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A spatially-distributed cost-effectiveness analysis framework for controlling water pollution

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A B S T R A C T

With the aim of comparing various agro-environmental measures to control pesticide pollution in surface waters, we propose a methodological framework for spatially-distributed cost-effectiveness analysis. We use the Soil and Water Assessment Tool (SWAT) model to assess the effectiveness of the measures applied, and we develop an aggregated bio-economic model using the General Algebraic Modelling System (GAMS) to evaluate the costs of their implementation. Finally, we propose a ranking of these measures based on their cost-effectiveness ratios. This approach is applied to the Gers river basin in southwest France. The findings clearly demonstrate that of all the measures we considered, grass strips and mechanical weeding are the most cost-effective in reducing pesticide-related water pollution. On the other hand, measures such as longer rotation sequences and catch crops, although relatively inexpensive to implement, fall short in terms of reducing pesticide pollution. Furthermore, we found that the cost and effectiveness of measures largely depended on where they were implemented, as the framework proposed takes account of physical variables and farm activities scattered within the watershed. Possible uses of this integrated framework as a communication tool in participatory river basin management are also discussed.

1. Introduction

Intensification of agricultural practices over the last few decades, along with a growing use of fertilisers, has led to a widespread use of pesticides in fighting crop pests and reducing competition from weeds. This increased reliance on pesticides has resulted in the pollution of soil and water via spray drift, dispersal of pesticides into the soil, runoff during or after cleaning of equipment, and uncontrolled disposal. To combat the problem of water pollution, the European Union (EU) has put in place a number of regulations and directives, such as the Nitrate Directive (91/676/EEC), the Water Framework Directive (2000/60/EC), and more recently the Pesticide Directive (2009/128/EC). Compliance with the Water Framework Directive (WFD) implies a reduction in the impact of agricultural pressures. The implementation of agro-environmental programmes is now compulsory for Member States in their rural development plans (1992 and 2003 CAP reform), and new agro-environmental measures offer a range of support to EU countries in return for their commitment to the reduction of pesticide use.

Furthermore public participation in water management required in international conventions (United Nations, 2000; Aarhus Convention, UNECE, 1998; World Water Commission, 2000; Water Framework Directive, 2000/60/EC) must also be taken into consideration, particularly in cases involving complex issues, and where there is a high degree of uncertainty.

Questions of spatial, temporal, and technological heterogeneity make devising environmental mitigation programmes a complicated exercise. The precise extent of the damage caused to the environment by the use of pesticides is difficult to assess, due to the delay between their application and the appearance of any quantifiable effects. In addition, these relationships are subject to a number of stochastic influences outside the farmers' control. For example, pesticide readings in the water can increase as the result of a heavy rainstorm. Consequently, it is almost impossible to attribute damage to an individual farm, especially since the characteristics of agricultural production (soil types, slopes, farming systems, proximity to streams) can vary enormously across a river basin.

Agro-environmental measures defined at national or regional level can thus lead to extremely different results in terms of implementation costs and environmental effectiveness. In addition to these uncertainties, Government and Water agencies have access to a limited amount of money. Making best use of the funding available is therefore a key consideration. Moreover, the working

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group guidelines for WFD implementation state that a Cost-Effectiveness Analysis (CEA) should be carried out in order to identify which measures will achieve the desired environmental objectives, at the lowest cost to society (WATECO, 2002).

To address these issues, this study investigates the possibility of using a spatially-distributed CEA (Fig. 1). We illustrate in this paper how the use of modelling tools in analysing the different impacts and costs of environmental policy measures could help evaluate their relative interests as a function of the characteristics and opportunities of a catchment. The framework proposed (Fig. 1) is a bottom-up approach focussing on the cost of implementing measures at the field, sub-basin and watershed level, while assessing environmental effectiveness at the sub-basin and watershed level.

Bottom-up approaches, which consider decisions made at local or regional level, can reveal the most relevant stakeholders and elements of agricultural land use (Busch, 2006).

Feedback on the use of models as policy support tools for stakeholders – in particular decision-makers – is another important issue in land cover change modelling (Verburg and Veldkamp, 2001) and participatory river basin management (Welp, 2001). The paper is organised as follows: The methodology is presented in Section 2 with the use of the hydrological and economic modelling. This modelling framework is then applied to a small catchment in southwest France for some agro-environmental measures dealing mainly with changes of agricultural practices (Section 3). Models put in place are presented in Section 4 for cost calculation (4.1) and effectiveness assessment (4.2). Results are reported in Section 5 for effectiveness (5.1), cost assessment (5.2) and CEA (5.3). We finally discuss the potential benefits of the proposed framework in Section 6, which is followed by a conclusion.

2. Modelling framework

Because the marginal costs of mitigation measures are not equal (between measures and for a same measure between locations where it is implemented), it is theoretically possible to obtain the same level of water pollution reduction at lower cost by shifting from high-cost measures to lower-cost measures (Brouwer and De Blois, 2008) and from one place to another.

Furthermore, the effectiveness of remediation measures can be assessed with regard to intermediate goals (reduction of pressure) by the use of indicators. However, for final goals (impacts) models need to be used. Given that the objectives laid down in the WFD call for water bodies to be returned to "good" ecological status by for 2015, impacts need to be evaluated. Hydrological modelling, which has been used for several decades in the evaluation of Non-Point Source (NPS) pollution, is an effective means of assessing the short and long-term impacts of agro-environmental measures and alternative practices.

Although models always depend on the assumptions and priorities of their creators (Alkan Olsson and Anderson, 2007), it is generally assumed that results obtained through them are an objective source of information that can be used to support decisions.

Many studies report on the integration of ecological and economic assessment methods for policy analysis, or as decision support system (DSS). For example, a spatial DSS has been developed by Volk (Volk et al., 2008) to help in the implementation of the WFD. A linear programming model is used to optimise agricultural production programmes under different management scenarios and costs are estimated from the loss in total gross margin. However, economic assessment methods frequently use econometric approaches in assessing agricultural conservation practices: Antle (Antle and Capalbo, 2001) developed empirical economic models for use in integrated assessment research. Wu (Wu et al., 2004) linked econometric estimates based on micro level data with environmental production functions to assess the economical and environmental effect of "green payment" incentives for environmentally friendly land use. Fine-scale spatial data is also used by Fezzi (Fezzi and Bateman, 2011) in developing a spatially disaggregated econometric model of agricultural land use and production for agro-environmental policy appraisal. The econometric approach is used also by Fezzi (Fezzi et al., 2010) to estimate costs of WFD-related measures. Cost estimates are based on the estimated changes in the gross profit margins of a large data set of farms. Prediction of the water quality changes made from a hydrological model allows measures to be compared based on their cost-effectiveness. Langpap (Langpap et al., 2008) combined an econometric model of land use choice with watershed health indicator models to analyse the effects of targeted land use policies. Such approaches can allow refined spatial scale analysis by capturing spatial heterogeneity in land use and agricultural practices. Another advantage is that econometric models automatically provide measures of uncertainty derived directly from statistical inference rather than requiring sensitivity analysis.

Although econometrics is effective in overcoming specific relationships, data availability remains a real obstacle to such approaches. Mathematical programming works best in incorporating elements for which empirical evidence is still missing.

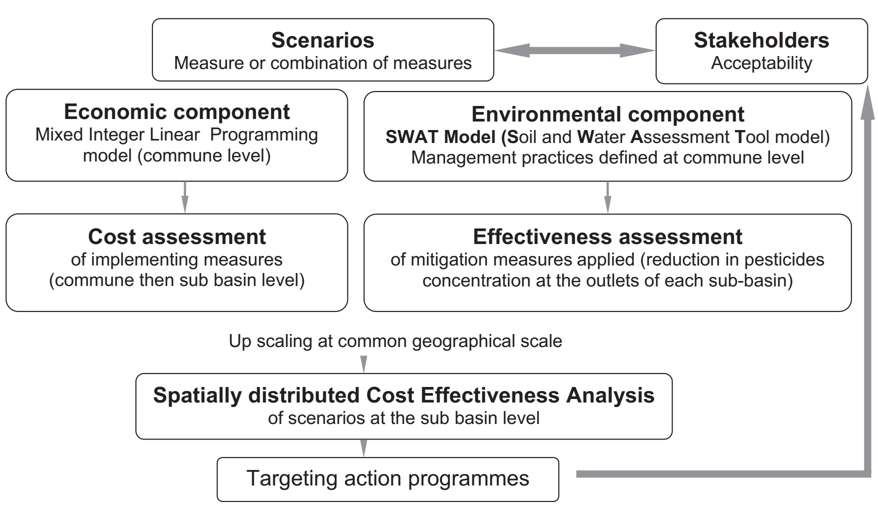

Fig. 1. Cost-effectiveness analysis framework.