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Analysis

Bio-economic modeling of water quality improvements using a dynamic applied general equilibrium approach

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ABSTRACT

An integrated bio-economic model is developed to assess the impacts of pollution reduction policies on water quality and the economy. Emission levels of economic activities to water are determined based on existing environmental accounts. These emission levels are built into a dynamic economic model for the Dutch economy and subsequently coupled to a national water quality model. The modular approach has the advantage that the impacts on the economy and water quality are evaluated simultaneously, but each within their own domain based on the appropriate scale and level of detail. The dynamic nature of the economic model allows us to also evaluate a derogated water policy as foreseen in the European Water Framework Directive. The indirect costs of different water quality improvement policy scenarios are at least as high as the direct costs related to investments in pollution abatement technology. The stricter the policy scenario, the more important the role of economic adjustment and restructuring mechanisms at the macro-economic level. Significant water quality improvements can be achieved through stringent domestic emission reductions. However, reaching water quality standards is highly dependent on water quality improvement policy in surrounding river basin countries and climate change.

1. Introduction

Methods of analysis to conduct economic evaluation of water policy interventions such as cost-effectiveness and cost–benefit analysis are often ad-hoc and based on a partial economic equilibrium analysis (Brouwer and Hofkes, 2008). The limited number of existing input–output and general equilibrium models addressing water policy issues focuses on the optimization of water resource allocation across different uses, mostly agriculture, or the wider economic impacts of different resource allocation rules (e.g. Strzepek et al., 2008; van Heerden et al., 2008; Velázquez, 2006). Cost–effectiveness analysis of water quality improvements typically focus on the direct cost of policy measures to reduce emission levels of water polluting substances such as nutrients and pesticides (e.g. Gren et al., 1997; Ribaudo et al., 2001; Schleiniger, 1999; van der Veeren and Lorenz, 2002). Studies addressing the impact of these emission reduction measures on water quality, and hence minimizing costs based on water quality objectives, are rare (e.g. Barton et al., 2008; Brouwer and De Blois, 2008). In those cases where emission reduction levels are linked to a water quality model, the economic part consists at most of a partial equilibrium analysis. The only study attempting to estimate the total economic costs of emission reduction water policy scenarios using an applied general equilibrium (AGE) model we are aware of is the one by Brouwer et al. (2008). However, they use a static economic model, with no further details of the impact of the emission reduction scenarios on the national economy and its sectoral components in time.

In this paper, we present the results of an extended dynamic AGE model coupled to a water quality model for the Netherlands. The main objective is to illustrate the use and usefulness of a coupled bio-economic model to simultaneously assess the impacts of water policy interventions on the national economy and water quality. The novelty of the model presented here is twofold. First, it is based on a dynamic representation of the (Dutch) economy. Second, the emission levels of nutrients (nitrogen N and phosphorus P) and a number of eco-toxic metals (cadmium Cd, copper Cu, nickel Ni and zinc Zn) associated with specific water polluting economic activities are linked to a spatially explicit water quality model, allowing us to assess the impact of changes in emission levels on water quality conditions in the main water systems in the country. Thus, we are able to dynamically trace the entire chain from economic activity to emissions to changes in water quality in different water systems and the other way around. More specifically, we test to what extent emission reduction policy scenarios, for instance in the context of the European Water Framework Directive (WFD), affect

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both the national economy and respect or exceed existing water quality standards measured in the Netherlands by a pollutant's maximum permissible concentration (MPC). The latter are based on eco-toxicological understanding of the risks of adding specific pollutants such as nutrients and metals to aquatic ecosystems (lakes, rivers etc.) and are fixed by the Dutch Environmental Assessment Agency.

The effects of six different policy scenarios on the economy and water quality are assessed: a lenient scenario aiming to reduce 20% of emission levels in 2000 by 2015 when the environmental objectives of the WFD have to be achieved for the first time, a strict scenario aiming for a 50 percent emission reduction by 2015 compared to emission levels in 2000, and a ‘precautionary scenario’ where the necessary economic adaptation is determined by the necessary emission reduction to achieve the WFD water quality objectives in all water bodies. Both the lenient and strict scenarios are assessed using two different assumptions related to the influx of water pollution from neighboring countries. One where these levels remain as they currently are and one where it is assumed that water quality levels at the border are reduced by neighboring countries to MPC level as these neighboring countries too have to comply with the new environmental water quality objectives in the WFD. The Netherlands are part of the international river basins of the Rhine, Meuse and Scheldt, and as is typical for downstream transboundary basins, more than half of all the water pollution in Dutch waters is of foreign origin.[1] The impacts of a sixth water policy scenario are also estimated. In this scenario reaching the stringent reduction level is delayed in time until 2027. This is a possibility provided in the WFD to delay reaching the environmental objectives in time, and the dynamic AGE model is especially suited to investigate the impacts of following this option. Finally, the impact of climate change on reaching water quality standards in Dutch water bodies is investigated.

The remainder of this paper is organized as follows. Section 2 describes the integrated bio-economic modeling procedure. Section 3 addresses model calibration, while model results are presented in Section 4. Section 5 discusses the direct and indirect economic impacts of the investigated water quality improvement scenarios. Finally, Section 6 concludes.

2. Model Description

2.1. The Economic Model

The economic model is a forward-looking neo-classical growth model based on DEAN (Dellink, 2005).[2] This model type has the advantage that the specification is fully dynamic: the agents take not only the current state of the economy, but also future situations into account when making decisions that affect current and future welfare. Moreover, the transition path from the original balanced growth path to a new growth path is more flexible in a model with an endogenous savings rate (Barro and Sala-i-Martin, 1995). The original model DEAN is adapted to study water quality issues. The economic part is described in detail elsewhere (Dellink and Van Ierland, 2005). The main features are briefly summarized here.

Consumption of different goods and environmental services are combined in a nested CES utility function using the Linear Expenditure System approach. Producer behavior is specified through a nested CES production function for domestic supply and through a zero-profit condition. On the production side, 27 producers of private goods are identified. There are two consumer groups: private households and the government. The private households have income from the sale of their endowments of capital goods and labor. The government has three sources of income: sale of the pollution permits, lump sum transfers from the private households and tax revenues. The lump sum transfers between government and private households are endogenously adjusted to ensure budget balance for the government. Effective labor supply grows with an exogenous rate as a combination of demographic developments and increases in labor productivity. Capital formation is based on an exogenous interest rate and endogenous capital stock. To account for capital stocks after the model's time horizon, a transversality condition is included that ensures that investment to GDP ratios are not declining in the last periods.

The Dutch economy is highly dependent on international markets and the typical small open economy specification is used. World market prices are exogenously given, and the international market is big enough to satisfy demand for imports and absorb supply of exports at these international prices. The response on the markets to changes in domestic prices is specified using the Armington approach by assuming that domestic and foreign goods are imperfect substitutes. The current account balance is exogenously given and the endogenous exchange rate ensures that equilibrium is attained. The market balance conditions for produced goods, domestic demand, the capital and labor market are satisfied by adjusting relative prices. In line with the general equilibrium framework, a unique set of equilibrium prices ensures that all markets are balanced simultaneously.

2.2. Linking the Emission of Water Pollutants to Economic Activities

Production and consumption processes lead to the emission of water polluting substances. Emission levels are provided in the environmental accounts compiled every year by Statistics Netherlands (2007–2010)[3] using the Dutch Pollutant Release and Transfer Register. Based on these data the emission intensity of different economic activities can be estimated, thereby linking emissions to economic activities. So, essentially sectoral emissions are coupled to the corresponding sector's production levels. Since the relative contribution of each sector to total emission levels is known, this relationship is used to trace back aggregate emission levels to their economic sector origins. Producers and consumers are able to reduce the emission intensity of their activities in two different ways. First, they can take pollution abatement measures, either end-of-pipe or process integrated measures. Second, producers and consumers can reduce their production and consumption of pollution intensive goods.

Pollution abatement measures are included as ‘goods’ in the model and provided by a separate producer whose production inputs represent the cost components of the underlying technical measures (cf. Dellink, 2005). These costs of the supply of abatement goods consist of abatement cost curves, estimated using detailed technical data of best available techniques. A constant elasticity of substitution function is estimated, which determines how much additional abatement effort is needed to reduce pollution by one additional unit. The cost function hence reflects marginal abatement costs. An exogenous technical potential to reduce pollution through abatement activities, i.e. without economic restructuring, provides an absolute upper bound on technical abatement in the model.

Autonomous pollution efficiency improvements result in a relative decoupling of economic growth and pollution, i.e. emission intensities are declining over time even in the absence of new policies. The development of abatement possibilities and abatement costs over time is captured via specific parameters that govern the changes in technical potential for pollution reduction over time and efficiency improvements in the abatement sector. In the specification of the model, these developments in the abatement possibilities and costs, i.e. innovation of new abatement measures, are driven by exogenous parameters.[4] However, the model contains endogenous diffusion of existing abatement technology.

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[1] In 2005, 67% of all metals and 51% of all nutrients in the Dutch water system came from abroad (Statistics Netherlands, 2007–2010).

[2] Model codes for the core DEAN model are available on www.enr.wur.nl/uk/gams.

[3] The sectors are based on the European nomenclature statistique des activités économiques dans la Communauté Européenne (NACE) classification and the United Nations international standard industrial classification of all economic activities (ISIC).

[4] Technological developments can be introduced and simulated, for example, by increasing the upper bound on the technical abatement potential in the model.