Ecological Economics 134 (2017) 11–21

Contents lists available at ScienceDirect

Ecological Economics

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

Analysis

Transferability of Policies to Control Agricultural Nonpoint Pollution in Relatively Similar Catchments

Ashar Aftab [a,*], Nick Hanley [b], Giovanni Baiocchi [c]

[a] Durham Business School, Mill Hill Lane, Durham DH1 3LB, United Kingdom
[b] School of Geography & Geosciences, Sustainable Development, Irvine Building, St Andrews, United Kingdom
[c] Department of Geographical Sciences, University of Maryland, 2181, Samuel J. LeFrak Hall, 7251 Preinkert Drive, College Park, MD 20742, USA

ARTICLE INFO

Article history:
Received 22 April 2016
Received in revised form 11 October 2016
Accepted 2 November 2016
Available online 10 January 2017

ABSTRACT

The EU's WFD requires cost-effective compliance with good ecological and chemical status across EU surface waters. Previous studies have modelled single catchments or been limited by their realism when investigating multiple catchments. We investigate whether the cost-effectiveness ranking of policy instruments to control agricultural nonpoint nitrate pollution (NP) is consistent across two relatively similar catchments. Transferability may interest regulators seeking to identify policies implementable in relatively similar catchments, rather than setting high transaction cost catchment specific policies. Detailed nonlinear stochastic biophysical economic optimisation models of two catchments are constructed. We estimate the distribution of daily river pollution for 10 years in each catchment without assuming an underlying pollutant distribution that is likely to distort policy ranking. We report consistency of policy rankings and outperformance in distinct regulatory target ranges in both catchments as well as pollution swapping. The transferability evidence may not be as robust as policymakers would like. Mixed instruments are cost-effective at higher regulatory targets and display characteristics suited to uniform application across catchments. Our study would benefit from improved modelling of farming heterogeneity, groundwater hydrology and policy transaction costs. Further research is required to identify catchment characteristics that determine transferability across a broader set of catchments.

1. Introduction

The EU's Water Framework Directive (WFD) (2000/60) requires cost-effective compliance with good ecological and good chemical status (GECS) across all EU surface waters. Several key principles underlie the Directive's aims including the polluter pays principle and the management of rivers on a river basin basis. In Scotland's rivers diffuse nutrient pollution from agriculture is the single most important pollution pressure (SEPA, 2007) since 24.3% of all rivers and 45% of estuaries fail to meet WFD targets due to such pollution (SEPA, 2005). In this paper, we estimate the cost-effectiveness of policies to control agricultural nonpoint nitrate pollution (NP) in two relatively similar mixed farming Scottish catchments with a diffuse nitrate pollution problem, the Motray and Brothock.

At present a variety of policy mechanisms to achieve GECS are being assessed by UK regulators. Since cost-effectiveness is a WFD criteria and there is evidence of the cost-effectiveness of economic instruments in the literature (see below), regulators have considered the role economic instruments can play (NERA, 2006). However, concerns exist over the environmental effectiveness, transactions costs and political acceptability of economic instruments to reduce nutrient pollution. Thus presently, regulators have employed a range of managerial controls (regulatory codes of good practice, general binding rules, best management practices etc.), including limits on fertiliser applications and timings, limitations on stocking rates etc. (under various cross-compliance schemes).

There is a growing consensus among UK policy makers/regulators[1] (DEFRA, EA and SEPA) and catchment stakeholders (rivers trusts, farmers' unions etc.) that a one size fits all agricultural diffuse pollution policy for catchments characterised by different agricultural systems, weather patterns etc. is inappropriate and cost-ineffective. However, unfortunately the high transaction costs of formulating and enforcing catchment specific policies may also be arguably prohibitively expensive. Thus recent and ongoing research in the UK[2] has focused on identifying cost-effective policies that can be applied to similar catchments, i.e. with similar agricultural systems, weather patterns and hydrogeology.

Economists have undertaken numerous single catchment studies to assess the cost-effectiveness of instruments to control NP. Yet, for

* Corresponding author.
E-mail addresses: Ashar.Aftab@Durham.ac.uk (A. Aftab), ndh3@st-andrews.ac.uk, baiocchi@umd.edu (N. Hanley).

[1] Department for Environment, Food & Rural Affairs (DEFRA), Environment Agency (EA) and Scottish Environment Protection Agency (SEPA).
[2] e.g. DEFRA's Demonstration Test Catchment research platform.

http://dx.doi.org/10.1016/j.ecolecon.2016.11.004
0921-8009/

practicality and wider consistency, regulators are looking for cost-effective policies that are in general consistently efficient across relatively similar water bodies.[3] We investigate the characteristics and consistency of policies, in particular mixed instruments, to control NP in two relatively similar catchments. The transferability of cost-effective policy instrument rankings across catchments is not something economists have addressed conclusively as previous cross catchment studies have been limited by their realism, modelling assumptions, simulated regulatory policies and/or ability to model farmer's response to them.

Moreover, cost-effective instrument ranking has not always been consistent in the empirical literature. This inconsistency could be attributed to differences in biophysical economic modelling sophistication, realism, assumptions (scale, resolution, fate, transport and hydrological modelling, heterogeneity, soil dynamics, livestock management, crop rotations, input substitution, transformation of regulatory concentration standards into load (mass) equivalents, farmer's behavioural response options etc.), economic incentives (prices, subsidies etc.), regulatory restrictions, geophysical catchment characteristics (Martinez and Albiac, 2004), and/or importantly the catchment weather patterns that drive the stochastic NP processes etc. In considering the stochastic nature of NP studies have made different distributional assumptions in estimating deterministic equivalents in chance-constrained optimisation models. Such differences affect the cost-effectiveness of regulatory instruments and render a comparison of NP policies in separate studies inappropriate, e.g. it is not meaningful to compare results of a study in semi-arid Spain (Martinez and Albiac, 2004) or California (Larson et al., 1996) with a high rainfall UK catchment (Kampas and White, 2004). Thus, in this research the modelling, assumptions and policy options were kept consistent enough to compare two separate catchments that differ in terms of scale, soils, crop rotations, arable to grassland ratio, agricultural activities, diffuse pollution levels, and importantly weather – but not drastically. Thereby allowing a meaningful comparison to help identify consistently cost-effective instruments across two relatively similar[4] catchments.

By using nonlinear stochastic biophysical economic modelling this paper 1) examines the cost-effectiveness and transferability of policies to control NP in two relatively similar catchments based on estimates of daily river concentration (mg/L) for 10 continuous years; 2) accounts for physical mixing, retention and lags in the diffuse pollutant transport process without assuming an underlying pollutant distribution - which is likely to distort instrument cost-effectiveness; 3) investigates the characteristics of mixed instruments (MI), comprising of economic instruments and managerial/regulatory controls, that make them more suited to being applied across catchments; and; 5) estimates pollution swapping (or substitution) of catchment phosphorus (P) and potassium (K) consumption from implementing policies to control NP. This is important as farmer's response to regulation may have unintended consequences and actually prevent attainting GECS.

2. Previous Work

Past research on the economics of NP control has largely focused on single instrument policies and concluded that economic instruments are generally cost-efficient under a range of restrictive conditions (Balana et al., 2011; Shortle and Horan, 2001; Weersink et al., 1998). Previous studies have also detailed the efficiency gains of using policies that combine two or more economic incentives to control NP. However, in practice the information, monitoring and enforcement transaction costs of such policies have prevented their uptake. One study reported the superiority of MI in 'wet weather' conditions and improvements in their relative cost-effectiveness at higher regulatory targets (RT) under 'mean weather' (Aftab et al., 2010). These results were based on weekly averages of NP for just one representative 'wet' and 'mean' year's weather, which may not realistically capture the stochastic nature of NP over time. This paper improves on these limitations and uses more realistic modelling assumptions to determine whether the cost-effectiveness of MI and other policies across relatively similar catchments is consistent and thus more broadly implementable.

Previous large-scale studies have provided valuable insights and modelled catchments by using either an econometric or applied general equilibrium approach. However, both approaches have their limitations. Econometric studies have been limited by: extremely broad classifications of land use incapable of differentiating between crops, grassland, livestock or set aside etc. (Langpap et al., 2008); unrealistically large land units of assessment (Wu et al., 2004); not permitting land use to change in response to policies (Fezzi et al., 2010). While an applied general equilibrium approach requires numerous simplifying assumptions, such as arbitrarily converting the loads of different pollutants into one generic nutrient unit (Brouwer et al., 2008). A few cross catchment comparison studies have used a biophysical economic modelling approach. These have been limited by: the absence of livestock and manure management (Brady, 2003); a simple linear economic model and infeasible high transaction costs policies (Volk et al., 2008); very small study areas as well as the assumption that livestock types and amounts remain constant (Vatn et al., 1997).[5] More importantly, these studies estimate average pollutant loads[6] and do not consider pollutant concentration, river mixing and the probability of achieving a concentration standard with a specific certainty as well as its impact on the cost-effectiveness of policies. Most assume an arbitrary average annual load reduction equates to compliance with an environmental concentration standard. Pollutant loads are not necessarily reliable proxies for concentration and environmental impact. There is a trade-off between the complexity/realism and the scale of modelling (Brady, 2003). Generally, an econometric approach is restrictive in: capturing diffuse pollution processes; the type of policies that can be simulated and the ability to model farmers' behavioural response to policies. Whereas landscape scale biophysical economic approach is more interdisciplinary, data intensive and, as discussed earlier, involves assumptions that can vary across studies and affect the cost-effective rankings of policies.

Most of the diffuse water pollution chance constrained (stochastic), biophysical economic literature (Elofsson, 2003; Milon, 1987) involves imposing a deterministic equivalent on the optimisation problem by assuming that the distribution of pollution estimates are normal (Gren et al., 2000), log-normal (Kampas and White, 2004) or truncated normal (Kataria et al., 2009). The normality assumption is motivated by the central limit theorem, i.e., the statistics of sample loads will asymptotically converge to a normal distribution, while the log-normality[7] and truncated normal assumption is justified by the need to avoid the possibility of negative pollution loads. Alternatively, a distribution-free approach uses the Chebyshev's inequality to approximate the probabilistic constraint (Wets, 1983). The literature is inconclusive and often contradictory as to which distribution should be used. Besides probabilistic programming models are sensitive to such distributional assumptions (Gren et al., 2002; Kampas and White, 2004; Xu et al., 1996; Zhu et al., 1994). More recent research has estimated that the

[3] The high transaction costs/political acceptability of tailoring policies to individual catchments necessitate this. Moreover, in practice operational EU "river-basin areas" can be considerably larger, e.g. Scotland comprises of only two river-basin (Scottish-Government, 2015).

[4] Identifying a set of relatively similar catchment characteristics that ensure the cost-effective transferability of policies is beyond the scope of this study. This would require an assumptions/methodologically consistent analysis of numerously more catchments with different characteristics.

[5] It compares annual pollutant loads in two catchments with a combined area of 4313 ha.

[6] Although Volk et al. estimate the concentration of total N they do not report how the stochastic variation impacts on the cost-effectiveness of policies (Volk et al., 2008).

[7] A 'theory of successive random dilutions' attempts to explain how lognormal distributions may arise from physical processes responsible for generating pollutant concentrations in the environment (Ott, 1990). However, more recent work by the US EPA has confirmed that such environmental datasets are not necessarily lognormally distributed (Simon, 2014).