Integrated Regulation of Nonpoint Pollution: Combining Managerial Controls and Economic Instruments under Multiple Environmental Targets

Abstract

Regulators are often reluctant to rely solely on economic incentives to achieve environmental standards. We evaluate a "mixed approach" of economic instruments and management standards when two environmental objectives need to be met simultaneously: minimum river flow rates and reductions in nitrate pollution. We show how the relative efficiency of such mixed approaches can depend on exogenous factors, in this case weather conditions. Results indicate that mixed instruments outperform stand-alone economic incentives or managerial controls under wet weather conditions, but not in 'average' years. However, the relative cost-effectiveness of mixed approaches increases considerably at higher levels of environmental standard compliance.

Keywords: diffuse water pollution; environmental regulation; minimum river flow; mixed instruments; nonpoint pollution

1. Introduction

Regulators have proved reluctant to use economic instruments as "stand alone" methods to address environmental problems, despite the strong case in favour of economic incentives made by economists over the last 30 years (Hahn 2000). Indeed, evidence shows that economic instruments still account for the minority of environmental measures employed within the OECD, although their use is increasing (OECD 1997; NCEE 2004). It can be argued this reluctance is due to the political economy of environmental regulation - for example, regulators may consider criteria other than economic efficiency[1] as more important when designing policies to regulate an environmental externality. This is the case for both point and nonpoint source pollution (NPP), with multiple decision criteria and worries over the shortcomings of economic instruments combining to restrict the up-take of such policies (Hanley et al. 1990). Moreover, economists have identified circumstances when a combination of measures – such as a tax combined with regulation – are better suited to achieve regulatory outcomes, for example in the case of stochastic pollutants (Baumol et al. 1988) and when both the mean and variance of pollutant concentration is of concern (Braden et al. 1993). Studying the effects of combining economic instruments with managerial or regulatory measures may thus be more relevant than the traditional simple comparison of economic instruments with regulation.

An important new policy context is the European Union's Water Framework Directive (WFD) (EU 2000). The WFD sets the target of 'Good Ecological Status' in surface waters throughout Europe. In some catchments this implies the joint imposition of minimum river flow restrictions (water quantity) and ambient pollutant standards (water

[1] Other criteria may include equity (distributional impacts), certainty of regulatory compliance, ancillary environmental benefits, simplicity, enforcement costs, political acceptability or perceived fairness. This is not to imply that economic instruments alone are necessarily most efficient, or cannot be perceived as fair or politically acceptable.

quality). A wider use of economic instruments is called for in the Directive, although not to the exclusion of managerial or direct regulatory approaches, whilst great stress is placed on cost-effectiveness of pollution control measures. Since the measurement of Good Ecological Status depends on a number of parameters, including nutrient status, biological oxygen demand and flow rates, then regulators are faced with the problem of achieving multiple environmental targets simultaneously (DEFRA 2007). This is an interesting context in which to assess the relative benefits of single versus combined instruments for environmental management, particularly since the processes which regulators are trying to manage are inherently stochastic.

In this paper, we develop a multi-farm catchment model which estimates the cost of improving water quality, where water quality depends both on diffuse-source nitrate pollution and river flows for a case study catchment in Scotland through combinations of management measures and economic instruments. The paper builds on Aftab et al. (2007)[2] and is more realistic in capturing multi-agent farm level heterogeneity. Both flow rates and nitrate levels are linked to agricultural land use, the former through irrigation. The 4,346 ha West Peffer catchment suffers from low flow problems in summer due to high rates of abstraction for potato farming and is presently subject to direct abstraction controls[3], and has N levels in breach of the EU guideline standard of 11.3 mg/l N. Diffuse nitrogen pollution, which can result in eutrophication, contamination of potable water and acidification, is a widely acknowledged problem in Scotland (Darcy et al. 2000). High rates of surface water extraction can lead to periods of unusually low river flows, adversely affecting

[2] Aftab et al. (2007) quantifies the increase in social welfare from co-ordinating policies to maintain river flows and nonpoint nitrate pollution and the conditions under which it is beneficial.

[3] The regulator stops abstractions through licence suspension when river flow falls to the 95%ile (or minimum acceptable flow) at specific gauging points.

river ecology and amenity values (Hanley *et al*, 2006). Responding to these two problems is likely to be best achieved by an integrated approach to catchment management: indeed, that is exactly what the WFD mandates for all catchments throughout the EU.

Previous work on the economics of agricultural NPP control has largely focussed on this problem in hydrological isolation. Economic instruments are known to be relatively cost-efficient way of reducing ambient nitrate levels under a range of restrictive conditions (Shortle et al. 2001). Numerous authors have previously considered the use of mixed approaches or policy 'packages': combining input taxes and a liability rule (Braden et al. 1993); input and ambient taxes (Horan et al. 1998); emission and ambient taxes (Xepapadeas 1995); emission and output tax (Schmutzler 1996); *ex post* negligence liability and *ex ante* pigouvian taxation (Kolstad et al. 1990); land use tax with an input tax (Goetz et al. 2006); and combining a subsidy/tax with marketable licences (Roberts et al. 1976). These studies report efficiency gains from the use of mixed instruments. However, although some studies have considered spatially untargeted land retirement (setaside) to reduce NPP from agriculture (Ribaudo et al. 1994) the literature has not considered the integration of direct regulation or managerial approaches, such as setaside and stocking density reduction, with economic instruments. Likewise, although there are studies investigating the joint control of both water and nitrogen as inputs (Weinberg et al. 1993; Helfand et al. 1995; Larson et al. 1996; Albiac et al. 2001), only one study to date has reported on the efficiency properties of economic instruments in the presence of river flow controls (Aftab et al. 2007).

Previous work has established that the variability in NPP generation requires combining instruments that apply to specific moments of the pollution distribution to ensure efficiency[4] (Braden et al. 1993). Baumol and Oates, in their classic text propose Mixed Instruments (MI) combining economic instruments and discretionary 'direct' controls when regulating stochastic point source emissions[5] (Baumol et al. 1988). Obviously, this is only possible with certain point source pollutants - the possibility of using direct control during a high pollution episode to control NPP is not feasible. The question thus remains as to which are the most cost effective instruments to combine, given the problems of implementing diffuse pollution controls. The main contribution of this paper to the literature is thus conceptual: in the context of NPP from agriculture and multiple environmental targets, is it better to use a combination of economic incentives and managerial measures, rather than economic incentives alone? This MI approach is relevant to the policy debate since the iterative approach to developing environmental policy which dominates OECD countries does not favour 'drastic' changes in policy choice e.g. from regulation only to economic instruments only. Efficiency requires regulation of NPP emissions at both the intensive and extensive margin (Shortle et al. 1998; Goetz et al. 2006). Moreover, the inclusion of transaction costs might make it cost effective to restrict the pollution reduction contribution from the extensive margin using managerial controls, such as setaside, in a MI setting. Weather variability turns out to be important in determining whether a MI approach is more cost-effective than using stand alone economic incentives. We use the same data set on which Aftab et al (2007) is based to investigate the efficiency gains from MI. However the focus of the paper is not on specific empirical results; but rather the conceptual contribution in a policy context.

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[4] Unless emissions mean and variance are correlated a single instrument will not ensure social optimality.

[5] "...we may realise the best of both worlds by taking advantage of the efficiency properties of tax measures in normal circumstances and invoking direct controls to copy with temporary periods of accentuated environmental deterioration" (Baumol et al. 1988).

2. Model Construction

The bio-physical-economic model improves on a previous model in the literature (Aftab et al. 2007) and differs in that the catchment is modelled as 4 separate profit maximising farms (f1 – f4). The 4 farms are hypothetical, as individual farm data is not made available due to confidentiality concerns, and represent variability in farm characteristics across the catchment. The farms differ in terms of 1) acreage, 2) proportion of 3 soil textures (hence crop mix and rotation), and 3) livestock production capacity[6]. The differences between the 4 farms serve as a proxy for catchment heterogeneity (Wossink et al. 2001) in terms of farming knowledge/experience, spatial characteristics, preferences and capital/infrastructure considerations.

Four major arable crops (winter wheat, spring barely, winter oilseed rape, and potatoes), livestock production (dairy, sheep, lowland suckler and intensive beef), permanent grazing grass and silage production were modelled. Farms also had the option to purchase silage from the market. Catchment agronomic practices and parameters, crop rotations and the existing baseline scenario were taken from the literature and catchment level farm survey data. Farm subsidies for both arable cultivation and livestock (SOAEFD 1997) were included. The farmer's decision to apply nitrogen depends on crop production functions for each crop (separate for each soil type) and profitability. The model was calibrated to the 1997/98 price level (SAC 1997). Potatoes were assumed to be the only irrigated crop (they account for 85% of irrigated catchment land in reality) and the cost of irrigation per hectare was incorporated.

[6] Of the total catchment area 20% is categorised sandy, 16.8% as silty and 63% as loamy. The four farms make up 15%, 30%, 34.6% and 20.4% of total catchment acreage; and 15%, 0%, 60% and 25% of baseline catchment livestock at a stocking density of 2 LU/ha.

The model determines the most profitable land and nitrogen allocation to each farm activity. Livestock waste is accounted for as a source of nitrate and is a substitute for artificial fertiliser on both types of modelled grassland. The model uses separate leaching functions to estimate the weekly average leaching for 3 'stylised' years (dry, mean and wet[7]) based on the actual weather in the 1989-98 period. Leaching functions were derived by regressing the output of NITCAT (Lord 1992) for each crop/soil combination within a reasonable range of nitrogen applications. The IRRIGUIDE model (Bailey et al. 1996) was used to give crop-dependent weekly values of evapo-transpiration over winter; while elution was modelled using the SLIMMER algorithm (Anthony et al. 1996). Grass land leaching was estimated using NCYCLE (Scholefield et al. 1991; Lockyer et al. 1995). Here, leaching refers to the nitrogen not taken up by the plant which drains to the sub soil water. Some is lost to groundwater, while most drains to the river. The model assumes the nitrogen leachate moves via drains to the river instantaneously. This enables relatively accurate approximation of diffuse nitrogen pollution levels for every week.

In Eastern Scotland, irrigation contributes to potato yield and quality. The West Peffer catchment is extensively used for surface water extraction and is presently subject to controls whereby abstraction licences are suspended when river flow falls to the 95th percentile (MAF) one-day flow at specific gauging points (Crabtree et al. 2000). The 95th percentile flow defines a flow exceeded naturally on 95% of days in a 'average' year (1989 – 1998 period) during which no abstraction took place. The DIY hydrological model was used to estimate naturalised flows (Dunn 1998) and the water available for potato irrigation before the 90th, 95th and 98th percentile MAF target was breached (the 90th percentile

[7] The mean weather scenario was based on the average weather data in the period, whereas the wet weather referred to the wettest in this period. The use of wet and mean 'weather' or 'weather conditions' refer to the wet and mean *weather year* in this period respectively.

imposes the greatest restriction on irrigation extraction while 98th percentile imposes the smallest[8]). The absence of any river flow restriction was also considered. The temporal distribution of available water was then inputted to a potato growth model. It was assumed the farmer could subject his potato crop to 3 separate levels of irrigation: optimal, restricted and no irrigation. Separate nitrogen potato production functions under 4 river flow restrictions, 3 irrigation regimes and 3 weather conditions were then approximated (Crabtree et al. 2000).

3. Economic Modelling of Control Policies

The entire bio-physical economic model is summarised in figure 1. The non-linear optimization model was written in GAMS (Brooke et al. 1998) and solved using the CONOPT II solver (Stolbjerg-Drud 1993) and confirmed by the MINOS 5 solver. The catchment is modelled as four economic decision makers (f) who are assumed to maximise individual farm profits $(\Pi_f^{\varpi r})$ by endogenously determining land and N fertiliser allocation to productive activities[9] on each soil type. The regulator's objective is to minimise the difference between the unrestricted catchment profit $\left(\sum_f \Pi_f^{\varpi r}\right)$ and the catchment profit under different pollution control policies subject to environmental constraints on minimum river flows and maximum nitrate levels[10]. The regulator's objective is:

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[8] The minimum acceptable river flow percentile seems counter intuitive, but this is a hydrological term. A 98th percentile one day flow is a less binding constraint, than the 90th percentile, as it would restrict abstraction only when flow fell to that exceeded on 98% of days.

[9] Productive activity refers to crops (including potatoes crops with different irrigation scheduling), livestock production (grassland) and setaside. Similar to previous bio-physical economic models in the economic literature.

[10] A referee thankfully pointed out that even though the model is represented as minimising farmer's abatement cost (Beavis et al. 1983; Kampas et al. 2004) , it is in effect forecasting farmer's profit maximising behaviour under different regulatory controls – a positive analysis.

(1) *Minimise* $$\sum_f \Pi_f^{\varpi r} - \sum_f \Bigg[\sum_c \sum_s \left(Y_{fcs} p_c - w^n n_{fcs} l_{fcs} \right) + \sum_i \sum_j h_{fij}^{\varpi r} p_j + \sum_b a_{fb} p_b$$

$$- w^n \left(\sum_i \eta_{fi}^{\varpi r} \lambda_{fi}^{\varpi r} - \sum_t \sum_s \mu_{fts} m_{fts} \right) - C_f + \mathrm{T}_f \Bigg]$$

where ϖ is the prevailing weather condition (dry, mean, or wet) and r is the catchment MAF restriction (no flow restriction or 98th, 95th or 90th percentile river flow restriction) enforced by the regulator. $\Pi_f^{\varpi\kappa}$ for each ϖr combination is the outcome of an unrestricted run of the model without any regulation on farm f. The catchment profit in the objective function is defined as the sum of the return to each producer's management and allocation of resources minus the cost of total farm nitrogen consumption ($\sum_c \sum_s w^n n_{fcs} l_{fcs}$ (arable crops), $w^n \sum_i \eta_{fi} \lambda_{fi}$ (potatoes), $w^n \sum_t \sum_s \mu_{fts} m_{fts}$ (silage and grazing grass)) and all other secondary costs of farming C_f. Exogenous terms in (1) include p_c the market price of arable crop c, p_j the market price of potato quality j and p_b is the market return from one livestock unit[11] (LU) of livestock type b. The number of livestock on each farm is represented by a_{fb}. w^n refers to the cost of nitrogen fertiliser, n_{fcs} and l_{fcs} is the nitrogen applied and land allocated to arable crop c (excluding potatoes and grassland) c on soil type s. m_{fts} and μ_{fts} refer respectively to land and nitrogen allocated to grassland type t (grazing and cutting). $\lambda_{fi}^{\varpi r}$ and $\eta_{fi}^{\varpi r}$ refer to land allocated and nitrogen applied to the potato crop under irrigation regime i (optimal, restricted or un-irrigated) resulting in potato yield $h_{fij}^{\varpi r}$ differentiated by quality j. T_f refers all transfer payments, positive for input and

[11] A livestock unit is defined in terms of the metabolised energy requirement. With one unit being the maintenance of a mature 625kg Friesian cow and the production of a 40-45 kg calf, and 4,500 litres of milk at 36 g/kg of butterfat and 86 g/kg s.n.f. Based on this the LU units of all livestock is calculated, e.g.: suckler cow (1 LU), ewe (0.15 LU), male cattle less than 2 years (0.6 LU), male cattle over 2 years (1 LU).

emission taxes and negative for subsides related to enforcing setaside or stocking density reductions, where relevant. Such transfer payments are not included in estimates of abatement costs (Kampas et al. 2004).

Thus, (1) estimates the social cost of regulation under different regulatory policies and weather conditions[12]. The model's baseline allocation was calibrated[13] to farm survey data on cropping and livestock intensities. The model's mean weather (no MAF restriction) base run predictions were similar to actual catchment data. The percentage deviation between the two being: -7.15% for arable crops, 4.90% for grassland, -11.79 % for set-aside land and -4.05% for catchment livestock units (LU)[14]. The model allocates slightly more land to grassland at the expense of arable land and setaside.

Depending on the most profitable land use and nitrogen input allocation, the model calculated the total nitrate emissions generated and the volume of water transporting them to the river, for different weather scenarios and MAF river flow restrictions (met via restrictions on the extraction of water for irrigation). The transaction costs of enforcing MAF river flow restrictions and NPP control policies are not included in our model and is an obvious limitation. The policy objective in all model runs was to reduce ambient nitrate concentrations below the EU 50mg NO_3^-/l (or 11.3 mg N/l) limit for a variable number of weeks while achieving various minimum river flow restrictions[15]. Nitrate concentrations vary naturally through the year due to fluctuations in rainfall and crop demands. We thus

[12] Further details of modelling can be found at: WEB ADDRESS.

[13] Calibration involved using proportional ratios and bounds, total grassland acreage was not fixed and allowed to vary to reflect changes in stocking density. Under some regulatory policy packages certain livestock constraints were relaxed to allow achieving stricter regulatory targets. In such circumstances we undertook appropriate sensitivity analysis in relaxing constraints. Standard agricultural modelling techniques were used (Barnard et al. 1973)

[14] For arable activities (grassland and setaside) percentage average deviation (PAD) = 20.58 and for livestock (LU) PAD = 10.13.

[15] MAF river flow restrictions were set independently of pollution control policy. The regulator could not resort to irrigation controls beyond those required to meet MAF river flow restrictions for the purpose of controlling NPP generation. Irrigation control by itself is not a cost effective pollution control option as only potatoes are irrigated. However the slight reduction in NPP generation due to MAF restrictions was considered in the design of pollution control regulation.

implement the nitrate standard as the number of weeks in which ambient concentrations are predicted to exceed the EU standard (a zero exceedance target is unrealistic).

A set of 'stand alone' policy options based on the literature and current policy discussions were chosen. These were: 1) estimated emission taxation 2) nitrogen input taxation (IT) (Kampas et al. 2004), 3) emission quotas, 4) nitrogen input quotas (Wu et al. 1995), 5) managerial restrictions resulting in farm livestock stocking density reduction (FSDR) and, 6) restriction on the minimum area of farm set-aside (farm land retirement - FLR[16]), since land retirement if correctly managed can be used to reduce diffuse pollution (Burt et al. 1993a; Ribaudo et al. 1994).

The main contribution of this paper, as noted earlier, is in evaluating environmental control strategies which combine economic incentives with managerial approaches – that is, in evaluating mixed instrument strategies in the presence of multiple environmental targets. Four types of mixed instrument policy packages were simulated. These were: a) FLR with IT, b) FLR with FSDR, c) FSDR and IT and d) both FLR and FSDR with IT. All policy options were considered both with and without a 90th percentile river flow restriction (the most stringent of those modelled), as illustrative of the impacts on policy choice of having multiple environmental targets, rather than a single target. All of the above control instruments were uniformly applied across the four farms (i.e. not modelled as farm specific targeted policies) and simulated as iterative runs of the model for each $\varpi\kappa$ combination. For example the catchment emission quota was incrementally decreased until the target compliance with the environmental standard was achieved. The managerial control options were also

[16] FLR was modelled both as a) a percentage of total farm area, and b) as a percentage of total arable area (winter wheat, spring barley, winter oilseed rape and FLR itself). The later measurement is used to qualify for subsides under the EU Common Agricultural Policy (CAP). In 1997/98 obligatory FLR was 5% of total arable area.

modelled as gradual increases in FLR and decreases in farm stocking density until the number of weeks the river nitrate concentration exceeded the EU standard was acceptable.

4. Results

Figures 2 and 3 represent the social cost of regulation as the percentage reduction from baseline catchment resource profit under different nitrate pollution control policies without river MAF restrictions in mean and with/without a MAF restriction in wet weather conditions respectively. A figure for mean weather conditions with MAF restrictions is not presented as it is consistent with the conclusions deduced from analysing figures 2. The nitrate standard was not breached under dry weather conditions[17]. The baseline profit under mean weather conditions without a MAF restriction was £8.91m while in the wet year it was £9.04m. The severity of nitrate controls increases when moving from left to right along the x-axis in each Figure, since this implies fewer weeks when the standard is breached[18]. Mixed instruments combining economic and managerial controls are represented by discontinuous lines (3 instrument mixes by dotted lines and 2 instrument mixes by dashed lines). The maximum pollution for each stimulated regulatory policy is represented by its starting point (left-most point).

The 8 and 4 week standard compliance ‘regulatory targets’ were arbitrarily chosen to illustrate the effect of progressively tightened regulatory targets, with the 4-week target being the tightest (see Tables 1, 2 and 3). The percentage reduction in social cost due to regulation relative to the baseline for each modelled scenario is provided in Table 1. It is interesting to note that in Table 1, both three-instrument MIs display the least variation in

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[17] In some catchments with different soils, slope, topography, weather patterns etc. the nitrate standard *maybe more* likely to be breached in dry weather conditions because less water is available for dilution. However, here the dilution factor is offset by the reduced rainfall-induced runoff and leaching under dry weather conditions.

[18] Figures 2 and 3 in order represent increasing soil profile water drainage and hence more NPP generation.

catchment resource cost across the modelled scenarios. With a stand- alone IT, catchment resource cost varies between 1.7% and 28.5% whereas for a combined FSDR(40% LU/ha) + FLR(35% ha) + IT the range is only between 14.7% and 18.2%. Although Table 2, a ranking of policies based on social resource cost, simplifies the results it masks the magnitude of social resource cost differences between policies. Uniform (estimated) emission taxation is superior to other controls (Johnson et al. 1991) and outperforms input taxation provided the emission function exhibits increasing returns to scale (Stevens 1988). There are nominal differences between nitrogen IT and nitrogen quotas - a result which is likely if heterogeneity in leaching or production functions is present (Wu 1999; Wu et al. 2001). However the cost-effective difference between the two becomes more apparent at higher regulatory targets.

Table 3, which is a comparison of instrument levels required to induce compliance under the modelled scenarios, is intuitively consistent in that instruments levels required to control pollution at the 8 week target are lower than those required for the 4 week target. Similarly the instrument levels required to achieve any target under mean weather 90th percentile MAF are lower than those required under mean weather without any MAF restriction, which in turn are lower than those required under wet weather.

4.1 Ranking under mean weather conditions

Mean weather results (Figures 2) illustrate the superiority of economic instruments when compared to stand-alone managerial approaches such as set-aside and livestock density reduction. It is interesting to note that although single instrument economic approaches generally perform better than MI policies there are exceptions. A FSDR (1.4 LU/ha) + IT mix out performs IT at the 2 week regulatory target and onwards in the mean year without any

MAF restriction. Mixed managerial policies do better than single managerial policies at higher levels of standard compliance. A combination of FSDR and FLR is more cost effective at meeting the 5 week ambient pollution standards than FLR alone. In addition the managerial combination achieves the 4 week regulatory target whereas each managerial instrument by itself does not.

The difference in cost-effectiveness between economic and managerial policies increases as the regulatory target is tightened, i.e. managerial control lines exhibit a greater negative slope. FSDR does slightly better than FLR on the whole. However the difference in social cost between the two is reduced at higher levels of standard compliance and undergoes a 'cross-over' at the 5 week regulatory target in the case without MAF (figure 2). Interestingly, both combinations of FLR (14%) + IT and the FSDR (1.4LU/ha) + IT outperform IT alone at the 4 and 2 week regulatory target respectively. These results confirm that the relative cost-effectiveness of mixed instruments improves as the regulatory target is tightened.

4.2 Ranking under wet weather conditions

Since flow rates are higher in wetter years, abstraction constraints do not affect control instruments in the wet weather scenario. However, some interesting results still emerge. Although estimated emission taxes remains the most cost effective policy in a wet year, the relative efficiency of other policies changes considerably (figure 3 and table 2). In wetter conditions, nitrogen leaching rates (emissions) are considerably higher with a leaching baseline of 18 weeks of river nitrogen levels in excess of the standard, compared to 14 weeks in the mean year (compare the baseline water quality statistics in table 4 and 5). Another notable change under wetter conditions is that economic controls targeting inputs (input taxation and quota) do not perform as well, especially at high standard compliance levels (refer to the 4 week target - figure 3). In comparison, mixed instrument policies perform considerably better in wet weather conditions. The cost effectiveness of FLR/set-aside mix policies increases as the regulatory target is tightened - consider the difference in the social costs between input taxation and FLR/set-aside mix polices at 10, 8, 6 and 4 week standard compliance target (or compare ranking in table 2). In fact from the 8 week regulatory and onwards (stricter compliance) FLR + IT mixes are second only to estimated emission taxation.

The most dramatic cost-effective ‘cross-over’ involves FLR improving relative to IT as the regulatory target is tightened. At best in figure 3 IT outperforms FLR left of the shaded zone (figure 3) at the 10 week target by 7.29%, however right of the shaded zone FLR delivers the 4 week regulatory target with an improvement of 8.05% over IT. In figure 3 the shaded zone represents the 9-5 week regulatory target zone in which 2 instrument mixes prevail over single input based instruments. Both FSDR + IT and FLR + IT combinations manage to be more efficient than IT by itself. The FLR + IT combinations dominate the stricter end of this zone. Interestingly, 3 instrument mixes comprising of FSDR + FLR + IT extend the cost-effective lead of mixed instruments over the best feasible stand alone instrument, IT. In fact 3-instrument mixes dominate the strict end of the regulatory target spectrum, i.e. from the 5 week regulatory target onwards[19].

[19] To illustrate, at the 4 week target a FSDR (40% LU/ha) + FLR (35%) + IT mix confers a catchment resource cost gain of 13.373% over IT (table 1 and figure 3). Other mixed instruments provide further efficiency gains at the more stringent end of the regulatory target spectrum. E.g. a policy mix of FLR (50%) + IT provides an efficiency gain of 10.792% over IT at the 3 week regulatory target (not shown in figure 3).

4.3 Impact of policies on water quality metrics

Even though the same regulatory target can be achieved at varying cost by different policies the actual impact on water quality is likely to differ. Mean weather river N concentration metrics (mg N/l) at the 8 regulatory standard are presented in table 4. Economic instruments have a lower maximum, 90th percentile and standard deviation than MI and stand alone managerial controls. Water quality effects from economic instruments are also negatively skewed whereas managerial and most mixed instruments are positively skewed. Interestingly the 3 instrument MI policies are notably different in that there is conspicuous reduction in a) the mean, b) the degree of negative kurtosis, and c) the 80th percentile river concentration relative to other policies. Wet weather river water metrics (table 5) reflect higher pollution levels relative to mean weather, e.g. mean > median and positive skewness. However the greatest increase in positive skewness is associated with the 3 instrument MI policies. Interestingly, in table 5, the 3 instrument mixes are leptokurtic (positive kurtosis) whereas all other instruments are platykurtic (negative kurtosis). This implies that the 3 instrument mixed instruments have more acute peaks with fatter tails relative to a normal distribution. They also exhibit the lowest 80th percentile value (table 5).

Both FLR and FSDR exhibit greater positive skewness and relatively positive excess kurtosis across the weather conditions when compared to stand alone economic controls. Thus, in both weather conditions, the presence of FLR in any mixed policy tends to result in more positive skewness and kurtosis. This Implies that although FLR mix policies allow higher value outliers for ambient pollution levels they also exhibit a tendency to be tightly clustered around the mean. In other words, in weeks the standard is violated river N concentration is likely to be higher under FLR mix policies than under stand alone economic instruments. However there is more clustering of weeks around the mean N concentration.

For example the 80th percentile in table 5 falls near the 11.3 mg/l N standard for most economic instruments, but coincides with lower concentrations of 10.528 and 9.853 mg/l N for the two 3 instrument policy mixes.

The trade off between catchment resource cost and water quality is more apparent when water quality metrics are considered. The 3-instrument MIs are nearly 10 times more expensive than IT under mean weather conditions because they ‘over-abate’ pollution (consider the lower mean, 80th percentile and relatively higher excess kurtosis). River water quality with both 3 instrument MI is, on the other hand, far better than under IT alone in mean weather conditions – even though they meet the same regulatory target. However, our results for water quality metrics dismiss the notion that stand-alone managerial policies are less efficient because they ‘over-abate’. In actual fact they are both costly to farmers and do *not* over-abate pollution to ensure compliance with regulatory targets. The mean and standard deviation of ambient pollution with pure managerial policies remain consistently higher than all other controls.

4.4 Discussion

In a second best world instruments which regulate indirectly by controlling a subset of production choices (inputs or management practices) which are relatively easy to observe and correlated with emissions. However regulating the intensity of one input affects the intensity of all other inputs, thus an input tax (intensive margin) should be accompanied by a restriction on land acreage (extensive margin) (Shortle et al. 1998). This may take the form of a lump sum tax on extra-marginal land/firms or some managerial restriction.

Our main results, summarised in Table 6, indicate a change in policy ranking in wetter conditions which can be intuitively explained by the difference in the impacts of each instrument at the intensive and extensive margin. In a second best world, as both the allocation of land to particular uses and N fertiliser application intensity effect diffuse pollution moments, both should be regulated to ensure social welfare (Braden and Segerson, 1993). Economic and managerial controls limit pollution generation in different ways. While set-aside removes land from agriculture (i.e. acts at the extensive margin), input quotas and taxation do not. Although input taxation and quotas provide an incentive to decrease nitrogen consumption per hectare (intensive margin), farmers still apply nitrogen and the incentive to take land out of production is too low[20]. Thus the potential to leach remains in a wet year. During a high rainfall pollution episode setaside confers a dilution effect, i.e. the N concentration from leachate and run-off is very low and offsets the higher concentration diffuse pollution from intensively used agricultural land (low FSDR grassland offers less of a dilution – depending on the stocking density). If the regulator sets an input tax based on expected (mean) nitrate loss then the ambient nitrate target (number of weeks exceeding standard) will only be met on average. If wetter weather prevails more nitrate is leached and the required compliance level is not achieved[21]. Thus single instruments based on mean emissions do not account for the risks of stochastic loads, and may be neither efficient nor effective (Shortle et al. 1998; Elofsson 2003).

In contrast, farm stocking density reduction (FSDR) reduces the intensity of land use (intensive margin) by either re-allocating land from arable crops to grassland or by reducing the number of livestock in production or both. Both changes would reduce nitrogen input use on grassland. Very low stocking density rates are associated with near-zero N input to

[20] Provided the benefit of growing a crop exceeds the cost - everything considered. Goetz *et al.*(2006) note that the crop mix may change as a result of levying an input tax.

[21] To illustrate, the optimal tax level ensuring standard compliance at the 4 week regulatory target given mean weather conditions is an after tax input cost of £1.50/kg nitrate (see table 3). However in wet conditions this results in the standard being violated in 11 weeks. The significantly higher after tax input cost of £25.53/kg nitrate is required to achieve the 4 week target in wet weather conditions.

grassland, which is in effect similar to taking land out of production, similar to setaside. FSDR therefore performs relatively better under wet conditions than mean weather conditions when compared to an input tax or quota. (compare the 6-week standard in Figures 2 and 3)[22]. Obviously the greater the livestock density in a catchment, the more effective leverage FSDR policies exert.

Overall our results imply the existence of cross-overs in the relative efficiency ranking of policies across weather scenarios[23]. NPP is determined by land management, physical soil properties, topography and weather - pollution episodes are highly correlated with periodic flash rainfall (Burt et al. 1993b) . Thus evidence for efficiency 'cross overs' from mean to wet weather, or that cost-effective regulation may vary depending on weather makes sense intuitively. Previous empirical studies have reported such cross-overs across abatement cost frontiers (Miltz et al. 1988; Braden et al. 1989) but not across weather scenarios. It should be noted that although estimated emission taxes remain the least cost option in all weather/flow requirement scenarios, their supremacy is misleading as in reality they are impractical[24].

The results are best explained by the difference in incentives provided by economic and managerial instruments at the intensive and extensive margin. It is likely that the efficiency of MI would improve further if the managerial components were spatially targeted to more 'leaky' soils[25], unfortunately our modelling did not permit such analysis. This superiority of MI at higher regulatory target levels is encouraging if one takes the view

[22] Additionally a FSDR (1.4 lu/ha) + IT mix, which is second to input based policies, in the 15 – 10 week regulatory target range manages to outperform IT from the 9 week target onwards (Fig. 3).

[23] In a stochastic model with probabilistic environmental constraint this would be the equivalent of saying that policy ranking is not consistent across reliability (target) levels.

[24] Estimated emission taxation is off the political agenda because it assumes farmers: a) perfectly understand the regulator's modelled relationship between management practices, nitrogen applications, weather patterns and emissions, b) are risk neutral (Schmutzler 1996), and c) have the same weather expectations as the regulator (Shortle et al. 1986). Models at present cannot estimate emissions accurately enough to withstand legal challenges and the transaction costs of complex models can be substantial (Shoemaker et al. 1993).

[25] Land retirement, if appropriately targeted, can generate sufficient benefits to outweigh social costs (Ribaudo et al. 1994).

that regulators are likely to prefer integrating economic instruments with managerial/regulatory approaches, rather than relying entirely on either alone, since environmental objectives are often ratcheted up over time.

We also considered the impact of the weather variability on policy choice. Ultimately the regulator faces the difficult decision of choosing a policy instrument level(s) which meets the regulatory target cost effectively across a variety of weather conditions, or of setting instrument level(s) and choices on the basis of "most sensitive" conditions. As nitrate loadings are highly variable both within and among different years (Halstead et al. 1991), i.e. weather is stochastic, the regulator's decision should be based not only on the expected weather but also its variance (Braden et al. 1993; Teague et al. 1995; Shortle et al. 1998). However, another important consideration is the required level of standard compliance and the regulator's aversion to the regulatory target being exceeded in wet years or, in the extreme case, at all. If the regulator wants to ensure the standard is achieved most of the time with certainty and adopts the precautionary principle, instrument levels should be based on the wet weather scenario, albeit at a greater compliance cost. The greater the aversion to the standard's violation the more likely the regulator will favour policies which perform better in wet years[26]. Thus the trade-off between regulatory certitude of compliance in wet weather versus increased social cost of compliance in mean weather conditions. By implicit implication a regulator's risk aversion determines policy choice[27]. Indeed, efficiency is very unlikely to be the sole criteria by which a regulator considers instruments (Hanley et al. 1990) . In addition a control policy based on wet weather may be

[26] As our model does not factor the accumulation of N in the soil it implies that instruments which achieve lower levels of standard compliance may actually fail over time.

[27] In the literature this is indirectly recognised as policy ranking not being consistent across various reliability levels (Kampas et al. 2004).

the most cost effective route given the transaction costs of designing a truly stochastic control framework[28].

Goetz *et al.* (2006) extend the need to complement regulating the intensive margin with restrictions on the extensive margin further. They modelled a dynamic product mix which was not restricted to a pre-specified set of production (crop) activities - and demonstrated that regulating the extensive margin should extend from land under cultivation to land allocated to particular crops. They report the superiority of combining a spatially non-differentiated land use specific (crop) taxes[29] with a uniform N input tax. However the introduction of a crop specific instrument to regulate the extensive margin is likely to raise enforcement costs. The absence of transaction costs, i.e. explicitly or implicitly zero costs, "*creates confusion and errors both in defining the problem and in the search for solutions*" (Vatn 1998). Unfortunately, there are few reliable transaction cost estimates (Shortle et al. 1998; McCann et al. 1999; Kampas et al. 2004) and the addition of a crop specific land use tax may have regional political implications as well.

In contrast, we propose regulating the extensive margin by using land setaside, as part of a MI approach. Managerial approaches are arguably cheaper to implement, since existing stocking density and set-aside restrictions currently enforced as cross-compliance requirements under the European-wide Single Farm Payment Scheme mean a data collection and monitoring infrastructure is already in place. In fact the monitoring costs of permanent setaside would be significantly lesser. In addition, setaside is associated with reduced insecticide, herbicide, fungicide, nitrogen, phosphorus and sediment pollution (Ribaudo et al. 1994). The accumulative transaction costs of designing, enforcing and

[28] Assuming wetter winter conditions are likely to prevail in Scotland with climate change (Kerr et al. 1999) it is possible future diffuse nitrogen regulation may be similar to that outlined in the 'wet' weather year scenario we consider.
[29] Although it isn't clear whether they considered spatially undifferentiated land use taxes differentiated by crop type alone or crop type and cultivation technique. Obviously, the more differentiation the greater the enforcement cost.

monitoring separate economic instruments to control each NPP externality may be prohibitive and warrant a more integrated and simpler approach. We note that a problem-by problem, information-intensive approach to NPP is not practical, and the focus on such approaches in the economics literature possibly explains the limited uptake of economic instruments to control complex agricultural externalities. Managerial options can also generate ancillary environmental benefits in terms of wildlife habitat and landscape amenity value which would increase their cost-effectiveness by reducing their net social costs (Hanley et al. 1999) and sustain the multi-functionality of agriculture.

5. Conclusions

This study has focussed on evaluating combinations of economic instruments with managerial measures to achieve a reduction in nitrate pollution while maintaining an environmental target of ensuring minimum river flows. Such multiple-objective management seems likely to become more prevalent in the EU as a result of the Water Framework Directive, whilst policy evolution seems certain to take in a mixed instrument approach, combining economic incentives with regulation. For economists to lobby policy makers on the basis of a preference for “pure” economic instruments seems likely to be unproductive in political economy terms, and this paper has investigated what the pay-offs (both positive and negative) might be of focussing instead on a mixed approach. Surprisingly, combining economic instruments and direct regulation to control NPP has not been highlighted in the economics literature before. MIs make sense when the nature of the environmental problem(s) being considered (highly spatially diverse and time-varying; many actors; imperfectly observable actions and effects) means that neither economic nor regulatory approaches alone can achieve acceptable levels of effectiveness and efficiency.

Conceptually, would a MI strategy be better than a single instrument in another catchment? The transferability of our results depends on weather and the degree of regulatory strictness. In catchments with wet weather MI comprising of economic and managerial regulation will fare better. Of course, defining ‘wet weather’ is relative and indeed determining a pattern in instrument efficiency ‘cross-overs’ warrants further research.

References

Aftab, A., N. Hanley, et al. (2007). Coordinated Environmental Regulation: Controlling Nonpoint Nitrate Pollution while Maintaining River Flows. Environmental and Resource Economics 38 (4): 573-593.

Albiac, J. M., S. U. Karaj, et al. (2001). Water Quality Protection through Irrigation Management. working paper Unidad de Economia Agraria.

Anthony, S., P. Quinn, et al. (1996). Catchment scale modelling of Nitrate Leaching (Modelling in Applied Biology: Spatial Aspects). Aspects of Applied Biology 46: 23-32.

Bailey, R. and E. Spackman (1996). A model for estimating soil moisture changes as an aid to irrigation scheduling and crop water use studies: I. Operational details and Description. Soil Use and Management 12(3): 122-128.

Barnard, C. S. and J. S. Nix (1973). Farm Planning and Control, Cambridge University Press.

Baumol, W. and W. Oates (1988). The Theory of Environmental Policy, Cambridge University Press.

Beavis, B. and M. Walker (1983). Random wastes, imperfect monitoring and environmental quality standards. Journal of Public Economics 21: 377-387.

Braden, J., G. Johnson, et al. (1989). Optimal Spatial Management of Agricultural Pollution. American Journal of Agricultural Economics 71: 404-413.

Braden, J. and K. Segerson (1993). Information Problems in the Design of Nonpoint-Source Pollution Policy. Theory, modelling, and experience in the management of nonpoint source pollution. C. Russell and J. Shorgen. Massachusetts, Kluwer Academic Publishers pp.

Brooke, A., D. Kendrick, et al. (1998). GAMS. Washington, D.C., GAMS Development Corporation.

Burt, T. and N. Haycock (1993a). Controlling Losses of Nitrate by Changing Land Use. Nitrate: Processes, Patterns and Management. T. Burt, A. Heathwaite and S. Trudgill. Chichester, Wiley & Sons pp.

Burt, T. P., A. L. Heathwaite, et al., Eds. (1993b). Nitrate: Processes, Patterns and Management, John Wiley and Sons.

Crabtree, J. R., N. Chalmers, et al. (2000). Evaluating the Economic Impact of Irrigation Controls. Aberdeen, MLURI: 100.

Darcy, B. J., J. B. Ellis, et al. (2000). Diffuse Pollution Impacts: The Environmental and Economic Impacts of Diffuse Pollution in the U.K. U.K., CIWEM Publications.

DEFRA (2007). Draft partial regulatory impact assessment (RIA) on potential costs and benefits associated with new environmental standards and conditions proposed for Water Framework Directive (WFD) implementation. London.

Dunn, S. (1998). Development of an Application of a Distributed Catchment Scale Hydrological Model for the Ythan, NE Scotland. Hydrological processes 12: 401-416.

Elofsson, K. (2003). Cost-effective reductions of stochastic agricultural loads to the Baltic Sea. Ecological Economics 47: 13-31.

EU (2000). EU Water Framework Directive. EU Official Journal OJ L 327.

Goetz, R.-U., H. Schmid, et al. (2006). Determining the economic gains from regulation at the extensive and intensive margin. European Review of Agricultural Economics 33(1): 1-30.

Hahn, R. W. (2000). The impact of economics on environmental policy. Journal of Environmental Economics and Management 39: 375-399.

Halstead, J., S. Batie, et al. (1991). Impacts of uncertainty on policy costs of managing nonpoint source ground-water contamination. Journal of Sustainable Agriculture 1: 29-48.

Hanley, N., S. Hallett, et al. (1990). Why is more notice not taken of economists' prescriptions for the control of pollution? Environment and Planning A 22(11): 1421-1439.

Hanley, N., M. Whitby, et al. (1999). Assessing the Success of Agri-environmental Policy in the UK. Land Use Policy 16(2): 67-80.

Helfand, G. and B. House (1995). Regulating nonpoint-source pollution under heterogeneous conditions. American Journal of Agricultural Economics 77: 1024-1032.

Horan, R., J. S. Shortle, et al. (1998). Ambient Taxes When Polluters Have Multiple Choices. Journal of Environmental Economics and Management 36: 186-199.

Johnson, S., R. Adams, et al. (1991). The On-Farm Costs of Reducing Groundwater Pollution. American Journal of Agricultural Economics 73: 1063-1073.

Kampas, A. and B. White (2004). Administrative Costs and Instrument Choice for Stochastic Non-point Source Pollutants. Environment and Resource Economics 27(2): 109-133.

Kerr, A., S. Shackley, et al. (1999). Climate Change: Scottish Implications Scoping Study. Edinburgh, Scottish Executive Central Research Unit: 75.

Kolstad, C., U. Thomas, et al. (1990). Ex Post Liability for Harm vs. Ex Ante Safety Regulation: Substitutes or Complements? American Economic Review 80(4): 888-901.

Larson, D. M., G. E. Helfand, et al. (1996). Second-best tax policies to reduce nonpoint source pollution. American Journal of Agricultural Economics 78(4): 1108-1117.

Lockyer, D., D. Scholefield, et al. (1995). N-CYCLE. Aberdeen, MERTAL Courseware.

Lord, E. (1992). Modelling of nitrate leaching: nitrate sensitive areas. Aspects of Applied Biology 30: 19-28.

McCann, L. and K. W. Easter (1999). Transaction costs of policies to reduce agricultural phosphorous pollution in the Minnesota River. Land Economics 75(3): 402-414.

Miltz, D., B. Braden, et al. (1988). Standards versus Prices revised: The case of Agricultural Non-point Source Pollution. Journal of Agricultural Economics 39(3): 360-368.

NCEE (2004). International experiences with economic incentives to protect the environment. Washington DC, National Center for Environmental Economics, US EPA.

OECD (1997). Environmental Taxes and Green Tax Reform. Paris, Organisation of Economic Cooperation and Development.

Ribaudo, M., C. Osborn, et al. (1994). Land retirement as a tool for reducing agricultural nonpoint source pollution. Land Economics 70: 77-87.

Roberts, M. and M. Spence (1976). Effluent charges and licenses under uncertainity. Journal of Public Economics 5: 193-208.

SAC (1997). Farm Management Handbook 1997/98. Edinburgh, Scottish Agricultural College.

Schmutzler, A. (1996). Pollution Control with Imperfectly Observable Emissions. Environmental and Resource Economics 7: 251-262.

Scholefield, D., D. Lockyer, et al. (1991). A model to predict transformations and losses of nitrogen in UK pastures grazed by beef cattle. Plant and Soil 132: 165-177.

Shoemaker, R. A., D. E. Ervin, et al. (1993). Data Requirements for Modeling and Evaluation of National Policies Aimed at Controlling Agricultural Sources of Nonpoint Water Pollution. Theory, Modeling and Experience in the Management of Nonpoint- Source Pollution. C. S. Russell and J. F. Shogren. Norwell, Mass, Kluwer pp.

Shortle, J. S. and J. Dunn (1986). The Relative Efficiency of Agricultural source Water Pollution Control Policies. American Journal of Agricultural Economics 68: 668-677.

Shortle, J. S. and R. Horan (2001). The Economics of Nonpont Pollution Control. Journal of Economic Surveys 15(3): 255-289.

Shortle, J. S., R. Horan, et al. (1998). Research Issues in Nonpoint Pollution Control. Environmental and Resource Economics 11: 571-585.

SOAEFD (1997). Scottish Agriculture: A Guide to Grants and Services. Edinbugh, Scottish Executive.

Stevens, B. (1988). Fiscal Implications of Effluent Charges and Input Taxes. Journal of Environmental Economics and Management 15: 285-296.

Stolbjerg-Drud, A. (1993). GAMS/CONOPT. GAMS (The Solver Manuals). Washington DC, GAMS Development Corporation: 55 pp.

Teague, M. L., D. J. Bernardo, et al. (1995). Farm Level Economic Analysis Incorporating Stochastic Environmental Risk Assessment. American Journal of Agricultural Economics 77: 8-19.

Vatn, A. (1998). Input versus Emission Taxes: Environmental Taxes in a Mass Balance and Transaction Costs Perspectives. Land Economics 74(4): 514-525.

Weinberg, M., C. L. Kling, et al. (1993). Water Markets and Water Quality. American Journal Agricultural Economics 75(278-291).

Wossink, G. A., A. Oude-Lansink, et al. (2001). Non-separability and heterogeneity in integrated agronomic-economic analysis of nonpoint-source pollution. Ecological Economics 38: 345-357.

Wu, J. (1999). Input Substitution and Pollution Control Under Uncertainty and Firm Heterogeneity. Journal of Public Economic Policy 2(2): 273-288.

Wu, J. and B. A. Babcock (2001). Spatial Heterogeneity and the Choice of Instruments to Control Nonpoint Pollution. Environment and Resource Economics 18(2): 173-192.

Wu, J., M. Teague, et al. (1995). An Empirical Analysis of the Relative Efficiency of Policy Instruments to reduce Nitrate Water Pollution in the U.S. Southern High Plains. Canadian Journal of Agricultural Economics 43: 403-420.

Xepapadeas, A. (1995). Observability and choice of instrument mix in the control of externalities. Journal of Public Economics 56: 485-498.

Figure 1: Catchment Model – Crop, livestock type, soil, N application, irrigation scheduling are the main decision variables

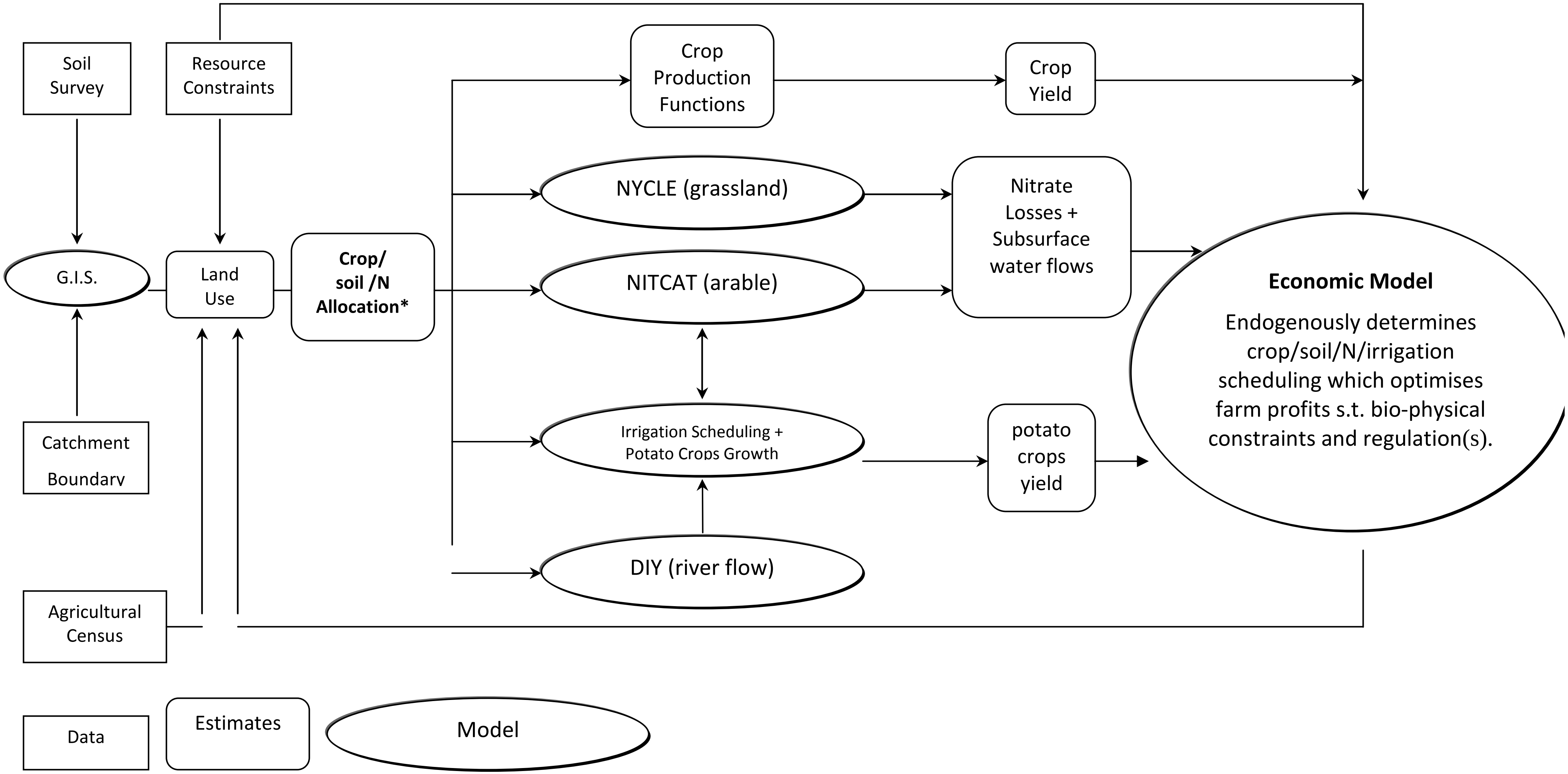

Figure 2. Mean Weather Without MAF

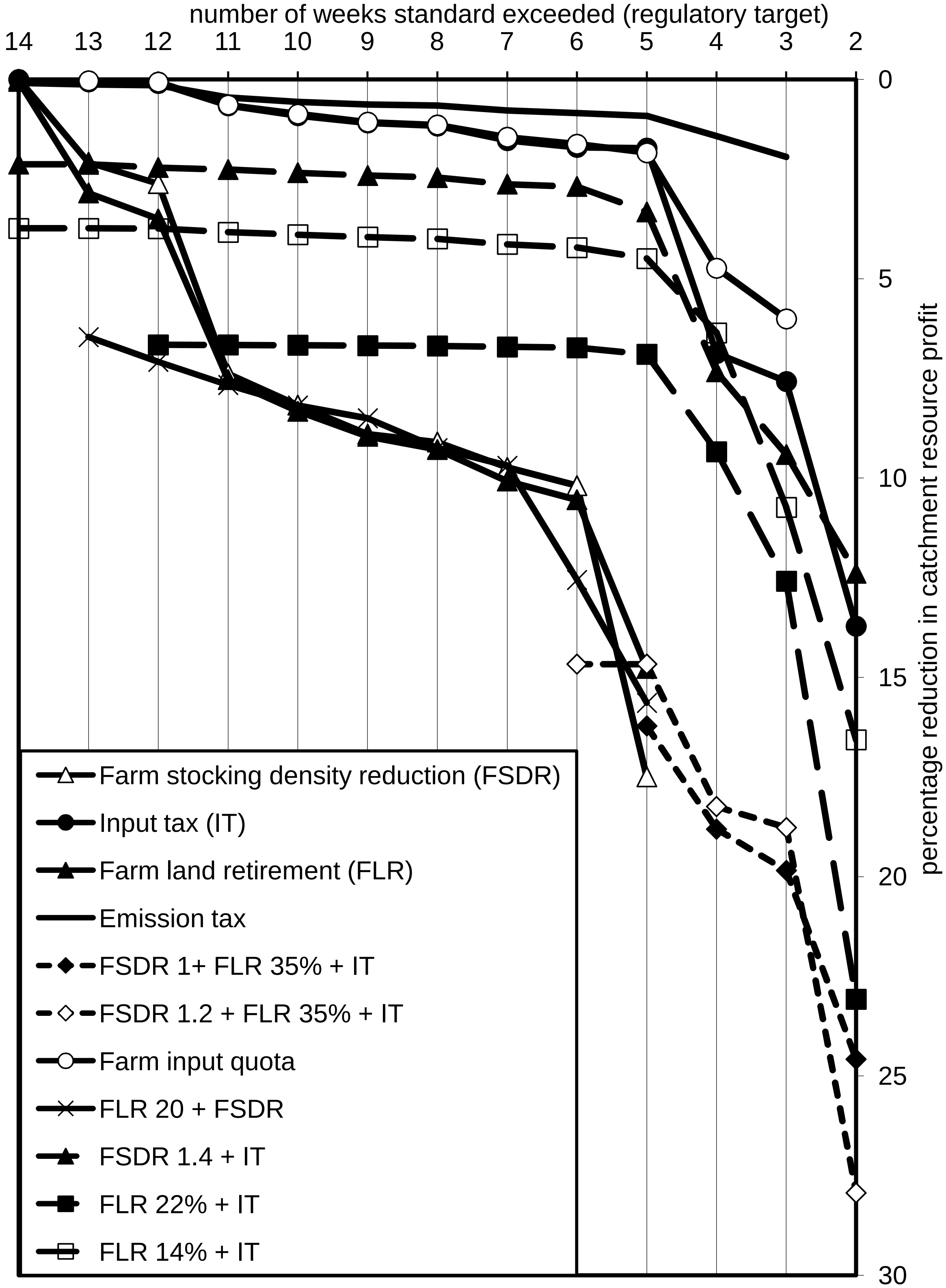

Figure 3. Wet Weather With/Without 90th Percentile MAF

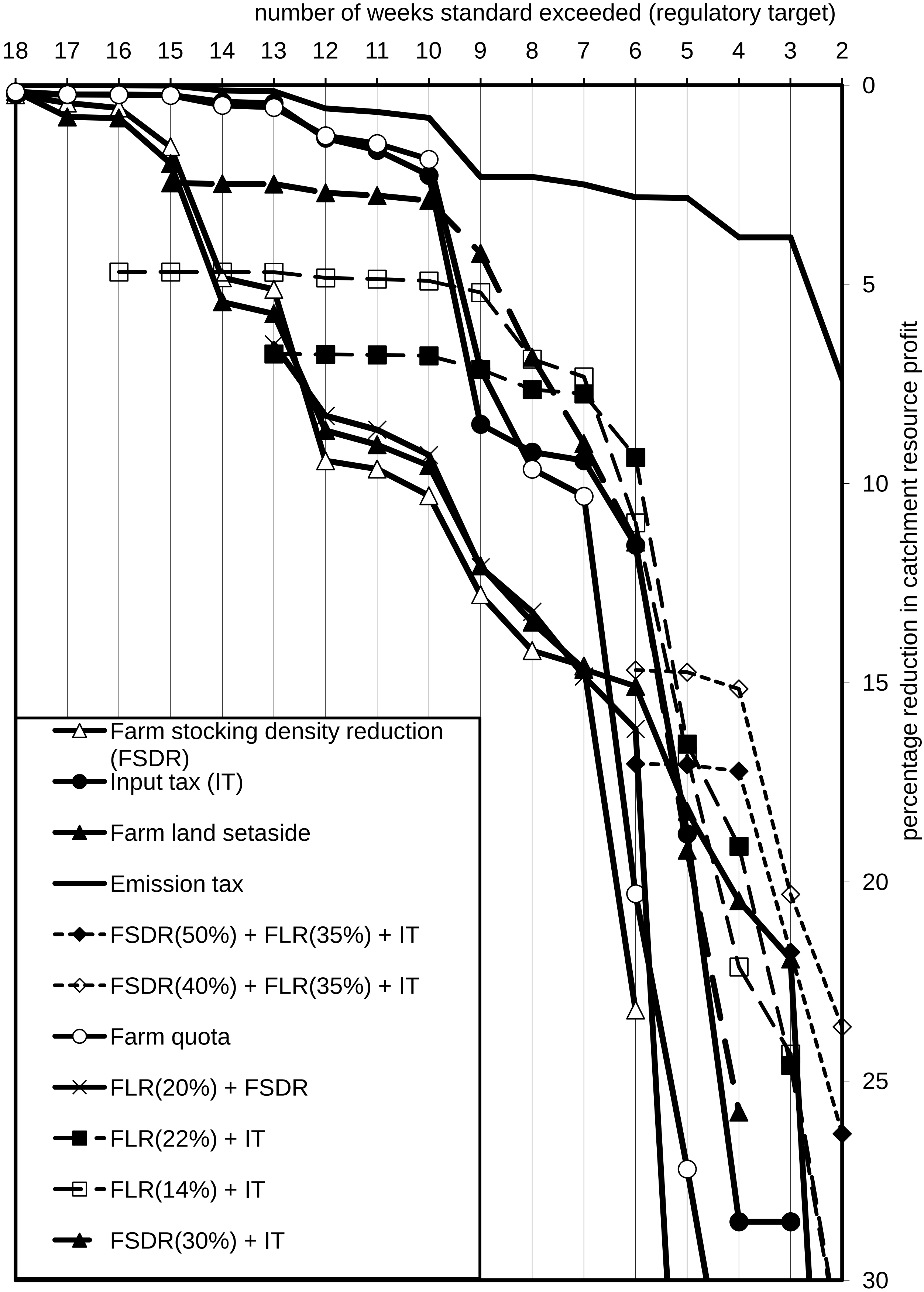

Table 1. Percentage Reduction in Catchment Resource Cost of Policies at the 8 and 4 Week Regulatory Target

Weather	Mean weather				Wet weather	
River Flow Restriction	**90th percentile**		**No MAF restriction**		**With and without MAF restriction**	
Regulatory Target	**8 week**	**4 week**	**8 week**	**4 week**	**8 week**	**4 week**
Emission tax (£/mg N)	1.035	1.235	0.660	1.431	2.304	3.821
N Input tax (IT) (£/kg N)	1.705	2.417	1.170	6.876	9.211	28.531
Input quota (% restriction)	1.567	2.322	1.146	4.736	9.637	34.647
FSDR (30% LU/ha) + IT	2.541	6.661	2.465	7.340	6.957	25.781
FLR (14% ha) + IT	7.675	7.956	4.002	6.358	6.991	22.134
FLR (22% ha) + IT	7.853	9.710	6.689	9.341	7.670	19.106
FSDR (40% LU/ha) + FLR (35% ha) + IT	17.272*	17.272	14.671*	18.245	14.681*	15.158
FSDR (50% LU/ha) + FLR (35% ha) + IT	19.138*	19.138	18.808*	18.808	17.034*	17.218
FLR (20% ha) + FSDR (LU/ha)	12.004	18.862	9.250	NA	13.221	44.840
FLR (‘setaside’, i.e. % of arable land)	10.291	NA	9.288	NA	13.482	20.476
FSDR (LU/ha)	9.699	NA	9.103	NA	14.195	NA

*: Overachieves regulatory target. NA: Regulatory target not achieved.

Table 2. Catchment Policy Ranking Under Different River Flow and Weather Conditions

Weather	Mean weather				Wet weather	
River Flow Restriction	90th percentile		No MAF restriction		With and without MAF restriction	
Regulatory Target	8 week	4 week	8 week	4 week	8 week	4 week
Emission tax (£/mg N)	1	1	1	1	1	1
N Input tax (IT) (£/kg N)	3	3	2	4	5	8
Input quota (% restriction)	2	2	3	2	6	9
FSDR (30% LU/ha) + IT	4	4	4	5	2	7
FLR (14% ha) + IT	5	5	5	3	3	6
FLR (22% ha) + IT	6	6	6	6	4	4
FSDR (40% LU/ha) + FLR (35% ha) + IT	10*	7	10*	7	10*	2
FSDR (50% LU/ha) + FLR (35% ha) + IT	11*	9	11*	8	11*	3
FLR (20% ha) + FSDR (LU/ha)	9	8	7	NA	7	10
FLR ('setaside', i.e. % of arable land)	8	NA	9	NA	8	5
FSDR (LU/ha)	7	NA	8	NA	9	NA

*: Overachieves regulatory target. NA: Regulatory target not achieved.

Table 3. Instrument Levels to Induce Compliance with Regulatory Targets under Modelled Scenarios

Weather	**Mean weather**				**Wet weather**	
River Flow Restriction	**90th percentile**		**No MAF restriction**		**With and without MAF restriction**	
Regulatory Target	**8 week**	**4 week**	**8 week**	**4 week**	**8 week**	**4 week**
Emission tax (£/mg N)	35.40	75.40	45.50	90.50	51.60	**57.20**
N Input tax (IT) (£/kg N)	1.2	1.56	1.3	3.56	7.15	24.53
Input quota (% restriction)	34.80	43.65	35.25	63.25	79.05	97.00
FSDR (30% LU/ha) + IT	0.86	2.66	0.88	3.11	2.87	22.12
FLR (14% ha) + IT	0.68	0.92	0.81	2.09	2.23	14.6
FLR (22% ha) + IT	0.52	1.98	0.54	2.32	1.3	11.12
FSDR (40% LU/ha) + FLR (35% ha) + IT	0.42*	1.5	0.42*	4.1	0.42*	1.25
FSDR (50% LU/ha) + FLR (35% ha) + IT	0.42*	2.02	0.42*	3.25	0.42*	0.9
FLR (20% ha) + FSDR (LU/ha)	23.5	62.5	38.5	NA	58	78.70
FLR (‘setaside’, i.e. % of arable land)	33.3	NA	34.6	NA	49.1	74.5
FSDR (LU/ha)	66.5	NA	67.5	NA	76	NA

*: Overachieves regulatory target. NA: Regulatory target not achieved.

Table 4: Policy Ranking and Water Metrics (mg/l N) under Mean Weather, 8 week target with 90th percentile MAF Restriction

Regulatory Policy	Rank	Mean	Median	Standard deviation	Skewness	Kurtosis	80th percentile	90th percentile	Maximum
BASELINE*		**10.272**	**10.272**	**5.385**	**-0.359**	**-1.297**	**14.671**	**16.177**	**16.969**
Emission tax (£/mg N)	1	7.469	8.072	4.421	-0.233	-1.505	11.544	12.528	13.483
N Input tax (IT) (£/kg)	3	7.512	8.149	4.295	-0.265	-1.489	11.553	12.470	13.189
Input quota (% restriction)	2	7.282	8.138	4.444	-0.252	-1.597	11.551	12.404	13.029
FSDR (30% LU/ha) + IT	4	8.189	8.814	4.449	-0.375	-1.173	11.601	13.897	14.374
FLR (14% ha) + IT	5	7.691	8.212	4.552	-0.201	-1.419	11.544	13.212	14.622
FLR (22% ha) + IT	6	8.200	8.018	4.722	0.022	-1.114	11.626	14.911	16.146
FSDR (40% LU/ha) + FLR (35% ha) + IT	10**	6.785	6.149	5.026	0.616	-0.594	9.175	15.213	17.315
FSDR (50% LU/ha) + FLR (35% ha) + IT	11**	6.745	5.709	5.065	0.987	-0.011	8.491	15.313	18.128
FLR (20% ha) + FSDR (LU/ha)	9	7.874	8.005	5.041	0.076	-1.173	11.634	15.296	16.919
FLR (‘setaside’, i.e. % of arable land)	8	8.053	7.940	5.276	0.141	-1.161	11.672	15.789	17.319
FSDR (LU/ha)	7	8.058	7.877	5.239	0.174	-1.148	11.612	15.245	17.401

*: Baseline water metrics for mean weather with 90th percentile MAF restriction. **: Overachieves regulatory target.

Table 5: Policy Ranking and Water Metrics (mg/l N) under Wet Weather, 8 week target with and without MAF restrictions

Regulatory Policy	Rank	Mean	Median	Standard deviation	Skewness	Kurtosis	80th percentile	90th percentile	Maximum
BASELINE*		**9.872**	**9.872**	**6.356**	**0.143**	**-1.314**	**17.156**	**18.785**	**21.813**
Emission tax (£/mg N)	1	6.957	6.666	4.300	0.137	-1.227	11.232	12.656	14.983
N Input tax (IT) (£/kg)	5	6.674	6.408	4.528	0.187	-1.318	11.370	12.821	14.730
Input quota (% restriction)	6	6.743	6.408	4.466	0.200	-1.305	11.366	12.845	14.563
FSDR (30% LU/ha) + IT	2	6.962	6.246	4.338	0.378	-1.058	11.328	13.206	15.756
FLR (14% ha) + IT	3	6.812	6.347	4.452	0.361	-1.082	11.318	12.894	16.047
FLR (22% ha) + IT	4	7.104	6.444	4.481	0.455	-0.831	11.324	13.048	17.312
FSDR (40% LU/ha) + FLR (35% ha) + IT	10**	7.232	5.950	5.383	1.038	0.324	10.528	15.859	22.339
FSDR (50% LU/ha) + FLR (35% ha) + IT	11**	6.838	5.491	5.643	1.210	0.764	9.853	15.438	22.519
FLR (20% ha) + FSDR (LU/ha)	7	7.852	6.788	5.677	0.772	-0.276	11.943	16.524	21.863
FLR ('setaside', i.e. % of arable land)	8	7.576	6.505	5.335	0.833	-0.064	11.323	15.714	21.901
FSDR (LU/ha)	9	7.537	6.488	5.331	0.819	-0.122	11.322	15.703	21.675

*: Baseline water metrics for wet weather with and without 90th percentile MAF restriction. **: Overachieves regulatory target.

Table 6: Summary of empirical results

1)	Single instruments display efficient abatement 'fatigue' at higher regulatory targets. The relative cost effectiveness of MIs improve as: a) the regulatory target is tightened, and b) as weather conditions become wetter.
2)	Irrigation water abstraction restrictions required to comply with MAF do not fundamentally alter instruments ranking - however they do alter required instrument levels.
3)	The existence of 'cross-overs' imply that cost effective rankings maybe target dependent and vary across weather scenarios.
4)	Water quality metrics reveal that FLR MIs pollution levels are more tightly clustered around the mean - even though they permit higher ambient N pollution events than stand alone economic instruments.