Agricultural Water Management 132 (2014) 79–88

Contents lists available at ScienceDirect

Agricultural Water Management

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

Implications of fairness for the design of nitrate leaching policy for heterogeneous New Zealand dairy farms

Luke M. Holland[a], Graeme J. Doole[a,b,*]

[a] Department of Economics, Waikato Management School, University of Waikato, Private Bag 3105, Hamilton, New Zealand
[b] Centre for Environmental Economics and Policy, School of Agricultural and Resource Economics, Faculty of Natural and Agricultural Sciences, University of Western Australia, 35 Stirling Highway, Crawley, Western Australia 6009, Australia

ARTICLE INFO

Article history:
Received 22 April 2013
Accepted 12 October 2013
Available online 8 November 2013

Keywords:
Abatement cost
Environmental policy
nonpoint pollution

ABSTRACT

The implementation of environmental policy may be eased when perceived outcomes are fair. The primary objective of this study is to investigate how the consideration of fairness in policy design affects the cost-effectiveness of instruments aimed at reducing nitrate leaching from heterogeneous dairy farms in New Zealand. The cost-effectiveness of each policy is compared across different levels of leaching restriction and the number of regulated farms. The cost-effectiveness of fair policy alternatives, relative to the least cost outcome, is extremely variable. Accordingly, there is no one fair policy that is the most cost-effective in any situation. Nonetheless, uniform policies that require an equivalent proportional reduction in baseline leaching load or an equivalent absolute level of mitigation are optimal, or close to it, across all simulated levels of N reduction. The implementation of such policies is promoted by their pragmatism, as baseline N loads and the associated abatement levels can be estimated through biophysical modelling. The suitability of fair policies for environmental protection is promoted by an inverse relationship between the amount of N that must be abated and the Cost of Fairness. In contrast to previous theoretical work, this empirical analysis also shows that the cost of a fair policy, relative to a differentiated policy, need not increase as the number of agents affected by a policy rises.

1. Introduction

Declining water quality is increasingly being acknowledged as a major factor in the global water crisis (UNEP, 2012; Li et al., 2013). Indeed, many New Zealand water bodies are at threat of eutrophication due to nitrogen leaching from pastoral agriculture, with algal blooms becoming more prevalent and causing a reduction in water resource value (Marsh, 2012). This is of increasing concern due to the impact of low water quality on several important economic sectors that rely on this resource, including recreational uses, crop and orchard irrigation, and drinking water. Non-point source pollution from agricultural activity is the greatest cause of deterioration in water quality in agricultural lands (Zhang et al., 2011). In New Zealand, it is widely accepted that the dairy industry produces the greatest annual load of nitrogen (N) per ha of this nation's pastoral enterprises (Monaghan et al., 2007; Doole, 2010). Accordingly, there is a growing consensus that this industry should play a major role in reducing the environmental impact of pastoral farming on water quality in this country (Jay, 2007).

The soils found within New Zealand dairy systems can only absorb a certain amount of N, particularly as many ryegrass pastures are already supported by N-fixing clovers. Around 95% of leached N comes from cow urine patches, which contain the equivalent of 1 t N ha^{-1} and are distributed on around 25% of paddock area each year (Di and Cameron, 2002). A large proportion of this N leaches into groundwater, and subsequently surface water, during wet weather when soil N exceeds those levels required by plants (Gibbs et al., 2011). Once in the aquatic environment, bioavailable N allows the mass growth of algal cells, potentially causing large algal blooms (Marsh, 2012). These blooms form unsightly green or red floating masses, and often produce chemical toxins that can kill fish and harm people. These mats can also reduce the oxygen levels found in a stream or lake, resulting in an unsuitable habitat for many types of fish and native organisms (Gibbs et al., 2011).

The cost effectiveness of alternative instruments that could help attain reduced leaching, and hence improved water quality, is of primary concern. Key studies have indicated that the cost of a differentiated policy, one in which producers can trade entitlements to leach a given level of N, is lower than that of a policy that does not allow spatial variation in mitigation according to differences in abatement cost. Doole and Pannell (2012) studied a catchment

* Corresponding author at: Department of Economics, Waikato Management School, University of Waikato, Private Bag 3105, Hamilton, New Zealand.
Tel.: +64 7 838 4134; fax: +64 7 838 4063.
E-mail address: gdoole@waikato.ac.nz (G.J. Doole).

0378-3774/$ – see front matter © 2013 Elsevier B.V. All rights reserved.
http://dx.doi.org/10.1016/j.agwat.2013.10.008

of around 61,650 ha, consisting of around 498 farms. The total profit within the catchment prior to regulation was approximately $NZ82.5 m. Doole and Pannell (2012) found that a differentiated policy in which leaching entitlements were traded could be 15% less costly for a 30% N reduction or 9% less costly for a 50% N reduction, relative to a uniform restriction in which all farmers must reduce their pollutant load by an equivalent proportion. The differentiated policy incurred a reduction in profit of 4% and 14% to achieve the 30% N and 50% N reduction, respectively. In contrast, the uniform policy incurred a reduction in profit of 5% and 16% to achieve the 30% N and 50% N reduction, respectively. Moreover, these authors found that using a representative farm approach—the use of a hypothetical, average farm to represent a cluster of actual farms—in policy evaluation can underestimate abatement costs; thus, highlighting the importance of multi-agent models for policy analysis. In comparison, Doole (2012) studied a catchment of around 50,156 ha, consisting of around 410 farms. The total profit within the catchment prior to regulation was around $NZ70.4 m. Doole (2012) identified that a 30% N reduction would cost approximately $3.52 m (5%) and $2.1 m (3%) for a uniform and differentiated policy, respectively, whereas a 50% N reduction would cost around $14.08 m (20%) and $12.67 m (18%) for a uniform and differentiated policy, respectively. The magnitude of the percentage reductions in farm profit indicates the extent to which such policies could be expected to harm agriculture. However, the impact of these costs on the regional economies will be magnified through multiplier effects also, particularly given the importance of dairy production in this area (NZIER, 2010).

Alongside their cost implications, concern has been expressed by the dairy industry that the analysis of these policies has not considered their broad implications for the income distributions of farmers (Howard et al., 2013). Rather, the focus has been on economic efficiency, as assessed at the societal level. A proactive focus on policy design that accounts for a fair distribution of entitlements among farmers is particularly important, as recent analysis indicates that the allocation of N leaching allowances has strong implications for the viability of New Zealand dairy farms (Howard et al., 2013). The distributional effects of environmental policy on the New Zealand dairy industry is significant because this industry is responsible for around 3% of New Zealand's Gross Domestic Product, producing approximately a quarter of total merchandise exports as the country's largest exporter (NZIER, 2010).

Fairness and equity are generally used interchangeably in the literature, although equity is often referred to as a form of justice (Pascual et al., 2010). Thus, the broad term "fairness" is used throughout this paper. Fairness is used here to denote a broad notion that the policy design accounts for some effort to standardise the allocation of rights to pollute among farmers. The ambiguity surrounding this concept has led to the long-term development of numerous notions of fairness and equity (Butler and Williams, 2002). Accordingly, this paper does not state a single, preferred definition of fairness. Rather, four alternative ways of viewing fairness are evaluated, relative to each other and a differentiated policy in which firms can trade nutrient entitlements (see Section 2.2 for more details). The differentiated policy is consistent with classical utilitarianism, which aims to maximise total utility and omits concerns regarding the distribution of individual utilities (Mill, 1906).

Classical utilitarianism is consistent with the identification of policies that satisfy an environmental goal at least cost (Doole, 2010; Bertsimas et al., 2011). However, fair policies need not be least-cost policies, and so realistically can be expected to reduce efficiency, relative to the utilitarian outcome. The inefficiency of fair policies generally increases with the number of agents involved (Bertsimas et al., 2011). This has interesting implications for non-point policy evaluation, given that the number of agents in a policy setting can be large and the costs associated with an efficient differentiated policy are decreasing with increasing inter-firm heterogeneity (Newell and Stavins, 2003; Doole and Pannell, 2012). Oftentimes, policies for reducing pollution will require a trade-off between economic efficiency and equity. Even if net benefits are positive at an aggregate level, some individuals may still find themselves worse off after the trade-off and may consequently require compensation, depending on the policy and fairness notions used (Doole, 2010). In contrast, under some circumstances, the consideration of fairness in policy may not incur a cost at all (Smith, 1994; Butler and Williams, 2002). Indeed, Caplan and Silva (2007) identified that equity and efficiency can actually be complementary, in the context of decreasing point-source pollution. Nevertheless, efficiency and fairness will generally be opposed, as the latter involves the addition of constraints to a utilitarian (least cost) configuration which, according to optimisation theory (Bazaraa et al., 2006), cannot increase efficiency.

The primary objective of this study is to investigate how the consideration of fairness in policy design affects the cost-effectiveness of instruments aimed at reducing nitrate leaching from heterogeneous Waikato dairy farms. The Waikato region is the fourth-largest region in New Zealand and covers approximately 25,000 km^2 of the central North Island. It is also the primary dairy farming region in New Zealand, containing 25% of the nation's dairy cows and 30% of the nation's dairy herds (LIC, 2013).

A non-linear optimisation model (Bazaraa et al., 2006) is developed and applied to investigate this issue. The cost-effectiveness of five policy instruments is assessed for catchments of different sizes to ascertain the impact of fairness criteria and the number of farms involved on the relative suitability of these alternative mitigation policies. Abatement cost curves used in the model were computed for individual farms within a catchment of the Waikato River in Doole (2012). These curves are used given that they allow unique insight into the distributional effects of environmental policy at an individual level, particularly given their description of substantial heterogeneity among farmers. The relative fairness of each policy is ascertained using a Cost of Fairness—a parsimonious measure that concisely represents the difference in cost-effectiveness between a fair policy and the utilitarian outcome. This metric follows that developed for the comparison of policies in Bertsimas et al. (2011).

Catchment-level analysis is an appropriate means to study non-point pollution management, as these problems typically involve the degradation of a water resource receiving the nutrient outflows of multiple farmers (Shortle and Horan, 2001). Catchment models are also beneficial in that they integrate complex information from multiple sources, both biophysical and economic, but can be constrained by structural and parametric uncertainty (Cherry et al., 2008; Nordblom et al., 2010). Accordingly, a number of modelling formulations have been developed that explicitly address the inability of such models to deal with uncertainty (e.g. Zhang et al., 2011; Li et al., 2013). However, despite these developments, most models typically do not represent the abatement cost curves of individual producers. Nonpoint pollution problems in agriculture are characterised by nonpoint pollution arising from multiple farmers, for whom the cost of abatement is broadly divergent (Shortle and Horan, 2001; Newell and Stavins, 2003). However, only a handful of recent studies consider heterogeneity in abatement cost among a realistic number of farms. Doole (2010) combined 100 detailed farm-level models to identify cost-effective means to reduce N leaching through input standards. Doole (2012) extended this analysis, through estimating individual abatement cost curves for around 410 farms, and integrating them within a framework that aimed to reach a certain abatement level at least cost. There is a dearth of analysis pertaining to the implications of environmental policy for fairness among individual agents, as this requires the representation of diverse abatement cost functions across actors. Employing the Doole (2012) framework allows this constraint to