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Estimating the environmental and resource costs of leakage in water distribution systems: A shadow price approach

María Molinos-Senante [a,b,c,]*, Manuel Mocholí-Arce [d], Ramon Sala-Garrido [d]

[a] Departamento de Ingeniería Hidráulica y Ambiental, Pontificia Universidad Católica de Chile, Av. Vicuña Mackenna 4860, Santiago, Chile
[b] Escuela de Arquitectura e Instituto de Estudios Urbanos, Pontificia Universidad Católica de Chile, El Comendador 1916, Santiago, Chile
[c] Centro de Desarrollo Urbano Sustentable CONICYT/FONDAP/15110020, Av. Vicuña Mackenna 4860, Santiago, Chile
[d] Department of Mathematics for Economics, University of Valencia, Avd. Tarongers S/N, Valencia, Spain

HIGHLIGHTS

- The environmental and resource costs of leakage are estimated.
- The shadow price of leakage was calculated using the directional-distance function.
- For the Chilean water industry, the average shadow price of leakage was 0.23 €/m^3.
- The methodology proposed will ease the estimation of the sustainable economic level of leakage.

GRAPHICAL ABSTRACT

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ABSTRACT

Water scarcity is one of the main problems faced by many regions in the XXIst century. In this context, the need to reduce leakages from water distribution systems has gained almost universal acceptance. The concept of sustainable economic level of leakage (SELL) has been proposed to internalize the environmental and resource costs within economic level of leakage calculations. However, because these costs are not set by the market, they have not often been calculated. In this paper, the directional-distance function was used to estimate the shadow price of leakages as a proxy of their environmental and resource costs. This is a pioneering approach to the economic valuation of leakage externalities. An empirical application was carried out for the main Chilean water companies. The estimated results indicated that for 2014, the average shadow price of leakages was approximately 32% of the price of the water delivered. Moreover, as a sensitivity analysis, the shadow prices of the leakages were calculated from the perspective of the water companies' managers and the regulator. The methodology and findings of this study are essential for supporting the decision process of reducing leakage, contributing to the improvement of economic, social and environmental efficiency and sustainability of urban water supplies.

1. Introduction

Water scarcity is one of the main problems facing many societies and the world in the XXIst century. Currently, approximately 1.2 billion people live in areas of physical water scarcity, and 500 million people are approaching this situation. Moreover, water scarcity already affects every continent (UNDESA, 2016). Within the urban water cycle, one of the main challenges that water utilities worldwide face in the context of water scarcity is to reduce non-revenue water, in general, and leakages, in particular (Lin et al., 2015). In the current context of climate change, the need to reduce leakages from water distribution systems has gained almost universal acceptance (Delgado-Galván et al., 2010).

* Corresponding author at: Departamento de Ingeniería Hidráulica y Ambiental, Pontificia Universidad Católica de Chile, Av. Vicuña Mackenna 4860, Santiago, Chile.
E-mail address: mmolinos@uc.cl (M. Molinos-Senante).

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It should be noted that water losses are more important in water for irrigation than in urban water. Because of water losses during pumping and transport, approximately 60% of the water intended for crop irrigation never reaches the crop (Pimentel et al., 2004).

Leakage is an example of economic, social and environmental inefficiency in the water supply process (Hernández-Sancho et al., 2012). On the one hand, because lost water yields no revenue, heavy leakage also makes it more difficult to keep water tariffs at a reasonable and affordable level. Thus, reducing water losses will help postpone capital investments for developing new water sources. Moreover, a high level of leakage has a severe and negative impact on customers because high leakage increases flow rates in the pipe network, which can cause high-pressure losses that affect customers and often lead to supply interruptions (Asia Development Bank, 2010). On the other hand and from an environmental point of view, leakage involve energy and material losses since they are necessary to transfer and treat the water in a distribution system that is subsequently lost (European Commission, 2013). In other words, reducing leakage is essential to the overall efficiency and financial sustainability of urban water because it provides additional revenues and reduces costs (Berardi et al., 2014).

Due to the importance of identifying and reducing water losses, many papers describing technical procedures to control leakage have been published (e.g., Marques and Monteiro, 2003; Xu et al., 2014; Li et al., 2015). From an economic point of view, the most important component of the leakage control strategy is setting a target for the Economic Level of Leakage (ELL). The ELL is the level of leakage at which the marginal cost of reducing leakage is equal to the benefit gained from further marginal leakage reductions (Islam and Babel, 2013). Leakage not only involve direct costs for water companies but also environmental, resource[*] and social costs that are ignored in the estimation of the ELL. By 2000, the importance of and need for including the economic value of externalities in calculating the ELL to determine the optimal level of leakage (Ashton and Hope, 2001) began to receive wide attention. The economic regulator of the water sector in England and Wales (Ofwat) pioneered the concept of Sustainable Economic Level of Leakage (SELL) to internalize some of the leakage externalities in the estimation of the ELL (Ofwat, 2007).

The SELL is the level of leakage of a water distribution network at which the unit cost of leakage control measures for the water service provider equals the unit cost of water, including the water service provider's costs and the environmental and resource costs that are external to the water service provider (European Commission, 2013). Even though many water management policies and regulations, such as the Water Framework Directive (WFD) (Directive 2000/60/EU), have recognized the need to include environmental and resource costs in the decision-making process, the SELL concept has rarely been used to determine the optimal level of leakage. From a methodological point of view, the key element in the overall calculation of the SELL is the way in which the environmental and resource externalities are calculated. Thus, the absence of a generalized method that allows water company managers and policy makers to determine the extent of these environmental and resource costs has been an underlying reason for their general exclusion of leakage control in decision-making considerations (European Commission, 2015).

From economic theory, different methodologies for the quantification and internalization of environmental externalities have been developed (Mäler and Vincent, 2005; Ferreira et al., 2014). In the SELL framework, Ofwat (2007) and the European Commission (2013) proposed specific methods to internalize environmental and social externalities. Thus, Ofwat published the guidelines "Leakage methodology review: providing best practice guidance on the inclusion of externalities in the ELL calculation" (Ofwat, 2007). Nevertheless, the approach suggested by Ofwat mainly focused on greenhouse gas emissions associated to water losses (Ofwat, 2008). The European Commission (2013) proposed target-based associated costs in which the levelized cost of water for the integrated management and protection of water resources to achieve compliance with WFD objectives is used as a proxy for the environmental and resource cost of water. This is only a useful method for Europe, where each river basin has a defined a program of measures to achieve the good ecological status of water bodies.

In the framework of efficiency studies, Färe et al. (1993) proposed an alternative method to estimate the environmental costs of undesirable outputs that are produced jointly with desirable outputs. By using the concept of the distance function or directional-distance function (Färe et al., 2006; Tang et al., 2016), a shadow price is calculated for undesirable outputs. Within the urban water supply process, leakage is an undesirable output because they have a negative economic and environmental impact (De Witte and Marques, 2010). Several applications have used the methodological approach proposed by Färe et al. (1993, 2006) to compute the shadow price of different undesirable outputs as a proxy of estimating their environmental cost. A review of existing studies in this field was conducted by Zhou et al. (2014). Most of the studies focused on estimating the shadow prices of environmental pollutants, such as SO_2, NO_x, CO_2, COD, N, and P (e.g., Bond and Farzin, 2007; Molinos-Senante et al., 2010, 2015a; Lee and Zhou, 2015). Nevertheless, the shadow prices of alternative undesirable outputs, such as non-performing bank loans (Fukuyama and Weber, 2008), commercial salmon-fishing licences (Färe et al., 2009) or a lack of service quality in the provision of drinking water (Molinos-Senante et al., 2016) have also been estimated. Thus, the shadow price approach is a well-established method to estimate the economic value of undesirable outputs under different frameworks.

Against this background, the main objective of this paper is to compute the shadow price of leakage as a proxy of estimating their environmental cost. Moreover, as a sensitivity analysis, the shadow prices of leakage were computed both from perspectives of water companies, as well as regulators and society. The empirical application focused on the main Chilean water companies from 2010 to 2014. Chile presents an interesting case within the context of this research because since 2004 the water companies in Chile have been private and regulated at the national level. In spite of this regulation, the percentage of leakages in the water distribution network has not decreased.

This paper is the first to estimate the shadow price of leakage in a water distribution system as a proxy of the environmental and resource costs of water losses. Hence, this study introduces a pioneering and novel approach in the framework of leakage control because the estimation of these costs is essential to calculate the SELL to improve the sustainability and efficiency of the urban water cycle.

From a policy perspective, the methodology and results of this research are expected to be of great interest and use to managers of water companies and regulators as a decision-support tool because they provide the first estimates of the shadow price of leakage. Being able to evaluate the environmental and resource costs of leakage is an essential first step for regulators to develop and introduce incentives to water companies to effectively reduce water losses in the water distribution network. One notable advantage of the approach followed in this research is that the variability of the shadow prices of leakage across water companies is shown. In other words, the findings of this study also allow water company managers and regulators to prioritize the adoption of leakage control measures. In summary, this paper significantly contributes to the implementation of the SELL concept as a criterion to support decision-making for leakage control.

[*] Environmental costs are defined as representing the costs of damage that water uses impose on the environment and ecosystems. Resource costs are defined as the costs of foregone opportunities which other uses suffer due to the depletion of the resource (Wateco, 2002).