

A whiter shade of pale: on the political economy of environmental regulatory instruments

by

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Abstract: We consider an inter-temporal policy game between changing governments that differ in their attitudes towards environmental pollution. When in power a government will choose policy instruments and set strictness of regulation with a view to influencing the policy of future, possibly different, governments. We demonstrate that a ‘grey’ government favours pollution permits over effluent taxes, as permits establish property rights that are costly to reverse. Conversely, a ‘green’ government prefers to regulate by taxes, in order to limit the incentives of future ‘grey’ governments to ease regulations. Strategic behaviour tends to exaggerate policy differences, making ‘green’ governments ‘greener’, and ‘grey’ governments ‘greyer’, than if such strategic considerations were not an issue.

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1. Introduction

The economic analysis of environmental policy instruments has typically taken the preferences of government as given and fixed. However, governments – which in democracies will gain and lose power as time passes – have different views on the proper level of environmental protection and how environmental concerns should be balanced against industrial development.

The preferences of governments for environmental outcomes may be reflected in their choice of policy instruments. For example, different policy instruments will vary with respect to the ease with which governments can commit themselves and future governments to the set level of environmental protection. Considering the whims of voters, the consequent probability of losing their mandate and the leeway other governments of a different mind have to adopt new policies, this aspect of policy instruments may affect the decision of governments on environmental policies.

Two instruments – prices and quantities, or taxes and quotas – which have been thoroughly studied in relation to a plethora of economic and environmental characteristics provide a point in case.¹ A tax on emissions of a pollutant, say, is a flexible policy instrument: the tax rate can be changed in the budgetary process each year or even abolished without violating the rights of firms as protected by law.² Thus, the adoption of tax regulation and a given tax rate does not commit future governments to such policy; future governments can both adopt a higher or lower tax rate or change policy altogether and, for example, choose to regulate with emission quotas.

Controlling emissions of a pollutant by a system of tradable quotas allocated to individual firms may be described as involving two basic steps. First a target (or maximum) level of pollution is chosen and then some amount of quotas are allocated to polluting firms, usually

¹ While regulation by quotas and taxes is equivalent under certainty, Martin Weitzman showed in his seminal (1974) paper that in a static model with quadratic cost curves and uncertainty about marginal abatement costs, taxes, compared to quotas, become more attractive as a regulatory tool the greater is the slope of the marginal abatement cost function relative to the marginal environmental damage function. Weitzman's result was followed up by Adar and Griffin (1976), Fishelson (1976) and Roberts and Spence (1976) and has been generalised and refined in a large literature. Recent contributions include Baldursson and von der Fehr (1998, 2002).

² For the purposes of simplicity of exposition we shall assume that firms are the polluting agents.

on the basis of historical emissions (Stavins, 1999). The total volume of quotas allocated *may* be equal to the emission target, but may also be less than or greater than the target; in the two latter cases the authorities must act in the subsequently arising quota market selling or buying quotas, respectively, to equate the amount held by firms to the emission target.

The allocation of quotas involves an assignment of property rights to firms.³ These rights may be permanent or limited in time depending on the terms set when quotas are allocated, but, while they are in place ownership is protected by law. In particular, quotas cannot be expropriated without compensation to owners – the same applies to taxation of emissions which is so high as to amount to expropriation of emission rights. A quota system therefore commits present and future governments to the regime in a much stronger way than a tax regime does.

An important asymmetry between these instruments has to do with public finances: if a tax regime is in place, then, due to greater revenue losses, relaxing environmental policy by lowering taxes is more costly than doing so in a quota regime by increasing emission limits when some quotas have already been allocated. Conversely, it is less costly for the policy maker to enforce a stricter environmental policy by raising taxes than by cutting quotas.

In this paper we study, in a stylised two-party model, how different commitment levels of policy instruments affect governments' preferences for policy instruments. We focus especially on quota regimes and the ability of an incumbent government to influence future governments with (possibly) different attitudes towards pollution by allocating a smaller or larger amount of quotas. We begin with a simple four-stage set up where governments play a one-shot policy game, choosing regimes and their strictness at the outset knowing that with positive probability a new government may come into power at a later stage of the game and change the regime – if taxes were the instrument favoured initially – or its strictness, i.e. the tax rate or the quota allocated. Firms are non-strategic participants in the game, taking aggregate variables and the actions of governments as given when maximising their profits. Abatement activities only take place in the last stage of the game, whereas quota trading can begin in the first stage. Formally, this is a principal-agent set up where the incumbent is the

³ It may be argued that when the public interest demands that the use of a common property resource be regulated, allocation of rights of use, such as emission quotas, to agents that were already operating before the introduction of regulation, merely amounts to a formalisation of previously existing, indirect property rights.

principal and the future government the agent. The key idea is that the incumbent may prefer to choose a policy instrument, and a level of strictness of the instrument, that ties the hands of the future government to the largest possible degree. Similar games have been studied in the literature on political economy in a macroeconomic context, but we do not know of such work in the environmental economics literature.⁴

We begin by showing that in this particular set up the tax regime can be ‘simulated’ by allocating zero quotas in the quota regime. Therefore we can restrict the formal analysis to quota regimes in the one-shot game. The key result of our analysis is that the probability of being replaced by a government with different valuation of environmental damage leads governments to ‘exaggerate’ their ‘natural’ behaviour: governments which place a relatively low value on the environment (i.e. are ‘grey’) will – in an effort to tie the hands of future governments – allocate more quotas at the outset (and, in particular, will favour a quota regime) than they would have if they had been sure of re-election; governments which place a relatively high value on the environment (are ‘green’) will always favour zero allocation of quotas at the initial stage, in effect choosing a tax regime. The model and the analysis of the four stage game is presented in Sections 2-4.

In Section 5 we formulate a dynamic version of a game in which the two types of governments come and go out of power at random. We assume a quota regime is in place, effectively taking for granted that a grey government will use the first opportunity to put one in place. Again, the governments will engage in exaggerated behaviour, trying to tie the hands of one another, generating fluctuations in emission limits and quota prices. This model is reminiscent of the so-called ‘rational partisan’ model of Alesina (1987), which was designed to model political business cycles.

Section 6 concludes.

Thus no new rights are created or transferred on the introduction of a quota system with grandfathering allocation. In this paper we assume that quotas are auctioned off to firms; hence, no grandfathering takes place.

⁴ In the macroeconomic (monetary policy) context the seminal papers are those of Persson and Svensson (1989) and Alesina and Tabellini (1990). See also the reviews in Chapter 7 of Drazen (2000) and Chapter 13 of Persson and Tabellini (2000).

2. The modelling framework

We consider a model in which governments play a policy game, choosing instruments and their levels of strictness to achieve their ends to the highest possible degree. Firms, which are assumed to be infinitesimally small, identical and to take prices and other aggregate variables as given, are non-strategic participants in the game, responding only to the incentives created by the government so as to maximise their profits, but entertaining rational expectations about future developments.

2.1 *General assumptions*

We take decisions of the firms in goods and (non-environmental) factor markets, as well as their costs and profits prior to abatement activities, to be exogenous and given. All firms produce the same amount of pollutant prior to abatement, which we take to be equal to 1 without loss of generality. However, firms have access to abatement technology at some cost: if a firm emits an amount y of pollutant the cost to the firm is $c(y)$, where c is a smooth function, decreasing in y (the smaller the emissions the larger the costs to the firm) and convex (unit costs of abatement are increasing in the amount of abatement $a = 1-y$). Without loss of generality, we can take the mass of firms to be equal to 1 and, since firms are perfectly symmetric, aggregate emissions, denoted by Y , and aggregate cost of abatement, denoted by C , are equal to y and c , respectively. Since aggregate and firm level emissions and costs can be identified we do so and use the lower case letters for both variables in what follows.

There are two types of government, green (G) and grey (R). These types differ in their valuation of environmental damage of pollution. This is formalised by different social damage functions $D_i(y)$, $i = G, R$ which are assumed to be convex, smooth and increasing in aggregate emissions of the pollutant. The green government is assumed to value the costs of environmental damage higher than the grey, *viz.*

$$\begin{aligned} D_G(0) = D_R(0) = 0, \text{ and} \\ D'_G(y) > D'_R(y), \text{ for all } y \in [0,1] \end{aligned} \tag{1}$$

2.2 *The four-stage game*

In the simplest version of our model the governments play a four-stage game. We describe the four stages in order below.

Stage 1

In the *first* stage of the game the present government chooses the instrument it wants to use and sets tax rate or allocates quotas according to its preferences, taking into account the possible events in later stages of the game. If a quota regime is implemented, an amount, q of quotas is allocated to firms. Apart from the formal difference between instruments – one setting price of emissions and the other their quantity – there is an important additional distinction between the two policy instruments, *viz.* that if a quota regime is adopted, later governments cannot abolish it, but can only change the aggregate amount of quotas held by firms through transactions in the market for quotas.⁵ The implementation of a quota system is therefore assumed to be an irreversible decision tying the hands of later governments through the creation of property rights.⁶ If a quota system is adopted at this stage, quotas are allocated by a market mechanism, e.g. through the auctioning of quotas. Firms – the buyers and users of quotas – are assumed to entertain rational expectations about future events and in particular the quota price at Stage 1 will, in equilibrium, be equal to the expected quota price in Stage 3 below.

Stage 2

In the *second* stage of the game there is an election and there may be a change in government. We assume this is a random event, probabilistically independent of prior events.⁷ Thus a green government is elected with probability $p \in (0,1)$ and a grey government is elected with probability $1-p \in (0,1)$. Note that the probability of election or re-election is independent of the policies set by the government in the first stage of the game.

Stage 3

⁵ In principle, a future government could, at later stages, repurchase all outstanding quotas and implement a tax system. We ignore this possibility (which in any case would almost surely be suboptimal) in our model.

⁶ This is of course a strong assumption; rarely are property rights so perfectly enforced, see e.g. Rose (2000).

⁷ Clearly this model can be generalised, e.g. to Markovian probabilities of transition where the probability of election of a given type of government depends on what type was in power prior to the election. Also, the actions of the government might be assumed to influence its chances of re-election. These are elements of the ‘New Political Economy’ (see Alesina and Tabellini (2000) and Drazen (2000)). Keohane, Revezs and Stavins (1998) focus on the interaction between interest groups and legislators. The former have ‘demands’ for particular instruments, the latter provide political support, or ‘supply’ for such instruments.

In the *third* stage of the game the government now in power re-evaluates the environmental policy. If taxes were chosen as the instrument of regulation at Stage 1, the new government may change the tax rate or abolish tax regulation altogether and regulate by quotas instead. If, however, a quota regime was put in place at Stage 1 the government can only change its emission target. Moreover, this must be done in the marketplace; if the government desires lower emissions than are covered by firms' quota holdings carried in from Stage 1 it must purchase quotas from firms. If it deems higher emissions are justifiable it can allocate additional quotas.

Stage 4

In the *fourth* and last stage of the game firms make their abatement decisions. We assume their choices are based on profit maximisation, or equivalently in our model, minimisation of the costs of abatement, subject to the regulatory constraints and costs they face.

Analysing the model

As usual with this type of model the analysis proceeds backwards – from the last stage to the first one. We do this in the next two sections.

3. Model analysis: stages 3 and 4

3.1 Tax regime

We first consider the case in which a tax regime is chosen at Stage 3. Then, at Stage 4, firms minimise total cost of emissions $c(y) + ty$, so that the first order condition for optimal abatement is

$$-c'(y) = t. \quad (2)$$

Differentiating with respect to t on both sides we get

$$\frac{dy}{dt} = -\frac{1}{c''(y)} < 0 \quad (3)$$

At Stage 3, the government chooses a tax rate to minimise net aggregate cost of emissions. This is given by the sum of environmental damage – as valued by the type of government in power – and abatement costs less the tax revenue multiplied by the marginal cost of funds to the government, ***m***

$$W_i(y, t) = c(y) + D_i(y) - \mathbf{m}y, \quad i = G, R. \quad (4)$$

The government will minimise W_i subject to (2) above.⁸ The first-order condition for this problem may be written:

$$c'(y^T) + D'_i(y^T) = \mathbf{m} \left[1 - \frac{1}{\mathbf{e}} \right], \quad (5)$$

where y^T is the optimal tax rate and

$$\mathbf{e} = - \left. \frac{dy}{dt} \frac{t}{y} \right|_{y=y^T} = \frac{-c'(y^T)}{y^T c''(y^T)} > 0 \quad (6)$$

is the elasticity of emissions with respect to the tax rate. Hence, strictness of emissions tax policy depends on the elasticity of emissions with respect to the tax rate:

$$c'(y^T) + D'_i(y^T) > (<) 0 \Leftrightarrow \mathbf{e} > (<) 1. \quad (7)$$

3.2 Quota regime

We next consider the case in which a quota regime was implemented at Stage 1 and it was decided to allocate an aggregate amount of quotas, Q , to firms. Recall that firms are symmetric so the quota allocated to each firm, q , is equal to the aggregate amount and as with emissions and costs we identify the aggregate and firm level variables, using the lower case letter for both.

At Stage 4, the total cost of emissions of a firm emitting y amount of pollution, holding quota q and taking the market price of quotas p as given, is $c(y) + p[y - q]$. The firm will minimise this expression, which leads us to the first order condition

$$-c'(y) = p. \quad (8)$$

Analogously to the tax case

$$\frac{dy}{dp} = - \frac{1}{c''(y)} < 0. \quad (9)$$

⁸ Recall that aggregate emissions (Y) and emissions at the representative firm (y) are equal. The same applies to aggregate costs of abatement (C) and firm level costs of abatement (c).

At Stage 3 the government – new or old – will set a new emission target (or reaffirm its prior one) which we denote by \bar{y} . Note that if $\bar{y} \neq q$ the government must buy or sell quotas to achieve its emissions goal. Funds raised by auctioning of quotas at Stage 3 are equal to $p[\bar{y} - q]$ (if this expression is negative the government decided to buy back some quotas). The net cost of emissions is therefore valued by the government to be

$$W_i(\bar{y}, q) = c(\bar{y}) + D_i(\bar{y}) - mp[\bar{y} - q], \quad i = G, R, \quad (10)^9$$

and will be minimised subject to (8) above. Note that in quota market equilibrium (8) must hold with \bar{y} substituted for y . The first-order conditions for this problem may therefore be written:

$$\begin{aligned} c'(y_i) + D'_i(y_i) &= mp \left[1 - \frac{y_i - q}{y_i} \frac{1}{e} \right], \\ p &= -c'(y_i) \end{aligned} \quad (11)$$

where y_i is the optimal emission target (note that we dispense with the bar to indicate an emission limit) and

$$e = - \left. \frac{dy}{dp} \frac{p}{y} \right|_{y=y_i} = \frac{-c'(y_i)}{y_i c''(y_i)} > 0 \quad (12)$$

is the elasticity of emissions with respect to the quota price.

Now suppose a tax regime was selected at Stage 1. Then, obviously, no quotas are carried by firms into Stage 3. However, it is clear that the analysis above still holds with $q = 0$.

Furthermore, by comparing (11) and (5) we see that the optimal choice of an emission target of a given type of government in the quota regime will be equivalent to the optimal choice of tax in the tax regime if, and only if, $q = 0$, i.e. there were no quotas allocated to firms at Stage 3.

Consequently, if a tax regime was adopted at Stage 1 or if a quota regime was selected with no quotas allocated, governments will be indifferent at Stage 3 between a tax regime and a quota regime. By the same token, at Stage 1 governments will be indifferent between choosing a tax regime and a quota regime with zero quotas. This implies that governments

⁹ We abuse notation by using the same symbol for aggregate cost in a tax regime and a quota regime.

can achieve the ends they want within a quota regime and we may as well disregard the possibility of choosing a tax regime. In what follows we do this and in effect assume a quota system is already in place at the start of the game. A government then only has the choice of amount of quotas it allocates at Stages 1 and 3.

We can rewrite the first order condition (11) as

$$D'_i(y_i) = -c'(y_i) - \mathbf{m}\{c''(y_i)[y_i - q] + c'(y_i)\}. \quad (13)$$

Note that if we allow y to vary we can interpret the right hand side of (13) as an ‘adjusted’ marginal benefits curve, i.e. marginal benefits to firms of allowing an extra unit of polluting, adjusted for the marginal benefits of government income from selling the added quotas. The optimal quota is given by the intersection of the damage curve and the adjusted benefits curve. These curves are shown in Figure 1 for both types of government.

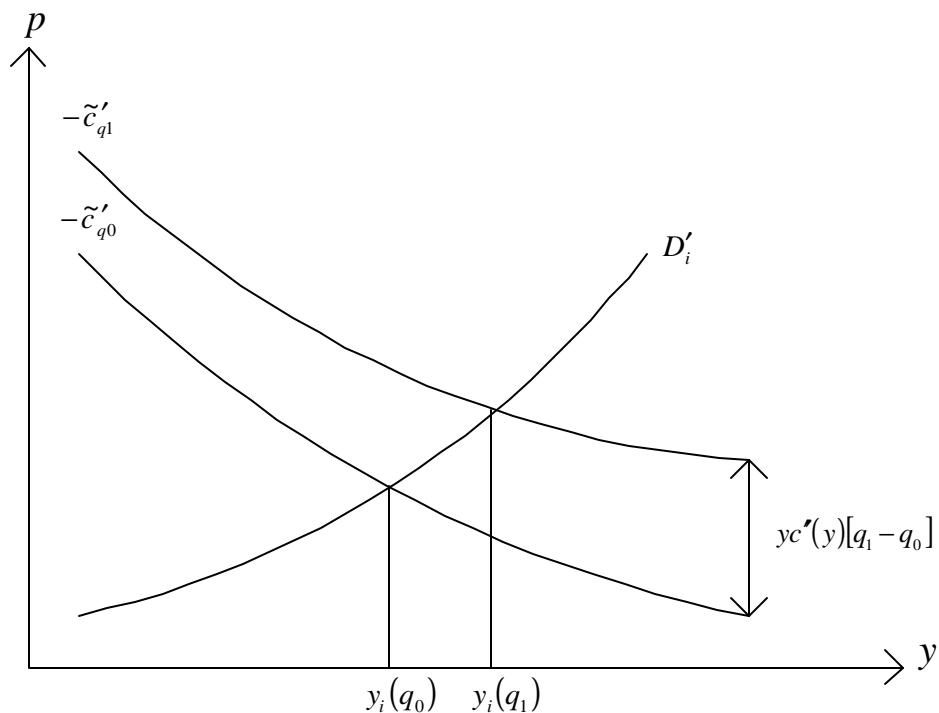


Figure 1:

The ‘adjusted’ marginal benefits curve with marginal damage curves for the two types of governments. y_i^* , $i = G, R$ are the ‘first-best’ emission limits where $D'_i = -c'$, whereas y_i , $i = G, R$ are the optimal emission limits for governments of type G and R , respectively.

Observe that since the marginal benefit curve is independent of the type of government and the damage curve shifts up from a grey government to a green one, the following is immediate:

Result: For a given amount of quotas carried into Stage 3 a grey government will always allocate more quotas at that stage than a green government, i.e. $y_G < y_R$.

The above result is also easily confirmed analytically from the first-order conditions. It is worth noting that if $y_i > q$ it may coincide with the first-best, i.e. when $D'_i(y) = -c'_i(y)$, but in general this is not the case and the emission limit may be higher than or lower than the first best level. If $y_i < q$, then the emission limit is unambiguously higher than the first best level.

The second derivative of the total costs of pollution is given by,

$$H(y, q) = c''(y) + D_i''(y) + \mathbf{m}[c'''(y)[y - q] + 2c''(y)], \quad (14)$$

and the second order condition for a minimum at y_i is of course that

$$H(y_i, q) > 0. \quad (15)$$

It is of interest to study the dependence of y_i on q . If we differentiate the first order condition

$\frac{\partial}{\partial y} W_i(y_i(q), q) = 0$ with respect to q and solve for $\frac{dy_i}{dq}$ we get

$$\frac{dy_i}{dq} = -\frac{\frac{\partial^2}{\partial q \partial y} W_i(y_i, q)}{\frac{\partial^2}{\partial y^2} W_i(y_i, q)} = \frac{\mathbf{m}c''(y_i)}{H(y_i, q)} > 0. \quad (16)$$

Hence we have the following

Result: Irrespective of the type of government, the emission limit y_i is an increasing function of quota allocation, q , at Stage 1.

We illustrate the above result graphically in Figure 2.

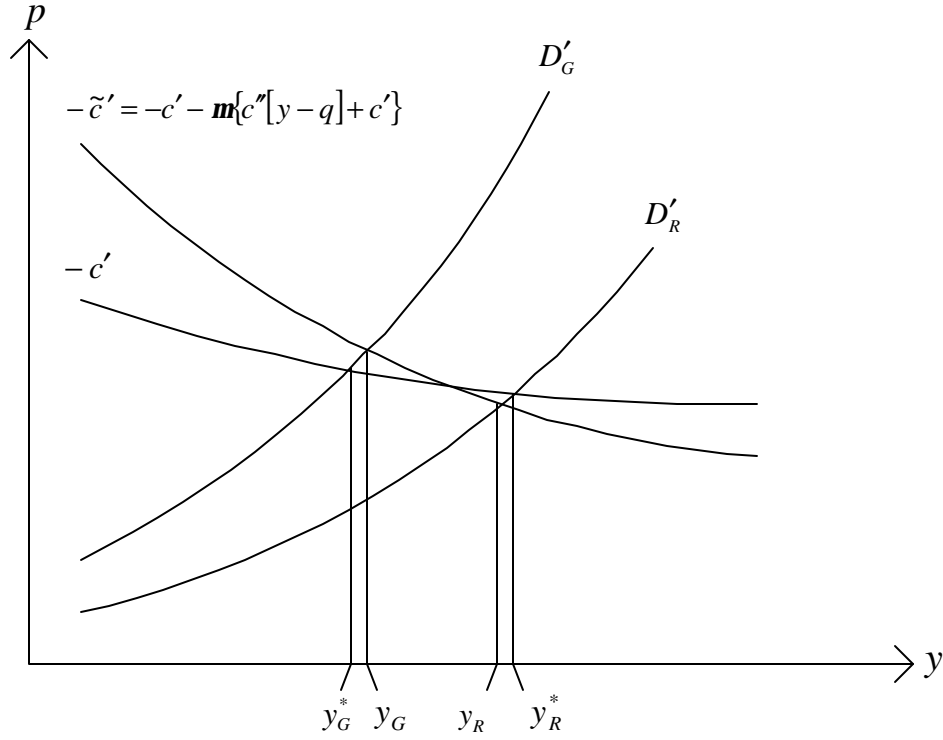


Figure 2:

Note from the right hand side of equation (13) that for a fixed y the marginal benefit curve is increasing in q . Therefore, as q increases from q_0 to q_1 the marginal benefit curve is shifted upwards from $-\tilde{c}'_{q_0}$ to $-\tilde{c}'_{q_1}$. The marginal damage curve is unchanged, however, and therefore the optimal emission level is increased from $y_i(q_0)$ to $y_i(q_1)$.

Finally, in this section, we analyse the dependence of the quota price on the initial quota. From (8) we get

$$p_i(q) = -c'(y_i(q)), \quad (17)$$

where $p_i(q)$ is the quota price at Stage 4 under government of type i with initial quota q .

Using (17), (16) and the convexity of c we have

$$\frac{dp_i(q)}{dq} = -c''(y(q)) \frac{dy_i}{dq} < 0. \quad (18)$$

Hence, quota prices are decreasing in the amount of initial quota, in accordance with intuition.

4. Model analysis: stages 1 and 2

We now analyse the decisions of a government at the outset of the game. Recall that we work with quota systems only and a government is therefore restricted to choosing the amount of

quotas allocated, q , rather than being allowed a choice of regime as in the initial version of the model. We assume the quotas are auctioned off to firms that will have use for them at Stage 4. Furthermore, we assume firms entertain rational expectations about election results and actions of future governments. Firms are risk neutral and the price of quotas will therefore find an equilibrium where it is equal to the expected price of quotas at Stage 4.

Governments are also assumed to be rational and take their chances of re-election and the actions of future governments into account. They also value income from quota sales in the same way as at Stage 3.

Governments at Stage 3 will only respond to the amount of quota carried in, ignoring the type of the initial government. Therefore, irrespective of government, the expected quota price at Stage 1 is given by

$$\bar{p}(q) = \mathbf{p} p_G(q) + [1 - \mathbf{p}] p_R(q), \quad (19)$$

where we have indicated the dependence of future (Stage 4) prices on the initial quota and type of government.

4.1 Grey government at Stage 1

Suppose a grey government is in power at Stage 1. Then that government will value the action of a possible future green government on its own scale. Hence, expected total costs of emissions, taking into account the possibility of a change in government and realising that firms have rational expectations, may be written:

$$\bar{W}_R(q) = \mathbf{p} W_R(y_G(q), q) + [1 - \mathbf{p}] W_R(y_R(q), q) - \mathbf{m} \bar{p}(q) q \quad (20)$$

The government will want to minimise $\bar{W}_R(q)$ with respect to q . Application of the Envelope Theorem (to the second term on the right hand side of the equation) and the definition of the welfare measure, leads to the following simplification of the derivative of \bar{W}_R with respect to q :

$$\frac{d\bar{W}_R}{dq} = \mathbf{p} \left. \frac{\partial W_R}{\partial y} \right|_{y=y_G(q)} \cdot \frac{dy^G}{dq} - \mathbf{m} q \frac{d\bar{p}}{dq}. \quad (21)$$

Since $y_G < y_R$ and by the first order condition for the optimality of y_R in the case of a grey government we have that

$$\left. \frac{\partial W_R}{\partial y} \right|_{y=y_R(q)} < 0. \quad (22)$$

By (16) and (22) the first term of (21) is negative, whereas by (18) the latter term is positive.

It is also clear that for $q=0$, $\frac{d\bar{W}_R}{dq} < 0$. Therefore, the grey government will want to increase q up to an interior optimum where $\bar{W}_R(q)$ attains its minimum or some maximal level of q if an interior optimum is not attainable. In what follows we assume an interior minimum is attained.

Consider the case in which a grey government can be sure of re-election, i.e. $1 - \pi = 0$. Then (20) simplifies to

$$\begin{aligned} \bar{W}_R(q) &= W_R(y_R(q), q) - \mathbf{m}p_R(q)q \\ &= c(y_R) + D_R(y_R) + \mathbf{m}c'(y_R)y_R. \end{aligned} \quad (23)$$

Differentiating with respect to q , we get

$$\frac{d\bar{W}_R(q)}{dq} = \left[c'(y_R) + D'(y_R) + \mathbf{m} \left[c'(y_R) + c''(y_R)y_R \right] \right] y'_R. \quad (24)$$

Note that y_R is a minimum of W_R and therefore satisfies the first-order condition (13). Therefore

$$c'(y_R) + D'(y_R) + \mathbf{m} \left[c'(y_R) + c''(y_R)y_R \right] = \mathbf{m}c''(y_R)q \quad (25)$$

and

$$\frac{d\bar{W}_R(q)}{dq} = \mathbf{m}c''(y_R)qy'_R. \quad (26)$$

Recalling the convexity of c and the positive slope of $y_R(q)$ (recall (16)) we can conclude from (26) that $\frac{d}{dq}\bar{W}_R(q) \geq 0$ with strict inequality holding for positive q , but equality at $q = 0$. Thus, the first-order condition for a minimum at $q = 0$ is satisfied for the case of certain re-election of the grey government. This is in contrast to the case analysed above where re-election is not certain and the grey government will allocate a positive amount of quotas at Stage 1. We therefore have the following result:

Result: If there is a positive probability of a green government coming into power at Stage 2, a grey government behaves in a ‘darker shade of grey’ (i.e. it hands out more pollution quotas) at Stage 1 than it would if it were certain of re-election.

4.2 *Green government at Stage 1*

Now consider the situation in which a green government is in power at Stage 1. In an analogous manner to (20) we derive its cost as a function of q to be:

$$\bar{W}_G(q) = \mathbf{p}W_G(y_G(q), q) + [1 - \mathbf{p}]W_G(y_R(q), q) - \mathbf{m}\bar{p}(q)q. \quad (27)$$

The first derivative of $\bar{W}_G(q)$ with respect to q simplifies to

$$\frac{d\bar{W}_G}{dq} = (1 - \mathbf{p}) \left. \frac{\partial W_G}{\partial y} \right|_{y=y_R(q)} \cdot \frac{dy_R}{dq} - \mathbf{m}q \frac{d\bar{p}}{dq}. \quad (28)$$

Since $\frac{dy_R}{dq} > 0$ and $y_R > y_G$, the first term of (28) is positive and (by the same arguments as for (21)) so is the second term. It is immediate that the green government will always allocate zero quotas at Stage 1. If negative quotas were allowed at Stage 1 the green government would prefer to use that option.

Note, however, that if the green government could be sure of re-election i.e. $\pi = 0$, then it is easily shown in an analogous manner to the argument for the grey government that $q = 0$ is an unconstrained optimum for the green government. It therefore behaves in a ‘greener’ manner¹⁰ than it would otherwise do if it is not sure of re-election.

4.3 *Linear example*

For purposes of illustration we work out a linear example as a specific case of the above analysis. This also serves as a preparation for the dynamic model of Section 5.

Assume that the marginal benefits of emissions (reduced abatement costs) are given as

$$-c'(y) = \mathbf{a} - \mathbf{b}y, \quad (29)$$

where $\mathbf{a}, \mathbf{b} \geq 0$ are non-negative constants. Assume further that the functional form, irrespective of the type of government, of the marginal damage of emissions is given by

¹⁰ Or a ‘whiter shade of pale’.

$$D'(y) = \mathbf{g} + \mathbf{d}y, \quad (30)$$

where $\mathbf{g}, \mathbf{d} \geq 0$ are non-negative constants.

Inserting in (11) and solving, we find the *ex post* optimal emissions limit and corresponding quota price:

$$\begin{aligned} \bar{y}_g(q) &= \frac{\mathbf{a}[1+\mathbf{m}] - \mathbf{g} + \mathbf{m}\mathbf{b}q}{\mathbf{b}[1+2\mathbf{m}] + \mathbf{d}} \\ p_g(q) &= \frac{\mathbf{a}[\mathbf{d} + \mathbf{m}\mathbf{b}] + \mathbf{b}\mathbf{g} - \mathbf{m}\mathbf{b}^2q}{\mathbf{b}[1+2\mathbf{m}] + \mathbf{d}} \end{aligned} \quad (31)$$

Assume that the governments differ with respect to the intercept term of the marginal damage function only, with $\mathbf{g}^G > \mathbf{g}^R$. Let $\bar{\mathbf{g}}^G = \mathbf{p}\mathbf{g}^R + [1-\mathbf{p}]\mathbf{g}^G$ ($\bar{\mathbf{g}}^R = \mathbf{p}\mathbf{g}^G + [1-\mathbf{p}]\mathbf{g}^R$) be the expected value of the intercept term given that the initial government is green (grey).

Then, if the initial government is grey, the *ex ante* expected quota price becomes

$$\bar{p}^R(q) = \frac{\mathbf{a}[\mathbf{d} + \mathbf{m}\mathbf{b}] + \mathbf{b}\bar{\mathbf{g}}^R - \mathbf{m}\mathbf{b}^2q}{\mathbf{b}[1+2\mathbf{m}] + \mathbf{d}}. \quad (32)$$

Substituting into the first-order condition (21) and solving, we find the optimal initial quota allocation of a grey government:

$$q^R = \frac{\mathbf{p}[\mathbf{g}^G - \mathbf{g}^R]}{\mathbf{m}\mathbf{b}} > 0. \quad (33)$$

Inserting into this expression into (31), we find equilibrium emissions for each realisation of the *ex post* government (again, given that the initial government is grey):

$$\begin{aligned} y_{R,G} &= \frac{\mathbf{a}[1+\mathbf{m}] - \mathbf{g}^G + \mathbf{p}[\mathbf{g}^G - \mathbf{g}^R]}{\mathbf{b}[1+2\mathbf{m}] + \mathbf{d}} \\ Y_{R,R}^Q &= \frac{\mathbf{a}[1+\mathbf{m}] - \mathbf{g}^R + \mathbf{p}[\mathbf{g}^G - \mathbf{g}^R]}{\mathbf{b}[1+2\mathbf{m}] + \mathbf{d}} \end{aligned} \quad (34)$$

Note that, in either event, emissions exceed the levels in the corresponding tax case (if the initial government were green the opposite result would emerge).

The *ex ante* expected value and variance of emissions become

$$\begin{aligned}
E(Y_R) &= \frac{\mathbf{a}[1+\mathbf{m}]-\bar{\mathbf{g}}^R + \mathbf{p}[\mathbf{g}^G - \mathbf{g}^R]}{\mathbf{b}[1+2\mathbf{m}] + \mathbf{d}} \\
\text{var}(Y_R) &= \mathbf{p}[1-\mathbf{p}] \left\{ \frac{\mathbf{g}^G - \mathbf{g}^R}{\mathbf{b}[1+2\mathbf{m}] + \mathbf{d}} \right\}^2
\end{aligned} \tag{35}$$

Result (linear case): A grey government would strategically allocate quotas initially so that, compared to in the tax regime, the distribution of emissions is skewed towards higher levels without, however, affecting the variance of the distribution.

5. A dynamic model

In this section we sketch a dynamic model where governments are elected into and out of power in the same manner as in Stage 2 of the one-shot game above. We restrict our attention to a quota system. This is based on what is still a conjecture based on the simpler four stage game of Sections 2-4, *viz.* that a grey government will always adopt a quota system in favour of a tax regime when it has the chance to do so.

We assume the game is now played on an infinite horizon. Time is measured in discrete units, assumed to be fixed in length and corresponding to terms of governments. The participants of the game include the same as before, *i.e.* the two types of governments and firms that operate under the same conditions as before, *i.e.* those described in Section 2.1. Benefits and costs are brought to present value terms by a discount factor $\mathbf{b} \in (0,1)$. As in the four-stage game we assume quotas are absolutely permanent assets – property perfectly protected by law.

A new government is elected at the beginning of each term; a green one with probability π – a grey one with probability $1-\pi$. Let I_t denote the type of government elected for term t . Then $\{I_t; t = 0,1,2,\dots\}$ is a sequence of i.i.d. random variables with

$$P\{I_t = G\} = \mathbf{p} = 1 - P\{I_t = R\}. \tag{36}$$

In term t firms carry y_{t-1} quotas into the term and the newly elected government will want to set a new emission limit y_t . Firms will abate pollution until marginal cost of abatement equals the current rental price of quotas:

$$-c'(y_t) = r_t. \tag{37}$$

For inter-temporal equilibrium in the quota market, it must hold that the quota price in the present term is equal to the rental price if quotas in the period plus the discounted expected quota price of next term:

$$p_t = r_t + \mathbf{b}E p_{t+1} \quad (38)$$

Applying (38) recursively we come to the result that the price of permanent quotas will be the expected present value of future rental prices:

$$p_t = \sum_{j=0}^{\infty} \mathbf{b}^j E [r_{t+j}]. \quad (39)$$

The government must buy or sell quotas to achieve its emission limit. If $y_t > y_{t-1}$ the government will sell $y_t - y_{t-1}$ quotas at an auction; if $y_t < y_{t-1}$ it will buy back $y_{t-1} - y_t$ quotas from firms. The term (stage) cost of the game is

$$w_i(y_t, y_{t-1}) = c(y_t) + D_i(y_t) - \mathbf{m}p_t [y_t - y_{t-1}], \quad i = G, R, \quad (40)$$

and the expected present value of present and future costs is

$$W_i(y_t, y_{t-1}) = w_i(y_t, y_{t-1}) + \sum_{j=1}^{\infty} \mathbf{b}^j E [w_i(y_{t+j}, y_{t-1+j})]. \quad (41)$$

Of course the present government can only control its policy in its own term. It can, however, influence later governments by setting the conditions under which they operate, e.g. which level of quotas firms bring into the next term, which in turn will influence the government after that etc. A government of type i in term t will therefore choose y_t so as to minimise $W_i(y_t, y_{t-1})$ entertaining rational expectations about the political process I and behaviour of future governments. Given quotas carried in $y_{t-1} = y$, denote the optimal cost by $\hat{W}_i(y)$ and the optimal policy by $y^i(y)$. Note that since our set up is time homogenous we can safely assume these functions are independent of the time argument. The sequence of future policies is then a random process, given recursively by

$$y_{t+j} = y^{I_{t+j}}(y_{t+j-1}), \quad j = 1, 2, \dots \quad (42)$$

It is fairly clear that in the repeated game formulated above – as in the one-shot game – grey governments will allocate more quotas than green ones when faced with the same amount of quotas carried into a term. Furthermore it seems likely that when governments are uncertain

about re-election, in an effort to tie the hands of future governments, incumbents will engage in 'exaggerated' behaviour, i.e. green governments will allocate fewer quotas than they would have under certain re-election and grey governments will allocate more quotas. Intuitively, it seems this will happen in stages, so that when, say, a 'grey' government comes into power after a 'green' government has held the reins there will first occur an abrupt increase in the allocation of quotas followed by more gradual increases in subsequent terms of the 'grey' government. The opposite will occur with a 'green' government: it will decrease quotas abruptly when coming into power and reduce quotas more gradually in the following terms it holds its mandate. Finally, average pollution will lie between the different levels different types of government would choose if they were permanently in power.

6. Conclusion

We have studied inter-temporal policy games between governments which differ in their attitudes towards pollution. We have argued that, from a strategic policy point of view, effluent taxes and quotas have very different characteristics. A tax is a flexible policy instrument that is easily adjusted; however, easing regulations by reducing the tax rate is costly in revenue terms. Quotas, on the other hand, are inflexible as established property rights cannot be altered without the consent of the holder of these rights; however, given that some quotas have already been issued, easing regulations by issuing more quotas is relatively cheap. It follows that a 'green' government prefers taxes while a 'grey' government prefers quotas. Moreover, when a quota regime is established (which it will be once a 'grey' government has taken power) a 'green' government will purchase quotas, and a 'grey' government will sell quotas, with a view to influencing future policy; consequently, strategic considerations tend to exaggerate inherent policy differences.

7. References

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