Journal of Environmental Management 227 (2018) 44–54

Contents lists available at ScienceDirect

Journal of Environmental Management

journal homepage: www.elsevier.com/locate/jenvman

Research article

Policy choice and riverine water quality in developing countries: An integrated hydro-economic modelling approach

Asha Gunawardena[a,c,*], Ben White[a], Atakelty Hailu[a], E.M.S. Wijeratne[b], Ram Pandit[a]

[a] Discipline of Agricultural and Resource Economics, UWA School of Agriculture and Environment, University of Western Australia, Australia
[b] School of Civil, Environmental and Mining Engineering and the UWA Ocean Institute, University of Western Australia, Australia
[c] Institute of Policy Studies of Sri Lanka, Sri Lanka

ARTICLE INFO

Keywords:
Hydro-economic modelling
Industrial water pollution
Optimization
Policy instrument
Developing countries
Pollution trading

ABSTRACT

Industrialization and urbanization, as a result of rapid economic development, have led to the deterioration of water quality in many rivers in developing countries. The Kelani River in Sri Lanka provides drinking water to Colombo and a range of market and non-market ecosystem services; but these services are threatened by deteriorating water quality. We apply a hydro-economic model that accounts for spatial patterns of water quality and abatement cost variability between firms in the catchment. The hydro-economic model combines a hydrological model of water quality with an economic optimization model to determine a cost-effective policy under alternate policy regimes. These include: the existing policy based on effluent concentration standards, effluent trading and effluent trading with multiple zones and an effluent tax. Tradeable permits with multiple zones are the least cost policy option that accounts for both spatial externalities and abatement costs. However, given current institutional capabilities, an effluent tax would be a more realistic second best policy as a transition from the current policy of effluent concentration standards to a policy based on the quantity of effluents.

1. Introduction

In recent years developed countries have made significant progress in abating industrial point source pollution (Neal et al., 2006; Shortle and Horan, 2008; Xepapadeas, 1992, 2011). Partly as a result of globalization and the shift of manufacturing to low labour cost economies in developing countries have had an increase in industrial pollution (Coria et al., 2010; Olmstead, 2010). This is mainly due to the rapid industrialization, and a lack of investment in water treatment infrastructure (Biswas and Tortajada, 2009). Further the rapidity of industrialization has meant that environmental regulations, which were designed for agrarian societies, are not designed to regulate a growing industrial sector in terms of limiting effluents, providing incentives for cost-effective abatement and monitoring of effluents to ensure compliance.

Traditional command–and-control (CAC) policies for water quality, result in policy outcomes that are not cost-effective because they do not account for abatement cost heterogeneity (Stavins, 2003). In addition, the lack of incentives to comply with emission standards and weaknesses in monitoring and enforcement have resulted in low levels of compliance by firms (Blackman and Harrington, 2000). Non–uniform mixing of water pollutants makes the design of policy instruments complex because the reduction in river water quality due to effluents depends on their location in the hydrological, social and economic landscape (Boyd, 2009; Hung and Shaw, 2005). Therefore, designing innovative alternative policy instruments that accounts for cost heterogeneity as well as spatial heterogeneity of pollution sources (Fisher-Vanden and Olmstead, 2013; Hanley et al., 2007; McGartland, 1988; Olmstead, 2010) to improve surface water quality is of paramount importance for regulatory agencies and policy makers.

This paper explores the cost-effectiveness of a command-and-control (CAC) and market-based policies. The Kelani river is the main source of drinking water to around a million people in Colombo. Water quality in many locations along the river is low and deteriorating suggesting that the current regulatory policy is inadequate (Herath and Amaresekera, 2007). The environmental authority is in the process of reviewing the legislative framework to move towards the implementation of market-based instruments (Vasantha, 2008). To date the application of market-based instruments (MBIs) to manage water pollution in developing countries has been limited (Eskeland and Jimenez, 1992; Kathuria, 2006; O'Connor, 1999; Rammont and Amin, 2010). Case studies from Malaysia, Poland and Colombia showed that effluent charges or taxes

* Corresponding author. Discipline of Agricultural and Resource Economics, UWA School of Agriculture and Environment, University of Western Australia, Australia.
E-mail addresses: asha1oct@gmail.com, asha.gunawardena@uwa.edu.au (A. Gunawardena).

https://doi.org/10.1016/j.jenvman.2018.08.065
Received 15 January 2018; Received in revised form 9 July 2018; Accepted 14 August 2018
0301-4797/

with active enforcement increased compliance with standards (Blackman, 2009; Kathuria, 2006). In addition, Chinese industries reduced emissions in response to pollution levies (Jiang and McKibbin, 2002; Wang and Wheeler, 2005). However, effluent taxes are often not set high enough to reflect the marginal social cost of emissions (Stavins, 2003).

Tradeable permits achieve an abatement standard by restricting the total number of permits allocated and the permit price is determined by a market. Tradeable permits[1] received much attention due to their attractive features such as cost efficiency, flexibility and incentives for innovation and investment in pollution control (Brill et al., 1984; Kraemer et al., 2004; Lyon, 1989). Despite some successful cases[2] the global experience with tradable water pollution emission trading is not extensive (Shortle and Horan, 2013). There has been limited experimentation with tradeable permits in developing countries. Environmental regulators in China have experimented with a number of tradable emission permit schemes (Cao and Ikeda, 2005; Zhang et al., 2013). Experiments with tradable permits in Chile[3] highlighted the financial and institutional challenges in designing a well-functioning trading program in a less developed country (Coria et al., 2010; Coria and Sterner, 2010). Efficiency gained from tradeable permits can be higher for developing countries given that there is less sunk investment in treatment facilities and establishing low cost abatement may avoid the need for investment (Lyon, 1989).

The analytical framework used in this study is an integrated hydrology-economic model (Brouwer and Hofkes, 2008; Coombes, 2005; Pulido-Velazquez et al., 2008; Volk et al., 2008).

We developed a hydro-economic model that combines a model of water quality of the Kelani river catchment with an economic model of the response of profit maximizing polluters. Other studies that use this linked model approach in developed countries include (Brill et al., 1984; Hanley and Moffatt, 1993; Moffatt et al., 1991; O'Neil et al., 1983) and less developed countries (Rahman and Ancev, 2014; Wang et al., 2004).

The contribution of this paper is that it develops a generic approach to linking and calibrating hydrology and abatement cost sub-models for a catchment with limited hydrology, water quality and firm specific economic data. The integrated hydro-economics model uses the outputs of these sub-models to determine a cost-effective allocation of abatement across firms. This integrated approach can be widely applied to assess the costs of market-based and regulatory policy regimes.

The rest of the paper is organised as follows. Section 2 describes study site and policy context. Section 3 describes the development of the integrated hydro-economic model. Section 4 presents and discusses the results. Section 5 concludes the paper with some policy implications.

2. Study site and the policy context

Kelani rises in the central hills of Sri Lanka in a forestry and agricultural region and flows to the Indian Ocean in Colombo (Fig. 1). The river provides a diverse range of ecosystem services: it supplies Colombo with drinking water, hydroelectricity, irrigation, bathing, washing, socio-cultural activities and the removal and assimilation of industrial and agricultural pollution.

Concerns about water quality in the river led to the initiation of a monitoring scheme under the Clean River Program in 2002. The review found that water quality at the drinking water extraction point (Ambatale) was not suitable for drinking without intensive treatment. The main pollutants were organic matter, faecal and heavy metals. Industrial emissions accounted for most of the organic pollution in the river (Herath and Amaresekera, 2007). The river below Ambatale is of poor water quality and, as a result, the estuarine ecosystem is heavily degraded.

The current approach to the control of industrial organic pollution in Sri Lanka is the use of CAC regulatory measures applied as a concentration-based effluent standard. The Central Environmental Authority (CEA) provides mandatory Environment Protection Licenses (EPL) to new business. There is evidence that the current approach to pollution regulation is ineffective (AECEN, 2006; Vasantha, 2008) for several reasons. First, effluent standards regulate effluent discharge concentration, but do not restrict the total load. Second, EPL do not provide an incentive to reduce pollution as all industries are charged a uniform fee per firm irrespective of their effluent loads. Third, CEA has limited regulatory power and weak enforcement mechanisms. Fourth, budgetary constraints, due to a lack of a separate CEA fund, have resulted in limited resources to monitor polluters. Lastly, the lack of a well-managed information system on site monitoring is also a hindrance to effective enforcement.

In 2007, CEA proposed the Wastewater Discharge Fee (WDF) program. However, its implementation presented a number of challenges due to poorly defined institutional responsibilities between agencies and lack of procedures to set and collect fees. Some of these issues are addressed by regulations resulting from the Amendment of National Environmental Act of 1980, enacted in 2008 that eliminated legislative and regulatory constraints to earmark funds collected through discharge fee. The funds collected are expected to be used in improving the capacity of the regulatory authority to administer more complex pollution polices. Despite some improvements in institutional settings, technical, informational and economic aspects of implementing such a program has not received much attention within Sri Lanka (Vasantha, 2008).

3. Development of the hydro-economic model

The use of hydro-economic models to manage river catchments integrates hydrological, engineering, environmental and economic aspects to determine efficient and cost effective management decisions (Heinz et al., 2007). Such an integrated systems framework (Coombes and Barry, 2015) is needed to make socially optimal policy decisions. These models operationalize economic concepts by including them at the centre of water resource management (Harou et al., 2009). Despite the widespread use of hydro-economic models to manage different aspects of water resources, application of such models to simulate policy options to control wastewater pollution is limited. The European Union Water Framework Directive for nitrate pollution management led to a number of key studies (Aftab et al., 2007; Cools et al., 2011; Gömann et al., 2005; Peña-Haro et al., 2009) and a smaller number of studies addressed BOD emissions (Hanley et al., 1998; Hanley and Moffatt, 1993; Moffatt et al., 1991). Biochemical Oxygen Demand (BOD) is a measure of quantity of oxygen used by microorganisms in the oxidation of organic matter. This is a commonly used measure of water quality. There are a few studies on emerging countries (Ning and Chang, 2007; Qin et al., 2011; Wang et al., 2004).

The hydro-economic model was developed combining outputs from two models; transfer coefficients from the hydrology model of water quality and the abatement costs from parametric input distance functions. These outputs were used in an economic optimization model to stimulate a range of policy options.

[1] However, trading can cause water quality to deteriorate in some parts of a catchment. Therefore designing a tradeable permit system needs to take the spatial effects into account. Empirically, location-based trading ratios have been shown to be efficient in taking spatial impacts into account (Hung and Shaw, 2005).

[2] Nutrient Trading Program in North Carolina in the US, Hunt River Salinity Program in Australia and South Nation River Phosphorous Management Program in Canada.

[3] Chile was the first country outside the OECD to implement permit trading.