An Incentive Mechanism for Decentralized Water Metering Decisions

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Abstract

Metering water consumption has been long advocated by economists in developing countries as a way to curb waste and prevent resource depletion. However, very few of these economists have studied the inefficiencies brought about by universal metering or the conditions under which decentralized water metering decisions are optimal. If the decision where to install water meters rests on either the consumer or the Company providing the service this paper shows that if left unregulated, both the consumer's and the Company's decentralized water metering decisions are sub-optimal. This is because the firm when installing meters, does not take into account the fall in consumer surplus and the consumer, when voluntarily installing a meter in his dwelling, does not take into account the effect of his decision on the Company's profits. To solve this externality problem and make the decentralized decision optimal, an incentive mechanism is proposed. The mechanism works through a series of Pigouvian taxes imposed by the regulator on the party creating the externality. By means of these taxes, externalities are internalized and both the consumer and the Company reach the socially optimal solution in a decentralized way. The implementation of this mechanism in practice is materialized through a Coasian property rights approach where the parties involved reach the efficient solution by bargaining over welfare gains. The party installing the meter has to buy the "right to meter" from the metered party by fairly compensating him thus internalizing the externality and reaching the efficient outcome. To illustrate the incentives involved in metering water consumption, the rate structure and metering policies of two water concessions in Argentina are studied: Buenos Aires and Córdoba. Conclusions and policy recommendations are drawn from the theory and the two practical cases.

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

JEL Classification L95

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1. Introduction

Pricing a natural resource such as water is no easy task. First it is hard to establish how much consumers are willing to pay for it. Generally the decision to have running water and sewerage services is not made by the user but collectively by a group of users (neighborhood) or mandated by the local government. If this is the case then it is not generally correct to speak of access demand given a price. Besides, service disconnection is often not allowed once installed. Second it is hard to determine an opportunity cost for this resource in case of shortages. This is so because the opportunity cost of water depends on several factors such as source of extraction (i.e wells, rivers etc.) the region climate and the resource relative abundance. Finally, water consumption may involve hard – to - measure externalities. An excessively low consumption may endanger population health contributing to the spread of infectious and parasitic diseases like cholera and diarrhea[1]. On the other hand, a high level of consumption can cause a drop in the level of water reservoirs hampering service continuity in hot seasons.

When users consume water, they do not consider the effect of this consumption on future resource availability, nor do they internalize their decision on the consumption level of others. If water services are not charged based on actual consumption, the user lacks an incentive to curb consumption and consequently may incur in waste. In these cases, prices act by signaling the consumer the relative abundance of this resource. At times of scarcity (drought), the price of the resource should be higher to ration consumption and reflect the situation of relative shortage.

The price reflecting the resources that must be committed by society for the production of one additional unit of water is marginal cost. Only in the event that society is willing to pay the cost of producing and distributing the last cubic meter of water, must it be produced. What are the defining concepts of marginal cost? 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). The literature on water pricing and costs is vast and it is not the purpose of this article to review it but a deep study on this subject should

[1] Alberini et al. (1996) show that a reliable water service (i.e. with a low number of interruptions) matters more than water quality when trying to prevent diarrheal disease in Jakarta, Indonesia

include Turvey (1976), IBRD (1977[a,b]), Albouy (1983), OECD (1987), and Elnaboulsi (2001).

Currently in most Argentine provinces[2] (as in several other countries) water services are charged following a rateable value system based on the physical features of the dwelling like covered area, total area, land price, age of the building etc. This rate scheme has several problems: Since real consumption is not charged, customers consume until their willingness to pay is equal to the marginal price (zero) and incur in waste. It also fails when trying to detect leaks in pipes which leads to overproduction of water and waste. It also generates a thick weave of cross subsidies among customers sometimes with no relationship with willingness to pay. Lastly, the rateable fee may be greater than the utility the consumer gets from the service. Since the rateable fee has no relationship with actual water consumption and since service disconnection is not allowed, the user may end up getting a negative net utility level from the service (i.e. utility from water and sewerage services – rateable monthly fee < 0).

Since this rate structure is so inefficient several provincial and municipal governments are imposing mandatory universal metering[3]. However, universal metering is expensive and may not even be justified on economic grounds. If the decision to meter is not the consequence of a careful benefit - cost analysis, metering consumption may entail a reduction in consumer surplus, an increase in deadweight loss and an increase in metering costs that may more than offset any reductions in water production costs. If this is the case, then metering is not a profitable investment and should not take place[4].

This paper addresses many important issues on the economics of water metering, namely when to meter, whom to meter, who should bear the cost of metering and who should decide when and where to meter. The paper proceeds as follows: Section 2 lays the main argument, this is when to meter. Section 3 deals with the question of who should be and who should not be metered and more importantly who should make the decision to meter. This section shows that, if left unregulated, both the consumer's and the firm's water metering decisions are sub-optimal. Section 4 introduces an incentive mechanism whereby decentralized decisions become optimal and Pareto efficiency is restored. Section 5 presents a Coasian property rights approach

[2] See IADB (1996) for an analysis of water concessions in Argentina.
[3] This is the case of (among others) Córdoba, Mendoza, Corrientes and Buenos Aires
[4] OFWAT (2001) recommends metering only "…when it is cheap or economic to do so..." for example in houses with gardens or pools. OFWAT does not advocate universal metering (2001, pp.40)

where both the firm and the user can reach the optimal solution through bargaining. Lastly, Section 6 illustrates two practical cases of water concessions in Argentina. The paper concludes in Section 7 by making policy recommendations drawing from the theory and the two practical cases.

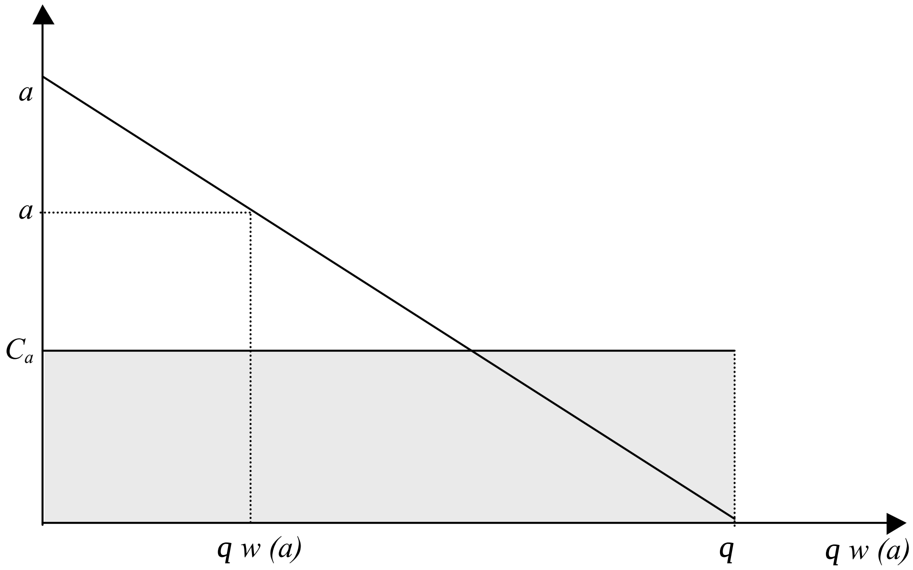
2.Theoretical background

There is a firm that provides water services to a city with N dwellings, each of which has a water demand function of $\boldsymbol{q}\ w(a)$ where $\boldsymbol{q}$ is a demand parameter (say, the number of dwellers or square feet of garden per house) and $w(a)$ £ 1 is the unitary water demand function (i.e per dweller or per square foot of garden). 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 (presumably with φ < 1) and a volumetric charge of a [\$ / m^3] for water consumption (and eventually sewage generated and treated too) in excess of a threshold $\boldsymbol{q}\ w^*$. If the dwellers consume less than $\boldsymbol{q}\ w^*$, they will only be charged the fixed fee φh. If they consume more than the allowed threshold, they will be charged for consumption in excess of the threshold, $\mathrm{T}(a) = \boldsymbol{j}\ h + \boldsymbol{q}\ a\,(\max\,[0,\,(w(a) - w^*)])$. 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. This cost represents the per dwelling incremental cost brought about by metering this specific dwelling.

When water consumption is not metered, 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 costs discussed in the Introduction and is assumed constant for simplicity. Figure 1 illustrates the water demand level of a dwelling with consumption parameter θ and for different values of the volumetric charge a.

Before metering, dwellers reach their satiation levels θ as marginal consumption is free. When the meter is installed, dwelling consumption falls to $\boldsymbol{q}\ w(a)$. The shaded rectangle in Figure 1 shows pre metering water production costs θ C_a per dwelling. Before metering the Company may or may not recover these variable costs through the fixed rateable charge since this charge has no relationship with actual water consumption and may well be below or above the true costs of providing the service.

Figure 1: Change in demand with metering

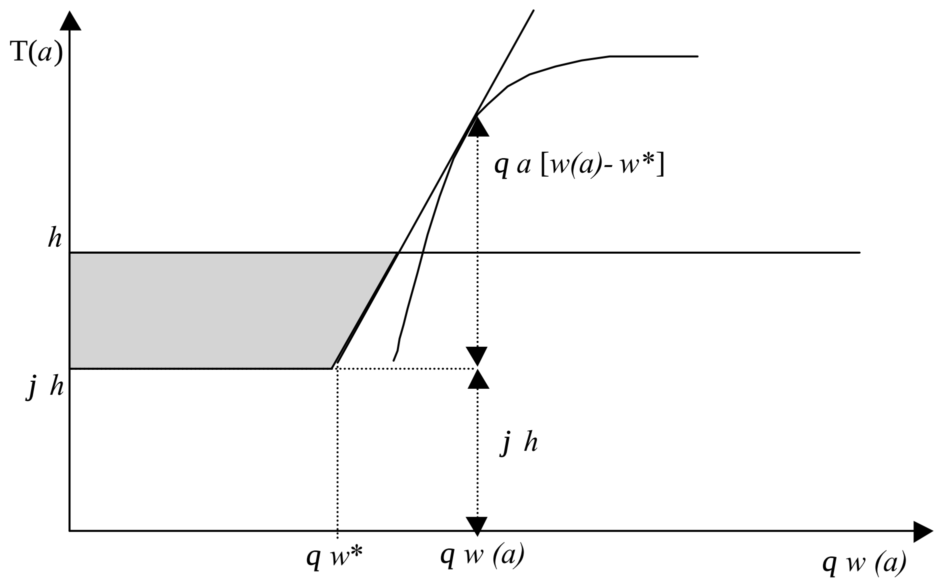


The fixed rateable monthly fee h $\in \left[\underline{h}, \overline{h}\right]$ is distributed with density g(h) and cumulative density G(h). The form of these distribution functions will depend on the distribution function of the variables underlying the calculation of the rateable fee h such as covered area of the building, lot size, land price etc. Demand parameter θ $\in \left[0, \bar{q}\right]$ 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 functions as they should follow the distribution of, say, the number of inhabitants per house in any specific city. The analysis is general enough to allow for any specific form of these distribution functions. θ is assumed conditional on h because as h increases (presumably because the house is larger or because it has a garden) average θ should also increase as satiation levels (after the meter has been installed) should be higher. If the demand parameter θ is related to the number of dwellers or to the square feet of garden, it is reasonable to assume that a larger house (higher h) will have a higher water demand. The total number of water connections the Company has (both metered and unmetered) will be given by (1):

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

The monthly payment T(a) collected by the Company is illustrated in Figure 2 for a dwelling with metered monthly consumption θ *w(a)* **in excess** of the allowed threshold ***q*** *w**, rateable monthly charge h before metering and φh after the meter has been installed (with φ presumably less than 1). When dwellers consumed below the threshold they were charged only the fixed rateable fee h. After the meter has been installed, dwellers consume at a point where their indifference curve is tangent to the monthly payment curve (per unit price equal to marginal willingness to pay). They will pay the Company an amount of money equal to the vertical distance between the horizontal axis (at θ *w(a))* and the tangency point.

Figure 2: Monthly payment T(***a*** **) before and after metering**



2.a. The decision to meter consumption

The decision whether or not to install a meter depends on who makes the decision. If that decision is left to a regulator with perfect information he / she will install meters in those dwellings that bring about an increase in marginal welfare. For a generic dwelling with rateable monthly fee h and demand parameter θ (both known by the regulator), welfare before metering will be

$$W_{before} = q \int_{0}^{\infty} w(x)\, dx - h + (0 - C_a)q + h = q \left[\int_{0}^{\infty} w(x)\, dx - C_a \right] \qquad (2)$$

After the meter is installed with metering costs borne by the Company and actual consumption charged beyond the allowed threshold, welfare becomes

$$W_{after} = q \left\{ \int_0^\infty w^* \, da + \int_a^\infty \left[w(x) - w^* \right] dx \right\} - f \; h + q \; \left\{ (0 - C_a) w^* + (a - C_a) \left[w(a) - w^* \right] \right\} + f \; h - C_m$$

(3)

The variation in welfare will be given by

$$\Delta W = q \left\{ a w^* + \int_a^0 w(x) \, dx - C_a w^* + C_a q + (a - C_a) \left[w(a) - w^* \right] \right\} - C_m \qquad (4)$$

Rearranging,

$$\Delta W = q \left\{ \int_a^0 w(x) \, dx + (a - C_a) w(a) - (0 - C_a) \right\} - C_m = q \; DWL(a) + q \; C_a - C_m$$

(5)

This is, charging the consumer based on actual consumption will bring about an increase in welfare $(DW > 0)$, only if water production costs before metering $(\theta \;\; C_a)$ were high enough to compensate for the dead weight loss ($DWL(a) < 0$) created by the increase in the volumetric charge and metering costs (C_m). Obviously, this condition will not always hold. For a given volumetric charge a, metering will make sense in those dwellings where water consumption was high (q is high), whenever water production costs C_a are high, or when metering costs C_m are low. The cutoff demand parameter θ will be

$$\Delta W = 0 = q_R^* \left\{ \int_a^0 w(x) \, dx + (a - C_a) w(a) - (0 - C_a) \right\} - C_m = 0 \qquad (6)$$

The term within brackets in (6) has to be positive, which in turn means that for metering to be welfare enhancing ($DW > 0$), the increase in the Company's marginal profits has to more than offset the fall in consumer surplus and metering costs C_m. The higher the $q_R{}^*$ in (6) the more positive the equation will be and the greater will be the welfare gains brought about by metering.

Solving for the cutoff $q_R{}^*$,

$$q_R^* = \frac{C_m}{\int_a^0 w(x)\, dx + [(a - C_a)\, w(a) - (0 - C_a)]} \tag{7}$$

Meters should be installed in all dwellings with $q > q_R{}^*$. In these dwellings, the increase in the Company's marginal profits will more than offset the fall in consumer surplus and metering costs bringing about an increase in welfare. The optimal number of meters from the regulator's perspective will be

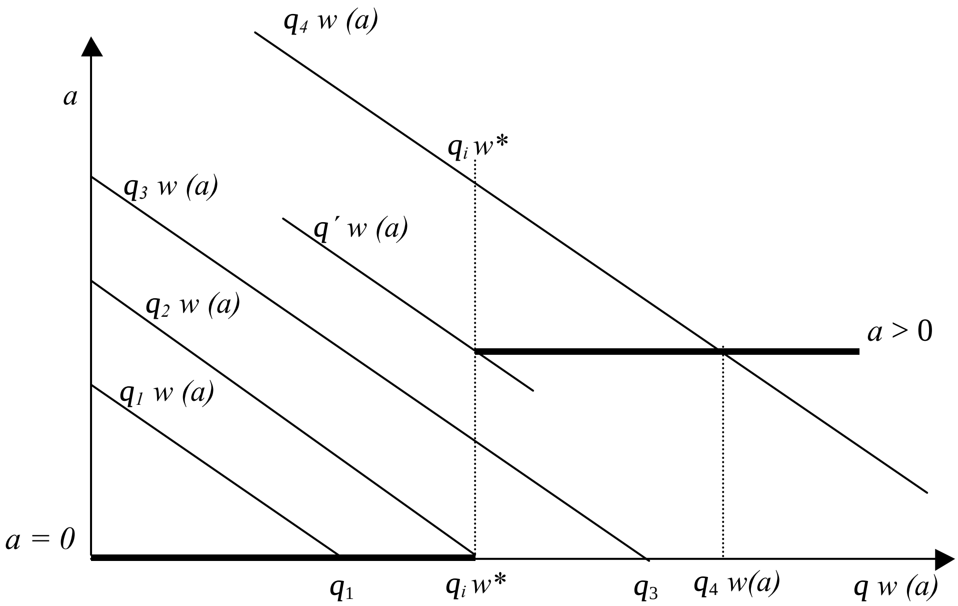
$$N_m^R = N \int_{\underline{h}}^{\overline{h}} \left\{ \int_{q_R^*}^{\overline{q}} dF(q \;/ h) \right\} dG(h) \tag{8}$$

Furthermore, if (ex ante) satiation levels fell below or at the minimal threshold w^* it would not make sense to meter. The following Lemma demonstrates this more formally.

Lemma 1: For dwellings with ex – ante satiation levels below or at the threshold , q^*_R ® ¥ and $N^R{}_m$ ® 0, then no meters should be installed.

Proof: Given the existence of the threshold q_i w^* for each kind of dwelling, there are four cases to be studied and these are illustrated in Figure 3. The figure shows demand functions for four kinds of dwellings compared to a generic threshold q_i w^*: q_1 that falls below its threshold, q_2 that falls right on the threshold, and q_3 and q_4 that fall above it. Since the marginal rate $a = 0$ below the threshold, type q_1 consumers will consume water until they are satiated at q_1. q_2 consumers will also reach satiation but right at their threshold level q_2 w^*. Type q_3 consumers will also consume at the threshold but they will not reach satiation because to be able to do that they should pay a marginal water rate a greater than their willingness to pay. Only type q_4 consumers will consume above the threshold because only they can afford the marginal water rate.

Figure 3: Consumption below and above the threshold



To prove Lemma 1 we need to analyze case by case. It is clear that for type q_1 consumers, no meters should be installed as consumption would not fall. This type of consumers will consume at their satiation level because they still face a marginal water rate equal to zero and $w(a) \Rightarrow 1$. More formally and with the help of (7) we have that

$$q_R^* = \frac{C_m}{\int_0^0 w(x)\, dx + \left[(0 - C_a) - (0 - C_a)\right]} \rightarrow \infty \tag{9}$$

Therefore $N^R{}_m \rightarrow 0$ Q.E.D

The same result applies to type q_2 consumers. These will also reach satiation as they also face a marginal rate of zero. This result is indicating that *universal metering is incompatible with uncharged consumption thresholds. Dwellings with ex - ante satiation levels at or below the threshold should not be metered.* Put differently, if regulators want to meter they should never set thresholds above satiation levels.

Type q_3 consumers however do reduce their consumption levels when the meter is installed. Before metering, they satiated themselves at q_3 but after metering they cut consumption down to the threshold w^*q_3. This is because they cannot afford the marginal water rate a set by the regulator (a is above their willingness to pay). Since there is indeed a reduction in consumption, for some of these consumers metering will make sense. For type q_3 consumers the cutoff type looks like the following:

$$q_R^* = \frac{C_m}{\int_0^0 w(x)\,dx + [(0-C_a)w^* - (0-C_a)]} = \frac{C_m}{C_a(1-w^*)} \tag{10}$$

The optimal number of meters will depend on the ratio of the costs involved and the threshold level. The higher metering costs, the lower water production costs and the higher the threshold, the fewer meters should be installed and vice versa. For type q_4 consumers the cutoff type will be exactly the same as in (7).

3. Decentralized metering decisions

Now assume that the regulator sets the thresholds below satiation levels $(q\ w^* < q\ w\ (a))$ and decides to leave the decision on where to install meters to the Company or the consumer because he / she lacks complete information. Moreover assume that the Company and the consumers have full information on demand parameters. It is easy to show that neither of the decentralized alternatives leads to a socially optimal solution.

Lemma 2: If left unregulated, both the consumers and the Company will install a sub–optimal number of meters

Proof**:** If the Company providing the water service is in charge of deciding where to install meters, it will do so by choosing to meter those dwellings that will increase its profits. Therefore, for a dwelling with rateable fixed charge h and a demand parameter θ, the Company's benefits before metering consumption will be:

$$p_{before} = h + (0 - C_a)q \tag{11}$$

After incurring C_m and charging consumption above the threshold, the Company's marginal profits are:

$$p_{after} = q\ \{(0-C_a)w^* + (a-C_a)\,max\,[0, w(a)-w^*]\} + j\ \ h - C_m \tag{12}$$

The change in Company's marginal profits,

$$\Delta p = q \left\{(a - C_a)\ w(a) - aw^{*} - (0 - C_a)\right\} - (1 - j)h - C_m \tag{13}$$

And the cutoff demand parameter q^{*}_{F},

$$\Delta p = 0 = q_F^{*} \left\{(a - C_a)\ w(a) - aw^{*} - (0 - C_a)\right\} - (1 - j)h - C_m = 0 \tag{14}$$

If φ is ≤ 1, the term within brackets in (14) has to be positive meaning that the higher the q_F^{*}, the higher the Company's increase in marginal profit and therefore the more the incentive to meter consumption. Solving for the cutoff q_F^{*},

$$q_F^{*} = \frac{C_m + (1 - j)h}{\left[(a - C_a)\ w(a) - (0 - C_a)\right] - a\ w^{*}} \neq q_R^{*} \tag{15}$$

For each value of h and for a given marginal rate a, the Company will install meters in those dwellings with $q > q^{*}_{F}$. It can be easily seen that for φ = 1, $q_F^{*} < q_R^{*}$ and the firm's optimal number of meters N_F^{m} will be larger than the optimal N_R^{m}. That is, the firm will install more meters than socially optimal[5]. The optimal number of meters from the Company's point of view is now

$$N_m^F = N \int_{\underline{h}}^{\bar{h}} \left[\left\{ \int_{q_F^{*}}^{\bar{q}} dF(q/h) \right\} \right] dG(h) > N_m^R \qquad \text{Q.E.D} \tag{16}$$

The Company will install a sub-optimal number of meters, because when switching to the metered regime, it does not take into account the fall in consumer surplus caused by the increase in the marginal water rate a (an externality). The Company however, could offer the consumer a reduction in h (through φ) that could offset the fall in consumer surplus and make the consumer voluntarily accept the change in regime. But the Company has no incentive to do so because lowering h causes a first order fall in the firm's revenues and profits.

[5] See Appendix for a formal proof

The second part of Lemma 2 is demonstrated as above but in this case for the consumer. This one will have the Company install a meter in his dwelling and start paying for actual consumption as long as he experiences an increase in consumer surplus. Before metering consumer surplus is

$$CS_{before} = q \int_{0}^{\infty} w(x)\, dx - h \tag{17}$$

After having the meter installed and payed m to the Company for metering costs, the consumer gets

$$CS_{after} = q \left\{ \int_{0}^{\infty} w^* \, da + \int_{a}^{\infty} \left[w(x) - w^* \right] dx \right\} - j\ h - m \tag{18}$$

The change in consumer surplus and equilibrium condition will be given by

$$\Delta CS = q^*_C \left\{ aw^* + \int_{a}^{0} w(x)\, dx \right\} + (1 - j\,)h - m = 0 \tag{19}$$

The term within brackets in (19) has to be negative and the only way there can be an increase in consumer surplus will be through a decrease in the fixed charge (φ < 1). The reduction in h (through φ) should be high enough to offset the term within brackets and meter charges m. It is also clear from (19) that for those dwellings with $q > q^*_C$ installing a meter would entail a fall in consumer surplus (equation (19) becomes more negative). Consumers will therefore voluntarily install meters in those dwellings with $q < q^*_C$ as long as there is a reduction in the fixed charge h (φ > 0). Otherwise no voluntary meter take – up will take place. The optimal cutoff θ from the consumer's point of view will be

$$q^*_C = \frac{(1 - j\,)h - m}{\int_{0}^{a} w(x)\, dx - aw^*} \neq q^*_R \tag{20}$$

Again, if it is up to the Company to offer a reduction in the fixed charge h to have some users switch to the metered regime it will not happen. This is because a reduction in h causes a direct reduction in the Company's revenues and benefits. The optimal number of meters from the consumer's perspective and assuming a reduction in the fixed charge h is given by

$$N_m^C = N \int_{\underline{h}}^{\bar{h}} \left\{ \int_0^{q_C^*} dF(q/h) \right\} dG(h) \neq N_m^R \qquad \text{Q.E.D} \qquad (21)$$

Here the difference stems from another externality: when choosing where to meter the consumer does not take into account the fall in water production costs or the increase in the Company's marginal profits brought about by the decrease in consumption (and the increase in the marginal water rate). He only cares about the impact of the new regime on consumer surplus so he acts accordingly. Here there is a clear conflict between the Company and the user: for the latter to voluntarily switch to the metered regime he needs a cut in the monthly fee h but a reduction in h will entail a first order fall in revenues and profits for the Company. If the decision to set φ is left to the firm, there will be no discounts and no consumers will voluntarily switch.

4. An Incentive Mechanism

So far it was demonstrated that without any kind of intervention by the regulator the decentralized decisions are sub – optimal. Only by sheer chance can the three thetas coincide and this is because there are externalities involved in metering water consumption. How can the decentralized decisions be optimal? The natural answer to this question would be to make both agents internalize the externalities. Only in this case would the three solutions coincide.

Lemma 3: Under the incentive mechanism the firm will install the socially optimal number of meters

Proof: Assume that the regulation establishes that the firm is responsible for choosing where to meter but at the same time it has to comply with the following demands. It has to compensate the user for the fall in consumer surplus and it has to pay for metering costs. Box 1 illustrates the payments involved.

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

If the firm proceeds as the regulation establishes then, for a generic dwelling:

$$p_{before} = h + (0 - C_a)q \tag{22}$$

After incurring metering costs and compensating the user for the fall in consumer surplus, the firm gets:

$$p_{after} = q\left\{(a - C_a)w(a) - aw^* - \int_0^a w(x)\,dx + aw^*\right\} + h - C_m \tag{23}$$

The change in the Company's marginal profits and the equilibrium condition will be given by

$$\Delta p = q_F^*\left\{(a - C_a)\,w(a) - (0 - C_a) - \int_0^a w(x)\,dx\right\} - C_m = 0 \tag{24}$$

Again, solving for the cutoff θ,

$$q_F^* = \frac{C_m}{\left[(a - C_a)\,w(a) - (0 - C_a)\right] + \int_a^0 w(x)\,dx} = q_R^* \tag{25}$$

And the decentralized decision becomes socially optimal. The trick here was to make the firm internalize the externalities created by the increase in the marginal water rate a. The regulator set a Pigouvian tax to the firm equal to the externality it created thus internalizing the cost it imposed on the consumer.

Now, what about the consumer? Is he better off with this incentive mechanism? It turns out that he is the same off as he was before metering generating a Pareto optimal allocation of resources. The changes in consumer surplus is calculated now as

$$CS_{before} = q \int_0^\infty w(x)\, dx - h \tag{26}$$

$$CS_{after} = q \left\{ aw^* + \int_a^\infty w(x)\ dx + \int_0^a w(x)\ dx - aw^* \right\} - h \tag{27}$$

$$CS_{after} = q \left\{ \int_a^0 w(x)\ dx + \int_0^\infty w(x)\ dx + \int_0^a w(x)\ dx \right\} - h \tag{28}$$

$$CS_{after} = q \int_0^\infty w(x)\, dx - h \tag{29}$$

$$\Delta CS = q \int_0^\infty w(x)\, dx - h - q \int_0^\infty w(x)\, dx + h = 0 \qquad \text{Q.E.D} \tag{30}$$

Under the incentive mechanism the consumer is the same off as before metering reaching the efficient solution.

Lemma 4: Under the incentive mechanism the user will choose to install a meter in his dwelling only if it is socially optimal to do so

Proof: Now if it is the consumer who is entitled to choose whether or not to install a meter, then the regulation should establish the following rules: the firm must reimburse the consumer with any increases in profits brought about by metering. Also the consumer should pay for metering costs himself and there should be no discounts in the monthly fixed charge h. Box 2 illustrates the side payments involved.

Box 2: If the consumer chooses where to meter then:

i. The regulator sets φ = 1

ii. The user gets a refund of $q\ \{[(a-C_a)w(a)-(0-C_a)]-w^*a\}$ from the firm

iii. The user pays for metering costs through m

Consumer surplus before metering will be again

$$CS_{before} = q\int_0^{\infty} w(x)\,dx - h \tag{31}$$

After receiving the payment from the Company and paying for metering costs through m, the consumer gets

$$CS_{after} = q\left\{aw^* + \int_a^{\infty} w(x)\,dx + [(a-C_a)w(a)-(0-C_a)] - aw^*\right\} - h - m \tag{32}$$

And assuming that $m = C_m$ the equilibrium condition is given by

$$\Delta CS = q_C^*\left\{\int_a^{0} w(x)\,dx + [(a-C_a)w(a)-(0-C_a)]\right\} - C_m = 0 \tag{33}$$

Solving for the cutoff θ,

$$q_C^* = \frac{C_m}{[(a-C_a)\ w(a)-(0-C_a)] + \int_a^{0} w(x)\,dx} = q_R^* \tag{34}$$

And the decentralized decision becomes socially optimal. In addition, the firm ends up the same off as before metering generating a Pareto increase in welfare. The firm gets before metering

$$p_{before} = h + (0 - C_a)q \qquad (35)$$

And after reimbursing the user with the increase in marginal profits it gets

$$p_{after} = q\ \{(a - C_a)w(a) - aw^* - (a - C_a)w(a) + (0 - C_a) + aw^*\} + h - C_m + m \qquad (36)$$

$$p_{after} = h + q(0 - C_a) \qquad (37)$$

$$\Delta p = q\ (0 - C_a) - q\ (0 - C_a) + h - h = 0 \qquad \text{Q.E.D} \qquad (38)$$

Again, optimality is restored. The mechanism induces both parties to reach the socially optimal solution in a decentralized way by means of mutual compensations.

5.A Coasian property rights approach: information asymmetries

The key in achieving the optimal solution through a decentralized mechanism was to make both the firm and the user internalize the externalities that they created. In theory this is a very simple thing to do as it was demonstrated. The problem arises when trying to implement this mechanism in practice since the firm has no way of calculating consumer surplus to then write a check for that amount to the user whose consumption is about to be metered. Nevertheless, this is a typical externality problem that can be solved using a Coasian property rights approach. This is because property rights over charging regimes can be easily assigned to either party and the transaction costs involved in bargaining are very low. In this scenario there are only two agents involved: the Company and the user and bargaining between them is relatively easy and unexpensive.

Suppose that the firm is responsible for deciding where to install meters but following the rules set by the regulator in Box 1. That is, set $\varphi = 1$, compensate the consumer for the fall in consumer surplus and incur metering costs. Suppose furthermore that the consumer has the right to stay with the rateable value system if he / she so wishes. That is, no one can make the consumer switch to the metered regime if he / she does not wish to do so. At the same time however, the user can give up that right and switch to the metered regime in exchange for a payment from the Company. This is, the Company can "bribe" the consumer to make him give up that right and have him voluntarily abandon the rateable value system to switch to the metered one[6].

To be able to bargain effectively over welfare gains the firm needs to get as much information on the consumers / dwellings as it can before installing the meters. That is, the firm needs to have prior information on demand parameters q's and on unitary demand functions *w(a)*. It can be assumed that the firm can gather information on θ's since these parameters are a function of either the number of dwellers per house or the number of square meters of garden / construction and this information can be easily obtained. Furthermore, since the firm charges services following the rateable value system it already has information on the physical characteristics of all dwellings and it can also have an accurate idea of the distribution of q. Besides, q's also represent satiation levels that the firm can obtain by installing meters in strategic places with the sole objective of studying dwellers' demand patterns before making any changes in the rate regime.

Information on the unitary water demand function *w(a)* appears as a little more complicated to find though since meters have not been installed. However, it can always extrapolate results from other countries or cities with similar rate regimes and demand patterns. Nevertheless, the best the Company can do is to assume a unitary demand function $\tilde{w}(a)$ which can be different from the real one *w(a)*. It will also be assumed that the Company can know in advance if a particular dwelling's consumption level will be below or above the minimum threshold once metered. This is a reasonable assumption as the Company is assumed to have experience in providing the service. The rest of the relevant variables are supposed to be known by the Company.

Now if the Water Company wants to install a meter in any given dwelling then, and by definition, a slightly modified equation (14) has to hold:

$$\Delta p = q_F^* \left\{ (a - C_a)\ \tilde{w}(a) - aw^* - (0 - C_a) \right\} - (1 - j)h - C_m \geq 0 \qquad (39)$$

6 Gans, King and Woodbridge (2000) have suggested a similar property rights approach for telephone number portability. Applying a property rights approach to water metering is more appropriate than in number portability though since metering costs are fully per user costs whereas number portability are mainly fixed costs that have to be sunk before any customers switch companies.

Then for all dwellings with q ³ q_F* the Company will make more money metering consumption. However, the regulation (Box 1) also imposes the restriction that $\varphi = 1$ and that the firm has to "buy the right to meter" from the consumer by fairly compensating him / her. This compensation will be T dollars per dwelling. Therefore, for the firm to be willing to meter consumption condition (40) has to hold:

$$\Delta p = q_F^* \ \{(a - C_a)\ \tilde{w}(a) - aw* - \ (0 - C_a)\} - T - C_m \geq 0 \qquad (40)$$

How much money would the firm be willing to pay the consumer to make him switch? Or more importantly, how much money will the customer demand as a compensation? Obviously, the user has no incentive to truthfully reveal his consumer surplus change to the firm, and the firm wants to spend as little money in the process as possible because every dollar in compensation is a dollar less in profits. The compensation T will probably have a lower bound given by the increase in the monthly bill experienced by the consumer. In other words, the consumer will not accept a lower compensation than the expected increase in his monthly bill, from this value upwards. On the other hand, the compensation the firm will be willing to pay has also an upper bound that is given by the value of T that makes (40) bind, otherwise installing a meter in that dwelling would entail a loss for the Company. Any value between these two can be an equilibrium in the bargaining game between the Company and the user. The final outcome will depend on the relative bargaining power and the level of information of each player.

The bargaining game will probably start with the firm making bids to the consumer from $T = 0$ upward until the consumer feels that he has been properly compensated. When will that be? At any point between the increase in the expected monthly bill given by

$$\Delta B = a\,q\ [w(a) - w*] + h - h = a\,q\ [w(a) - w*] \qquad (41)$$

And the maximum compensation T_{max} given by (40) binding:

$$T_{\max} = a\,q_F^*\ [\tilde{w}(a) - w*] + q_F^*\ C_a[1 - \tilde{w}(a)] - C_m = \Delta B + \Delta C_a - C_m \qquad (42)$$

The maximum compensation the Company will be willing to pay is the expected increase in the consumer's bill plus expected savings in water production costs (brought about by the reduction in consumption) minus metering costs. The exact fall in consumer surplus generated by metering is given by

$$\Delta CS = q\left[\int_0^a w(x)dx - aw^*\right] \approx \Delta B \tag{43}$$

To the extent that the elasticity of water demand is low the fall in consumer surplus will be similar to the expected increase in the monthly water bill. If this assumption is made, any value of compensation T agreed upon between these two bounds will entail a Pareto increase in welfare. If both the firm and the consumer agree on the lower bound $T_{min} = \Delta CS \cong \Delta B$, the user will be compensated and all the increase in welfare will accrue to the firm. If this is the case, replacing T = ΔCS in (40) gives

$$\Delta p = q_F^* \left\{(a - C_a)\ \tilde{w}(a) - (0 - C_a) - \int_0^a w(x)\ dx\right\} - C_m = 0 \tag{44}$$

Which is nothing but the optimal metering formula (6) where $q_F^* = q_R^*$ and the firm will choose to install meters in only those dwellings where it is socially optimal to do so.

If, on the other hand, both the firm and the consumer agree upon the upper limit for T (T_{max}), all the increase in welfare will accrue to the consumer and the Company will be indifferent between metering and not metering. Obviously, the number of meters in this case will be lower than in the previous case because the firm will not capture the benefits of metering, consumers will. The final outcome (i.e the value of T agreed upon) will depend on the relative bargaining power and the information regarding demand parameters that both agents have. If the Company is relatively more informed about demand and has relatively more bargaining power than the consumer (as expected), T will be closer to $T_{min} = \Delta CS \cong \Delta B$ and the firm will install the socially optimal amount of meters. If, on the other hand, it is the consumer who has relatively more information on demand and has relatively more bargaining power (less likely), T will be closer to T_{max} and the Company will install fewer meters than socially optimal. Again, and in any case, bargaining over welfare gains will result in a Pareto improvement over the current situation and total water costs (production + metering) will be lower than before. The share of welfare that each party captures will depend on the relative information and bargaining power they have.

Unfortunately, the same property rights approach cannot be used when it is the consumer who chooses where to meter and the water Company is given the right not to meter. This is, the consumer may want the firm to meter his consumption but since the firm has now the right to choose the charging mechanism it wishes, it may refuse to install the meter. The problem lies in the fact that now the consumer cannot "bribe" the firm to meter his consumption because to reach the optimal solution it is the firm that has to pay the consumer the increase in profits according to the policy steps in Box 2. In other words, the firm would have to give the consumer the increase in profits brought about by its decision to meter the consumer's dwelling. If the firm has the right not to meter then it does not have the incentive to negotiate anything with anybody and the mechanism breaks down.

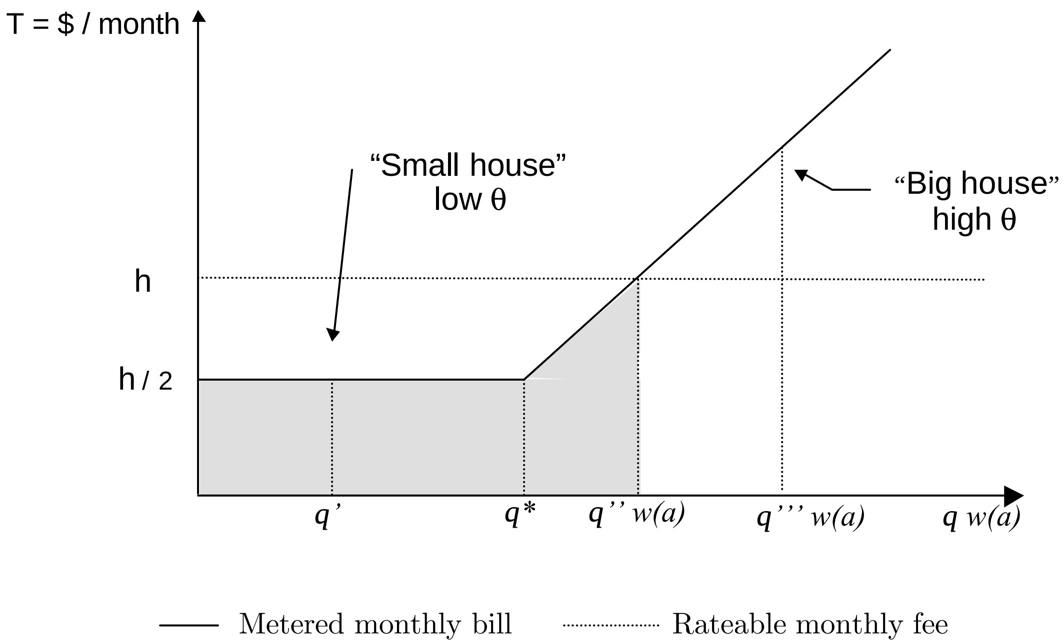
The following section illustrates two water concessions in Argentina showing the perverse incentives involved in their metering policies and rate structures. These policies are generally designed by regulators with imperfect information on water demand patterns creating incentives that lead to over investment and to a socially inefficient amount of metering reducing aggregate welfare. The incentive mechanism presented here can be easily implemented with minor changes in the legal status of these concessions creating a more level playing field for both the Company and the users.

6. 2 Water Concessions in Argentina: Buenos Aires City and Córdoba

The Company that has the concession in Buenos Aires has three kinds of customers: residential, non residential and empty lots. There are also two kinds of rate regimes, metered and unmetered. For non residential customers metering is compulsory and metering costs are borne by the customer. For residential customers however, metering is optional and metering costs are borne by the party choosing to meter be it the Company or the consumer.

Both rate regimes charge a rateable value monthly fee h that is calculated based on the following physical features of the dwelling: area, covered area, kind of dwelling, location and land price. Figure 4 shows the rate structure for a residential consumer before and after metering. According to the regulations, if the consumer voluntarily switches to the metered regime he gets a 50% discount on the rateable fee and has a monthly consumption allowance of 30 m^3 beyond which he starts paying a (\$ / m^3) for water services and another a (\$ / m^3) for sewerage. Since either the consumer or the Company can decide whether to install a meter one can easily see from Figure 4 which consumers will select the metered regime (and which will not) and which dwellings the Company will select to meter and which it will not.

Figure 4 : Buenos Aires Concession rate structure for a residential user



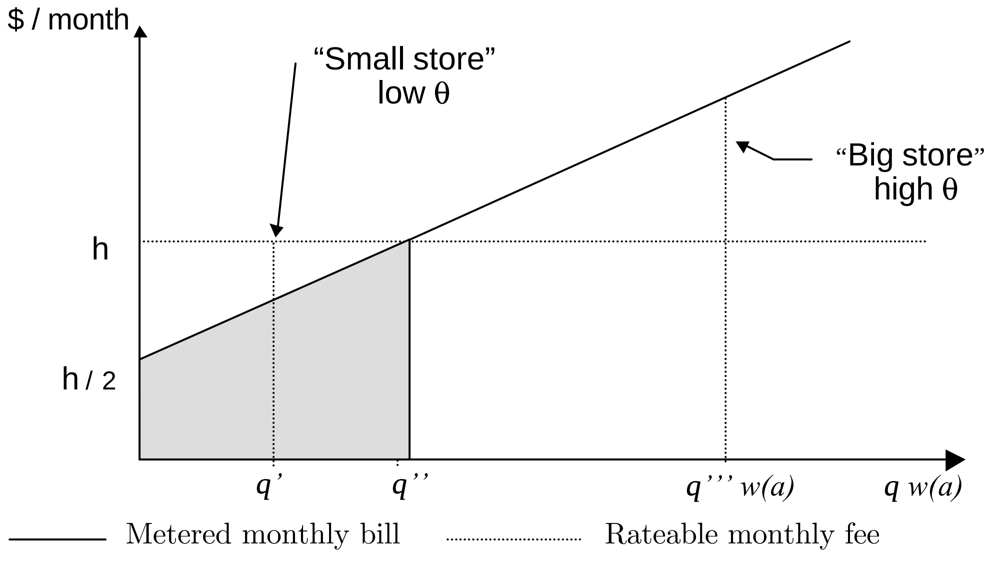
For each value of h, all dwellings with demand parameters up to q'' will seriously consider installing a meter because their monthly bills (gross of metering costs) will fall by half for dwellings up to q^* and between half and zero in dwellings between q^* and q''. However, and as demonstrated by Lemma 1, dwellings with thetas between $q = 0$ and q^* should not be metered as their consumption levels will not fall. Some consumers between q^* and q'' will also consider switching to metering because their monthly bills may fall. Therefore for some of these consumers metering may make sense but only if the consumption and cost fall is large enough to offset metering costs. The flip side of this is that the Company will see a sharp revenue shortfall for consumers whose consumption levels fall within the range [0, q'' *w(a)*]. If revenue stability is guaranteed by the concession contract, the regulator may face a huge headache in trying to bring revenue back to its pre – metering level with this kind of rate structure.

For all dwellings with $q \leq q$'' the Company will see a reduction in revenues that may or may not be offset by the cost reductions caused by the reduction in water consumption.

The Company will choose to meter those dwellings with $q > q$'' because by doing so it will increase revenues (See Figure 4). Since it also has to incur metering costs, the Company will see an increase in profits whenever the increase in revenues is high enough to cover water production and metering costs. This could happen for example for dwellings with q''' in Figure 4. However this is not the socially optimal cut off q because it does not contemplate the fall in consumer surplus generated by the increase in the marginal water rate a. q''' will be lower and consequently the number of meters will be higher than the socially optimal.

This rate structure is clearly inefficient as it sends the wrong investment signals. It induces the users to switch to metering in those dwellings that should not be metered and induces the Company to install meters without taking into account the fall in consumer surplus. This rate structure could easily be made efficient by applying the incentive mechanism. Give the authority to install meters only to the Company, eliminate discounts on fixed fees and make the company compensate the user.

Figure 5 : Buenos Aires Concession rate structure for a commercial user



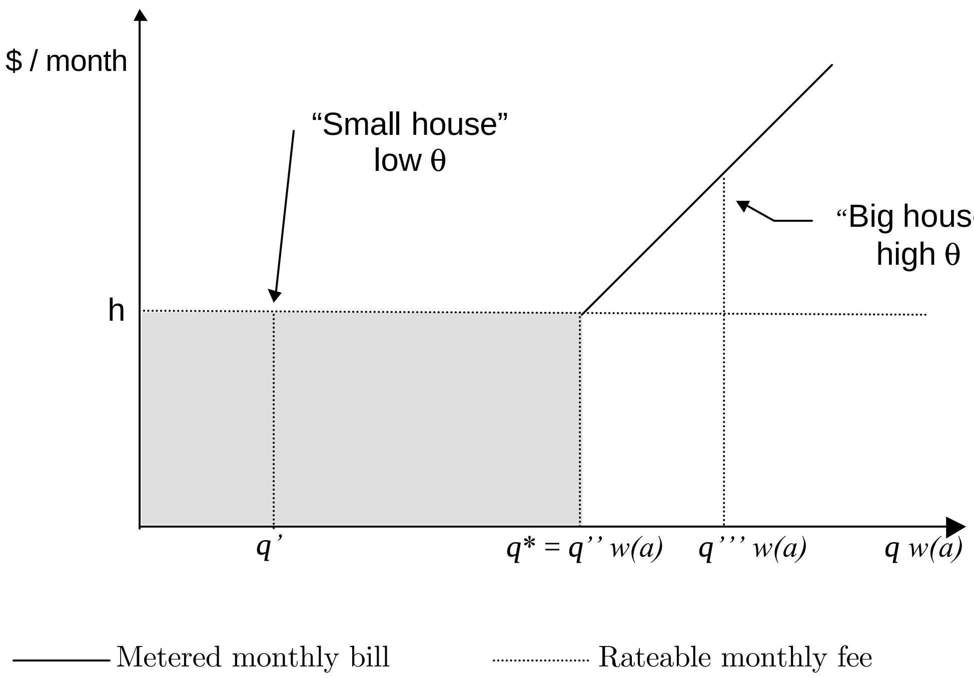
For a commercial user though the rate structure does not have a threshold. They start paying for actual consumption since the very first cubic meter they consume but they also see their fixed charge h cut in half. Besides, metering is compulsory and metering costs are borne by the Company. In this case the Company will not probably choose to meter those dwellings with $q < q''$ (Figure 5) because it will lose revenues. Metering will occur to the right of q'' for those dwellings that offset water production and metering costs. Again, this policy induces and inefficient amount of metering because it does not take into account the fall in consumer surplus.

The Cordoba Water Concession: Rate structure and metering policy

The rate structure of Cordoba´s Concession Company is slightly different from that of Buenos Aires in three aspects. On one hand, universal metering is mandatory. On the other hand, metering costs should be borne by the Company and there are no reductions in the monthly fixed charge h ($\varphi = 0$) for any type of consumer. For residential consumers there are important allowed consumption thresholds whereas for commercial customers there are not.

Figure 6 illustrates both the unmetered rateable monthly fee h and the metered monthly fee (both equal to h) up to the threshold and from that volume on the variable charge that applies for consumption above the threshold.

Figure 6 : Cordoba Concession rate structure for a residential user



First of all and as demonstrated by Lemma 1, universal metering whenever there are consumption thresholds is senseless. The Company will install meters it should never have installed (from $\boldsymbol{q} = 0$ to $\boldsymbol{q}^*$ in Figure 6). These meters will lie idle and unread and the Company will cut losses by not doing any maintenance or repair on them. On the other hand the Company will start making money metering those dwellings where the increase in revenues cover water production and metering costs but we already know that these meters will be too many from the social point of view. Notice besides, that under this mechanism no consumer will ever be better off since there is no reduction in the monthly fee or compensation form the company.

For the commercial user the story is similar but with one slight difference: the pointless meters will be fewer as there are no allowed consumption thresholds. In sum the wrong policies with the wrong incentives.

7. Conclusion and Policy Recommendations

Universal metering is seldom socially optimal, and it is sub - optimal whenever there are uncharged consumption thresholds. Regulators should be warned not to mandate universal metering unless there is clear evidence that no satiation levels fall below the minimum consumption threshold.

The optimal policy recommends keeping the current system of rateable monthly fees (i.e no discounts) which in turn implies that metering costs should be recovered through the volumetric charge a. This is because were metering costs recovered through any other charge (i.e, a fixed fee like m), the Company should reimburse this charge to the user as it applies the optimal policy of compensation. Therefore under the optimal mechanism the Company has no other way of recovering metering costs than through the volumetric charge a.

The optimal number of meters depends on the volumetric charge a but at the same time however, a depends on the optimal number of meters, therefore both variables should be calculated simultaneously in the same optimization problem.

The decentralized decisions are not optimal. Therefore, the Regulator has to establish some rules. These are illustrated in Boxes 1 and 2 and are based on payments from the firm to the user to reach the optimal solution. These payments take the form of Pigouvian Taxes that make the party internalize the externality they create in order to regain optimality. Metering costs should be borne by the party making the decision to meter.

The Coasian property rights approach suggests that the Company should be the one deciding where to install the meters and the negotiations should involve giving the user the right to choose the charging regime he pleases. At the same time however, the user can give up that right in exchange for a payment from the firm. The magnitude of this compensation will depend on the relative bargaining power and information regarding demand parameters that both the firm and the consumers have. Since it is the firm the party with more bargaining power / information, all the welfare gains brought about by the bargaining game will probably accrue to the firm with the user being compensated for the fall in consumer surplus thus reaching the optimal solution.

The rate structures of both concessions analyzed in section 6 indicate that metering policies designed by regulators in developing countries are often misguided and erroneous. The incentive mechanism presented in this paper can eliminate inefficiency without the use of discretionary regulation by simply establishing a rule to then let both parties reach the optimal solution through free negotiation.

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Appendix

For φ = 1, the following has to hold:

$$q_R^* = \frac{C_m}{\int_a^0 w(x)\,dx + \left[(a - C_a)\,w(a) - (0 - C_a)\right]} > q_F^* = \frac{C_m + (1-j)h}{\left[(a - C_a)\,w(a) - (0 - C_a)\right] - a\,w^*}$$

Which in turn means that $N_F^m > N_R^m$ and the firms installs more meters than socially optimal.

Proof: To prove this result it will suffice to show that $\int_0^a w(x)dx > aw^*$

On one hand $aw^* = \int_0^\infty w^*\,da + \int_\infty^a w^*\,da = \int_0^a w^*\,da$

and on the other hand $\int_0^a w(x)dx = \int_0^\infty w(x)dx + \int_\infty^a w(x)dx$

But at the same time we also know that by definition $w(x) > w^*$, then:

$\int_0^a w(x)\,dx > \int_0^a w^*\,da$ and therefore $\int_0^a w(x)\,dx > aw^*$ Q.E.D