^*} dF(q) = \Delta CS \qquad (36)$$

The first term of the right hand side of equation (36) is positive but the second term is negative and greater than the first in absolute value (See Figure2). Therefore, optimal metering will bring about an increase in welfare whenever the savings in metering costs under (OM) relative to (UM) (third term on the right hand side of (36)) more than outweigh the first two terms on the right hand side of (36).

The first term in (36) represents the increase in consumer surplus as the volumetric charge falls from $a = C_a$ to zero but only for those users that are not metered in the optimal metering scheme but are under universal metering. The flip side of this increase in consumer surplus is the increase in water costs as a result of the increase in consumption also as a goes from C_a to zero for the same users that are metered under UM but not under OM. As can be seen from Figure 2 this difference is negative for $a = C_a$ and optimal metering will bring about an increase in welfare as long as the savings in aggregate metering costs are high enough to compensate for this loss.

7. Water pricing under Decentralized Metering (DM)

Chambouleyron (2003)designed an incentive mechanism whereby the Company can install the socially optimal number of meters in a decentralized way. Assume that the Company is faced with the following regulation[5]

Box 1: If the firm chooses where to install a meter then:

i. The regulator sets $\varphi = 1$

ii. The firm pays $q\left[\int_0^a w(x)dx - aw^*\right]$ to the user to be metered

iii. The company incurs C_m

This is, the government does not allow discounts on the fixed rateable fee h ($\varphi = 1$). It furthermore obligates the Company to pay the user a compensation for the fall in consumer surplus as a result from metering his consumption and also prohibits the firm from recovering metering costs through the specific fee m (i.e m = 0 in this mechanism).

[5] See Chambouleyron (2003) for further details. This article shows that this mechanism can be materialized in practice through a Coasian approach that assigns property rights over the pricing regime.

Faced with this restriction, Chambouleyron (2003, *Lemma 3*) shows that the Company will install the socially optimal number of meters because it internalizes the fall in consumer surplus, this is

$$q_F^* = \frac{C_m}{\left[(a - C_a)\, w(a) - (0 - C_a)\right] + \int_a^0 w(x)\, dx} = q_R^* \tag{37}$$

At the aggregate level, the firm will set the volumetric charge *a* that maximizes profits subject to an aggregate version of the user compensation restriction in Box 1. The profit function now is similar to (24) but with m = 0 and φ = 1. Hence, the Company's problem will be

$$\max_{a,T} \left\{ \left[(a - C_a) w(a) - a w^*\right] \int_{q_F^*}^{\bar{q}} q\, dF(q) - C_a \int_0^{q_F^*} q\, dF(q) + \right. \\ \left. + (H - C_m) \int_{q_F^*}^{\bar{q}} dF(q) + H \int_0^{q_F^*} dF(q) - F - T \right\} \tag{38}$$

$$\text{subject to} \quad T \geq \left[\int_0^a w(x) dx - a w^* \right] \int_{q_F^*}^{\bar{q}} q\, dF(q) \tag{39}$$

The F.O.C's of this problem with respect to T and *a* and assuming that λ is the shadow price of restriction (39), are the following

$$T: \; -1 + l = 0 \quad \text{therefore} \quad l = 1$$

$$a: (a - C_a) w'(a) \int_{q_F^*}^{\bar{q}} q\, dF(q) + \left\{ \int_0^a w(x) dx - \left[(a - C_a) w(a) + C_a\right] \right\} q_F^* \; f(q_F^*) \frac{\partial q_F^*}{\partial a} + \\ + C_m \; f(q_F^*) \frac{\partial q_F^*}{\partial a} = 0$$

Since $q_F^* = q_R^*$ and $\frac{\partial q_F^*}{\partial a} = \frac{\partial q_R^*}{\partial a}$, then replacing in the F.O.C above

$$a:(a-C_a)w'(a)\int_{q_F^*}^{\bar{q}} q\ dF(q)-C_m\ f(q_F^*)\frac{\partial q_F^*}{\partial a}+C_m\ f(q_F^*)\frac{\partial q_F^*}{\partial a}=0$$

$$a:(a-C_a)w'(a)\int_{q_R^*}^{\bar{q}} q\ dF(q)=0 \qquad \text{Therefore} \qquad a_{dm}=C_a \tag{40}$$

And the optimal cutoff θ (and hence the optimal number of meters) coincides with the socially optimal,

$$q_{om}^*=q_{dm}^*=\frac{C_m}{\int_{a=C_a}^{0} w(x)dx+C_a}>0 \tag{41}$$

If the Company charges C_a per unit of water consumed beyond the threshold and eliminates m ¿How does it finance now water metering costs C_m? The following Lemma shows how.

Lemma 2: Under DM, the Company completely finances metering costs C_m through the elimination of the discount (1 - j) on the fixed rateable fee h.

Proof: Totally differentiating Π_{om} (24)

$$d\Pi_{om}=\frac{\partial \Pi_{om}}{\partial m}dm+\frac{\partial \Pi_{om}}{\partial j}dj$$

Following the incentive mechanism of Box 1, the variations in m and φ are (0 – m) and (1 - φ) respectively, then

$$d\Pi_{om}=\int_{q_R^*}^{\bar{q}} dF(q)\ \ (0-m)+H\int_{q_R^*}^{\bar{q}} dF(q)\ \ (1-j)$$

As m → 0 and φ → 1, the variation in the Company's profits

$$d\Pi_{om} = \int_{q_R^*}^{\bar{q}} dF(q)\ \left[H(1-j) - m\right] \to 0 \qquad (42)$$

And the Company finances metering costs exactly out of the elimination of the discount (1 - φ) on the fixed rateable fee h keeping consumer surplus constant Q.E.D

In sum, under (DM) the Company installs the socially optimal number of meters because it is forced by the regulation to internalize the damage it imposes on the users: the fall in their consumer surplus. To be able to do this, the Company has to eliminate the metering fee m that it charges under (OM) and it also has to eliminate the discount 1 - φ on the fixed rateable fee h. It turns out however that the elimination of m is exactly offset by the elimination of the discount 1 - φ as *Lemma 2* shows leaving consumer surplus constant and financing metering costs out of the elimination of the discount on h. The optimal water rate a is again equal to marginal cost and the optimal number of meters coincides with that under (OM).

8. Conclusions and recommendations for policy makers

The results of the analysis indicate that should water consumption be metered at all, marginal cost pricing of water (and eventually wastewater too) should be the default recommendation to policymakers and Water Authorities. Whether these should decide to follow decentralized or decentralized metering policies, marginal cost pricing should be the rule. The recovery of metering costs however depends on the mechanism selected by the authorities. Under (UM) and (OM) the optimal policy recommends recovering metering costs through a fixed fee m paid by the final user but at the same time it imposes a discount of (1 - φ) on the fixed rateable fee h that metered users pay. Finally, under (DM) the discount on h is eliminated but m is also eliminated keeping consumer surplus unchanged and recovering metering costs through the elimination of (1 - φ).

Even though all metered regimes recommend pricing at marginal cost and allow the recovery of metering costs through fixed fees not all mechanisms induce the installation of the optimal amount of meters. Universal metering will be optimal as long as metering costs are low enough to compensate for two factors. On one hand the fall in consumer surplus imposed on those consumers that are metered under (UM) but would not be metered under (OM). And on the other hand, the extra reduction in water costs caused by (UM) on those connections that would not be metered under

(OM) but are under (UM). The final outcome of course will depend on the ratio of metering costs to consumer surplus change plus unitary water costs (equation (20))

Both (OM) and (DM) induce the socially optimal amount of meters to be installed but only (DM) does it in a decentralized way. In countries without reliable institutions such as developing countries it is always advisable to rely on market forces rather than powerful bureaucrats that may be prone to corrupt practices. Chambouleyron (2003) designed an incentive mechanism that, under some regulations, lets the Company and the user reach the efficient outcome by bargaining over a compensation to be received by the user to be metered. This mechanism can be easily implemented by giving the user the property right over the charging regime and at the same time giving him the ability to sell that right to the Water Company in exchange of a payment or compensation. Chambouleyron (2003) shows that the outcome of this bargaining game is Pareto superior to the Status Quo and depending on the relative levels of information, the socially optimal number of meters can be installed in a decentralized way.

This paper showed that besides inducing the socially optimal installation of meters, the mechanism induces the firm to price water services at marginal cost reaching the efficient solution in a decentralized way.

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