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Managing the trade-off between economic growth and protection of environmental quality: the case of taxing water pollution in the Olifants river basin of South Africa

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Abstract

A series of pollution control measures have been introduced to protect water quality in the Olifants river basin, the third most water-stressed and most polluted basin in South Africa. This paper employed an environmentally extended computable general equilibrium (CGE) model to analyse the economic and environmental implications of a tax on water pollution in the basin. Implications of increasing the pollution tax rate currently in place for the levels of economic activities and water quality have been simulated under alternative tax revenue recycling schemes. Results of our policy simulations suggest that internalising the cost of water pollution through the tax regime achieves its environmental goals of protecting the aquatic ecosystem, by shifting production away from pollution-intensive sectors. This, however, comes at some cost to the regional economy of the basin. Recycling the tax revenue through income transfers to households or a subsidy to pollution abatement mitigates the adverse economic impacts.

Keywords: Environmental CGE model; Market-based incentives; Olifants river; Pollution control policy; Water quality

Introduction

South Africa (SA) is a water-stressed country with mean annual rainfall (490 mm) below the world's average (814 mm) (Council for Scientific and Industrial Research (CSIR), 2010). Groundwater resources are also not enough to augment surface water due to the predominantly hard rock nature of the country's geology. Further to these limiting supply factors is the deterioration of water quality

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induced by anthropogenic activities which add pressure to the limited amount of water available (CSIR, 2010; Department of Water Affairs and Sanitation (DWS), 2011a). These human-induced water quality problems are associated with agricultural activities which use chemical inputs (e.g., fertilisers and pesticides), industries that discharge chemical waste, poorly functioning sewage treatment works that add excessive nutrients to water resources due to untreated or partially treated effluents, and mines that introduce metals to water resources (Department of Environmental Affairs (DEA), 2011). The major processes contributing to water quality deterioration include salinity (measured as total dissolved salts), eutrophication or nutrient load (measured as total nitrogen and total phosphorus), microbial contamination and sedimentation (CSIR, 2010; DEA, 2011; DWS, 2011a). Pollution of water quality has adverse effects on the economy, human health, as well as the health of aquatic ecosystems. Therefore, it is imperative to protect the country's aquatic ecosystems to ensure an adequate water supply of suitable quantity and quality for sustainable socio-economic development (National Water Resources Strategy (NWRS), 2013).

The National Water Act of SA (National Water Act (NWA), No. 36 of 1998) provides the legal basis for the protection of water resources through two measures: resource directed measures (RDM) and source directed controls (SDC). RDMs are meant to protect the quality, quantity, in-stream biota and riparian habitat of water resources while SDC outlines the limits and constraints imposed on users of a water resource to achieve the desired level of protection (DWS, 2006). Combined, these measures are intended to control and remedy the effects of pollution and protect water resources while meeting water users' needs (NWRS, 2013). Considerable progress has been made in the implementation of these measures, especially in water management areas such as the Olifants and Vaal river systems. However, there is a demonstrable drop in water quality across the country and increased stress on water resources despite the legislative requirements and progress made in its implementation. For instance, a national assessment of the state of surface water quality conducted by the DWS revealed that the in-stream water quality of most rivers across the country did not comply with the generic set of resource water quality objectives (RWQO) (DWS, 2011a). Over 70% of the monitored sites show non-compliance for phosphate and 30% of the sites show unacceptably high levels of salts. Overall, only 17% of the 276 selected monitoring sites met all the RWQOs for all water quality variables.

The government thus intends to enhance enforcement of the pollution control policies in a cost-effective manner to improve the current state of surface water quality. However, pollution control policies have unintended direct and indirect cost implications for economic activities through impacting prices, employment, trade and income distribution (Xie & Saltzman, 2000; O'Ryan *et al*., 2005; Brouwer *et al*., 2008). It is, therefore, important to evaluate the potential economic impacts of these policies to inform assessments of the cost-effectiveness of alternative measures and interventions to protect water quality.

Previous studies (DWS, 2003, 2011b) on the basin-wide impacts of water quality management policies (WQMPs) have failed to capture the structural realities of the regional economy. Models employed assumed an economy linear in costs, and with fixed prices that did not account for impacts on pollution abatement activities. These assumptions do not fit real-world economies, which are characterised by price adjustment and nonlinear substitution possibilities (Xie, 1995). The computable general equilibrium (CGE) framework overcomes these limitations by allowing for substitution possibilities in supply and demand systems, and endogenous price determination. Previous CGE applications to water policy reforms in SA however, only focused on quantity allocations (Letsoalo *et al*., 2007; Juana *et al*., 2008; Van Heerden *et al*., 2008; Blignaut & Van Heerden, 2009; Gill & Punt, 2010; Hassan & Thurlow, 2011). Studies that analyse quality dimensions of water management in SA using the CGE framework are, to the best of our knowledge, non-existent. As a result, the economy-wide effects of WQMPs in SA remain unclear. This paper is an extension of previous CGE modelling efforts, attempting to integrate information on water pollution and abatement measures to assess the basin-wide[1] impacts and effectiveness of WQMP in the Olifants Water Management Area (OWMA) in SA.

The rest of the paper is organised as follows. The section immediately below reviews relevant literature on environmental CGE modelling, and is followed by a section presenting the general features of the regional model and environmental extensions. Then, we present the sources of the data used to implement the model to our case study area. Results of the policy simulation analysis of impacts of implementing a water pollution tax in the OWMA, under alternative revenue recycling schemes are next presented and discussed. The final section is the conclusion.

Approaches to evaluating impacts of changes in environmental policy

Both partial and general equilibrium approaches have been employed to evaluate and compare alternative environmental management policies and measures. Since sectoral policies may have large unintended impacts on other sectors, partial equilibrium models have been considered deficient as they do not account for economy-wide implications. General equilibrium models have thus been employed to trace impacts of such interventions throughout the entire economic system. For example, the CGE modelling approach has been used to study, among others: the economic impact of environmental instruments (Jorgenson & Wilcoxen, 1990; Hazilla & Koop, 1990); the impact of trade agreements on the environment (Grossman & Krueger, 1991; Beghin *et al*., 2002); the impact of climate change, especially the reduction and stabilisation of major greenhouse gases (Jorgenson & Wilcoxen, 1993; Nordhaus, 1994; Edwards & Hutton, 2001); and impacts of energy taxation on pollution control costs (Hudson & Jorgenson, 1974; Wiese *et al*., 1995).

The CGE approach has also been used extensively to analyse the economic costs and effectiveness of environmental management policies in SA. Several studies have employed the framework to analyse the economic and environmental impacts of a greenhouse gas (GHG) mitigation policy in SA (Devarajan *et al*., 2011; Alton *et al*., 2014; Van Heerden *et al*., 2016). In water management, studies have analysed the impact of water policies on water use and allocation as well as the associated costs and trade-offs (Hassan & Thurlow, 2011). Other studies have focused on the impacts of water pricing (Letsoalo *et al*., 2007; Van Heerden *et al*., 2008; Gill & Punt, 2010), climate change (Juana *et al*., 2008) and macroeconomic policies (Blignaut & Van Heerden, 2009) on sectoral water allocations, the environment, household welfare and economic growth. However, the focus has so far been only on managing the quantity of water and, to the best of our knowledge, no effort has so far been made to analyse water quality management dimensions using the CGE framework in SA. The present study attempts to contribute to bridging this gap in the literature by constructing a CGE model that integrates information on water pollution and abatement measures to analyse the basin-wide impacts and effectiveness of WQMPs. To support such an analysis, we constructed a new database for the basin that incorporates both water pollution-related and economic information using the framework of an environmentally extended social accounting matrix (SAM).

[1] We use basin and region interchangeably.

Our model specification extends standard CGE formulations to include a production function for pollution abatement activities and treat their 'output' as special intermediate goods bought by polluters. The incorporated pollution abatement sectors have the responsibility of providing the best available cleaning or purification services to help polluters meet prescribed environmental standards. The amount paid by polluters for these special intermediate goods constitute their abatement cost. Our model also assumes that not all pollution generated in the economy can be removed by the abatement sectors, so the government levies a tax on the amount not removed (unabated pollution). Therefore, the cost of pollution control which includes water pollution tax and abatement cost is included in the cost of production (i.e., based on the 'polluter pays' principle).

Specification of the regional CGE model for water policy evaluation

This section provides the general features of our regional environmental CGE model. The mathematical statement of the model is presented in Table A1 (available with the online version of this paper). Our model adapts the IFPRI standard static CGE model specifications of Löfgren *et al*. (2002)[2].

As in standard formulations, production and consumption decisions in our model follow the assumptions of profit and utility maximisation of producers and consumers, respectively. However, the optimal behaviour of producers in this adapted version is influenced by the cost of pollution control. That is, the addition of pollution control cost causes producers to re-optimise production levels to maximise profit. Production activities follow a nested production structure. At the top level of the technology nest, a Leontief production function, which allows for limited substitution on the production side, combines aggregate value-added and aggregate intermediate input. Intermediate inputs are demanded in fixed proportions relative to the output of each sector, and each intermediate input is a constant elasticity of substitution (CES) function of a domestic good and its imported equivalent. Imported goods include imports from the rest of the world (ROW)[3]. Also, exported domestic outputs are distinguished from those produced and sold in the study region using a constant elasticity of transformation (CET) function. Aggregate value-added which is a combination of different labour skills (unskilled, skilled and highly skilled) and capital is modelled using a CES aggregation function. We assume that higher skilled labour (highly skilled and skilled) and capital are fully employed with flexible real wages and capital rental price. On the contrary, and to reflect the reality in the SA labour market, unskilled labour is assumed to be not in full employment at a fixed real wage. Each sector produces one unique product and the cost of production includes the cost of value-added, intermediate input use, production taxes and the cost of pollution control. In the model, all sectors including the incorporated pollution abatement sectors share this production structure except that input proportions and behavioural parameters differ among them.

Institutions in this regional CGE model are represented by households, government, enterprise and the ROW. Household income derives from the supply of production factors in addition to transfers from other institutions. Factor incomes are distributed to households, who spend their income on paying taxes, buy consumer goods or save. Household consumption demand is modelled as a linear

[2] Due to lack of data, we omit certain features of the generic model. For example, our model does not include home consumption of domestically produced goods and the assumption that activities produce multiple products. It is important to note that the omission of these features does not impact on the validity of our model.

[3] ROW in this case includes all other regions in SA (i.e., outside study region), in addition to foreign countries.

expenditure system (LES) that differentiates between necessities and luxury goods. Imperfect substitutability between domestic and imported commodities is modelled using a CES structure (Armington, 1969). The government receives income from various tax accounts (including water pollution taxes) and transfers from the ROW. The government uses its income to finance public consumption and for transfers to other institutions. Government consumption is assumed to be fixed in real terms, whereas its saving is determined residually. Trade with other regions in SA and foreign countries is allowed through transacting with the ROW sector. We adopt the standard assumption of a small open economy, thus, import and export prices are determined in the world market which is assumed to be large enough to absorb all exports and meet all import demands.

The environmental component[4] of this regional CGE model includes information on water pollution and abatement activities of production sectors and pollution taxes. As indicated earlier, producers incur two types of pollution control costs: water pollution taxes and the costs of removing pollution (a service provided by pollution abatement sectors) in order to comply with set water quality standards. Thus, the cost of pollution control influences output supply and factor demand decisions by producing sectors. That is, pollution is linked to total production of each sector on the input side of the production function. The demand and price of pollution abatement services are endogenously determined in the model based on prevailing market conditions. The model also includes different pollution-related indicators such as total amount of pollution abated/cleaned up and the amount of pollution discharged into the environment. The water quality problems considered are salinity and nutrient load (nitrogen and phosphorus) with total dissolved salts, total nitrogen, and total phosphorus, respectively, being the indicators. These constitute the major pollutants in our case study region. The two main equations for adding pollution and pollution abatement activities to the model are as follows:

$$PETAX_a = \sum_g tpe_g.d_{g\,a}.QA_a.(1 - cl_g) \tag{1}$$

$$PACOST_a = \sum_g PAG_g.d_{g\,a}.QA_a.cl_g \tag{2}$$

where $PETAX_a$ and $PACOST_a$ are, respectively, the total cost of pollution taxes and pollution abatement services to sector a for discharging pollutant g. $d_{g,a}$ is production pollution coefficient of pollutant g in sector a, QA_a is total output of sector a, PAG_g price of pollution cleanup services for pollutant g, tpe_g is the per unit tax levied by the government for discharging pollutant g, and cl_g is economy-wide cleanup rate of pollutant g.

Finally, the choice of a closure rule is an important aspect of CGE modelling, as it represents assumptions about how institutions in the economy operate and ensures that there is a balance between the number of endogenous variables and independent equations to obtain a unique solution (Löfgren, 1995). Nonetheless, it is difficult to argue for a single rule. Therefore, we examine in our policy simulations' section alternative macro closure scenarios to evaluate trade-offs involved between achieving environmental conservation goals and pursuing economic growth.

[4] The environmental part follows closely that of Xie & Saltzman (2000). We, however, exclude certain features such as consumption pollution because of data limitations, and since production activities constitute the major source of pollution in our case study area – the OWMA (DWS, 2011c).

The case study area and the database

The Olifants Water Management Area (OWMA), which straddles three provinces in SA (Limpopo, Mpumalanga and Gauteng provinces) and covers an area of about 54,570 km^2, has been chosen as the case study region for conducting this investigation. Selection of the OWMA out of the nine water management areas in SA was because it ranks as the third most water-stressed as well as the most polluted basin (DWS, 2011c; Wambui *et al*., 2016). It is also of high strategic importance to the national economy as it supports 48% of the total power generating capacity and contains almost half of SA's strategic water source areas (United Nations Environment Programme (UNEP), 2015). The chronic water deficit and deterioration of water quality faced in the basin are due to increasing water demand and pollution activities from mining, irrigation agriculture and industrial waste disposal (DWS, 2011c). For instance, agricultural activities in the middle and lower sub-areas of the basin result in irrigation return flows and seepage which contains salts from fertilisers and other agrochemicals. Also, mining activities produce mine water which is high in dissolved salts such as sulphate, calcium and magnesium. This contributes to low pH and increases salinity and sediment loading which affect in-stream biota as well as riparian habitat. Furthermore, untreated and partially treated sewage pumped into the Olifants River by poorly functioning sewage treatment plants compound the pollution situation of the river. The effects of these pollutants include increased water treatment costs, widespread eutrophication and toxic water quality, which threatens water supply in the basin (De Lange *et al*., 2012). Thus, the deteriorating water quality in the OWMA has significant social, economic and health repercussions.

We employ the SAM framework, which captures the transactions and transfers between different agents in an economy for a particular year, widely used in the literature as tools for policy analysis and for calibrating CGE models (Round, 2003). The SAM is specifically a square matrix with balanced corresponding rows and columns representing the income and expenditure of each agent. A typical SAM, however, does not provide information on the interactions between economic activities and the environment. Thus, a conventional SAM will not meet our current need of assessing the economic and environmental implications of WQMPs in OWMA. As a result, a new integrated SAM, which captures the relationships between economic and pollution abatement activities, was constructed for the basin using the framework of environmentally extended SAM developed by Xie[5] (2000). The pollution-related information includes sectoral payments for pollution abatement services, pollution taxes and pollution abatement subsidies. The integrated SAM serves as a consistent database for calibrating our environmental CGE model and makes it possible to quantitatively analyse the economic and environmental impacts of WQMP at the basin level.

The SAM used for analysis is a consolidated version of three provincial SAMs[6] for the year 2012. The consolidated SAM has ten producing sectors (aggregated from the 46 sectors' provincial SAMs) with information on intermediate inputs, value added, consumption, taxes and trade. The aggregation of sectors was done based on the type of pollutant discharged into the environment. Sectors of our model include agriculture (disaggregated into field crops, horticulture crops, livestock and other

[5] Xie (2000) developed a framework for extending a SAM to include pollution-related information such as pollution abatement activities, sectoral payments for pollution abatement services, pollution emission taxes, pollution abatement subsidies and environmental investment.

[6] The initial SAMs were developed by the Development Bank of Southern Africa (DBSA) for the year 2006 and were updated for the year 2012 using information from statsSA.

agriculture), mining, manufacturing (disaggregated into chemical manufacturing, wood and paper, food, beverage and tobacco and other manufacturing) and services. In addition to the ten producing sectors, the SAM is extended to include three pollutants (salinity, nitrogen and phosphorus), and three corresponding pollution abatement sectors. Specifically, the conventional commodity by pollution abatement activity matrix contains intermediate inputs of pollution abatement sectors. On the other hand, the pollution abatement commodity by production activity matrix reflects sectoral demand for/ or spending on pollution abatement services. Thus, pollution abatement services are treated as special intermediate goods and added to the commodity accounts. The entry in the activity by pollution abatement commodity shows the total value of pollution abatement service or pollution clean-up. Furthermore, the SAM has three pollution tax accounts which receive payments from production sectors for their water pollution discharges. These taxes are transferred to the consolidated government account.

Because a SAM with water pollution information for the OWMA has not been built before, we adopt an indirect approach to estimate the pollution-related data by pollutant and sector. Using data from the DWS Water Management System (WMS) for the year 2012, we estimated the load for each pollutant at selected monitoring sites along the Olifants River using the volume of flow and median concentration for the month. The estimated load from the monitoring sites was summed to obtain total load per pollutant for the base year. This was disaggregated by sector using best available information from previous studies (DWS, 2011b, 2011c; Dabrowski & de Klerk, 2013). The pollution intensities of each pollutant by sector were then calculated using data on sectoral output and pollution load (Table 1). The cost of operating a standard treatment plant to reduce pollutants to achieve in-stream water quality was obtained from previous DWS studies in the OWMA (DWS, 2003, 2011b). These data were disaggregated using the estimated pollution intensities to obtain the pollution abatement cost of each production sector and for each pollutant. The calibration procedure was used to estimate parameters of the model using trade and output elasticities from Hassan & Thurlow (2011). A sensitivity analysis employing different elasticity parameters was conducted to check the robustness of the model.

As Table 1 indicates, manufacturing (primarily food processing and other manufacturing activities), agriculture (especially horticulture and livestock sectors) and mining are the sources of water pollution in the study area. It is also clear from Table 1 that polluting sectors are relatively capital intensive and contribute marginally to employment of unskilled labour. On the other hand, polluting sectors generate the bulk of the Olifants' export earnings, but they are also major users of imported goods. As will become clear in the subsequent policy simulation analysis, these structural features (e.g., degree of exposition to foreign trade, etc.) are key determinants of the economic impacts of taxing water pollution in the river basin.

Policy simulations and key findings

The environmental CGE model developed for the OWMA is used in this paper to analyse the economic and environmental impacts of water pollution management policies to reduce nutrient load (total nitrogen and total phosphorus) in the study region. We assume arbitrarily that the government raises the pollution tax rate on nutrient load by 50% with reference to the base value. Three policy regimes are implemented and compared in the following sections. The first scenario assumed that all revenue generated from the pollution tax is absorbed in the government budget balance. Results of this scenario are reported under the *no-revenue recycling* scenario. Two other policy scenarios are tested to evaluate two

Table 1. Economic structure and pollution-related information in the study area (base year 2012).

		%age shares in total emissions		Emission intensity (kg/Rands)		Factors' shares in industry costs (%)					
Sectors of economic activity	%age shares in RGDP	Nitrogen	Phosphorus	Nitrogen	Phosphorus	Unskilled labour	Capital	%age shares in total exports	%age share of exports in industry	%age shares in total imports	%age shares of imports in domestic demand
Agriculture	3.7	26.58	26.18	0.0243	0.0213	4.70	19.83	4.9	20.50	3.7	14.17
Field crops	0.8	0	0	0	0	9.2	22.5	0.4	13.3	1.3	33.9
Horticultural crops	1.0	13.63	13.58	0.0233	0.0193	2.3	18.4	4.1	63.6	0.8	25.8
Livestock	0.7	12.95	12.60	0.0350	0.0260	2.6	16.9	0.2	5.7	0.6	15.4
Other agriculture	1.2	0	0	0	0	6.3	22	0.2	3.5	1.0	17.7
Mining	26.6	17.68	18.06	0.0182	0.0154	6.0	45.4	52.6	68.9	6.3	21.4
Manufacturing	21.5	55.74	55.76	0.0298	0.0259	4.65	23.73	19.7	13.4	50.8	32.70
Chemical manufacturing	0.9	3.15	4.08	0.0258	0.0281	1.1	12.2	0.3	5.7	8.4	66.8
Food, beverage and tobacco	9.0	26.15	28.64	0.0327	0.0301	9.0	23.7	2.9	8.2	3.6	11.0
Wood and paper	1.7	2.80	3.44	0.0192	0.0198	6.9	17.1	1.1	16.0	6.1	52.0
Other manufacturing	9.9	23.64	19.60	0.0192	0.0133	1.5	25.7	15.4	31.9	32.7	49.2
Services	46.1	0	0	0	0	5.2	30.3	22.8	14.8	39.2	22.6

Source: Olifants environmental SAM.

Note: Sectors with zero emissions imply negligible share in total emissions.

alternative options for recycling tax revenue to mitigate the impact of the pollution tax on economic activity. One of the complementary policies tested is to reinject the pollution tax proceeds back into the economic system by recycling all revenue through a direct subsidy to consumers as a lump-sum *transfer to households*. The second tax revenue recycling regime is to return the tax revenue to pollution abatement sectors in the form of *production subsidy*. Thus, there are three policy simulations including the reference scenario where the government does not recycle the tax revenue (i.e., the pollution tax revenue is used for fiscal adjustment).

Due to space limitations, we report here results of simulations of the pollution tax policy on nitrogen. The simulation results on phosphorus and salinity are presented in Tables A2 and A3, respectively (available with the online version of this paper). The proposed tax rate on nitrogen emissions used amounted to R 0.6 per kilogram. While using a single test pollutant is valid for illustration, it would be interesting to investigate the combined effects of a simultaneous imposition of the tax on multiple pollutants. Table 2 shows that the pollution tax achieves its purpose of reducing nitrogen emissions.

The environmental goal of protecting water quality, however, comes at an economic cost of lower real regional gross domestic product (RRGDP), as imposition of the tax raises the cost of production in polluting sectors causing them to re-optimise at lower output levels. On the other hand, non-polluting sectors (such as field crops and services) record an increase in production due to the fall in their production costs, compared with polluting activities. The fact that the 'other agriculture sector' buys over 40% of its intermediate inputs from the chemical and other manufacturing sectors (polluting upstream sectors) explains the drop in production of this activity, highlighting the indirect impact of the tax through increased production costs in upstream input supply sectors.

In the new equilibrium, demand for pollution-intensive goods (such as horticultural crops and chemical manufacturing) declines (both domestically and export) due to increasing domestic prices. This leads to a fall in domestic production of polluting activities, negatively impacting demand for primary factors, particularly capital[7], and in turn, reducing remuneration to factors of production and household income. In general, the water pollution tax leads to an increase in the relative price of exports which prompts a depreciation of the real exchange rate (i.e., makes imports more attractive). This confounds the impact on polluting sectors as they are the most trade-exposed, i.e., high export and import components. Production in the horticultural crop and chemical manufacturing sectors are severely affected due to their high trade shares (Table 1). Mining and horticultural crop production, for instance, which export over 60% of their output became less competitive and lose market shares on the international market. Similarly, domestic production was readily replaced by cheaper imports in manufacturing, particularly the chemical and wood and paper sectors, which source very high shares of their inputs' demand from imports (Table 1).

Under the no-recycling scenario the model solves by clearing the government account leading to higher government balance (savings) as government consumption is fixed and transfers are held constant (Equation (38) in Table A1). Higher government savings, in turn, will lead to lower savings by households to maintain the economy-wide saving–investment balance, since total investment levels are kept exogenously fixed (Equation (39) in Table A1). Lower private savings' levels leave households

[7] Although prices of both capital and labour drop, capital bears the burden of the tax increase, because the reduction in capital by polluting firms outweighs the reduction in labour since polluting firms are relatively capital intensive (Table 1). This is reflected in a fall in the economy-wide capital to labour price ratio.

Table 2. Micro and macro level impacts of a 50% increase in pollution tax on nitrogen emission under alternative revenue recycling scenarios (%age change relative to base-run).

	Base-run (units)[a]	Scenario 1: No-revenue recycling (%age change)	Scenario 2: Uniform transfers to households (%age change)	Scenario 3: Production subsidy to pollution abatement sectors (%age change)
Total nitrogen discharged	1.805	−0.33	−0.26	−0.21
Changes in sectoral output				
Field crops	3.273	0.17	0.47	0.05
Horticultural crops	6.557	−1.57	−1.49	−0.33
Livestock	4.093	−0.37	−0.36	−0.10
Other agriculture	5.975	−0.11	0.08	−0.04
Mining	78.186	−0.06	−0.03	0.03
Chemical manufacturing	4.478	−1.04	−0.75	−0.18
Food, beverage and tobacco	35.997	−0.33	−0.22	−0.12
Wood and paper	7.124	−0.45	−0.32	−0.04
Other manufacturing	49.378	−0.42	−0.38	−0.27
Services	157.614	0.21	0.24	0.06
Changes in macro-aggregates				
RRGDP	214.947	−0.03	0.02	−0.01
Private consumption	125.623	−0.05	0.04	−0.013
Exports	102.360	−0.10	−0.06	−0.02
Imports	96.357	−0.11	−0.06	−0.02
Real exchange rate	1.0	0.012	0.021	0.001
Unskilled labour employment	16.805	−0.21	−0.34	−0.06
Government revenue	46.876	0.66	0.79	0.86
Aggregate government transfer	1.147	0	39.33	0
Government savings (surplus)	−1.354	−28.64	0	−8.82
Aggregate household savings[b]	25.689	−1.31	0.10	−0.18
Total absorption	208.944	−0.03	0.02	−0.01

Source: Olifants environmental CGE model.
[a]Except for employment (in thousands of workers) and total nitrogen discharged (in 1,000 kilograms), base year units are in millions of Rands.
[b]Aggregate household savings include savings by enterprises.

with more disposable income to spend on household consumption (Equation (24) in Table A1). This represents an indirect subsidy to consumption demand, which mitigates the negative impacts of the tax on economic activity.

Under scenario 2, the revenue from the water pollution tax is returned to the economy as uniform government transfers to households. Compared with the no-revenue recycling scenario, which can be considered an indirect subsidy to households in the form of an income tax break, this scenario is a direct subsidy to households in the form of cash grants. Households' income is boosted by the transfers which increase their purchasing power and enhance demand for consumption goods. As a result, production is stimulated in both polluting and non-polluting sectors, positively impacting real regional GDP.

In the third scenario, the pollution tax revenue is returned to pollution abatement sectors in the form of production subsidy. This is a supply-side subsidy that reduces the cost of production in pollution abatement sectors, thus boosting the capacity of the regional economy to clean-up. The effect is a marginal increase in production in polluting sectors softening the negative impact of the tax policy. As a result, the output of polluting sectors falls by a smaller margin compared with the previous two scenarios. Since this study assumes that the output of pollution abatement sectors is a special intermediate good bought by polluters, the fall in their prices due to the increased government subsidy encouraged polluters to increase their demand. At the macro level, the real exchange rate depreciates by a smaller margin under this scenario due to the increased competitiveness of domestic firms.

The two complementary recycling policy regimes yield positive outcomes in managing the trade-off between economic growth and protection of environmental quality objectives (Table 2). Recycling through a direct subsidy to consumers (scenario 2) however, generates stronger responses by more than offsetting the negative impacts on economic activity while achieving relatively bigger reductions in emission of pollutants, compared with the production subsidy to abatement activities policy regime (scenario 3). The lower impact of scenario 3 is caused by the restrictive specification of the fixed coefficients Leontief production technology, which does not allow substitution flexibility between inputs. The biggest rigidity in our model is the restrictive specification of the supply of pollutants and demand for abatement services in production. Production activities in our model buy abatement for only a fixed ratio of total pollution generated and the remainder is disposed of in the environment, making the supply of pollutants move in direct proportion to the level of economic activity. Relaxing this limitation through more flexible specification in the structure of production activities will most likely generate a double dividend in managing the trade-off between economic growth and protection of water quality in the study region.

It is also important to note that our analysis underestimates economic gains from improved water quality, as we do not account for beneficial feedback effects of reduced water pollution, such as positive impacts on human health and aquatic ecosystems. Previous attempts to estimate such benefits in SA indicate that they are significant, and may exceed economic costs of the water pollution tax policy, estimated above. Employing the cost of illness approach (COI)[8], De Lange *et al.* (2012) estimated the direct and indirect costs of microbial pollution in the Olifants river basin to amount to, respectively, R0.704 and R1.141 billion per year. In another study, the department of water and sanitation (DWS, 2003) estimated the downstream benefits of reducing salinity in SA to be R0.467 billion per year. Another caveat to note in considering the results of this study, however, is the fact that our analysis has not covered a major water pollution source in the Olifants, which is municipal waste.

Conclusions and implications for research and policy

The declining water quality in South Africa due to increased surface and groundwater pollution from mining activities, irrigation agriculture and industrial waste disposal is of great national concern. The government has, therefore, implemented a series of pollution control measures to mitigate pollution and water shortage. The economic costs and effectiveness of these measures remain unclear though. Using the Olifants river basin as a case study, this paper developed and used a regional environmental

[8] The COI approach measures benefits of pollution prevention by estimating the direct and indirect costs of associated illnesses avoided. Direct costs are typically estimated using direct healthcare expenditures on treating waterborne diseases, such as cholera and diarrhoea. Indirect costs are estimated based on a composite measure of the burden of the disease, e.g., forgone income due to illness (De Lange *et al.*, 2012).

CGE model to evaluate the economic and environmental implications of a tax on water pollution policy. Our CGE model was calibrated using an extended SAM database that integrates water pollution abatement activities for the Olifants basin.

The results indicate that internalising the negative externality of water pollution in the Olifants river basin will effectively reduce pollution discharge (i.e., achieve its environmental goals). As expected, the pollution tax policy changes the structure of economic incentives in favour of less polluting sectors. Environmental protection however, is achieved at some cost (not accounting for the potential benefits of clean water) to the regional economy, e.g., loss in RGDP. The economic burden of the pollution tax happens to be insignificant though, due to the small relative share of the water pollution supply and abatement costs in total production costs. This suggests that a large tax rate on water pollution will have little impact on economic activity and can obtain larger water quality dividend.

Simulations of alternative programs for recycling the revenue from the pollution tax suggest a high potential for fiscal policy regimes to mitigate the economic burden of the tax. The negative impact of the pollution tax on economic activity was totally offset by a tax revenue recycling regime of direct transfer to consumers. This fiscal programme also achieved relatively bigger reductions in emission of pollutants, compared with the subsidy to abatement activities revenue recycling option.

Results of our analysis, however, need to be considered with caution due to some limitations inherent in basic assumptions of this study, particularly in modelling the production structure of pollution abatement supply and use activities. Demand for pollution abatement services by production sectors, for instance, is specified in a simple way using exogenously determined clean-up rates and the assumption that unit costs of pollution abatement are fixed. Future research efforts should aim to relax these rigid assumptions as better data become available for more realistic specification of abatement demand functions and endogenously determined clean-up rates. Our analysis also does not account for the economic benefits from water quality improvements as well as from technological advancements that lead to reduced pollution intensities.

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