An Optimal Pricing Approach for the Control of EU Urban Pollution: Implementation of the Urban Wastewater Treatment Directive

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Abstract

Several EU Directives have been adopted and influenced the control of urban water pollution especially the EU Urban Wastewater Treatment Directive and the Integrated Control and Preventive Directive. The Water Framework Directive will also have an additional impact in the coming years on the control of urban water pollution in particular related to storm overflows. It requires the achievement of good ecological and chemical status in all waters. Our analysis will focus on public wastewater utilities facing demand and capacity shocks. The paper deals with the simultaneous determination of an economic incentive mechanism for the control of water pollution and investment rules under an ex ante maximum demand charge. We will characterize the welfare-optimal capacity selection rule and the welfare-optimal maximum demand pricing rule. Heterogeneous consumers' demands are considered when tariffs are set ex ante.

Key Words: Incentive mechanism, Pricing Policy, Pollution Control, Capacity planning, Public Utilities, Investments needs, Water Pollution.

Jel: D4, H4, L95, Q25, Q53, R32.

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Introduction

Today, the European Union is bringing together across its 27 Member States, a population of more than 492 million people. Wastewater generated by this huge population as well as by the different European industries, is a major source of pollution of all EU waters. Wastewater discharges have wide-ranging impacts on ground waters, rivers and lakes as well as on regional seas. Impact on drinking water supplies, over-fertilization or eutrophication[1] and loss of biodiversity are few examples of these impacts.

Up until 30 years ago, wastewater services were considered as simple labor-intensive activity. Focus was mainly on collection and urban hygiene. The main strengths have been to simply remove wastewater from users in order to prevent unhygienic conditions and to remove storm water to avoid damage from flooding. Today these services can not continue to be seen as we used to look at them. The main purpose still the same but all this should be done without harming the environment, and must fulfill a fundamental requirement, sustainability. Water sectors Directives characterize the different phases of environmental policy evolution, from an emphasis on public health protection to environmental protection per se, and from "end-of-pipe" solutions to preventive and environmental integrated management approaches.

EU environmental legislation affecting the water sector can be divided into three categories: legislation on the protection of water sources, including the control of pollution by commercial activities; acts directly regulating municipal activities in the water and wastewater sector; and finally the Water Framework Directive (WFD). In principle, these Directives aimed to achieve better protection of water resources, but in some areas the effectiveness was questionable, as water quality continued to deteriorate during the 1980's largely as a result of agricultural pollution. As a reaction to the inadequacies of the first wave of legislation, the Directives for controlling certain sources of pollution were adopted.

From the point of view of urban supply, the sector Directives have contributed to the improvement of raw water sources. The Directive on drinking water quality (Council Directive 98/83/EC on water intended for human consumption) and the Urban Wastewater Treatment Directive (UWWTD) affected municipalities and water authorities directly by prescribing minimum water quality standards for human consumption and standards for wastewa-

[1] Eutrophication: enrichment of water by nutrients, especially compounds of nitrogen and/or phosphorus, causing an accelerated growth of algae and higher forms of plant life to produce an undesirable disturbance to the balance of organisms present in the water and to the quality of the water concerned.

ter collection, treatment and disposal, and so imposed extra costs on water and wastewater services. The UWWTD imposed huge costs on local water authorities throughout Europe by requiring major capital expenditure on wastewater treatment plants in a relatively short timescale, thus creating technical and financial difficulties[2]. The Directive triggered particularly large investments in accession states[3]. Finally, The WFD introduced overall principles for the sector, including requirements for public participation in decisions on water resources, and pressure for full cost from user charges.

The UWWTD is addressing environmental pollution challenges by measures at the source of the pollution by providing for collection and treatment of wastewater in all settlement areas and areas of economic activity above a certain size (agglomerations[4]). As a general rule, only areas sufficiently concentrated and having a population of more than 2000 people or the equivalent in wastewater (population equivalent, P.E.[5]) are covered. For biological wastewater treatment (secondary treatment), the Directive provides a drastic reduction of biodegradable pollution in wastewater, which otherwise would severely impact on oxygen balance and ecosystems of EU waters. In the catchments of particularly sensitive waters (sensitive areas), such as those suffering from eutrophication, more stringent treatment measures are required, to additionally eliminate nutrient pollution (nitrogen and/or phosphorus) from wastewater. Proper implementation of the Directive is also indispensable for achieving the objective of "good status" for all waters as set in the WFD.

For the 15 Member States, the time schedules for achieving the environmental objectives are staged (1998-2000-2005), depending on the characteris-

[2]On 24.06.2004 the European Court of Justice condemned Greece for not taking the measures necessary for the installation of a collecting system for urban wastewater.

[3]For example, the Czech government estimated the figure for achieving EU water standards at USD $2.5 billion to be invested in the water sector by 2010, for 99 new treatment plants, 21 new sewerage systems and 141 upgrades.

[4]Agglomeration as defined in article 2(4) of the Directive is a community of homes, shops, hospitals and certain industries which are sufficiently concentrated for the wastewater to be collected for treatment at a sewage treatment works. Agglomeration usually refers to cities or towns. The generated load of agglomerations can be used as a parameter to calculate the capacity of treatment plants in the planning stage. The plant is dimensioned based on this load, after including an additional multiplying factor in the calculation (i.e. to take account of seasonal variations and a possible extension of the agglomeration).

[5]Population equivalent (P.E.) is the standard unit for calculating the organic biodegradable pollution load and refers to the organic pollution in wastewater. 1 P.E. means the amount of oxygen-demanding substances (biological oxygen demand, BOD_5) whose oxygen consumption during biodegradation equals the average oxygen demand of the wastewater produced by one person (60g O_2/day over a time period of five days).

tics of the affected waters and the size of the wastewater pollution load. For the new Member States, staged transition periods have been set in a clear and legally binding way within the Accession Treaties[6].

In 2000, the European Parliament's Council conciliation committee reached a final agreement on the proposed Framework Directive for Community action in the field of Water (WFD). The Directive affects not only member states but also accession countries and marks an important trend towards an ecosystem-based approach for water policy and water resources management. The WFD will thus have important overall implications in shaping developments in water policy and management at an international level. Key premises of the WFD are the notions of sustainable development, integrated management, and subsidiarity.

The WFD can be considered the first framework for EU action in the field of water policy and water resources management, setting new goals for the condition of Europe's water and introducing new means and processes for achieving them. The Directive constitutes a new approach in Europe, integrating the ecological, economic and social aspects of water policy and water resources management at the level of river basins. The main objectives of the WFD are to protect and improve the EU's aquatic environment and to make a contribution to sustainable, balanced, and equitable water use. All waters (surface, underground, and coastal) are to attain the goal of a good and nondeteriorating status.

The means of achieving the WFD goals are organization and planning at a hydrologic (river basin) level and implementation of a number of pollution-control measures. Each river basin plan is to include a number of mandatory "basic" measures, such as those required at a minimum to comply with the requirements of the directive. In addition, any "supplementary" measures may be implemented if relevant, such as demand management measures, additional legal and/or economic measures, rehabilitation projects, etc. Moreover, member states are asked to take account of the principle of full recovery of costs (operational, capital, and environmental/resource) of water services,[7] apply economic concepts such as the polluter pays principle, adopt approaches and tools based on cost-effectiveness analysis, and consider economic instruments, such as incentive water pricing.[8] As mentioned in the

[6] Transition periods must not exceeds 2015 and in one case, Romania, smaller agglomerations have to comply by 2019.

[7] The term "water services" has been introduced in the WFD, Article 2, point 38. The term was further specified in the WATECO guidance document since this term is of importance for taking into account the principle of recovery of the costs of water services including environmental and resources costs.

[8] As stated in the Directive, pricing is a "basic" measure (Art. 11-3b).

WFD, the contribution of economic instruments in environmental policies "promotes the use of water charging to act as an incentive for the sustainable use of water resources and to recover the costs of water services by economic sector. This will contribute to meeting the environmental objective of this directive in a cost-effective way." Social, environmental, and economic considerations as well as climatic and geographical differences are to be taken into account. The EU recommends a harmonized approach to water services pricing, not of prices, across the EU, using volumetric charges to reject and recover financial, environmental and resources costs. This approach, if applied effectively, will enhance the sustainability of water resources.

Over the last few decades, government authorities have been forced to give greater attention to the depletion of their water resources and environmental pollution. An excessive and persistent demographic growth, an increasing urbanization and marked inequalities in the economy, such as grants or subsidies to agriculture or some strategic industries, are some of several factors that are responsible for the increased pressure on the resource and the environment.

Most of the sewerage systems across Europe are of the combined type, although in some countries like in parts of Germany or France, separate systems for rainwater and wastewater can be frequently found. Sewage treatment plants and also some pumping stations are usually designed to accept a certain maximum flow expressed as a multiple of the dry weather flow (usually three times DWF). Any flow above the design flow is discharged through combined sewer overflows (CSOs) without further treatment to the aquatic environment. The frequency and duration of the overflows or spills depends on the frequency and intensity of rainfall and the design of the sewer system and treatment plant. To reduce the frequency and duration of the sills, storm tanks are provided at sewage works and/or storm sewage retention tanks are built into the sewer system. The content of the tanks is generally returned to the sewage treatment plant after the rainfall event. Discharges from sewage works are generally well regulated (and will be) in all countries with the implementation of the water Directives. But, the control of CSOs varies widely in Europe. In fact, CSOs are generally based on design parameters which are independent of the dilution available in the receiving water.

Public authorities are having today difficulties reforming pricing rules for the water sector and thus controlling urban water pollution. Governments adopt more shortsighted programs by using more politically correct tools to fight against the increasing demand of water resources and pollution issues. Efficient pricing policies are almost absent in must countries, and current water sector pricing systems are very distorted, leading to large deficits and over-consumption of the resource. Much more, public authorities are facing

wide investment needs driven by obsolete and worn out network systems on the one hand and by the imposition of EU quality standards on the other. However, in many EU countries those investment needs are subsidized (National and EC structural funds) which means that there is no clear link between investment levels and charges.

The purpose of this paper is to present an appropriate economic incentive mechanism for the control of urban water pollution. I examine the second-best nonlinear pricing for wastewater services, applied with stochastic demand problem and subject to commonly observable shocks. After a review of the economic and technical aspects of the provision of drinking water and sewage services in section 1, I will present the EU Regulations in the water sector in section 2. The water pollution model is presented in section 3. In section 4, I present the economic incentive mechanism and the pricing policy. Conclusions are in section 5.

1 The water industry

The legal basis for regarding water provision as a public utility was laid down in the 19th century when Pasteur discovered that contaminated water was an important cause of infectious diseases. Local municipalities were charged by law to provide pure drinking water to their inhabitants, and to collect and treat wastewater.

Today, Water Utilities have different objectives [11, 35]. First, they might want the most optimal resource allocation. Second, they have objectives with respect to the level of deficits of water management authorities. Third, they have to respect financial break-even constraints (budget constraints). Finally, and the most important objective in the context of growing water scarcity, reducing water consumption to prevent further depletion of the resource [2, 28]. Thus, Water Utilities are facing different water pricing options provided by economic theory[9] which generally requires that a pricing structure meet the four criteria of: efficiency, equity, financial viability, and simplicity[10]. Also,

[9] The economic theory provides us different and efficient pricing tools [5, 6, 7, 36, 39]. Theoretically, in a partial equilibrium state, the Pareto optimal prices would be equal to the marginal cost of producing water. However, given the cost structure of producing water, this type of pricing leads to deficits [37]. Consequently, authorities have to finance these deficits through taxes. The taxation methods are almost all distorted (the exception being a lump sum tax, but this form of taxation is seldom used for practical reasons).

[10] Two part tariffs have been adopted as the preferred pricing structure by most Water Utilities because they are allocatively efficient, equitable (in the sense that the user pays) and achieve financial viability because the access component ensures that sufficient revenue is recovered [35]. A two part tariff is comprised of a fixed component, intended to recover

any entity, public or private, that manages water services, has the obligation to ensure characteristics of a public service: continuity and dependability, mutability, equality (in terms of access to all consumers, tariffs, and service provided). Furthermore, they have to ensure that the interests of users are protected with respect to both prices and quality (water and level of service), and that there is no undue discrimination.

Compared to the electricity, telecommunication, and gas industries, water and wastewater activities are those where natural monopoly conditions are most prevalent [8, 33, 37, 38]. This natural monopoly derives from the established local networks of drinking water pipes and sewers. Duplication of the fixed network of mains and sewers is inefficient. The fixed assets have little or no alternative uses, their resale values are well below the cost of replacing them, and largely so are sunk costs. Environmental improvement and high quality standards require new processes and thus new sophisticated capital equipment. Given these sunk costs, it would not be economical for potential competitors to install rival networks.

Water supply involves the extraction of water from reservoirs, rivers or aquifers, its treatment in various ways, and its distribution under pressure to consumers through networks of mains [1, 11]. Raw water is extracted from underground (aquifer) and/or surface sources (rivers, lakes, or reservoirs). This extracted water is then treated to remove natural, manmade and synthetic pollutants in order to make it potable for consumption, and is distributed via a network of mains to the consumer. Groundwater usually needs less treatment than surface water due to the natural filtration process, but it is more expensive to abstract since it requires pumping from wells. The raw water treatment process involves filtration to remove suspended matter, disinfection with chlorine to kill harmful bacteria, and pH correction to minimize corrosion in the distribution system. Water quality is regulated, stringently for domestic purposes, by minimum standards related to microbiological, chemical, physical, and aesthetic properties.

Sewerage services involve the collection of domestic sewage, industrial effluent, and surface water, and the provision and maintenance of an adequate sewerage system to convey it. The sewage may be treated in various ways before final discharge, which must meet pollution control standards and national water resources management policies. In fact, used water is collected and pumped to wastewater treatment facilities, where solids and harmful bacteria usually are removed by sedimentation. Sludge is removed, incinerated and even dumped at sea or other specific discharge areas, or utilized as

the costs of access to the system, and a usage component, which varies with consumption [2, 28, 36, 39].

fertilizer on farm land.

Externalities exist at several stages of the water cycle. Rivers, lakes or aquifers from which water is abstracted can be polluted by effluent discharges (aluminum, cadmium, mercury, lead, nitrates, pesticides, etc.) from factories or sewage treatment plants sited further upstream. The decrease in stream flow quantity can be harmful too.

Effluent discharges are not the only pollution sources: underground water resources can be polluted by fertilizers or pesticides used in agriculture. These sources of pollution increase the costs of water treatment to achieve acceptable quality. Ocean dumping of sewage sludge can cause harm to fish stocks and raw sewage that is pumped out to sea or rivers can lower the quality of bathing beaches or recreational areas. These direct pollution (point sources of pollution) externalities must be controlled to improve raw water resources, environmental quality, and other environmental recreational public goods.

In cases where polluters behave badly, legal penalties must be taken. However, since it is not always possible to establish who has caused pollution (in particular the indirect pollution or non-point sources of pollution) only indirect methods of control are feasible, such as taxation, legal restriction uses, etc. [8, 29, 30, 34].

Domestic water demand is usually price-inelastic [9, 10, 40, 42] and is seasonal, reaching its peak period in summer time when the availability of raw water is at its lowest level. Customers in urban zones have metered drinking water supplies. In housing complexes such as public-sector housing, metering is often done collectively and then, water charges[11] are mostly based on the number of people by apartment or rarely on the habitation surface. In the other cases, water charges are based on individual demands.

The wastewater pricing regime is somewhat different than for water supply. Generally, households wastewater charges are either fixed or based proportionally on drinking water demand or the size of the building but bear no relation to actual pollution. In general, only industrial users pay in accordance with the quantity of pollution they create.

[11] In France, since 1992, flat rates are prohibited by law which suggests the use of non-linear pricing rules. The recommended pricing system involves a two-part tariff: an access tariff covering fixed costs of service (consumer's hook-up) and a linear charge based on usage, which can be increasing or decreasing with the quantity of water consumed [11]. In other countries that use a two-part tariff, such as Italy, Greece, Finland or Belgium, a social component is included into their increasing block tariffs. An initial free-of-charge block has been introduced and is applied to the first dozen of m^3 of consumption per person. Sometimes, the price of the first few cubic meters is fixed regardless of the actual consumption level [31].

Water demand is determined by the quality of the water and the standard of service provided by the supplier, which can be public or private, among other factors. Water quality has many dimensions. In fact, consumers can easily judge whether drinking water tastes or smells bad, or can see its discoloration. These aspects are observable to consumers. However, there are different aspects of water quality which are very important because they can affect public health. For example, high concentrations of metals such as lead, pesticides, nitrate, etc., which can not be checked by households, are dangerous to public health.

An external regulation is necessary to ensure that drinking water is not harmful and meets European Union Standards. This biological and physical regulation of drinking water is the responsibility of the local municipal organization in collaboration with federal states and governments departments and agencies[12] (environment, agriculture, and public health). Another aspect of quality is the level of service provided by a utility. Consumers want adequate water pressure, do not want to suffer flooding from sewers or from drinking water distribution systems failures, and require that leaks in the public system must be mended promptly.

Sewerage demand is complementary to the demand of indoor water use. Domestic wastewater services are priced homogeneously within a local community and wastewater charges are based on drinking water demand. Industrial wastewater (also called trade effluent) produces different types of effluent which vary in strength and nature depending on the corresponding industrial activity. Industrial wastewater services are priced according to effluent discharges in relation to both strength and quantity discharged. However, we may notice that these industrial users have the option of partially or totally pretreating their effluent: they can affect their costs by partially treating effluent before it enters the sewer system and so they reduce the costs of treatment by the sewerage firm or by bypassing the sewerage company altogether and doing all treatment on site.

Finally, water prices vary across regions and municipalities and reflect substantial variations in costs. Cost differentials are driven by a number of factors. These include the availability and proximity of water, environmental protection, variations in the quality of drinking water, and urban density (economies of scale). In general, less urbanized countries and regions face proportionately greater cost increases than more heavily urbanized countries and regions.

[12] Health authorities set a minimum quality standard which can be verified by a federal or independent laboratory.

2 EU Regulations

EU environmental and water policy can be roughly divided into three periods. The first period includes the first three environmental programs (1973-1986). In this period the EC had no mandate for environmental regulation but only in areas affecting the core objectives of the Community. During this period, 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. This was a period when the emphasis passed on to pollution control and environmental protection. The third phase is still under way and is largely characterized by the adoption of the WFD.

The EU UWWTD [21] adopted in 1991 provides the main legislation for the control of urban pollution. However, the Water Framework Directive [27] with its requirement to achieve "good" quality water for all surface and ground waters focuses further attention on urban pollution discharges. In addition, the Integrated Pollution and Prevention and Control Directive [25] is important for urban pollution control as it regulates the discharge of effluents from the most polluting industries to sewer and surface waters. Finally, the EU Product Directives are important for the quality of effluents discharged from sewer systems as they prohibit or restrict the use of substances discharged to sewer system or the entry of certain substances to the sewer system from diffuse inputs (e.g. pesticides).

2.1 1973 - 1986

In the first period, "environmental Directives" can be broadly characterized into two types: water use Directives mainly public-health oriented and water pollution Directive oriented to the harmonization of pollution control efforts in the EC. Water use Directive included standards for the quality of water intended for drinking [12] and after treatment [18], bathing [13] and for fish and shellfish harvesting [16, 17]. These Directives were based on quality objectives specified into imperative standards that should be respected in all cases and/or guidance standards.

In contrast, water pollutant Directives regulated the permissible levels of discharges of particular pollutants. The two key Directives were those for the emission of dangerous substances to surface [14] and ground water bodies [19]. Two lists of harmful substances were set: for list I substances, emission limit or quality standards were to be agreed by EC Ministers in subsequent substance-specific "daughter" Directives. For list II substances, Member

States were asked to come up with integrated programs for their reduction. For groundwater, rules were more stringent and all list I substances were prohibited from reaching aquifers.

2.2 UWWTD

During the second period, two new directives were introduced tackling the main sources of water quality deterioration: pollution from urban wastewater [21] and pollution from nitrates from agricultural run-off [22]. 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 [23], the habitats Directive [24] and the integrated pollution prevention and control Directive [25].

The aim of the UWWTD[13] is to avoid pollution of fresh and marine waters from urban sewerage systems. The Directive requires that:

- all agglomerations > 2000 P.E. should be provided with collection systems for urban wastewaters;
- the effluent from sewage treatment plants must meet certain minimum effluents standards as laid down in the Directive. The standards depends on the sensitivity of the receiving water [21];
- 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 (> 10000 P.E.) to "sensitive" waters must be also subjected, in addition to biological treatment, to nutrient removal. "Sensitive areas" are to be identified, based mainly on the risk of eutrophication and the exceedance of the drinking water standard for nitrate.

[13] The estimated cost for complying with the provisions of the Directive in the different EU 15 Member States is about 130 Billion Euro [41].

Member States must also ensure that all biodegradable discharges entering receiving water from biodegradable industrial wastewater (milk-processing, manufacture of fruit and vegetable products, manufacture and bottling of soft drinks, potato-processing, meat industry, breweries, etc.), where the discharge represents 4000 P.E. or more, are authorized and must meet the requirements set for that industry in national legislation. Sewage sludge must be recycled whenever possible.

The UWWTD does not lay down any standards for CSOs[14]. It is left to Member states to regulate CSOs but the Directive suggests that the regulations could be based on dilution rate, treatment capacity in terms of dry weather flow or spill frequency.

Six Member States under article 5(8) of the Directive (Belgium, Denmark, Luxembourg, The Netherlands, Finland and Sweden) have designated all their waters as sensitive. In addition eight Member States (Germany, Greece, Italy, Spain, France, Ireland, Portugal and the UK) have designated parts of their water as sensitive. Austria decided in December 2002 to apply article 5(8) over all its territory. Therefore, there is no need for designation of sensitive areas and more stringent treatment shall be provided in all agglomerations above 10000 P.E.

Member States have the option to designate certain coastal and estuarine waters as less sensitive provided they meet certain morphological, hydrological or hydraulic conditions. This is the case of the UK, Portugal, Greece and Spain for example. The designations for each country using this possibility are evaluated by the European Commission. For less sensitive areas less stringent treatment than secondary treatment (primary treatment) can be applied if this does not cause adverse effects on the environment.

Considerable progress has been made since the adoption of the Directive in improving the provision of sewage treatment facilities in the Member states. Whereas 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. Moreover indications are that a number of Member States will be unable to fully comply with the provisions of the Directive at the required implementation dates (Italy, Greece, and Portugal for example).

Concerning the EU 15 Member States, 349 out of the 571 "big cities" (i.e. agglomerations > 150000 P.E.) complied with the treatment requirements of the Directive without any need for upgrading the treatment as on January 2003. Still, there were 17 "big cities" without any wastewater treatment! But, it seems since then that several of these cities complied with the

[14]Combined Sewer Overflows.

UWWTD requirements.

The implementation of the Directive shows, based on reports received from Member States, considerable progress as well as deplorable shortcomings. For example, the compliance rate for adhering to objectives and deadlines due in 1998 and 2000 as reported by Member states is 81.4% in total based on wastewater pollution load and the number of "big cities" without adequate wastewater treatment has declined from 27 in 1999 to 17 in 2003.

But, as reported by Member States and identified by the Commission, we can underline the following important implementation gaps:

1. Inadequate reporting or lack of reporting: 444 agglomerations with a wastewater load of 56 million P.E. in Italy and Spain have been not reported at all or at the required time frame.

2. Inadequate treatment or lack of treatment: there is inadequate wastewater treatment from agglomerations discharging into designated sensitive areas (secondary treatment instead of more stringent treatment involving nitrogen removal), mainly for agglomerations in France, Belgium, Italy, UK, Luxemburg, Portugal, Finland and Sweden, accounting for about 10.3% of the total wastewater load (or 48.4 million P.E.). The Commission also reported inadequate wastewater treatment from agglomerations discharging into normal areas (primary treatment instead of secondary treatment), mainly for agglomerations in Spain, Italy, Portugal, Greece, Ireland, UK, France and Belgium, accounting for 8.9% of the total wastewater load (or 42 million P.E.). Finally, there is a lack of wastewater treatment (or preliminary treatment only) from a total of 283 agglomerations, mainly in Spain, Belgium, Italy, Portugal and Greece, accounting for 4% of the total wastewater load (or 18.7 million P.E.).

3. Insufficient designation of sensitive areas: following technical-scientific assessment, the Commission has come to the conclusion that across a range of Member States, an additional 104 sensitive areas and their related catchments should have been designated, mainly in Spain, UK, Italy, Ireland, France and Portugal, entailing the need for an upgrading of the treatment applied for a significant number of discharges, including 787 agglomerations, representing 21.5% of the total wastewater load (or 101 million P.E.). Consequently, the Commission has taken legal actions in all these areas.

2.3 IPPCD

The primary objective of the IPPCD is to prevent and where this is not possible to reduce emissions to air, water and land from most polluting installation. The Directive applies to effluents from 50 industry sectors (listed in the Annex of the Directive, EC, 1996) discharged to surface water and to sewers. The application of the best available techniques (BAT) is required for the control of emissions. As requested in the Directive, it is the responsibility of Member State Governments to prepare standards and guidance notes for the implementation of the directive. The EC established summary documents for the different industrial sectors using these national documents presented to the Commission. The application of this Directive to discharge to sewer will result in an improvement of effluent, discharged to sewer and in return of the effluent discharged to sewage treatment plants and the CSOs. In addition, the largest sewage treatment plants also falls under the IPPCD leading to an improvement in the quality of effluent discharged by the sewage treatment plants in particular related to dangerous substances.

2.4 Product Directives

These Directives are important as they are a mean of controlling pollution from diffuse sources. The general aims of these directives are either to make the product more environmentally acceptable or to restrict or prohibit the use of certain substance in products.

The Marketing and Use Directive [15] and its amendments prohibit or restrict the marketing and use of certain dangerous substance and preparations containing dangerous substance. For example, the Detergent Directive [20] requires a certain biodegradability of the surfactant before it may be marketed in detergents. The Pesticides [23] and the Biocides [26] Directives restrict the pesticides and biocides, which are approved for certain uses. These Directives contribute to the control of diffuse inputs to sewer and have therefore an important impact on the quality of the effluent discharged from CSOs.

2.5 WFD

As mentioned in the WFD, the contribution of economic instruments in environmental policies "promotes the use of water charging to act as an incentive for the sustainable use of water resources and to recover the costs of water services by economic sector. This will contribute to meeting the environmental objective of this directive in a cost-effective way". Concerning pollution,

the main requirement of the WFD is “to prevent deterioration of ecological quality and pollution of surface waters and to restore polluted surface waters to achieve good ecological and chemical status in all waters”. Thus, Member States must establish a register of all areas within a River Basin District requiring special protection.

In order to achieve good ecological and chemical water quality in all waters, Member States have to establish improvement programs. These may involve requirements to improve sewage treatment plant effluents in excess of the minimum standards laid down in the UWWTD and further improvements of the performance of CSOs.

In the European Commission point of view, the application of economic and environmental principles in water services pricing policies will limit the increasingly unsustainable use of water resources in many European river basins. Water and sewerage providers should base their pricing policies on an explicit assessment of costs, financial costs (capital and operating costs), environmental costs (the damages to the environment caused by a given activity) and resources costs (value of the alternative foregone by choosing a particular activity, i.e. opportunity costs) and benefits of water use.

For the EC, in many EU states, economic efficiency and environmental objectives are rarely considered in water policies. They failed to consider environmental and resources costs in their pricing policies. Instead, EU states have given preference to affordability and social concerns, the resulting subsidies almost invariably contradicting economic and environmental objectives by encouraging the wasteful use of water. Financial costs are often not fully covered by water services charges. Environmental and resources costs are rarely considered when determining prices for water services. Moreover, levels of cost recovery differ sharply between countries and between sectors (domestic, agricultural, industrial, energy, etc.), regions and municipalities in any one country.

Technical and political difficulties arise when a member state try to balance potentially conflicting economic, environmental and social objectives in the form of an optimal pricing regime. Technical difficulties arise because of the lack of adequate and robust information about economic and environmental costs and benefits. Political difficulties arise because increasing prices generate considerable resistance amongst water and sewerage customers.

The EC recommends a harmonized approach to water services pricing, not of prices, across the EU, using volumetric charges to reflect and recover financial, environmental and resources costs. Harmonization refers to "the adoption of common definitions for key cost variable [which] would facilitate the comparison between costs and prices and benchmarking for different water services, uses and countries" (European Parliament, 2000, p. 14). Har-

monization requires the adoption of common methodologies for the monetary valuation of environmental and resource costs and benefits. It also requires standardized accountancy practices for financial costs. This approach, if applied effectively will enhance the sustainability of water resources. Financial costs include the cost of providing and administrating water services. Environmental costs relate to the damage (caused by pollution for example) to ecosystems and to those who use the environment business, recreational or other purposes. Resources costs relate to over-abstraction of water sources in rivers, lakes, wetlands and aquifers, leading to the depletion of water resources and so denial of those resources for other uses. Resources costs must include potential users (current and future) opportunity costs. The EC argues that each user in different sector should pay for these three constituent costs in direct proportion to both the volumetric amount of water used and the pollution produced, i.e. the polluter-pays principle. These three costs can be recovered via a three-part tariff: a fixed component to cover the fixed financial costs of supply, a charge per unit of water used, and a charge per unit of pollution produced. Nevertheless, a two-part tariff can also be applied where the variable charge could include not just the operating cost of supplying water but also any environmental and resource costs.

3 The model

3.1 Consumers

We consider that consumers maximize their expected utility function. We suppose that there is a continuum of consumer types and that consumer preferences are indexed by a taste parameter $\theta \in [0,1]$. Larger demands are associated with large values of θ, thus we assume non-crossing demand curves. The number of consumers of type θ is given by $h(\theta)$, a continuous, strictly positive density function with cumulative distribution $H(\theta)$ for all θ. Each consumer has a von Neumann-Morgenstern utility function.

Consumers preferences and the firm's technology depend on the state of the world ω_τ for all $\tau, \tau \in [1, \Gamma]$ which is an independent real-valued random variable. The random variable, ω_τ, has a continuous and positive probability density function $f_\tau(\omega_\tau)$ on the compact, convex interval $[\omega_\tau^-, \omega_\tau^+] \subseteq \mathbb{R}$, and a cumulative distribution function $\mathcal{F}_\tau(\omega_\tau)$ for $\omega = \{\omega_\tau | \tau \in [1, \Gamma]\}$. ω_τ 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), and idiosyncratic shocks such as changes in consumer tastes and firm technology.

The consumer's utility function given by (1) is assumed to take a quasi-linear form,[15] where r is the residual income (numeraire commodity) which is supposed to be nonnegative, $u(\cdot)$ is the willingness-to-pay function at time τ with no intra-period variation and τ can be viewed as one of the equal-length subperiods of a billing period consisting of Γ periods.

$$\begin{cases} U(q,\theta,\omega,\tau) = \sum_{\tau=1}^{\Gamma} u(q,\theta,\omega,\tau) + r \\ U(0,\theta,\omega,\tau) = 0 \end{cases} \tag{1}$$

Each consumer has a goal to maximize his expected consumer's surplus under the following schema. After the state of the nature ω_τ is realized, the consumer is free to consume q_τ unit of the service at a price p, as long as his demand does not exceed the size of the sewer branch pipe which he purchased at a price k. k is an access tariff which represents consumer's hook-up. Consumer's demand is assumed to be bidimensional, and characterizes consumer's preferences in terms of quantity and the adequate quality of the service which is supposed to be exogenous parameter determined by the legislator (National and European standards). In other words, the public utility announces ex ante the different terms of contracts. Consumers choose ex ante their own contract. Then, the state of the nature $\omega = \{\omega_\tau | \tau \in [1,\Gamma]\}$ is realized and consumption q_τ occurs. Payments are made at the end of the billing period Γ. In this decentralized and incentive-compatible setting, consumers self-select their own branch pipe[16] size Ψ_θ ex ante and consumption level ex post fitting to their own type. Thus, a consumer of type θ has an optimization problem described by (2):

$$Max \sum_{\tau=1}^{\Gamma} \left\{ \underset{\omega}{E} \max_{q_\tau} \left(u(q_\tau,\theta,\omega_\tau) - pq_\tau \right) - k\Psi_\theta \right\} \tag{2}$$

subject to $\Psi_\theta \geq q_\tau \geq 0$ for all $\tau = 1,...,\Gamma$ and where E denotes the expectation with respect to $\mathcal{F}$ over ω_τ. In the absence of demand charge k, the ex post desired demand for each consumer of type θ, comes from maximizing consumer's surplus:

$$\underset{q_\tau \geq 0}{Max} \int_0^{q_\tau} u'(x,\theta,\omega_\tau,\tau)\, dx - pq_\tau \tag{3}$$

[15] 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.

[16] For large industrial users, we assume that branch pipe includes a wastewater meter. We can imagine that metering wastewater services may also concern small or domestic consumers.

where $u'(\cdot)$ is the marginal willingness-to-pay function of a consumer of type θ at time τ. Let $u(\cdot)$ be sufficiently continuously differentiable in q_τ, θ, strictly decreasing in q_τ, and increasing in θ for all ω_τ. Furthermore, $u(\cdot)$ is continuous and differentiable in the shock ω_τ. Without loss of generality, we consider the following conditions:

$$\frac{\partial u}{\partial q_\tau} > 0; \frac{\partial^2 u}{\partial q_\tau^2} < 0; \frac{\partial u}{\partial \theta} > 0; \frac{\partial u}{\partial \omega_\tau} > 0; \frac{\partial^2 u}{\partial q_\tau \partial \theta} > 0 \tag{4}$$

The first two derivatives mean that the utility function is positive and decreasing in q_τ. The third relation states that a given allocation gives the higher types a higher utility level. The fourth assumption means simply that the utility function is increasing in ω_τ: for example, a higher value of ω_τ means sever weather conditions implying an increase in wastewater demand. Most models used in the economic literature simplify the analysis by considering the cross-derivative $\frac{\partial^2 u}{\partial q_\tau \partial \theta}$ has constant sign, which is called the Spence-Mirrlees condition.[17] We suppose that this derivative is positive. This indicates that the indifference curves of two different types can only cross once, and a higher θ implies both a higher gross surplus and a higher willingness to pay for a given increase in q_τ. A high θ thus indicates a high demand for the service. So, it is easy to separate the different types of consumers. Necessary and sufficient conditions for a maximum at q_τ^* are:

$$u'(q_\tau^*, \theta, \omega, \tau) - p \leq 0, q_\tau^* \geq 0 \tag{5}$$

This equation means that individuals will consume positive quantities up to the point at which willingness to pay for a marginal unit just equals price. This later equation defines an implicit function $q_\tau^*(p, \theta, \omega_\tau)$ characterized by:

$$\frac{\partial q_\tau^*}{\partial p} < 0; \frac{\partial q_\tau^*}{\partial \theta} > 0; \frac{\partial q_\tau^*}{\partial \omega_\tau} > 0 \tag{6}$$

Once the ex post desired demand function $q_\tau^*(p, \theta, \omega_\tau)$ is derived, we will focus the problem on the consumer's choice for the size of branch pipe, Ψ_θ. Since $\frac{\partial u'}{\partial \omega_\tau} > 0$, given any size of Ψ_θ, price p, and type θ, there exists a unique state of the nature $\widehat{\omega}_\tau$ at which $q_\tau^*(p, \theta, \omega_\tau)$, the ex post desired demand for the consumer of type θ, just equals the size of his subscribed branch pipe $\Psi_{\theta\tau}$. $\widehat{\omega}_\tau(p, \Psi_\theta)$ is characterized by the solution to

$$q_\tau^*(p, \theta, \widehat{\omega}_\tau) = \Psi_\theta \tag{7}$$

[17] Also called the single-crossing condition or the *sorting condition* because it may allow us to sort through the different types of the consumer.

If $\omega_\tau \leq \widehat{\omega}_\tau$, consumption is given by $q_\tau^*(p,\theta,\widehat{\omega}_\tau) \leq \Psi_\theta$, the ex post desired demand. For $\omega_\tau \geq \widehat{\omega}_\tau$, consumption is equal to Ψ_θ. Thus the realized consumption $\widehat{x}_\tau$ under the ex ante branch pipe constraint will be:

$$\left\{ \begin{array}{c} if\ \omega_\tau \leq \widehat{\omega}_\tau \Rightarrow \widehat{x}_\tau = q_\tau^*(p,\theta,\widehat{\omega}_\tau) \leq \Psi_\theta \\ if\ \omega_\tau \geq \widehat{\omega}_\tau \Rightarrow \widehat{x}_\tau = \Psi_\theta \end{array} \right. \Rightarrow \widehat{x}_\tau(p,\theta,\omega_\tau,\Psi_\theta) = Min\{q_\tau^*, \Psi_\theta\} \tag{8}$$

Using (7) and (8), and for any given p, k, and Ψ_θ, the total expected maximum surplus of a consumer of type θ for the considered billing period is defined by

$$\begin{aligned} \underset{\omega}{E}(S_\theta) &= \sum_{\tau=1}^{\Gamma} \int_{\omega_\tau^-}^{\widehat{\omega}_\tau} \{u(q_\tau^*,\theta,\omega_\tau) - pq_\tau^*\}\, d\mathcal{F}_\tau(\omega_\tau) + \\ & \sum_{\tau=1}^{\Gamma} \int_{\widehat{\omega}_\tau}^{\omega_\tau^+} \{u(\Psi_\theta,\theta,\omega_\tau) - p\Psi_\theta\}\, d\mathcal{F}_\tau(\omega_\tau) - k\Psi_\theta \end{aligned} \tag{9}$$

Over a billing period of a length Γ a consumer θ facing p and k, chooses $\Psi_\theta^* = \Psi_\theta^*(p,k)$ which maximizes his expected surplus defined in (9):

$$\left. \frac{\partial \underset{\omega}{E}(S_\theta)}{\partial \Psi_\theta} \right|_{\Psi_\theta = \Psi_\theta^*} = \sum_{\tau=1}^{\Gamma} \int_{\omega_\tau^*}^{\omega_\tau^+} \{u'(\Psi_\theta^*,\theta,\omega_\tau) - p\}\, d\mathcal{F}_\tau(\omega_\tau) - k \leq 0 \tag{10}$$

$$\left. \frac{\partial \underset{\omega}{E}(S_\theta)}{\partial \Psi_\theta} \right|_{\Psi_\theta = \Psi_\theta^*} = 0;\ \text{and}\ \Psi_\theta^* \geq 0$$

Ψ_θ^* is the optimal branch pipe size for the consumer θ. This optimal size is determined by p, k, and the stochastic process $\omega = \{\omega_\tau | \tau \in [1,\Gamma]\}$. $\omega_\tau^*(p,\Psi_\theta^*)$ is the solution to

$$q_\tau^*(p,\theta,\omega_\tau^*) = \Psi_\theta^*(p,k) \tag{11}$$

At ω_τ^*, the ex post desired demand for a consumer, θ, $q_\tau^*(p,\theta,\omega_\tau^*)$, just equals his optimal branch pipe size given by (10). For $\Psi_\theta^* > 0$, these equations state that the consumer sets Ψ_θ^* at the level for which the price of an increase in branch pipe size equals the expected marginal consumer surplus over the billing period. Then $\underset{\omega}{E}(S^*)$ will be equal to $\underset{\omega}{E}(S_\theta)$ at the optimally chosen level of Ψ_θ^*.

From (10), we can write

$$\frac{\partial \Psi_\theta^*}{\partial p} = \frac{\sum_{\tau=1}^{\Gamma} \left[1 - \mathcal{F}_\tau\left(\omega_\tau^*\right)\right]}{\sum_{\tau=1}^{\Gamma} \int\limits_{\omega_\tau^*}^{\omega_\tau^+} \frac{\partial u'}{\partial \Psi_\theta^*}\left(\cdot\right) d\mathcal{F}_\tau\left(\omega_\tau\right)} < 0$$

and

$$\frac{\partial \Psi_\theta^*}{\partial k} = \frac{1}{\sum_{\tau=1}^{\Gamma} \int\limits_{\omega_\tau^*}^{\omega_\tau^+} \frac{\partial u'}{\partial \Psi_\theta^*}\left(\cdot\right) d\mathcal{F}_\tau\left(\omega_\tau\right)} < 0$$

Thus, if $\Psi_\theta^* > 0$, then:

$$\frac{\partial \Psi_\theta^*}{\partial p} = \frac{\partial \Psi_\theta^*}{\partial k} \sum_{\tau=1}^{\Gamma} \left[1 - \mathcal{F}_\tau\left(\omega_\tau^*\right)\right] \tag{12}$$

Equation (12) shows the relationship between the effect of marginal changes in usage price on the optimal branch pipe size and the effect of the marginal changes in branch pipe price on the optimal branch pipe size. It is obvious that $0 < \left[1 - \mathcal{F}_\tau\left(\omega_\tau^*\right)\right] < 1$. Thus, whenever k is positive, consumers set a branch pipe size strictly less than their greatest ex post desired demand. In other words, they do not fully insure themselves against adverse states of the world.

Now, let x_τ^* be the actual consumption function with an optimal ex ante branch pipe size Ψ_θ^*. x_τ^* is defined by

$$x^*\left(p, \omega, \Psi_\theta^*\right) = \widehat{x}_\tau\left(p, \theta, \omega_\tau, \Psi_\theta^*\left(p, k\right)\right) = Min\left\{q_\tau^*, \Psi_\theta^*\right\} \tag{13}$$

where $\widehat{x}_\tau\left(\cdot\right)$ is given by (8). These different equations will allow us to define the maximal level of expected consumers' surplus for all θ which is

given by the following relation:

$$\begin{aligned}
\underset{\omega}{E}\left(S^{*}\right) &= \int_{\widetilde{\theta}}^{1} \underset{\omega}{E}\left(S_{\theta}^{*}\right) dH\left(\theta\right) \\
&= \int_{\widetilde{\theta}}^{1} \left\{ \sum_{\tau=1}^{\Gamma} \int_{\omega_{\tau}^{-}}^{\omega_{\tau}^{+}} \left[u\left(x_{\tau}^{*}, \theta, \omega_{\tau}\right) - p x_{\tau}^{*}\right] d\mathcal{F}_{\tau}\left(\omega_{\tau}\right) - k\Psi_{\theta}^{*} \right\} dH\left(\theta\right) \\
&= \int_{\widetilde{\theta}}^{1} \left\{ \sum_{\tau=1}^{\Gamma} \int_{\omega_{\tau}^{-}}^{\omega_{\tau}^{*}} \left[u\left(q_{\tau}^{*}, \theta, \omega_{\tau}\right) - p q_{\tau}^{*}\right] d\mathcal{F}_{\tau}\left(\omega_{\tau}\right) \right\} dH\left(\theta\right) + \\
&\quad \int_{\widetilde{\theta}}^{1} \left\{ \sum_{\tau=1}^{\Gamma} \int_{\omega_{\tau}^{*}}^{\omega_{\tau}^{+}} \left[u\left(\Psi_{\theta}^{*}, \theta, \omega_{\tau}\right) - p \Psi_{\theta}^{*}\right] d\mathcal{F}_{\tau}\left(\omega_{\tau}\right) - k\Psi_{\theta}^{*} \right\} dH\left(\theta\right) \quad (14)
\end{aligned}$$

where $\widetilde{\theta}$ is the marginal participating consumers subscribing to a positive branch pipe size. In other words, for the consumers whose type is $\widetilde{\theta}$, the optimal branch pipe size $\Psi_{\widetilde{\theta}}^{*}$ is just equal to zero. There exists a unique marginal consumer type $\widetilde{\theta}$ characterized by

$$\widetilde{\theta}\left(p, k\right) = Sup\left\{\theta \middle| \Psi_{\theta}^{*}\left(p, k\right) = 0\right\} \quad (15)$$

Consumers of type $0 \leq \theta \leq \widetilde{\theta}$ consume nothing and neither receive a surplus nor make any contribution to profits. For those consumers, we assume that they have access to an alternative technology to collect and treat wastewater and thus have no preferences in terms of the public sewer system and treatment plant[18].

[18] While residential users have little freedom of choice for wastewater disposal and for altering the composition of their effluents, commercial and industrial water users have a wide range of technology, input and project choices that affect their water-born waste load. Facing an increasing in sewage charges, industrial and commercial users often find that the public sewer system is no longer the most cost-effective means of sewage disposal. Instead, recycling and reuse emerge as more economical options, and industries choose to switch to more self-treatment and effluent reuse. Also, facing more stringent regulation, several industries, including chemical, pulp and paper, textiles and metallurgy industries, have changed production processes and have made significant progress in reducing their waste services demands.

3.2 The wastewater utility

A representative utility is considered for ease of representation. The utility can be viewed as a natural monopolist subject to regulation. We assume that the wastewater utility has a service obligation and has to ensure universal access to such an important service. We assume that wastewater 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[19] at a unit cost of φ. The exogenous capacity shocks can represent technological effects such as equipment breakdown or exogenous demand that reduces available capacity. φ can be called the marginal penalty technology cost and should be in the range of $c < \varphi$ and $c\Gamma + \kappa < \varphi\Gamma$, otherwise the fixed proportions technology would be a strictly dominated technology.[20]

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

$$\sum_{\tau=1}^{\Gamma} \underset{\omega}{E} \left(CT_{\tau}\left(\Lambda, X_{\tau}\right)\right) = \sum_{\tau=1}^{\Gamma} \underset{\omega}{E} \left\{cMin\left(\Lambda, X_{\tau}\right) + \varphi\left[X_{\tau} - \Lambda\right]^{+}\right\} + \kappa\Lambda \tag{16}$$

where Λ is the installed capacity, φ is the marginal penalty technology cost (i.e. the rationing costs or the social cost of excess demand). The system demand at time τ is given by

$$X_{\tau}\left(p, k, \omega_{\tau}\right) = \int_{\widetilde{\theta}}^{1} x_{\tau}^{*}\left(p, k, \theta, \omega_{\tau}\right) dH\left(\theta\right) \tag{17}$$

and

$$\left[X_{\tau} - \Lambda\right]^{+} = Max\left[0, X_{\tau} - \Lambda\right] = \begin{cases} 0 \; if \; X_{\tau} \leq \Lambda \\ X_{\tau} - \Lambda \; if \; X_{\tau} \geq \Lambda \end{cases} \tag{18}$$

$\left\{cMin\left(\Lambda, X_{\tau}\right) + \varphi\left[X_{\tau} - \Lambda\right]^{+}\right\}$ is the sum of the expected operating cost and the expected cost of employing the penalty technology. $\kappa\Lambda$ is the capacity cost associated with an installed plants having size Λ. Given any Λ, p, and k, there exists a state of the nature at which system demand X_{τ} just equals the system capacity Λ:

$$\widehat{\omega}_{\tau} = \left\{\omega_{\tau} \middle| X_{\tau}\left(p, k, \omega_{\tau}\right) = \Lambda\right\} \tag{19}$$

[19] Economically and legally independent neighboring wastewater suppliers can physically connect their networks and made commercial exchange. In this case, φ can be considered as the market value of the service or environmental costs. It may be determined by usual procurement procedures such as competitive bidding or a negotiation process.

[20] For both, the assumed fixed proportional technology and the penalty technology to be an economical option, φ should be in the range defined above.

If $\omega_\tau \leq \widehat{\omega}_\tau$ then $X_\tau \leq \Lambda$ ($\frac{\partial u'}{\partial \omega} > 0$ and (17)). Thus, $Min\left(\Lambda, X_\tau\right)$ is equal to X_τ and $\left[X_\tau - \Lambda\right]^+$ equals zero. And for $\omega_\tau \geq \widehat{\omega}_\tau$, $Min\left(\Lambda, X_\tau\right)$ is equal to Λ and $\left[X_\tau - \Lambda\right]^+$ is nonnegative. Thus, the total expected costs can be written

$$\sum_{\tau=1}^{\Gamma} \underset{\omega}{E}\left(CT_\tau\right) = \sum_{\tau=1}^{\Gamma} \int_{\omega} \left\{cMin\left(\Lambda, X_\tau\right) + \varphi\left[X_\tau - \Lambda\right]^+\right\} d\mathcal{F}\left(\omega\right) + \kappa\Lambda$$

$$\sum_{\tau=1}^{\Gamma} \underset{\omega}{E}\left(CT_\tau\right) = \sum_{\tau=1}^{\Gamma} \int_{\omega_\tau^-}^{\widehat{\omega}_\tau} cX_\tau d\mathcal{F}_\tau\left(\omega_\tau\right) + \sum_{\tau=1}^{\Gamma} \int_{\widehat{\omega}_\tau}^{\omega_\tau^+} \left(c\Lambda + \varphi\left[X_\tau - \Lambda\right]^+\right) d\mathcal{F}_\tau\left(\omega_\tau\right) + \kappa\Lambda$$

$$\begin{aligned} \sum_{\tau=1}^{\Gamma} \underset{\omega}{E}\left(CT_\tau\right) &= \sum_{\tau=1}^{\Gamma} \left\{ \int_{\omega_\tau^-}^{\widehat{\omega}_\tau} cX_\tau\left(\omega_\tau\right) d\mathcal{F}_\tau\left(\omega_\tau\right) + \left(c - \varphi\right)\Lambda\left(1 - \mathcal{F}_\tau\left(\widehat{\omega}_\tau\right)\right) \right\} + \\ & \sum_{\tau=1}^{\Gamma} \varphi \int_{\widehat{\omega}_\tau}^{\omega_\tau^+} X_\tau\left(\omega_\tau\right) d\mathcal{F}_\tau\left(\omega_\tau\right) + \kappa\Lambda \end{aligned} \tag{20}$$

where $\mathcal{F}_\tau\left(\omega_\tau\right)$ is the distribution function of ω_τ, and $\mathcal{F}_\tau\left(\widehat{\omega}_\tau\right)$ is the probability of $\left\{\omega_\tau \leq \widehat{\omega}_\tau\right\}$ which is equal the probability of $\left\{X_\tau\left(\omega_\tau\right) \leq \Lambda\right\}$. This represents the system reliability or, in other words, the probability that total system demand X_τ at time τ does not exceed the installed capacity Λ.

The water utility expected profit is the sum of expected profits from each consumer of type θ, such as $\theta \in \left[\widetilde{\theta}, 1\right]$. For $\omega_\tau \leq \widehat{\omega}$, each individual consumes q_τ^*, and for $\omega_\tau \geq \widehat{\omega}_\tau$, he or she consumes Ψ_θ^* under the branch pipe constraint. Thus, the total expected profit is

$$\begin{aligned} \underset{\omega}{E}\left(\Pi\right) &= \sum_{\tau=1}^{\Gamma} \int_{\widetilde{\theta}}^{1} \underset{\omega}{E}\left(px_\tau^*\right) dH\left(\theta\right) + k\int_{\widetilde{\theta}}^{1} \Psi_\theta^* dH\left(\theta\right) - \sum_{\tau=1}^{\Gamma} \underset{\omega}{E}\left(CT_\tau\left(\Lambda, X_\tau\right)\right) \\ &= \sum_{\tau=1}^{\Gamma} \int_{\widetilde{\theta}}^{1} \left(\left(p - c\right) \left\{ \int_{\omega_\tau^-}^{\omega_\tau^*} q_\tau^* d\mathcal{F}_\tau\left(\omega_\tau\right) + \int_{\omega_\tau^*}^{\omega_\tau^+} \Psi_\theta^* d\mathcal{F}_\tau\left(\omega_\tau\right) \right\} \right) dH\left(\theta\right) \\ &\quad + k\int_{\widetilde{\theta}}^{1} \Psi_\theta^* dH\left(\theta\right) - \varphi\sum_{\tau=1}^{\Gamma} \int_{\widehat{\omega}_\tau}^{\omega_\tau^+} \left[X_\tau - \Lambda\right]^+ d\mathcal{F}_\tau\left(\omega_\tau\right) - \kappa\Lambda \end{aligned} \tag{21}$$

4 The Economic Incentive Mechanism

We consider the expected value of the traditional welfare function. The utility has a goal to maximize this welfare function subject to a break-even constraint. The task in this setting is to determine a system capacity Λ, a usage price p, and a demand or access charge k simultaneously so as to maximize the social welfare under the financial constraint

$$\begin{cases} Max \underset{\omega}{E}(W) = \underset{\omega}{E}(S^*) + \underset{\omega}{E}(\Pi) \\ \text{Subject to} \\ \underset{\omega}{E}(\Pi) \geq 0 \end{cases} \tag{22}$$

Using (14) and (21), the problem defined by (22) can be written as

$$\underset{(p,k,\Lambda)}{Max} \underset{\omega}{E}(\mathcal{L}) = \int_{\widetilde{\theta}}^{1} \left\{ \underset{\omega}{E}(S^*(p,k)) + (1+\lambda) \underset{\omega}{E}(\Pi(p,k,\Lambda)) \right\} dH(\theta) \tag{23}$$

where λ can be viewed as the shadow price of the binding break-even water utility constraint.

4.1 Capacity selection policy

The optimal condition[21] for a welfare-maximizing capacity selection is to differentiate (23) with respect to Λ. This condition is the same condition for a cost-minimizing problem (20) taking into account the break-even constraint. We obtain

$$\begin{aligned} \frac{\partial \underset{\omega}{E}(\mathcal{L})}{\partial \Lambda} = & -(1+\lambda) \textstyle\sum_{\tau=1}^{\Gamma} \Big[cX_\tau(\widehat{\omega}_\tau) f(\widehat{\omega}_\tau) \frac{\partial \widehat{\omega}_\tau}{\partial \Lambda} - cX_\tau(\omega_\tau^-) f(\omega_\tau^-) \frac{\partial \omega_\tau^-}{\partial \Lambda} \\ & + (c-\varphi)(1-\mathcal{F}_\tau(\widehat{\omega}_\tau)) + (c-\varphi)\Lambda \left(f(\omega_\tau^+) \frac{\partial \omega_\tau^+}{\partial \Lambda} - f(\widehat{\omega}_\tau) \frac{\partial \widehat{\omega}_\tau}{\partial \Lambda} \right) \\ & + \varphi X_\tau(\omega_\tau^+) f(\omega_\tau^+) \frac{\partial \omega_\tau^+}{\partial \Lambda} - \varphi X_\tau(\widehat{\omega}_\tau) f(\widehat{\omega}_\tau) \frac{\partial \widehat{\omega}_\tau}{\partial \Lambda} + \kappa \Big] \leq 0, \Lambda^* \geq 0 \end{aligned} \tag{24}$$

Using the obvious facts of $\frac{\partial \omega_\tau}{\partial \Lambda} = 0$, $\frac{\partial \widehat{\omega}_\tau}{\partial \Lambda} > 0$ by (19) and $\frac{\partial u'}{\partial \omega_\tau} > 0$, and $X_\tau(\widehat{\omega}_\tau) = \Lambda$, we obtain the necessary condition for the welfare-optimal capacity selection rule as the following equation $\frac{\partial \underset{\omega}{E}(\mathcal{L})}{\partial \Lambda} = 0$:

$$\kappa^* = (\varphi - c) \sum_{\tau=1}^{\Gamma} (1 - \mathcal{F}_\tau(\widehat{\omega}_\tau)) \tag{25}$$

[21] In the following we consider that the second-order conditions associated with the optimization problems, both locally and globally, are verified.

where κ^* is the long-run marginal cost of capacity expansion.

$(\varphi - c)\sum_{\tau=1}^{\Gamma}(1-\mathcal{F}_\tau(\widehat{\omega}_\tau))$ is the expected marginal cost difference between the marginal penalty technology cost and the marginal operating cost when excess demand occurs.[22] This term can also be viewed as an expected short-run marginal shortage cost over the whole period. Thus, the relation (25) requires that benefits and costs of new capacity should be equated at the margin: for an optimal size of capacity, expected short-run marginal shortage cost and long-run marginal capacity cost should be equal. In fact if the short-run marginal shortage cost exceeds the long-run marginal capacity cost, which is the undercapacity case, it is the public utility's interest to increase its capacity (building storm and sewer retention tanks to avoid environmental pollution), since it will meet demand while decreasing total cost. If the expected short-run marginal shortage cost is lower than the long-run marginal cost, which is the overcapacity case, the public utility can meet the demand at a lower cost by decreasing its capacity. Thus, since demand and supply costs are subject to random variable and since the public utility must minimize the mathematical expectation of its supply cost, then the mathematical expectation of the short-run marginal shortage cost and the long-run marginal capacity cost are equal.

Since we assumed that the fixed proportions technology is a strictly dominated technology, and since $0 < (1-\mathcal{F}_\tau(\widehat{\omega}_\tau)) < 1$ for all τ, the optimal capacity size Λ^* is positive but strictly less than the maximum possible level of system demand. In other words, the utility does not set fully reliable capacity size to insure itself against adverse states of the world. Equation (25) also provides the expected optimal utilization periods of the penalty technology: $\sum_{\tau=1}^{\Gamma}(1-\mathcal{F}_\tau(\widehat{\omega}_\tau)) = \frac{\kappa^*}{(\varphi-c)}$. This latter relation defines the expected length of peak-periods during which the public utility does not insure itself against very adverse sates of the world.

4.2 Optimal pricing policy

Given the optimal capacity selection rule (25), we now determine the optimal demand charges. The Kuhn-Tucker necessary conditions for maximizing the program in (22) with respect to p, and k will be:

$$\frac{\partial \underset{\omega}{E}(S^*)}{\partial k} = \int_{\widetilde{\theta}}^{1}\left(\left.\frac{\partial \underset{\omega}{E}(S)}{\partial k}\right|_{\Psi_\theta=\Psi_\theta^*}\right)dH(\theta) = -\int_{\widetilde{\theta}}^{1}\Psi_\theta^* dH(\theta) \tag{26}$$

[22] The term $(1-\mathcal{F}_\tau(\widehat{\omega}_\tau))$ can be considered, for example, as the probability that severe weather conditions occur or peak periods take place following a common shock.

$$\frac{\partial \underset{\omega}{E}(\Pi)}{\partial k} = (p-c)\sum_{\tau=1}^{\Gamma}\int_{\widetilde{\theta}}^{1} \frac{\partial \Psi_{\theta}^{*}}{\partial k}\left(1-\mathcal{F}_{\tau}\left(\omega_{\tau}^{*}\right)\right) dH(\theta)$$
$$+\int_{\widetilde{\theta}}^{1}\left(k\frac{\partial \Psi_{\theta}^{*}}{\partial k}+\Psi_{\theta}^{*}\right) dH(\theta) - \varphi\sum_{\tau=1}^{\Gamma}\int_{\widehat{\omega}_{\tau}}^{\omega_{\tau}^{+}} \frac{\partial(X_{\tau}-\Lambda)}{\partial k} d\mathcal{F}_{\tau}\left(\omega_{\tau}\right) \tag{27}$$

Combining (26) and (27), and taking into account the break-even constraint, the optimal condition for a maximum k is giving by

$$\frac{\partial \underset{\omega}{E}(\mathcal{L})}{\partial k} = \lambda\int_{\widetilde{\theta}}^{1}\Psi_{\theta}^{*} dH(\theta) + (1+\lambda)\left\{(p-c)\sum_{\tau=1}^{\Gamma}\int_{\widetilde{\theta}}^{1}\frac{\partial \Psi_{\theta}^{*}}{\partial k}\left(1-\mathcal{F}_{\tau}\left(\omega_{\tau}^{*}\right)\right) dH(\theta)\right\}$$
$$+(1+\lambda)\left\{k\int_{\widetilde{\theta}}^{1}\frac{\partial \Psi_{\theta}^{*}}{\partial k} dH(\theta) - \underbrace{\varphi\sum_{\tau=1}^{\Gamma}\int_{\widehat{\omega}_{\tau}}^{\omega_{\tau}^{+}}\frac{\partial(X_{\tau}-\Lambda)}{\partial k} d\mathcal{F}_{\tau}\left(\omega_{\tau}\right)}_{a}\right\} = 0 \tag{28}$$

Concerning p, we have

$$\begin{aligned}\frac{\partial \underset{\omega}{E}(S^{*})}{\partial p} &= \sum_{\tau=1}^{\Gamma}\int_{\widetilde{\theta}}^{1}\left(\left.\frac{\partial \underset{\omega}{E}(S)}{\partial p}\right|_{\Psi_{\theta}=\Psi_{\theta}^{*}}\right) dH(\theta) \\ &= \sum_{\tau=1}^{\Gamma}\int_{\widetilde{\theta}}^{1}\left\{\int_{\omega_{\tau}^{-}}^{\omega_{\tau}^{*}} -q_{\tau}^{*}(\theta)\, d\mathcal{F}_{\tau}\left(\omega_{\tau}\right) - \Psi_{\theta}^{*}\left(1-\mathcal{F}_{\tau}\left(\omega_{\tau}^{*}\right)\right)\right\} dH(\theta)\end{aligned} \tag{29}$$

$$\frac{\partial \underset{\omega}{E}(\Pi)}{\partial p} = \sum_{\tau=1}^{\Gamma}\int_{\widetilde{\theta}}^{1}\left\{\int_{\omega_{\tau}^{-}}^{\omega_{\tau}^{*}} q_{\tau}^{*}(\theta)\, d\mathcal{F}_{\tau}\left(\omega_{\tau}\right) + \Psi_{\theta}^{*}\left(1-\mathcal{F}_{\tau}\left(\omega_{\tau}^{*}\right)\right)\right.$$
$$\left.+(p-c)\left(\int_{\omega_{\tau}^{-}}^{\omega_{\tau}^{*}}\frac{\partial q_{\tau}^{*}(\theta)}{\partial p} d\mathcal{F}_{\tau}\left(\omega_{\tau}\right) + \frac{\partial \Psi_{\theta}^{*}}{\partial p}\left(1-\mathcal{F}_{\tau}\left(\omega_{\tau}^{*}\right)\right)\right)\right\} dH(\theta) \tag{30}$$
$$+k\int_{\widetilde{\theta}}^{1}\frac{\partial \Psi_{\theta}^{*}}{\partial p} dH(\theta) - \varphi\sum_{\tau=1}^{\Gamma}\int_{\widehat{\omega}_{\tau}}^{\omega_{\tau}^{+}}\frac{\partial(X_{\tau}-\Lambda)}{\partial p} d\mathcal{F}_{\tau}\left(\omega_{\tau}\right)$$

Combining (29) and (30), and taking into account the break-even constraint, the optimal condition for a maximum p is giving by (31)

$$\frac{\partial \underset{\omega}{E}(\mathcal{L})}{\partial p} = \lambda \sum_{\tau=1}^{\Gamma} \int_{\widetilde{\theta}}^{1} \left\{ \int_{\omega_\tau^-}^{\omega_\tau^*} q_\tau^*(\theta)\, d\mathcal{F}_\tau(\omega_\tau) + \Psi_\theta^* \left(1 - \mathcal{F}_\tau(\omega_\tau^*)\right) \right\} dH(\theta)$$
$$+ (1+\lambda) \left\{ (p-c) \sum_{\tau=1}^{\Gamma} \int_{\widetilde{\theta}}^{1} \left(\int_{\omega_\tau^-}^{\omega_\tau^*} \frac{\partial q_\tau^*(\theta)}{\partial p} d\mathcal{F}_\tau(\omega_\tau) + \frac{\partial \Psi_\theta^*}{\partial p} \left(1 - \mathcal{F}_\tau(\omega_\tau^*)\right) \right) dH(\theta) \right\}$$
$$+ (1+\lambda) \left\{ k \int_{\widetilde{\theta}}^{1} \frac{\partial \Psi_\theta^*}{\partial p} dH(\theta) - \varphi \underbrace{\sum_{\tau=1}^{\Gamma} \int_{\widehat{\omega}_\tau}^{\omega_\tau^+} \frac{\partial (X_\tau - \Lambda)}{\partial p} d\mathcal{F}_\tau(\omega_\tau)}_{b} \right\} = 0 \tag{31}$$

Equation (28) can be written as

$$(1+\lambda)(p-c) \sum_{\tau=1}^{\Gamma} \int_{\widetilde{\theta}}^{1} \frac{\partial \Psi_\theta^*}{\partial k} \left(1 - \mathcal{F}_\tau(\omega_\tau^*)\right) dH(\theta)$$
$$= -\lambda \int_{\widetilde{\theta}}^{1} \Psi_\theta^* dH(\theta) - (1+\lambda) k \int_{\widetilde{\theta}}^{1} \frac{\partial \Psi_\theta^*}{\partial k} dH(\theta) + (1+\lambda)\varphi a \tag{32}$$

Equation (31) can be arranged to give

$$(1+\lambda)(p-c) \sum_{\tau=1}^{\Gamma} \int_{\widetilde{\theta}}^{1} \frac{\partial \Psi_\theta^*}{\partial p} \left(1 - \mathcal{F}_\tau(\omega_\tau^*)\right) dH(\theta)$$
$$= -(1+\lambda)(p-c) \sum_{\tau=1}^{\Gamma} \int_{\widetilde{\theta}}^{1} \int_{\omega_\tau^-}^{\omega_\tau^*} \frac{\partial q_\tau^*(\theta)}{\partial p} d\mathcal{F}_\tau(\omega_\tau)\, dH(\theta)$$
$$-\lambda \sum_{\tau=1}^{\Gamma} \int_{\widetilde{\theta}}^{1} \left\{ \int_{\omega_\tau^-}^{\omega_\tau^*} q_\tau^*(\theta)\, d\mathcal{F}_\tau(\omega_\tau) + \Psi_\theta^* \left(1 - \mathcal{F}_\tau(\omega_\tau^*)\right) \right\} dH(\theta)$$
$$-(1+\lambda) k \int_{\widetilde{\theta}}^{1} \frac{\partial \Psi_\theta^*}{\partial p} dH(\theta) + (1+\lambda)\varphi b \tag{33}$$

At this stage, it is easy to show that under an ex ante maximum demand charge with $k > 0$ the achievable social welfare is strictly greater than that achievable with $k = 0$. In fact, for any $p > 0$ and $\Lambda > 0$, we can demonstrate that $\left.\frac{\partial \underset{\omega}{E}(\mathcal{L})}{\partial k}\right|_{k=0}$ is strictly positive. For $k = 0$ all consumers would simply choose a branch pipe size $\Psi_\theta^*(p,k)$ just equal to the ex post desired demand $q_\tau^*(p,\theta,\omega_\tau)$ at $\omega_\tau = \omega_\tau^+$, which is assumed to be bounded. By (12), we have $\frac{\partial \Psi_\theta^*}{\partial k} < 0$. And since $\Psi_\theta^* = q_\tau^*(p,\theta,\omega_\tau^+)$ implies $\omega_\tau^* = \omega_\tau^+$ from (11), then $(1 - \mathcal{F}_\tau(\omega_\tau^*))$ would equal zero for all ω_τ. In this case, (28) would reduce to:

$$\left.\frac{\partial \underset{\omega}{E}(\mathcal{L})}{\partial k}\right|_{k=0} = \lim_{k\to 0}\left[\lambda \int_{\widetilde{\theta}}^{1} \Psi_\theta^* dH(\theta) - (1+\lambda)\varphi \sum_{\tau=1}^{\Gamma} \int_{\widehat{\omega}_\tau}^{\omega_\tau^+} \frac{\partial(X_\tau - \Lambda)}{\partial k} d\mathcal{F}_\tau(\omega_\tau)\right] > 0$$

This equation is strictly positive because $\lambda \int_{\widetilde{\theta}}^{1} \Psi_\theta^* dH(\theta) > 0$ and we can show that $:-(1+\lambda)\varphi \sum_{\tau=1}^{\Gamma} \int_{\widehat{\omega}_\tau}^{\omega_\tau^+} \frac{\partial(X_\tau - \Lambda)}{\partial k} d\mathcal{F}_\tau(\omega_\tau) > 0$. In fact, for $\lambda \geq 0$, $\varphi > 0$, Λ is bounded by $0 < \Lambda \leq \int_0^1 q_\tau^*(p,\theta,\omega_\tau^+)\, dH(\theta)$, $\frac{\partial X_\tau}{\partial k} < 0$ for all τ by (12), (13) and (17), and $\widehat{\omega}_\tau < \omega_\tau^+$. Thus $\frac{\partial \underset{\omega}{E}(\mathcal{L})}{\partial k} = 0$ cannot be satisfied and the optimal k must be positive. Now, to see the consequences in terms of wastewater pricing issues, we consider two cases.

4.2.1 $\lambda > 0$

If $\lambda > 0$, using equation (32) and equation (33), and knowing by (12) that $\frac{\partial \Psi_\theta^*}{\partial p} = \frac{\partial \Psi_\theta^*}{\partial k} \sum_{\tau=1}^{\Gamma} [1 - \mathcal{F}_\tau(\omega_\tau^*)]$, these last two equations can be simplified to obtain

$$\frac{(p-c)}{p} = \frac{\lambda}{(1+\lambda)}\frac{1}{\mu_p} + \frac{\varphi}{\mu_p}\left[a\sum_{\tau=1}^{\Gamma}[1 - \mathcal{F}_\tau(\omega_\tau^*)] - b\right]\frac{1}{\sum_{\tau=1}^{\Gamma}\int_{\widetilde{\theta}}^{1}\int_{\omega_\tau^-}^{\omega_\tau^*} q_\tau^*(\theta)\, d\mathcal{F}_\tau(\omega_\tau)\, dH(\theta)} \tag{34}$$

where μ_p is the price elasticity of demand. This represents a modified version of the well-known Ramsey-Boiteux pricing rules or the Inverse Elasticity Rule [3, 4]. The Lerner index or the price-marginal operating cost ratio is the sum of two terms. The first term is $\frac{\lambda}{(1+\lambda)}$ times the inverse elasticity of demand, where λ[23] denotes the shadow price of the break-even constraint. The second

[23] λ can also be viewed as the shadow price of public funds [32].

term represents a weighted penalty function[24] depending on the sensitivity of consumers to demand excess.

(28) can be simplified and arranged to obtain

$$\frac{k+(p-c)\sum_{\tau=1}^{\Gamma}\int_{\widetilde{\theta}}^{1}\left(1-\mathcal{F}\left(\omega^{*}\right)\right)dH\left(\theta\right)}{k}=\frac{\lambda}{1+\lambda}\frac{1}{\mu_{\Psi}}-\varphi\frac{a}{\mu_{\Psi}}\frac{1}{\int_{\widetilde{\theta}}^{1}\Psi_{\theta}^{*}dH\left(\theta\right)} \tag{35}$$

where μ_{Ψ} is the price elasticity of the branch pipe size or the price elasticity of access. The last equation is also a Lerner index with k the optimal price of access or the optimal price of participation.

$(p-c)\sum_{\tau=1}^{\Gamma}\int_{\widetilde{\theta}}^{1}\left(1-\mathcal{F}_{\tau}\left(\omega_{\tau}^{*}\right)\right)dH\left(\theta\right)$ represents the marginal consumer access cost under uncertainty (random shocks) for all $\tau=1,...,\Gamma$, 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.

4.2.2 $\lambda=0$

If $\lambda=0$, equation (32) becomes

$$(p-c)\sum_{\tau=1}^{\Gamma}\int_{\widetilde{\theta}}^{1}\frac{\partial\Psi_{\theta}^{*}}{\partial k}\left(1-\mathcal{F}_{\tau}\left(\omega_{\tau}^{*}\right)\right)dH\left(\theta\right)=\varphi a-k\int_{\widetilde{\theta}}^{1}\frac{\partial\Psi_{\theta}^{*}}{\partial k}dH\left(\theta\right) \tag{36}$$

and equation (33) can be simplified to

$$\begin{aligned}&(p-c)\sum_{\tau=1}^{\Gamma}\int_{\widetilde{\theta}}^{1}\frac{\partial\Psi_{\theta}^{*}}{\partial p}\left(1-\mathcal{F}_{\tau}\left(\omega_{\tau}^{*}\right)\right)dH\left(\theta\right)\\&=-\left(p-c\right)\sum_{\tau=1}^{\Gamma}\int_{\widetilde{\theta}}^{1}\int_{\omega_{\tau}^{-}}^{\omega_{\tau}^{*}}\frac{\partial q_{\tau}^{*}\left(\theta\right)}{\partial p}d\mathcal{F}_{\tau}\left(\omega_{\tau}\right)dH\left(\theta\right)-k\int_{\widetilde{\theta}}^{1}\frac{\partial\Psi_{\theta}^{*}}{\partial p}dH\left(\theta\right)+\varphi b\end{aligned} \tag{37}$$

Recall (12) and equating (36) and (37), we obtain the optimal usage charge as

$$p=c+\varphi\alpha \tag{38}$$

[24] Recall that φ is the social cost of excess demand.

with $\alpha = \frac{b - a\sum_{\tau=1}^{\Gamma}(1-\mathcal{F}_\tau(\omega_\tau^*))}{\sum_{\tau=1}^{\Gamma}\int_{\widetilde{\theta}}^{1}\int_{\omega_\tau^-}^{\omega_\tau^*}\frac{\partial q_\tau^*(\theta)}{\partial p}d\mathcal{F}_\tau(\omega_\tau)dH(\theta)}$. From (38) and taking into account the definition of α, equation (36) gives us the optimal demand charge k:

$$k = \varphi\left(\frac{a - \alpha\sum_{\tau=1}^{\Gamma}\int_{\widetilde{\theta}}^{1}\frac{\partial\Psi_\theta^*}{\partial k}\left(1-\mathcal{F}_\tau\left(\omega_\tau^*\right)\right)dH\left(\theta\right)}{\int_{\widetilde{\theta}}^{1}\frac{\partial\Psi_\theta^*}{\partial k}dH\left(\theta\right)}\right) \tag{39}$$

If $\lambda = 0$, the optimal usage charge p is greater than the marginal operating cost and includes a weighted marginal penalty technology cost. The optimal demand charge k is given by (39).

As noted before, λ can be viewed as the shadow price of public funds. When $\lambda = 0$ taxation is not distortive and the optimal price tends to marginal cost plus a weighted social cost representing environmental costs or values.

5 Conclusion

The UWWTD and the WFD have been described as the most complex and most ambitious piece of environmental regulation ever undertaken by the EU. Both Directives introduces new standards, criteria, institutions, and processes for managing Europe's waters under an integrating ecosystem-based approach. They have to be welcomed and applauded for highlighting the need to consider economic and environmental factors as well as financial costs when setting water prices.

The WFD clearly integrates economics into water management and water policy decision-making. To achieve its environmental objectives and promote integrated river basin management, the Directive calls for the application of economic principles (e.g., the polluter-pays principle), the use of economic approaches and tools (e.g., cost-effectiveness analysis) and the consideration of instruments (e.g., water pricing). Thus, economics has a double role in the WFD process: to provide information in the decision-making process and to serve as a means of implementation.

Today, the need to conserve adequate supplies of a resource for which demand is continuously increasing is one of the Directives' most important innovations: the introduction of incentive pricing mechanisms. Adequate water sectors pricing acts as an incentive for the sustainable use of water resources and thus helps to achieve the environmental objectives under the WFD. The level of price has a direct impact on water demand and enhances the efficient use of water resources: the more external costs are internalized,

the more prices show the real cost of water uses and services. EU member states are required to ensure that the price charged to water consumers, such as for the abstraction and distribution of fresh water and the collection and treatment of waste water, reflects the true and full costs. Whereas this principle has a long tradition in some countries, this is currently not the case in others.

Domestic and industrial wastewater continues to be a major challenge for achieving European water protection objectives, due to its potential impacts on EU ground waters, rivers, lakes and regional seas. Step-by-step implementation of the UWWTD has already achieved remarkable success. In some parts, the Rhine is no more called the "sewer of Europe" and is again the home of the salmon, one of the symbols of good water quality. This is also the case of parts of the Elbe/Labe river basin. Implementation of the UWWTD and WFD together with comprehensive cooperation across administrative and political borders improved the quality of EU aquatic environment. Whilst considerable progress has been achieved, major challenges are still prevailing. Significant amounts of wastewater are still discharged without the necessary level of treatment, in particular as regards nutrient removal in the catchment of waters suffering from eutrophication.

I set out to write this paper because of a very important question: what is the economic incentive mechanism that can help implement the economic aspects of these Directives and controlling of EU urban pollution?

I analyzed an ex ante maximum demand charge under uncertainty. I examined the problem of state-contingent second-best Pareto optimal mechanisms under uncertainty. The firm is assumed to have incomplete information about consumer demand characteristics. In addition, demand and capacity are subject to commonly observable shocks. The economic incentive mechanism I found is much more complex than the actual applied water sectors prices in a large number of European countries. The following relatively strong conclusions stand out:

- The proposed incentive mechanism, applied with stochastic demand problem, allows consumers to self-ration and self-select by the size of their purchases. The difference between a two-part tariff, largely applied in Europe, and the proposed pricing schemes lies in the different way of charging the fee for the right to consume. For the simple two-part tariff, the fee for consumption participation is fixed among consumers, no matter how their actual consumption may vary. That is, once a consumer pays the stated fixed fee, he can consume as much as he wishes at a unit price for actual consumption. With the proposed pricing rule, however, the bill is directly related to the maximum

consumption level. Customers choose ex ante their contract and make a payment to the firm before observing the state of the world. This establishes a contingent contract with the firm. Output in each state of the world is then allocated across consumers on the basis of the maximum selected capacity levels. Further more, I showed that 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 wastewater suppliers can physically connect their networks and made commercial exchange of the service possible. Utilities facing capacity problems or shocks purchase the wastewater service from nearby better suppliers in order to overcome capacity problems. Several Swiss communities near Zurich have already connected their networks with the Zurich Water Utility in order to exchange or buy the service in case of capacity constraints. By including the cost of penalty technology in the case of system overload, we defined the optimal capacity selection rule and the optimal maximum demand pricing rule for the case of heterogeneous consumer demands. The maximum demand charge not only has the effect of discouraging variable or irregular consumption, but also has the feature of a connection or a hook-up fee as in a menu of two-part tariffs. But, the question of external markets needs a more comprehensive analysis to allow the public utility to sell its sevices to its neighbors at off-peak periods and to buy the service from a third party at peak-periods.

- Cost recovery is currently a top priority for managers of wastewater utilities. In this order, there is a need to gain a deeper understanding of what factors influence customers' willingness to pay for water services. To overcome the asymmetric information between the water utility and consumers, it is important to let the latter choose and reveal their private information. With the pricing rule defined above, the wastewater utility can maximize the social surplus under the budget constraint, and manage the pattern of system load efficiently under the described management figure of maximum demand charge by penalizing the peak-period users. Every consumer shares the total wastewater supplying costs through the optimal ex ante maximum demand charges. Each consumer self-selects his own branch size ex ante fitting to his type. He faces a usage charge and demand charge related to the diverse consumption patterns and his type. Thus, the water utility does not support the burden of the asymmetric information about

each consumer's willingness to pay because each consumer self-reports his willingness to pay: the consumer reveals his preferences and decides his own rationing status. Wastewater pricing can substantially support the efficient use of water and therefore help lead 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 our waters, 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 at the same time allows consumer diversity: each consumer's consumption is made after the state of the nature is known to himself, but cannot exceed his ex ante chosen branch size. This penalty cost plays an important role in avoiding over investment and wasting public funds, which are important and sensitive issues for decision-makers today.

- In this model, more importance is given to wastewater charges to act as an incentive for a more sustainable use of water resources (by taking into account the uncertainties and irregularities in wastewater flows) and cost recovery in the provision of wastewater services. The proposed pricing structure provides incentives for water use efficiencies and emphasizes the need for a more open pricing policy that accounts for environmental costs and to support sustainable demand-based policies. Nevertheless, pricing is not the only instrument that can be used to resolve water resource problems. A general policy in the field must include technology improvements, education, information provision, robust ways of managing and controlling abstraction, and trading of water rights and permits.

- The proposed approach, by including uncertainties, will limit the adverse impacts of hazards and implies an efficient environmental management. Today there is a need for reducing urban pollution plans which include prevention in order to reduce the risk and effects of uncertainty associated to extreme weather events. In fact, climate change impacts, including increased flooding and drought could enhance the risk of non-attainment of the objectives of the Directives.

The adoption of this kind of pricing system would require the implementation of a communications system to keep customers permanently informed

of the possibly frequent price changes, as well as more frequent meter readings, possibly through remote meter reading technology using telephone lines or cable television (telemeters which enable computerized remote monitoring and control of operations). This also requires knowledge of the different price elasticities of demand.

The mentioned Directives are the best current tool to ensure sustainable use of water and wetlands across Europe, in order to conserve and restore the functions and integrity of freshwater ecosystems. Implementation of the EU water sector directives together with comprehensive cooperation across administrative and political borders must improve the quality of EU aquatic environment. The success will therefore strongly depend on political will and further hard work, the full participation of all stakeholders, and the exploitation of synergies of the different tools which are provided in these directives. Whilst considerable progress has been achieved, especially concerning the UWWTD, major challenges still remain.

To strengthen the implementation process, pricing policies must take into account the EU environmental, economic, and social objectives within other sectorial, structural, and cohesion policies. EU water services pricing policies must be based on a logical and operational follow-on and not performed from "behind the desk" with the influence of and for the needs of office workers, sometimes without any valid justifications.

Charging households and industries directly for their wastewater discharges is not common even today. Usually, the wastewater fee is a fixed percent of the water bill or is a fixed charge per house or is included in the property tax. Charging wastewater discharges according to the strength and quantity of wastewater will motivate them to conserve water, reuse or recycle water, and switch to cleaner production processes. It is also highly recommended to undertake and implement parallel work on public education programs, convincing people that they should conserve water and be less wasteful in its use. Much remains to be done to phase-out perverse subsidies in the water sector, particularly those applied at EU and Member States levels. Any support measures or subsidies that lower the user costs of resource consumption, rather than encourages reduced or more efficient use of the resource, will contribute to potentially higher volumes of units, throughputs, and pollution. Subsidy removal is therefore a step towards full-cost pricing of environmentally harmful activities, providing an important complement to policies that internalize social and environmental costs of these activities.

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