Incentive Water Pricing Instrument

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Overview

- Introduction.
- Water pricing practices.
- EU legislation.
- Water services characteristics.
- Pricing theories.
- An incentive water pricing model.
- Optimal pricing policy.
- Conclusion.

Introduction (1)

"Will anyone compare the idle Pyramids, or those other useless, though much renowned structures of the Greeks, with these many indispensable aqueducts".

Sextus Julius Frontinus, De Aqueductibus Urbis Romae, a third-century book on the Roman aqueducts.

Introduction (2)

- Since early civilization, accessibility to water has been of great concern to public authorities $\longrightarrow$ water systems reflected the social aspects of each society. In general, water was often distributed according to social criteria.
- Today, water continues to be viewed as an essential public good. Public authorities remain responsible for its harvest and distribution among the population and different water consumers.
- Large infrastructures (with extremely expensive maintenance) continue to be built to improve the accessibility of water for the population.
- Unfortunately, treating water as a public good like in the past has greatly contributed to water scarcity on our planet $\longrightarrow$ Economists, Environmentalists, International Organizations among others have called to stop the hemorrhage and the extensive waste of water resources.

Introduction (3)

- Current and increasing water consumption levels are expected to lead to large water deficits in the near future: demographic growth, increasing urbanization, and marked inequalities in the economy (such as grants to agriculture or some strategic industries).
- But supplies are finite, and existing resources are becoming depleted leading to great damage to the natural environment.
- Also, adverse climatic conditions may be expected to occur more frequently in the future with the onset of global warming. Water scarcity is expected to rise, greatly increasing the need for an efficient water allocation system.
- Extra water supply must be treated less and less as an essential public good, and more and more as an economic commodity with an efficient pricing policy $\longrightarrow$ the alternative is economic and ecological waste, with too much costly investment in new capacity.

Problem: water pricing practices are inefficient

- Economic efficiency and environmental objectives are rarely considered in water policies: more attention is given to affordability and social concerns!
- Efficient pricing policies are almost absent in most countries, and current water pricing systems are much distorted, leading to large deficits and over-consumption of water.
- Public authorities are facing wide investment needs driven by obsolete and worn out pipeline systems on the one hand and by the imposition of EU quality standards on the other.
- Attention: in many EU countries those investment needs are subsidized which means that there is no clear link between investment levels and charges.

Problem: water pricing practices are inefficient

- Prices are based on average embedded utility costs using historical accounting costs.
- They fall to reflect the temporal and spatial variations in water and wastewater services demands.
- Water utilities do not consider the cyclicity of demands, the time-of-use, the real value of water resources and consumers types.
- These practices led to:
  - over investing in systems' facilities;
  - wasting public funds;
  - over using of water resources;
  - increasing deterioration of the environment.

Water Utilities' objectives

- Water Utilities have different objectives:
  - they might want the most optimal resource allocation;
  - they would have objectives with respect to the level of deficits of water management authorities;
  - they have to respect financial break-even constraint (budget constraint);
  - in the context of growing water scarcity, reducing water consumption to prevent further depletion of the resource.
- Water Utilities are facing different water pricing options provided by economic theory which generally requires that a pricing structure meet the four criteria of: efficiency, equity, financial viability and simplicity.
- Efficiency requires that water consumers are metered, and pay a "marginal price" for each extra cubic meter consumed, since only this provides a true incentive to avoid wasting water $\rightarrow$ a compromise must be reached between efficiency and at least three other conflicting objectives: raising revenue, simplicity, and fairness.

Water pricing trends

- A review of tariff rules for water supply in OECD countries (OECD, 2009) reveals the following trends:
  1. continued real price increases over recent years $\longrightarrow$ signal an increased role of tariffs in cost recovery;
  2. a continued decline in the use of uniform or flat fee systems in favor of two-part tariff with volumetric rates;
  3. the limited application of decreasing block tariffs for industrial uses in few OECD countries;
  4. the increased application of environmental taxes on the use of water resources in OECD countries;
  5. increasing separation of wastewater from drinking water charges and charging for wastewater on the basis of actual costs $\longrightarrow$ substantial increases in the price of wastewater management services;
  6. continued attention to social concerns, addressed through innovative tariff structures or parallel income-support mechanism.

Urgent need: re thinking water pricing

- Water pricing is increasingly seen as an acceptable instrument of public policy.
- Muchmore, water charge levels have been rising in most countries in recent years.
  1. water quality is getting worse as a result of over-consumption (especially where groundwater is used);
  2. water networks are getting obsolete $\longrightarrow$ increasing investment needs;
  3. drinking water quality standards and wastewater treatment regulations;
  4. government budgets have been stretched to the limit, putting upward pressure on charges.
- Thus, efficient and effective water pricing systems provide incentives for efficient water use and for water resources quality protection. At the same time, they generate funds for necessary infrastructure development and expansion, and provide a good basis for ensuring sustainability $\longrightarrow$ Pricing is the cornerstone of a sustainable cost recovery strategy.

EU legislation

- EU environmental legislation affecting the water sector can be divided into three categories:
  1. Legislation on the protection of water sources (including the control of pollution by commercial activities);
  2. Acts regulating municipal activities in the water and wastewater sector;
  3. and finally the Water Framework Directive (WFD).
- In some areas the effectiveness of these directives was questionable: water quality continued to deteriorate during the 1980's (agriculture).
- As a reaction to the inadequacies of the first wave of legislation, the Directives for controlling certain sources of pollution were adopted.

Three periods

EU environmental and water policy can be divided into three periods:

- The first period (1973-1986) includes the first three environmental programs. The EC had no mandate for environmental regulation but only in areas affecting the core objectives of the Community. Environmental Directives focus on public health protection and the harmonization of environmental rules to avoid market distortion.
- The second period (1987-1992) was marked by the Maastricht Treaty and the assignment of a European competence for a common environmental policy: the emphasis passed on to pollution control and environmental protection.
- The third phase (1993-$\cdots$) is still under way and is largely characterized by the adoption of the IPPCD (1996) and WFD (2000).

- "Environmental Directives" can be broadly divided into two types:
    - Water Use Directives mainly public-health oriented, and
    - Water Pollution Directives oriented to the harmonization of pollution control efforts in Europe.
- Water Use Directive included standards for the quality of water intended for drinking and after treatment, bathing and for fish and shellfish harvesting.
- Water Pollutant Directives regulated the permissible levels of discharges of particular pollutants: the emission of dangerous substances to surface and ground water bodies.

- Mainly two new directives were introduced tackling the main sources of water quality deterioration: pollution from urban wastewater and pollution from nitrates from agricultural run-off.
  - The UWWTD set clear infrastructural targets of wastewater treatment for all European urban settlements for different classes of sensitivity of the receiving waters.
  - The latter focused on establishing "best agricultural practice programs" to control the use of nitrates in agriculture.
- A number of other environmental directives also had indirect effects on water quality and management such as the plant protection products Directive, the habitats Directive and the integrated pollution prevention and control Directive.

UWWTD (1)

- Aim: avoid pollution of fresh and marine waters from urban sewerage systems:
  - all agglomerations should be provided with collection systems for urban wastewaters;
  - effluent from sewage treatment plants must meet certain minimum effluents standards depending on the sensitivity of the receiving water;
  - sewage discharge to "less sensitive" waters, which are defined as estuarine and coastal waters with a high dispersion capacity, may receive only primary treatment;
  - sewage discharges to a "normal" water must receive at least biological treatment;
  - sewage discharges to "sensitive" waters must be also subjected, in addition to biological treatment, to nutrient removal.

UWWTD (2)

- Considerable progress has been made since the adoption of the Directive in improving the provision of sewage treatment facilities.
- Some countries have already completed their investments like Sweden, Denmark, Finland and the Netherlands.
- Others still have to make considerable progress to comply with the Directive: Italy, Greece, and Portugal for example.
- Still important implementation gaps:
    1. Inadequate reporting or lack of reporting;
    2. Inadequate treatment or lack of treatment;
    3. Insufficient designation of sensitive areas.

WFD: the new opportunities

- The WFD is currently the best tool to ensure sustainable "use" of water and wetlands across Europe.
- Restructuring administration:
  - Establishment, for the first time, of a single legislative framework.
  - Long term planning in Water Resources Management.
  - Decentralization of management to the River basin levels.
- Rationalizing water costs.
- Promoting economic sustainability: in water management and uses.
- Prevention of further deterioration and achievement of good status for all waters.
- Involving the greater public in the protection of the environment.
  $\longrightarrow$ Efficient Integrated Management Approach.

Main Objective: sustainability!

- Promoting sustainable water use based on a long term protection of available water resources.
- Taking into account the principle of costs recovery of water services:
  1. An incentive water pricing policies for users to contribute to the environmental objectives: efficient use of water resources.
  2. An adequate contribution of the different water uses to the costs recovery, disaggregated into at least industry, households and agriculture and applying the Polluter-Pays Principle (PPP).
  3. the more external costs are internalized, the more prices show the real cost of water uses and services (social, environmental, etc.).
- Social, environmental and economic issues must be considered as well as climatic and geographical differences!
  → Pricing is a "basic" measure.

WFD: key economic inputs

- Mainly four economic inputs:
  1. Recovery of costs.
  2. Cost-effectiveness analysis.
  3. Cost-benefit analysis.
  4. Water pricing policies.

Costs Recovery

- The extent to which the costs associated to water uses are borne by those who generate them.
  - Attention: difference between "water services" (drinking water, irrigation, etc.) and "water uses" (navigation, fishing, etc.)
- It brings transparency on financial flows associated to water uses and services: understand which water services and which economic sector are actually paid for, to which extent, by whom and how.
  - who bears / will bear costs and damages associated to water uses?
  - who pays for these costs?
  - who bears the difference between prices and costs?....

Cost-effectiveness analysis

- To identify the (sets of) measure (s) that will best achieve the compliance with the goal at the lowest cost.
- Assess the cost-effectiveness individual measures: direct and indirect costs and benefits; economic and non-economic impacts, etc.
- To rank (sets of) measures that allow to reach the goal.
- Attention! It is important to take account of benefits, at least to identify them, and ensure fruitful cooperation between water professionals (effectiveness) and economists (costs).

Costs benefits analysis

- Why?
  - to compare variations of quantifiable costs and benefits, caused by the activities, for people affected by the policy under consideration.
  - Try to include all types of costs and benefits!
- When?
  - when potential measures to reach the objective have disproportionate costs: need to identify the least costly measures.

Water pricing policies

- Why do we care about pricing?
  - the level of price has a direct impact on water demand and water uses;
  - pricing policies may play as a measure contributing to the achievement of the environmental objective by enhancing efficient use of water resources;
  - the more external costs are internalized, the more prices show the real cost of water uses and services (social, environmental, etc.).
- Attention: keep the objective in mind! Ensure the fundamental requirement: sustainability.

Economic analysis is not an isolated exercise!

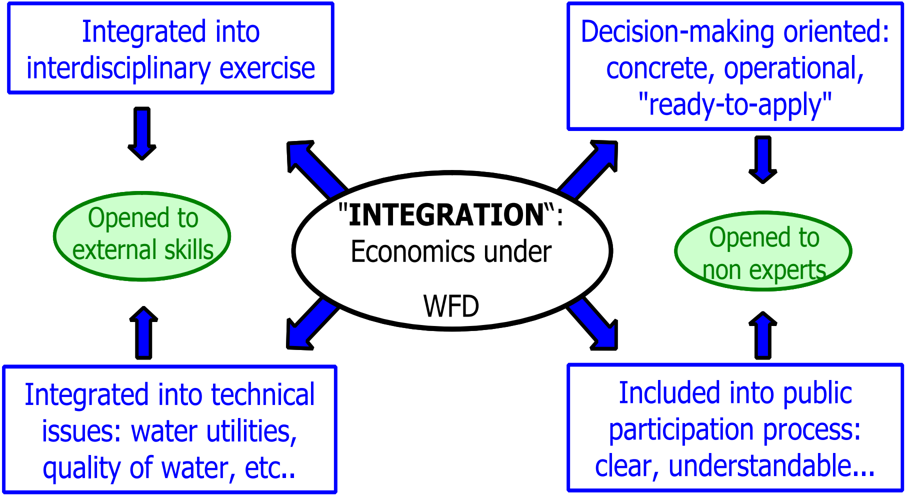
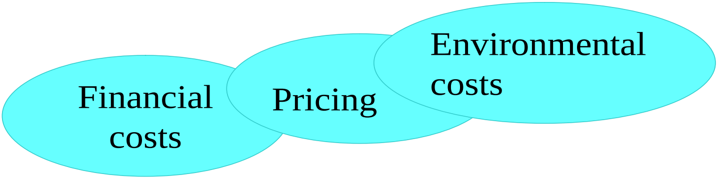


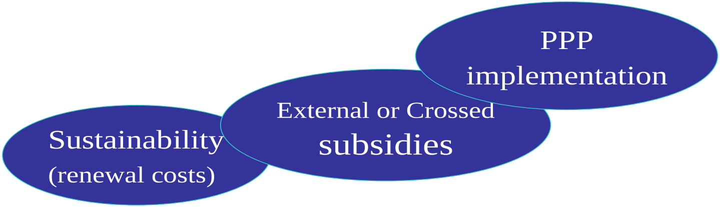
Figure 1: Economics under WFD

Economic Requirements

- To report on:



- It's also to report on:



- Identify incentive measures to achieve environmental objectives.

Key principles

- Mainly three issues to assess the implementation of incentive pricing and of cost recovery:
    1. The first one shall report on pricing. What are tariff's structures and prices for water and sanitation services? How polluter-pays principle is implemented?
    2. The second one shall report on investments and subsidies. It agrees to specify which are the amounts of work completed, the origins of the subsidies, and which economic sectors pay what.
    3. The third one is the financing of the annual costs, including maintenance costs, refunding of loan, renewal costs and environmental costs.

Water services characteristics

- Industrial and commercial local public services
  - Continuity: 24h a day, 7 days a week, etc.
  - Mutability (adaptability): flexibility, must take into account technology changes, new standards, environmental restrictions, etc.
  - Equality:
    - level and quality of the service;
    - tariffs;
    - access to the service.
- Local communities are responsible for providing water services.
- Water services management can be: public or private[1].
- Water utilities must be financially self-sufficient.
- Standards for pollution and drinking water must be met.

[1] Private participation does not relieve public authorities of their responsibilities to ensure safe and efficient water services and to prevent the abuse of monopoly dominant position.

Economic characteristics of the water industry

- A water network includes all facilities from the pumping plant (s) to the wastewater treatment plant (s). We can distinguish two types of activities in the water industry:
    1. Drinking water services: withdrawal and treatment prior use, storage and transportation, distribution to final users;
    2. Wastewater services: transportation and storage of used water, treatment.
- A network infrastructure is a costly long-term investment.
- Externalities exist at several stages of the water cycle $\longrightarrow$ important environmental damages.
- Water demand is usually price-inelastic and is seasonal:
  $\longrightarrow$ Quality.
  $\longrightarrow$ Quantity.

The water industry is a network (1)

Definition (1)

A network is a set of points or nodes, connection links built in order to transport some energy flows (electricity, heat, etc.), some information flows (sounds, data, images, etc.) or some materials flows (water and wastewater, freight, passengers, etc.). From an economic point of view, a network is an intermediation platform between one or several producers and one or several consumers.

Definition (2)

A node can be:
- a departure node from which a flow is emitted;
- a final node receiving a flow;
- an intermediate node conceived for transmission, storage, coordination, dispatching, etc.

The water industry is a network (2)

Definition (3)

An efficient network allows to minimize all the production costs.

Network System	**Nodes**	**Links**	**Flows**
Air Transportation	Airports	Airline Routes	Planes
Manufacturing and Logistics	Distribution Points	Routes	Parts/ Products
Communication	Computers	Cables	Messages
Energy	Pumping Stations and Plants	Pipelines	Oil, Gas, Water

Table 1: Some classical network systems.

Water and wastewater supply chains (1)

- Metropolitan water supply chains comprise the following key activities:
  - source of water supply: dams to capture and store surface water runoff, groundwater reservoirs, etc.;
  - treatment plants: to remove natural and other pollutants, and to treat raw water to a useable (potable or non-potable) standard;
  - distribution infrastructure: including large/trunk pipelines before and after treatment plants, and reticulation networks (medium and small pipelines), pumping stations and local reservoirs, to transport water from its source to treatment plants and then from treatment plants onto customers;
  - customer service activities, often referred to as retailing: including billing, meter reading, and responding to complaints or service failures.
- Water and wastewater utilities also have activities or assets that support these supply chain elements: for example, accounting, finance and general administration activities and assets (i.e., corporate overheads).

Water and wastewater supply chains (2)

- Wastewater service systems are typically made up of the following activities:
  - wastewater collection and transmission infrastructure: to transport wastewater from customers to treatment plants (reticulation pipelines and associated fittings to transport wastewater from source to trunk network, trunk pipelines to transport wastewater from the collection network to treatment plants, pump stations and overflow structures);
  - treatment and disposal facilities: comprise treatment plants to remove the sludge or biosolids from the wastewater, treat the wastewater to varying levels (e.g., primary or tertiary treatment, depending on the receiving environment and prevailing environmental standards), and then dispose of the wastewater via emissions to rivers or the ocean or by providing it for recycled water generation;
  - residuals management: involves removing sludge or biosolids from the wastewater, and then incinerating them, dumping them at sea or using them as fertilizer on farm land;
  - customer service activities: including billing, meter reading, and responding to customer issues.

Key Activities

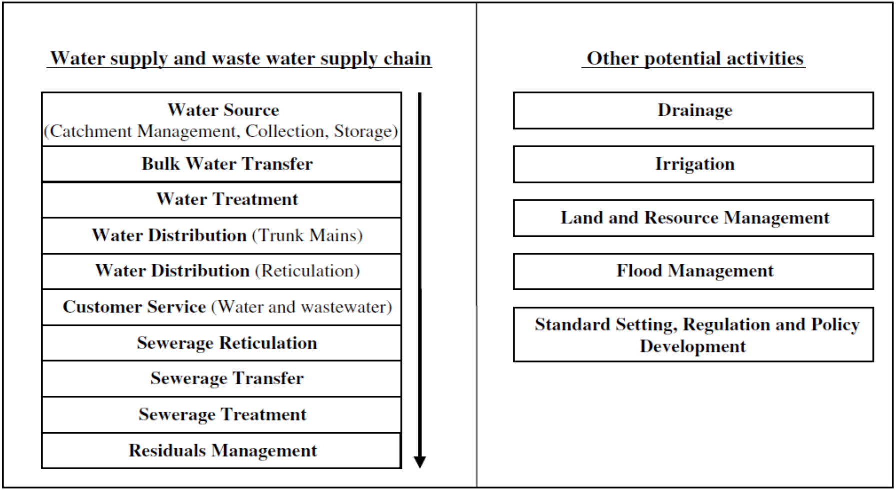


Figure 2: Water and wastewater key activities.

Natural Monopoly (1)

- Activity qualified as *natural monopoly*: sunk costs/increasing return to scale $\rightarrow$ General competition is not possible nor desirable.
- Let's consider the monoproduct case and assume that the total cost function is given by $C(q) = CF + CV(q)$, with CF representing the fixed costs, $CV(q)$ the variable costs. q is the production level and $(q_1, \ldots, q_n)$ denote fractions of the total production q such as $\sum_{i=1}^{n} q_i = q$.

Definition (4)

The cost function is strictly *subadditive* if:

$$\sum_{i=1}^{n} C(q_i) > C(q), \forall q, i \text{ with } q = \sum_{i=1}^{n} q_i$$

Natural Monopoly (2)

- It is less costly to jointly produce the bundle $(q_1, \ldots, q_n)$ through a single firm than to divide the production across two or more separated firms (or production units) $\longrightarrow$ Definition of a natural monopoly.
- *Remark: Subadditivity can be defined locally. A cost function is subadditive at q' if*

$$\sum_{i=1}^{n} C(q_i) > C(q'), \forall i \text{ with } q' = \sum_{i=1}^{n} q_i$$

- The natural monopoly character of the water industry is so strong that structural unbundling is rare, making vertical integration of utilities dominant even in industrial countries:
  - transportation and distribution involve important fixed costs;
  - it is very difficult to duplicate a water network which represent an entry barrier $\longrightarrow$ water industry $=$ non-contestable monopoly;
  - a lot of assets are specific: irreversibility of investment.

Economies of Scale

Definition (5)

Economies of scale characterize a production process in which an increase in the scale of the firm causes a decrease in the long run average cost. There are *scale economies* if the average cost $\frac{C(q)}{q}$ is decreasing $\forall q$.

Remark: Similarly there are local scale economies at q' if the average cost $\frac{C(q)}{q}$ is decreasing at $q = q'$.

Definition (6)

We measure the *degree of scale economies* (S) using the cost elasticity, μ_C, which is equal to the ratio of the marginal cost (MC) to the average cost (AC) :

$$S = \frac{1}{\mu_C} = \frac{AC}{MC}$$

There are scale economies *iif* $S > 1$.

Relationship between subadditivity and scale economies

Lemma (1)

Locally, scale economies are sufficient, but not necessarily, to have a decreasing average cost function. Decreasing marginal costs imply decreasing average costs which imply subadditivity but reciprocal false.

Proof.

See Panzar, 1989, p. 8, 25-27. □

If multiproduct firm → *economies of scope*. Consider q a vector of goods chosen among n $(i = 1, \ldots, n)$ possible goods.

Definition (7)

There exist *scope economies* if it is less costly to jointly produce several products $(q_1, \ldots, q_n)$ than to produce separately these goods

$$\sum_{i=1}^{n} C\left(0, \ldots 0, q_i, 0, \ldots, 0\right) > C\left(q_1, \ldots, q_n\right)$$

Few Empirical Studies (1)

Author(s)	Data sample	Functional form and cost specification	Model and method of estimation	Estimated economies of scale	Estimated economies of density	Corresponding mean output level
				at mean output levels		
Garcia and Thomas (2001)	55 French water utilities from 1995 to 1997	Translog VC function	GMM (IV method), SUR method	1.002	EPD: 1.142 (SR) 1.209(LR) ECD: 1.050 (SR) 0.872(LR)	0.41 m m^3
Garcia et al. (2007)	233 US water utilities (includes 15 distributors) from 1997 to 2000	Translog VC function	RE (GMM (IV method)), SUR method	1.185 (SR) 1.191(LR)	EPD: 0.914 (SR)	1.59 m m^3
Filippini et al. (2008)	332 observations for 52 Slovenian water utilities from 1997 to 2003	Translog total distribution cost function	Pooled, RE, True Fixed Effects (ML, GLS)	1.030–1.088 (for the median, depending on the model)	EOD: 3.042–3.874 ECD: 1.286–1.344 (each for the median, depending on the model)	2.30 m m^3
Fabbri and Fraquelli (2000)	173 Italian water utilities in 1991	Cobb-Douglas TC function, Translog TC function	Pooled (OLS)	0.986–1.009 (depending on the functional form)	EOD: 1.470–1.580 (depending on the functional form)	18.86 m m^3
Saal and Parker (2005)	30 UK water utilities from 1993 to 2003	Translog input distance function Malmquist and generalized Malmquist productivity index	Time-varying inefficiency	From 1.108 in 1993 decreasing to 0.978 in 2003 Small negative scale effects for WoCs	–	62.89 m m^3
Mizutani and Urakami (2001)	112 Japanese water utilities in 1994	Translog TC function	SUR method	0.921	END: 1.103	66.62 m m^3

ECD = economies of customer density, END = economies of network density, EOD = economies of output density, EPD = economies of production density, GMM = generalized methods of moments, IV = instrumental variables, RE = random effects, LR = long-run, SR = short-run, TC = total cost.

Figure 3: Few studies estimating economies of scale and density (Source: Walter et al. 2009).

Few Empirical Studies (2)

Author(s) and Date	Country	Results
Hayes, 1987	USA	Vertical integration is efficient for small companies, but not large ones.
Kim and Clark, 1988	USA	Economies of scope for joint production of residential and non-residential water.
Lynk, 1993	England & Wales	Greater inefficiencies in water only companies than water and sewerage companies, economies of scope for water and sewerage, economies of scope, water supply and environmental.
Hunt and Lynk, 1995	England & Wales	Economies of scope between regulation (environmental services) and water supply (though not sewerage); evidence of economies of scope between water and sewerage.
Saal and Parker, 2000	England and Wales	No evidence of economies of scope between water and sewerage services.
Garcia and Thomas, 2001	France	Positive degree of economies of scope (i.e. reduced network leaks), significant economies of scale.
Fraquelli and Giandrone, 2003	Italy	Vertical integration seems to produce significant scope economies; removed pollution load has a significant role in explaining variability of costs.
Stone and Webster Consultants for OFWAT, 2004	England & Wales	Diseconomies of scope for water and sewerage; economies of scope for vertical integration of water.
Martins et al., 2006	Portugal	Economies of scope between water and sewerage except for the largest businesses.
Garcia et al., 2007	USA	Disintegration may lead to cost savings, specialization of inputs and assets can lead to savings.

Figure 4: Studies of economies of scope (Source: Abbott and Cohen, 2009).

First-best or MC pricing (1)

- In its simple formulation, maximizing social welfare implies a public utility to use marginal cost pricing:

$$p = CM(q) + \gamma$$

  Where q is the volume produced by the water utility, $CT(q)$ is the cost function with $CT'(q) = CM(q) > 0$ and $CT''(q) > 0$ which means that marginal cost is positive and increasing in output. γ represents the marginal shadow price of water. The shadow price is positive when water is scare or when water withdrawals have environmental consequences.
- Marginal pricing gives the appropriate incentive for an efficient water use to consumers.

First-best or MC pricing (2)

- But it has its limitations:
  1. it requires volumetric pricing $\longrightarrow$ consumption must be metered which is not always the case;
  2. it requires that each user faces a price reflecting the *MC* of providing that specific user $\longrightarrow$ difficult task requesting considerable amounts of data (demand and cost of water services) $\longrightarrow$ asymmetric information!
  3. *MC* pricing requires tariffs to change over time and space depending on the location of consumers and the availability of water resources $\longrightarrow$ some technical and political problems for decision makers;
  4. It also requires tariffs to changes based on the installed and used capacity $\longrightarrow$ large variations magnitude in tariffs with significant increases as infrastructures approach capacity $\longrightarrow$ technically impractical and generating financial instability for water utilities;
  5. high fixed recurrent costs (e.g. meter-reading) under *MC* pricing are not covered $\longrightarrow$ use of two-part tariff to cover the water bill;
  6. in the absence of budget constraints, *MC* may provide managers with inappropriate incentives for cost reduction...

Second-best pricing

- In a second-best world where the water utility budget must be balanced, the optimal pricing mechanism is given by the Ramsey-Boiteux rule:

$$\frac{p - CM(q)}{p} = \frac{\lambda}{1+\lambda}\frac{1}{\mu}$$

  Where μ is the price elasticity of the water demand and λ a term representing the shadow price of the financial constraint.
  $\rightarrow$ a greater proportional mark-up is allocated towards the service which is relatively price inelastic, and a lesser proportional mark-up towards the service which is relatively price elastic.
- This pricing rule ensures that social welfare is maximized.
- But implementing such a policy requires a perfect knowledge of marginal cost and of demand price elasticity but these information are rarely available.

Average cost pricing

- These difficulties may explain why historically the alternative way in the design of water price consisted on applying the average cost pricing policy:

$$AVC(q) = \frac{CT(q)}{q}$$

- *AVC* pricing doesn't give the good signal of market value of water resources.
- Water demands are considered exogenous and thus there is no attempt to maximize social welfare $\rightarrow$ Decisions regarding a network's capacity or the pricing of the output are unlikely to yield to a social optimum.

Nonlinear pricing rule

- Price schedules are derived by a welfare-maximizing public utility facing a set of heterogeneous consumers given by some unobservable parameter $\theta \longrightarrow$ efficient price function specifying the marginal price at each level of consumption.
- In general, it can be shown, under specific conditions about the cost function and the distribution of θ, that the welfare-maximizing tariff involves the marginal price decreasing with the quantity purchased $\longrightarrow$ it is optimal to offer quantity discounts for the firms' output.
- An alternative way to think about nonlinear pricing with quantity discounts is that instead of the firm offering a single tariff, it offers consumers a choice from a menu of two-part tariffs. This menu would give consumers the option of trading off a high fixed charge and low usage charge against a low fixed charge and higher usage charge. $\longrightarrow$ the optimal nonlinear payment schedule can also be implemented by offering a menu of two-part tariffs where the firm lets the consumer choose among the continuum of two-part tariffs. (see Elnaboulsi 2001).

The model: the consumer

- There is a continuum of consumer types. Consumer preferences are indexed by a taste parameter $\theta \in [0, 1]$.
- The number of consumers of type θ is given by $g(\theta)$, a continuous, strictly positive density function with cumulative distribution $G(\theta)$ for all θ.
- Consumers preferences and the firm's technology depend on the state of the world ω which is an independent real-valued random variable.
- ω, has a continuous and positive probability density function $f(\omega)$ on the compact, convex interval $[\omega^-, \omega^+] \subseteq \mathbb{R}$, and a cumulative distribution function $\mathcal{F}(\omega)$.

The consumer optimization problem (1)

- Each consumer has a von Neumann-Morgenstern utility function. For simplicity, we consider a quasi-linear form. This function is given by:

$$\begin{cases} U(q,\theta,\omega) = u(q,\theta,\omega) + r \\ U(0,\theta,\omega) = 0 \end{cases}$$

- This implies that the consumer's marginal utility for money is constant. It simplifies some technical points, but mainly allows us to use surplus analysis. ω is supposed to govern the consumer's willingness to pay for the service in each period and represents both common shocks (such as weather conditions, the frequency and intensity of rainfall, water availability), and idiosyncratic shocks such as changes in consumer tastes and firm technology.
- A consumer of type θ has an optimization problem described by:

$$Max \left\{ \underset{\omega}{E} \max_{q} \left(u(q,\theta,\omega) - pq \right) - k\phi_\theta \right\}, \text{ subject to } \phi_\theta \geq q \geq 0$$

where $E \equiv$ expectation w/respect to $\mathcal{F}$ over ω.

The consumer optimization problem (2)

- Without loss of generality, we consider the following conditions:

$$\frac{\partial u}{\partial q} > 0 \text{ and } \frac{\partial^2 u}{\partial q^2} < 0 \tag{1}$$

This means that the utility function is positive and decreasing in q.

$$\frac{\partial u}{\partial \theta} > 0, \frac{\partial^2 u}{\partial \theta^2} > 0 \text{ and } \frac{\partial^2 u}{\partial q \partial \theta} > 0, \forall \theta, \forall q \tag{2}$$

It states that a given allocation gives the higher types a higher utility level, and the cross-derivative also called the *single-crossing condition* has constant sign. $\frac{\partial^2 u}{\partial q \partial \theta}$ implies that the indifference curves of any two different types can only cross once. Finally,

$$\frac{\partial u}{\partial \omega} > 0; \frac{\partial^2 u}{\partial \omega^2} > 0; \tag{3}$$

This assumption simply means that the utility function is increasing in ω (a higher value of ω means hotter and drier weather implying an increase in water demand, swimming pools, irrigation purposes, etc.).

The model: the utility (1)

- We assume that the representative water utility has a service obligation and has to ensure universal access.
- We consider that water is produced with a unit operating cost, c, and capacity cost giving by κ.
- The utility is assumed to use a simple, proportional cost technology. In the case of system overload, the welfare-maximizing utility is assumed to be able to meet excess demands at a unit cost of v by purchasing water from other water utilities. v can be called the marginal penalty technology cost. It represents the market value of water resources and may be determined by usual procurement procedures such as a competitive bidding or negotiation process. It should be in the range of:

$$\begin{cases} c < v \\ c + \kappa < v \end{cases}$$

otherwise the fixed proportions technology would be a strictly dominated technology.

The model: the utility (2)

- Total expected supply costs with a capacity size Z can be given by:

$$\underset{\omega}{E}\left(CT\left(Z,X\right)\right)=\underset{\omega}{E}\left\{cMin\left(Z,X\right)+\upsilon\left[X-Z\right]^{+}\right\}+\kappa Z$$

- The system demand is given by

$$X\left(p,k,\omega\right)=\int_{\widetilde{\theta}}^{1}x^{*}\left(p,k,\theta,\omega\right)dG\left(\theta\right)$$

and

$$\left[X-Z\right]^{+}=Max\left[0,X-Z\right]=\begin{cases}0 \text{ } if \text{ } X\leq Z\\ X-Z \text{ } if \text{ } X\geq Z\end{cases}$$

The model: timing

- Each consumer has a goal to maximize his expected consumer's surplus under the following schema:

1.	The public utility announces ex ante the different terms of contracts.
2.	Consumers choose ex ante their own contract.
3.	The state of the nature ω is realized.
4.	Consumption q occurs.
5.	Payments are made at the end of the billing period.

Table 2: Model Timing.

- In this decentralized and incentive-compatible setting, consumers self-select their own branch pipe size ϕ_θ ex ante and consumption level ex post fitting to their own type.

The program

- We consider the expected value of a traditional welfare function: the water utility has a goal to maximize this welfare function subject to a break-even constraint.
- The task is to determine:
  1. a system capacity charge,
  2. a usage price p,
  3. a demand or access charge k.
- The program can be written:

$$\begin{cases} Max \underset{\omega}{E}(W) = \underset{\omega}{E}(S^*) + \underset{\omega}{E}(\Pi) \\ \text{Subject to} \\ \underset{\omega}{E}(\Pi) \geq 0 \end{cases}$$

Capacity selection policy

Lemma (2)

For a positive capacity, the optimal capacity selection rule is given by:

$$\kappa^* = \left(\upsilon - C'\right)\left(1 - \mathcal{F}\left(\widehat{\omega}\right)\right)$$

Proof.

Straightforward using the optimality condition $\frac{\partial E_\omega(\mathcal{L})}{\partial Z} = 0$. $\square$

- This is the expected marginal cost difference between the marginal penalty technology cost and the marginal operating cost when excess demand occurs: long-run marginal cost of capacity expansion.
- Since $0 < \left(1 - \mathcal{F}\left(\widehat{\omega}\right)\right) < 1$, the optimal capacity size κ^* is positive but strictly less than the maximum possible level of system demand: the water utility does not set fully reliable capacity size to insure itself against adverse states of the world. $\left(1 - \mathcal{F}\left(\widehat{\omega}\right)\right)$ can be considered for example as the probability that severe weather conditions occur.

Pricing Mechanism: usage pricing (1)

Lemma (3)

The optimal usage pricing policy is given by the following Lerner index:

$$\frac{(p-c)}{p} = \frac{\lambda}{(1+\lambda)} \frac{1}{\mu_p\left(\widetilde{\theta}, \omega\right)} + \frac{\upsilon}{\mu_p\left(\widetilde{\theta}, \omega\right)} \left[a\left(1-\mathcal{F}\left(\omega^*\right)\right) - b\right] \frac{1}{Q\left(\widetilde{\theta}, \omega\right)}$$

where $\mu_p\left(\widetilde{\theta}, \omega\right)$ *is the price eslasticity of the aggregate demande function* $Q\left(\widetilde{\theta}, \omega\right)$*:*

$$Q\left(\widetilde{\theta}, \omega\right) = \int_{\widetilde{\theta}}^{1} \int_{\omega^-}^{\omega^*} q^*(\theta)\, d\mathcal{F}(\omega)\, dG(\theta)$$

Proof.

Differentiating the program with respect to p yields the optimal policy. $\square$

Pricing Mechanism: usage pricing (2)

- When consumption creates externalities, then Ramsey-Boiteux prices should be corrected to adjust to these externalities. In our case, water services offered by the public utility create environmental damage, damage being caused by pollution, over-abstraction, etc.
- The first term is the positive Ramsey-Boiteux term that reflects how the usage price has to be increased in order to satisfy the utility's break-even constraint: $\frac{\lambda}{(1+\lambda)}$ times the inverse elasticity of demand $\mu_p\left(\widetilde{\theta}, \omega\right)$, where λ denotes the shadow price of the break-even constraint.
- The second term represents a weighted penalty function which captures the social cost of excess demand, depending on the sensitivity of consumers to demand excess.

Pricing Mechanism: access pricing (1)

Lemma (4)

The optimal access pricing rule or the optimal price of participation is given by the following Lerner index:

$$\frac{k + (p - c) \int_{\widetilde{\theta}}^{1} (1 - \mathcal{F}(\omega^*))\, dG(\theta)}{k} = \frac{\lambda}{1+\lambda} \frac{1}{\mu_\phi} - \upsilon \frac{a}{\mu_\phi} \frac{1}{\int_{\widetilde{\theta}}^{1} \phi_\theta^* dG(\theta)}$$

where $\mu_\phi \left(\widetilde{\theta}, \omega \right)$ *is the price elasticity of the branch pipe size or the price elasticity of access.*

Proof.

Differentiating the program with respect to k yields the optimal policy. □

Pricing Mechanism: access pricing (2)

- The economic intuition behind the Ramsey-Boiteux term is that in order to finance the utility's fixed cost it is preferably to increase the access charge to those consumers less sensitive to price.
- $(p-c)\int_{\widetilde{\theta}}^{1}\left(1-\mathcal{F}\left(\omega^{*}\right)\right)dG\left(\theta\right)$ represents the marginal consumer access cost under uncertainty, where actual demand does not equal the optimal branch pipe size.
- This participation price includes a rationing marginal cost when excess demand occurs and depends on the degree of consumer diversity.

Pricing Mechanism: access pricing (3)

Lemma (5)

under an ex ante maximum demand charge with $k > 0$ the achievable social welfare is strictly greater than that achievable with $k = 0$.

Proof.

Fix any $p > 0$ and $Z > 0$. It is easy to show that

$$\left.\frac{\partial \underset{\omega}{E}(\mathcal{L})}{\partial k}\right|_{k=0} = \lim_{k \to 0} \left[\lambda \int_{\widetilde{\theta}}^{1} \phi_{\theta}^{*} dG(\theta) - (1+\lambda)\, \upsilon \int_{\widehat{\omega}}^{\omega^{+}} \frac{\partial (X-Z)}{\partial k} d\mathcal{F}(\omega) \right] > 0$$

Thus $\frac{\partial \underset{\omega}{E}(\mathcal{L})}{\partial k} = 0$ cannot be satisfied and the optimal k must be positive. □

Conclusion (1)

- The proposed incentive-based mechanism, applied with stochastic demand problem, allows consumers to self-ration and self-select by the size of their purchases.
- Under such mechanism the achievable social welfare is strictly greater than that achievable in the absence of demand charge k.
- We supposed that economically and legally independent neighboring water suppliers can physically connect their networks and made commercial exchange of the service possible: utilities facing capacity problems or shocks purchase water services from nearby better suppliers in order to overcome capacity problems.
- In this model, more importance is given to water charges to act as an incentive for a more sustainable use of water resources (by taking into account the uncertainties and irregularities in water flows) and cost recovery in the provision of water services $\longrightarrow$ the need for a more open pricing policy that accounts for environmental costs and to support sustainable demand-based policies.

Conclusion (2)

- The proposed water pricing model can substantially help leading to relaxation of water stress situations. Cost recovery could be a powerful tool not only to increase the effectiveness and efficiency of water system but to help prevent deterioration, to enhance and protect the status of water resources and finally to achieve sustainable water use in quantitative and qualitative terms.
- In setting a system capacity under uncertain demand, the public utility must consider the case of excess demand which occurs when system demands exceed its own installed capacity. The proposed rule for setting capacity avoids inefficient over-capacity problem.
- The proposed approach, by including uncertainties, will limit the adverse impacts of hazards and implies an efficient environmental management (for example drought management).

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