Assessing the Distributional Impacts of Transferable Pollution Permits: The Case of Phosphorus Pollution Management at a River Basin Scale

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Although the initial allocation of pollution permits is neutral in terms of efficiency, it does have a significant impact on distributive equity. In this paper, we examine the two main categories of permit allocation rules, the distributive and the reductive, for controlling phosphorus pollution in a small catchment in South West England. Based on the premise that the regulatory choice compromises efficiency and equity, the main result of this paper is that an allocation of permits in proportion to the intensity of environmental preferences is a "win-win" choice. The reason is that it simultaneously achieves two goals. First, it is efficient (or cost-effective) since a permit system achieves a pre-specified target at a minimum abatement cost, while second, it is the only allocation rule which reduces the income inequality of the baseline scenario.

Keywords: *pollution permits, phosphorus, nutrient management, export coefficient model, water quality, distributive justice, income inequality, Atkinson Index*

JEL Classification: Q52, Q25, Q58

Introduction.

Transferable pollution permits (TPP henceforth) seem to attract considerable attention among OECD countries for environmental and resource management (OECD, 2001). TPP refer to physical restrictions in the form of rights or obligations to agents and the permission to transfer these obligations or rights between agents under certain conditions specified by an administrative authority. This approach allows agents to choose the cost effective means of meeting the overall constraint set by the regulatory authority.

Montgomery (1972) proves that under specific assumptions, TPP are a cost-effective means for achieving a pre-specified target of environmental quality. These assumptions refer to perfect competitive product and permit markets, to clearly defined property and usage rights, and to negligible transaction costs. Furthermore, the least-cost property of such instruments is based on the premise that emission trading occurs simultaneously and multilaterally, while in most cases the realised emission trading has been bilateral

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and sequential. The latter is often considered as the most likely explanation why emission trading does not realise the full efficiency gains in controlling pollution (Atkinson and Tietenberg, 1991).

In the case of agricultural pollution, farmers can modify the distribution of polluting rights, initially allocated to them, by permit trading. The typical prerequisite for farmers to initiate permit trading is the abatement cost heterogeneity. For example, a low abatement cost farm may choose to abate more and sell some of its permits, while a high abatement cost farm may prefer to buy more permits and maintain its emission levels. The interaction of farmers' willingness to sell and willingness to buy emission permits determines a benchmark price, which is the market price for permits. This price is independent of the initial allocation of permits (OECD, 2001).

The major issue in designing an emission permit system is whether permits should be auctioned or should be freely distributed. There are strong arguments in favour of each distribution option. The authors advocating auction as the most appropriate means of distributing pollution permits primarily stress the importance of revenue recycling usually referred to as the "double dividend hypothesis". Under this hypothesis, the government revenues from permit auctions can be used to reduce pre-existing distortionary taxes and therefore result in efficiency gains to the economy as a whole (Crampton and Kerr, 1998).

In contrast, the traditional view in favour of grandfathering is that it provides greater political control over the distributional effects of pollution regulation (Stavins, 1997) The distributional impacts of tradable permits are quite crucial for the acceptability of such a policy by the agents (Dinar and Howitt, 1997). The reason is that only a permit system that allocates pollution rights free of charge, on the basis of some allocation rule, would guarantee that existing firms would be no worse off than they would be under a command-and-control system imposing the same degree of control (Tietenberg, 1998).

Although the possibility of using TPP for managing water quality at a watershed scale has been outlined before (see Tietenberg (2003) and Zylicz (2003)), there have only been limited applications in the relevant literature. Some recent exceptions are Tao *et al* (2000) and Kampas and White (2003). This paper brings two innovations to the analysis of permit allocations. First, it examines a much broader range of permit allocation rules which, to our best knowledge, have not been considered before at a river basin scale. Some of these rules are drawn from the related literature of greenhouse gasses control while some others have not been applied before. The second innovation of this study is that it assesses the distributional impacts of various permits allocation rules not only as transfers between agents- as it is standard in the relevant literature (Rose and Oladosu. 2002)- but also as to whether they alleviate income inequality.

The empirical application of this study uses the case of phosphorus (P henceforth) management at a small agricultural catchment in North England, the Kennet. P is usually the limiting nutrient for the formation of algal blooms in freshwater bodies. The greatest losses of P from the soil usually occur by surface run-off and erosion (Addiscott and Thomas, 2000).

The rest of the paper is organised as follows. Section 2 presents a possible range of permit allocation rules that could be applied for phosphorus management. Section 3 briefly describes the empirical application, while section 4 presents the results of our analysis. Finally, the main conclusions are drawn in section 5.

Possible Permit Allocation Rules

Following Gupta and Bhandari (1999) there are two main principles for allocating freely emission permits: a) the distributive one, which refers to the allocation of rights and b) the reductive one, which refers to allocation of emission reductions. This section outlines the major representative allocation rules from both principles.

Although an infinitive number of possible distributive rules exist, the so-called grandfathering rules tend to predominate (Tietenberg, 2003). Grandfathering refers to the initial allocation of emission on the basis of historic use. The most common grandfathering rule is the emission based, which is an allocation in proportion to the unrestricted level of emission released by the sectors in the base year, $\sum_i e_i$. On this basis, any sector i will initially receive an amount of permits $a_i\left(\bar{E}\right)$, where $a_i = \frac{e_i}{\sum_i e_i}$. The total number of permits is $\bar{E}$, where $\bar{E} = (1-\rho)\sum_i e_i \equiv \sum_i \bar{e}_i$ and ρ denotes the proportion of the required reduction in the unrestricted level of estimated P-load at the catchment scale. The emission-based allocation is the most frequently considered rule for distributing emission permits (see Hanley and Moffatt (1993) Rose and Stevens (1993) and Kampas and White (2003)).

Another grandfathering rule is the profit-based allocation, which is an allocation in proportion to the historical share of sector profits in the base year. On this basis, any sector i will initially receive $\beta_i\left(\bar{E}\right)$, where $\beta_i = \frac{\pi_i}{\sum_i \pi_i}$ and π_i is the initial profit of the *ith* sector. This allocation method is considered by Bohm and Larsen (1994) and by Kverndokk (1995).

The third grandfathering rule utilises a composite index for the initial distribution of emission permits. Such a composite index is defined as the weighted average of the emission shares, profits shares and land shares of the agents. On this basis, any sector i will initially receive $\gamma_i\left(\bar{E}\right)$, where $\gamma_i = w_1 \frac{e_i}{\sum_i e_i} + w_2 \frac{\pi_i}{\sum_i \pi_i} + w_3 \frac{b_i}{\sum_i b_i}$, and b_i is the utilised land of the *ith* agent. Note that $\sum_i w_i = 1$. Such an allocation is proposed by Ringius *et al* (1998), Simonis (2000) and Bohringer and Lange (2005).

The fourth scheme allocates the emission permits in proportion to the relative preferences for environmental quality which society attaches to various productive sectors. Such preferences are defined by society's willingness to pay for an improvement in environmental quality. Chander and Tulkens (1992) have shown that at equilibrium the sector marginal costs of reducing their emissions are equal to the society's preferences for environmental quality towards them. Consequently, any sector i will initially receive $\zeta_i\left(\bar{E}\right)$ amount of permits, where $\zeta_i = \frac{m_i}{\sum_i m_i}$ and m_i denoting the marginal cost of reducing the emissions of sector *ith*.

The fifth distributive rule allocates the number of permits in proportion to the sectors' ability to pay. Under this scheme, the permits are distributed inversely to the sector's income. The rationale behind such a scheme is that the more profitable sectors should shoulder a higher proportion of the mitigation costs. Therefore, any sector i will initially receive $\delta_i\left(\overline{E}\right)$ amount of permits, where $\delta_i = \frac{\pi_i^{-1}}{\sum_i \pi_i^{-1}}$. The "ability to pay" scheme is considered by Rose and Zhang (2004), Ringius *et al* (1998) and Ridgley (1996).

The last scheme considered in this study belongs to the class of allocation rules which refer to emission reductions. It starts with a uniform emission reduction and then adjusts them on the basis of an "Efficiency Index", EI_i. Such index is defined as the emission intensity of a sector (P load divided by income), normalised by the total emission intensity, $EI_i = \frac{e_i / \pi_i}{\sum_i e_i \Big/ \sum_i \pi_i}$. Therefore, any sector i will initially receive $\left(1-\rho EI_i\right)e_i$ amount of permits. The rationale behind such a scheme is that sectors with high emission intensity, $EI_i > 1$, are requested to abate more compared to the reference point of uniform reduction in all sectors. Note that the resulting allocation from such a scheme may need an appropriate scale-up to exhaust the prescribed number of emission rights. Gupta and Bhandari (1999) examine such a scheme.

As long as the initial allocation of permits is resolved, then each agent maximises the following profit function:

$$\max \pi_i\left(q_i, e_i\right) - p_1\left(e_i - \overline{e}_i\right) \tag{1}$$

where $\pi_i\left(q_i, e_i\right)$ stands for the profit of the *ith* sector, q_i is a vector of homogeneous products produced by the *ith* sector. The permit price is p_1 which is the imputed shadow price of the constraint $\sum_i \overline{e}_i = E$, where $\left(e_i - \overline{e}_i\right)$ stands for the difference between the emission level released by the *ith* sector, e_i, and the initial allocated permits, $\overline{e}_i$. Note that such a difference can be positive, negative, or even zero depending on the amount and the direction of permit trading.

The initial allocation of permits directly determines an income effect, since it involves a transfer of revenues between agents (directly between the State and the agents and indirectly between the agents). In turn, these transfers affect the income distribution of the agents. Consequently, the regulator may opt for a specific allocation that satisfies additional policy objectives. Such an additional objective may be the alleviation of income inequality. Policies such as the redistribution of income aim primarily at "socio-economic" equity and are among the main objectives of any tax system (Breton *et al*, 1996). Notwithstanding the reduction of income inequality is often conceived as an end in itself, the end may require justification. Arguably, such a justification may be based on the premise that "socio-economic" equity plays an important role in sustaining the social fabric, which is well acknowledged by the proponents of the welfare state (Roller, 1995).

In what follows, we assume that the regulator pursues a variety of objectives, one of which may be the alleviation of income inequality. Such an objective can be the guiding principle with which the regulator can choose among various allocation rules. Among various indices of income inequality we restrict our attention to the Atkinson Index, since it is the only measure which satisfies the Pigou-Dalton condition (Temkin, 1993)[1], and at the same time can be interpreted as an index of the potential gains from redistribution (Barr, 1998).

The Atkinson Index, A, is given by:

$$A = 1 - \left(\frac{1}{n} \sum_i \left({}^{I_i}\!/\!_{\mu} \right)^{1-\varepsilon} \right)^{\frac{1}{1-\varepsilon}} \qquad \varepsilon \neq 1 \tag{2}$$

where, I_i stands for the income of the *ith* sector, μ is the average income and n is the number of sectors. The parameter $\varepsilon > 0$ represents the weight attached by society to inequality in the income distribution. The higher the parameter ε is the higher the sensitivity attached to the transfers to the lower income classes. The index A ranges zero to $(1-n)^{-\frac{\varepsilon}{1-\varepsilon}}$. According to Atkinson (1975) the index A has a very natural interpretation being "… *the proportion of the present total income that would be required to achieve the same level of social welfare as if present incomes were equally distributed…*" (p. 48).

The index A explicitly introduces such judgements through the choice of the parameter ε, which ranges from $\varepsilon = 0$ meaning that society is indifferent about income distribution, to $\varepsilon = \infty$, which means that society is concerned only with the position of the least advantaged members of society. The latter case corresponds to what Rawls (1971) refers to as a contractual theory of justice, where inequality is assessed in terms of the position of the last advantaged members of society. Despite the numerous advantages of the A index (see Temkin (1993) pp:137-138) the main problem attached to it is that there is no way of fully calibrating ε. As a result someone is restricted to examine parametrically a range of values in estimating the Atkinson's index. Note that when $\varepsilon = 1$ the A index collapses to the Champernowne Index, C, which is given by $C = 1 - \frac{M}{\mu}$, where $M = \left(\prod_{i=1}^{n} I_i \right)^{\frac{1}{n}}$ (Yfantopoylos, 1990).

The Application of Phosphorus Pollution Management at a River Basin Scale

For the purposes of examining the distributional impacts of various permit allocation rules and the likely regulatory choice we consider the hypothetical case of emission permits allocation in an agricultural catchment in South England. In that catchment, the Kennet, the regulator considers the case of a cap and trade scheme in order to achieve a 20% reduction in the P emission level relative to the unregulated case.

The empirical model proceeded in three stages. First, a Geographical Information System (GIS) was used to classify land classes based on their soil properties and to identify the total area of the catchment. Second, an export coefficient model assessed the P loss possibilities. Finally, an aggregate non-linear programming model simulated producers' responses to the pollution control policy. Our approach is what Hazell and Norton (1986) refer to as an aggregate regional model, in which the regulatory objective is to maximise regional welfare. The full account of the modelling framework is given by Kampas *et al* (2002).

P is strongly retained in most soils and P losses are primarily associated with sediment carried in surface runoff during heavy rainfall (Haycock and Muscutt, 1995). However, quantification of losses are less well understood and advanced for P compared to nitrates (Edwards and Withers, 1998). There is considerable uncertainty with respect to the weighting that can be placed upon crop/agronomic practices against those landscape type features that influence loss (such as slope and soil texture). Within this paper we have taken the simplest method of predicting P loss – the export coefficient. In the form used here the export coefficient model ignores the highly episodic and spatially discrete nature of many erosion events and although these weaknesses are acknowledged it still probably represents the most appropriate assessment. Since P losses are likely to be linked with the catchment's cropping pattern and land management rather than the intensity of the inputs used, an export coefficient model is well suited to capture such a phenomenon.

Export coefficient models have been used extensively in the literature for environmental management analysis (Jones, 1996; Worral and Burt, 1999; Heathwaite, *et al* 2003). It is noteworthy that an export coefficient model gives estimates of the average annual P losses of different land classes ignoring their seasonal variation, which may be quite important (McDowell and Trudgill, 2000). On the other hand, export coefficient models are transparent and easy to implement. An export coefficient model can be written as follows:

$$L^P = \sum_{i=1}^{n} E_i A_i \tag{3}$$

where L^P is the P loss; E_i is export coefficient for nutrient source i; A_i is the area of the catchment occupied by land use type i (or number of livestock type i). For the purposes of our application we employed Jones' (1996) values for P export coefficients. The author empirically validated the P export coefficient models for two catchments in South England, which are adjacent to our case study, and therefore it was assumed that the Kennet catchment has the same pattern of export coefficients.

The following steps were followed to examine the likely regulatory preference for a specific permit allocation rule. First, we ran the unrestricted regional model to assess the baseline economic and environmental performance of the Kennet catchment. Then, we ran the restricted regional model to estimate the 'first best' solution for the particular regulatory objective examined, that of 20% reduction in the level of P emissions. The first best solution is characterised by the equimarginal principle, meaning that under such a solution the marginal cost of pollution control are the same for all sectors. The first best solution can be achieved either through emission taxes or through a scheme of permits trading. Note that the price for a unit of emission permit is given by the shadow price of the relevant environmental constraint (Hanley *et al*,1997). Table 1 gives the main results of the unrestricted (baseline) and the restricted solutions.

The choice of a permit allocation scheme is efficient neutral in the sense that the regional welfare is not affected, given that all allocation schemes redistribute the same amount of permits. By contrast, a particular choice of a permit distribution rule affects the income distribution. Therefore, it was assumed that a social planner may opt for a specific allocation rule which achieves a secondary regulatory objective such as the reducing income inequality. To this end, the Atkinson index was estimated for the range of allocation rules examined in this study. The next section discusses the results derived from our regional model decomposed into the involved agricultural sectors, namely the arable and the livestock farming systems. The focus of permit trading between productive sectors is typical practise in the relevant literature (see (Harrison and Radov, 2002)), which is directly analogous to what Computable General Equilibrium (CGE) models do, in the sense that the results are often decomposed into countries or block of countries.

Table 1. *Farm Adjustment and Land Use Changes induced by Pollution Control.*
(Δ% stands for change)

	Baseline Solution	**Restricted Solution**	Δ%
Land Use (000's ha)			
Arable	4.154	3.27	-21.28
Permanent Grassland	1.678	1.678	-
Temporary Grassland	1.505	1.053	-30.03
Rough Grazing	0.58	0.58	-
Total Grassland	3.763	3.311	-12.01
Set-aside		1.336	
Total Land	7.917	7.917	
Livestock Grazing Units (000's GLU)			
Cattle	4.875	4.111	-15.67
Sheep	1.16	1.16	-
Total	6.035	5.271	-12.66
Phosphorus Load (tons)			
Arable	2.776	2.174	-21.69
Livestock	1.746	1.444	-17.30
Total	4.522	3.618	-20
Profits (000's £)			
Arable	3976.889	3215.025	-19.16
Livestock	4995.835	4261.227	-14.70
Total	8972.724	7476.252	-16.68

Results and Discussion

The regulator objective of a 20% reduction in the estimated emission level at a catchment scale is equivalent to issuing domestic transferable permits equal to the 80% of the unrestricted solution. The various permit allocation rules proposed by the regulator have distinct impact on agents' profits as predicted from equation (1). Table 2 shows the different permit allocation schemes used in this study and the resulting emissions permits held by the agricultural sectors in the region.

From Table 2 it is possible to characterise the various allocation rules on the basis of sectors' preferences. The arable sector, for example, prefers the allocation which is proportional to the intensity of environmental preferences, followed by the grandfathering rule on the basis of the P-load shares. In particular, the arable sector is allocated more permits under the rule which is proportional to the intensity of environmental preferences since it is found to have a substantial higher marginal abatement costs than livestock. In addition, the second-best preference for the arable sector is the grandfathering rule on the basis of historic emissions given that it has a sizeable contribution to the overall P-load. All the rest of the allocation methods favour the livestock sector, since livestock is less polluting and more profitable in comparison to the arable sector.

Table 2. Permits allocation induced by various permit allocation rules (tons of P)

Permit Allocation Rules	**Arable**		**Livestock**	
	Permits	Δ%	Permits	Δ%
1. Grandfathering				
1.1. Proportional to the baseline P-load share	2.221	2.16	1.397	-3.25
1.2. Proportional to the baseline income share	1.603	-26.26	2.014	39.47
1.3. Proportional to a compromise index	1.907	-12.28	1.710	18.42
2. Proportional to the intensity of environmental preferences	2.551	17.34	1.067	-26.11
3. Proportional to the ability to pay	2.014	-7.36	1.603	11.01
4. Proportional to an efficiency index	2.068	-4.88	1.550	7.34
5. First Best Solution	2.174		1.444	

Given that the initial distribution has an income effect, it follows that the impact of various permit allocation methods on sectors' profitability should be examined. This is presented in the following Table.

Table 3. Income by Sector resulting from various permit allocation rules (000's of £)

Permit Allocation Rules	**Arable**		**Livestock**	
	Permits	Δ%	Permits	Δ%
1. Grandfathering				
1.1. Proportional to the baseline P-load share	3300.6	2.66	4175.6	-2.01
1.2. Proportional to the baseline income share	2179.7	-32.20	5296.5	24.30
1.3. Proportional to a compromise index	2731.8	-15.03	4744.5	11.34
2. Proportional to the intensity of environmental preferences	3899.4	21.29	3576.9	-16.06
3. Proportional to the ability to pay	2925.9	-8.99	4550.4	6.79
4. Proportional to an efficiency index	3023.3	-5.96	4453.0	4.50
5. First Best Solution	3215.0		4261.2	

It is clear that the pattern of income effects follows directly the pattern of the initial distribution of emission permits. In particular, the arable sector has a strong preference for the allocation which is proportional to the intensity of environmental preferences because such an allocation brings about a 21.29 % increase in the sector's income compared to the first best solution. By contrast, the livestock sector prefers an allocation of permits in proportion to the income shares since under such a scheme the sector's income is 24.30 % higher than the reference one. Table 4 presents the estimated inequality indices for the likely allocation rules.

According to Atkinson (1975) there are two ways of interpreting the A index. For example, the value $A = 0.00081$ in Table 4, regarding the baseline scenario under the assumption that $\varepsilon = 0.5$, means that we could reach the same level of social welfare, if incomes were equally distributed, with only 99.92 % (1-0.00081=0.9992) of the present total income. Alternatively, the gain from redistribution to bring about equality would be equivalent to raising total income by 0.081 per cent. Admittedly, income inequality is not much of a problem for our case study since the estimated A indices in Table 4 reflect a rather equal distribution of income between the agents in the regional economy. In addition, as it was expected, the magnitude of the reduction in income inequality is conditional to the choice of the Atkinson Index, ε . In particular, the higher the social aversion towards inequality is the higher the welfare gains from redistribution.

Table 4. The Atkinson Index under various permit allocation rules

Permit Allocation Rules	**Atkinson Index**					
	$\varepsilon = 0.5$	Δ%	$\varepsilon = 1$	Δ%	$\varepsilon = 3$	Δ%
1. Grandfathering						
1.1. Proportional to the baseline P-load share	0.00086	6.11	0.0069	6.11	0.07908	5.85
1.2. Proportional to the baseline income share	0.01158	1328.52	0.0910	1305.60	0.66182	785.86
1.3. Proportional to a compromise index	0.00465	473.29	0.0369	470.00	0.35655	377.24
2. Proportional to the intensity of environmental preferences	0.00012	-85.65	0.0009	-85.63	0.01110	-85.14
3. Proportional to the ability to pay	0.00300	270.08	0.0239	268.86	0.24854	232.67
4. Proportional to an efficiency index	0.00232	185.57	0.0185	184.93	0.19817	165.26
First Best Solution	0.00123	52.00	0.0098	51.91	0.11121	48.85
Baseline Scenario (unrestricted)	0.00081		0.0065		0.07471	

Arguably, what really matters is the relative ranking of the likely allocations rules in terms of their impact on income inequality, so there are a few points that do deserve attention. First, the most interesting result is that the only permit allocation method which alleviates income inequality is the one which is proportional to the intensity of environmental preferences. Note that the reference point for such a comparison is the unrestricted solution. All the other rules increase income inequality. Second, the first best solution achieved by permits trading represents a solution which increases income inequality. Third, the most known method of allocating emission permits, that of grandfathering on the basis of baseline emissions only marginally worsens income inequality.

To recapitulate, the permit allocation method which is proportional to the intensity of environmental preferences is among the rare situations termed “win-win” solutions since it achieves two goals simultaneously. The first goal refers to efficiency (or cost-effectiveness) since a permit system achieves pre-specified targets at a minimum abatement cost, while the second refers to equality since the allocation rule on the basis of environmental preferences reduces the income inequality of the baseline scenario.

Conclusions

In this paper we have examined a range of permit allocation schemes for the case of phosphorus management in a small catchment in South England. Although the choice of an allocation rule is neutral in terms of efficiency it has an income effect. Assuming that in most cases the regulator seeks a number of objectives, one of which may be the reduction of income inequality, the choice of a permit allocation scheme comes naturally as the one that achieves the lower income inequality. On the basis of this paper's simulated results we have found that the allocation which is proportional to the intensity of environmental preferences reduces the initial income inequality between the agricultural sectors in the region in question. Finally, it should be stressed that although such a result may be conditional to the prevailing situations at the particular region in question (site–specific), the identified option of a "win-win" policy outcome is very promising and needs to be confirmed by similar studies before it is established as such.

Note

[1] The Pigou-Dalton condition says that, other things equal, transfers from rich to poor decrease inequality and vice versa (quoted by Sen (1976) p.27)

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