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On the Design of Optimal Grandfathering Schemes for Emission Allowances

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Non-technical summary

To meet its emissions reduction commitment under the Kyoto Protocol, the EU plans to implement an emissions trading system within the European Community which covers large installations of energy-intensive industries. An important element of the Directive left open to Member States is the grandfathering mechanism of allowances across industries (installations). Several metrics have been proposed for the allocation of allowances across production facilities, most notably output-based approaches or emission-based approaches. However, dynamic grandfathering schemes which take production or emission levels as a basis for allocation can lead to strategic behavior of firms with adverse implications for overall economic efficiency. With respect to policy guidance, a key challenge from an economic point of view is to identify allocation rules that minimize efficiency losses.

In this paper, we study first- and second-best allocation rules for dynamic grandfathering schemes with concretions to an open or a closed emissions trading system:

- For (small) open trading systems where allowance prices are exogenous, first-best second-period grandfathering schemes must not depend on firm-specific decisions in the initial period. Second-best schemes are based on a weighted combination of first-period output and emission levels. They correspond to a Ramsey-type rule of optimal tax differentiation: The more inelastic output (emissions), the larger should be the weight to output (emissions). This highlights the importance of firms' (sectors') characteristics when designing a grandfathering scheme.

- If the emissions trading system is closed, first- and second-best rules coincide. To preserve efficiency, grandfathering must not depend on previous output levels. Optimal grandfathering schemes consist of an assignment proportional to the emissions in the first period plus a term which does not depend on firm-specific decisions in either of the two periods. The proportionality factor must not differ between firms (sectors).

On the Design of Optimal Grandfathering Schemes for Emission Allowances

by

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Abstract: To meet its commitment under the Kyoto Protocol, the EU plans to implement an emissions trading system whith grandfathering of allowances. Besides having distributional impacts, the choice of the grandfathering scheme may affect efficiency if firms anticipate how future allocations depend on upcoming decisions. In this paper, we determine central design rules for optimal grandfathering within a simple two-period model. We find that for (small) open trading systems, where allowance prices are exogenous, first-best second-period grandfathering schemes must not depend on firm-specific decisions in the first period. Second-best schemes correspond to a Ramsey rule of optimal tax differentiation and are generally based on both previous emissions and output. However, ofr closed emissions trading systems, i.e. endogeneous allowance prices, first- and second-best rules coincide and must not depend on previous output levels. They consist of an assignment proportional to the emissions in the first period plus a term which does not depend on firm-specific decisions in either of the two periods.

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1 Introduction

To meet its emissions reduction commitment under the Kyoto Protocol, the EU plans to implement a emissions trading system within the European Community (EU 2001) which covers large installations of energy-intensive industries. It is envisaged to link the trading scheme with other (non-EU-)schemes and project-based mechanisms like Joint Implementation (JI) and Clean Development Mechanism (CDM) under the Kyoto Protocol (UNFCCC 1997). The proposed scheme consists of several temporal stages: a first phase from 2005 until 2007, a second one from 2008 until 2012, coinciding with the launch of the Kyoto Protocol, and subsequent five-year-periods covering Post-Kyoto commitment periods. Member States will allocate emission allowances for free (grandfathering) until 2008 and can auction 10 per cent of the allowances in the second phase.

An important element of the Directive left open to Member States is the grandfathering mechanism of allowances across industries (installations). Several metrics have been proposed (Harrison and Radov 2002) for the allocation of allowances across production facilities, most notably output-based approaches (e.g. kilowatt-hours of electricity production) or emission-based approaches (e.g. tons of CO_2 emissions). With respect to policy guidance, a key challenge from an economic point of view is to identify allocation rules that preserve overall economic efficiency.

Grandfathering schemes lead to efficiency losses if firms can increase their grandfathered amount by choosing higher production or emission levels.[1] As a consequence, the literature has stressed the importance of static grandfathering schemes which are only based upon historical information. Abstracting from income and terms-of-trade-effects, the different metrics then simply have varying distributional impacts but leave production plans of firms unaffected. Grandfathering boils down to non-distortionary lump-sum transfers of allowances (Laan and Nentjes 2001; Woerdman 2001).

However, grandfathering schemes which take historical emissions as a basis for allocation within continuous planning cannot completely circumvent the problem of distor-

[1] For example, initial allocation can be based on past emissions or on standards from a previous command-and-control system. Within the European emissions trading scheme, Germany discusses to use (relative) emissions in 1990 as a basis for grandfathering, in order to not reward firms for "early actions".

tions: Upcoming firms' decisions will determine the emission levels that are "historical" in subsequent periods. For example, grandfathering in 2013-2017 might be based upon activities in 2008-2012. Dynamic grandfathering schemes that employ updated information along the time-path in general lead to strategic behavior of firms and, hence, also affect economic efficiency.

Dynamic incentives of grandfathering are studied by Laplante et al. (1997). They show that for specific grandfathering schemes strategic behavior of oligopolistic firms during the transition from a command-and-control regime to emissions trading does not necessarily imply welfare losses. In their setting, the aggregate emissions level is endogeneous.

The focus of our paper is different. We develop a simple two-period emissions trading framework to determine general design rules for optimal dynamic grandfathering schemes where the allocation of allowances can be based on output or emission levels of the previous period. Grandfathering, then, acts as a subsidy to production or emissions. We therefore relate the discussion of optimal grandfathering schemes to rules of optimal taxation. We find that the design of optimal grandfathering schemes crucially depends on whether the emissions trading system is closed or open to a larger (the world) market:

- For (small) open trading systems where allowance prices are exogenous, first-best second-period grandfathering schemes must not depend on firm-specific decisions in the initial period. Second-best schemes are based on a weighted combination of first-period output and emission levels. They correspond to a Ramsey-type rule of optimal tax differentiation: The more inelastic output (emissions), the larger should be the weight to output (emissions) in the grandfathering rule. In the extreme case, grandfathering is exclusively based on output (emissions). This highlights the importance of firms' (sectors') characteristics when designing a grandfathering scheme.

- If the emissions trading system is closed, first- and second-best rules coincide. To preserve efficiency, grandfathering must not depend on previous output levels. The optimal grandfathering scheme consists of an assignment proportional to the emissions in the first period plus a term which does not depend on firm-specific decisions in either of the two periods. The proportionality factor must not differ between firms (sectors). Although acting like a subsidy to emissions, this grandfathering scheme cannot lead to an increase of emissions in a closed system, and therefore only affects the nominal allowance price.

The remainder of this paper is organized as follows: We first describe our basic model and show the correspondence between grandfathering and subsidies. We then derive and discuss the conditions for first- and second-best grandfathering rules in the open and the closed emissions trading system. Policy implications are discussed and illustrated for some specific cost structures. Finally, we conclude.

2 Analytical Framework

We set up a simple two-period partial equilibrium model.[2] Firm (sector) i's technology in period t ($t = 1, 2$) is given by its cost function $c^{it}(q^{it}, e^{it})$ where q^{it} denotes the output level and e^{it} the emissions emerging from production. As usual, costs c^{it} are assumed to be twice differentiable and convex with $c^{it}_q = \partial c^{it}/\partial q^{it} > 0$; $c^{it}_e = \partial c^{it}/\partial e^{it} \leq 0$; $c^{it}_{qq}, c^{it}_{ee}, -c^{it}_{eq} \geq 0$; and $c^{it}_{qq} \cdot c^{it}_{ee} - (c^{it}_{eq})^2 > 0$. The firm sells output q^{it} at a competitive consumer price p_t, and must hold allowances for emissions e^{it}. Emission allowances can be traded on a competitive allowance market at an allowance price σ_t. Initially, firm i is assigned with $\bar{e}^{i1}$ grandfathered allowances in period 1. The assignment in period 2 might depend on firm's decisions in period 1 and other non-firm-specific economic parameters: $\bar{e}^{i2} = g^i(e^{i1}, q^{i1})$. Without loss of generality we assume that

$$\bar{e}^{i2} = g^i(e^{i1}, q^{i1}) = \lambda^i_0 + \lambda^i_q q^{i1} + \lambda^i_e e^{i1}$$

where the allocation rule is monotonic in q^{i1} and e^{i1}, i.e. $\lambda^i_q, \lambda^i_e \geq 0$. The grandfathering scheme is referred to as $G = (\lambda^i_0, \lambda^i_q, \lambda^i_e)_i$.

Firms anticipate the impact of their first-period decisions on the number of grandfathered permits they receive in period 2. Given an overall emission constraint over the time horizon, the regulatory authority has to guarantee that aggregate emissions assignments do not exceed a pre-specified level $\bar{E}^t$ in period t, i.e.

$$\sum_i \bar{e}^{i1} = \bar{E}^1 \qquad \text{and} \qquad \sum_i \bar{e}^{i2} = \sum_i g^i(e^{i1}, q^{i1}) = \bar{E}^2$$

[2] An extension of the two-period case to the multi-period case is straightforward.

In the following, we distinguish the cases whether the emissions trading system is open or closed to the world market.[3] In the former case, we assume that the world market price of emissions allowancs is exogenously given by σ_t^{WM} (small open economy). In the latter, emissions have to satisfy $\sum_i e^{it} = \bar{E}^t$ in both periods and the allowance price σ_t is endogeneous.

2.1 Socially optimal allocation

Given the openess/closeness of the system and assuming w.l.o.g. that there is no discounting, the optimal output and emission levels are obtained by maximizing

$$\max \sum_t \left[\sum_i \left[p_t q^{it} - c^{it}(q^{it}, e^{it}) \right] - \sigma_t^{\mathrm{WM}} \left(\sum_i e^{it} - \bar{E}^t \right) \right]$$

s.t. $\sum_i e^{it} = \bar{E}^t$ if the system is closed. This yields the following first-order conditions (note: index j is used interchangeably with index i)

$$p_t = c_q^{it} \tag{1}$$

$$-c_e^{it} = -c_e^{jt} =: \sigma_t^* \tag{2}$$

where the market price of emissions, σ_t^*, coincides with σ_t^{WM} for the open system. We refer to this as the social optimum $((q^{it*}, e^{it*})_i, \sigma_t^*)_t$.

As well-known, in the social optimum the consumer price equals marginal production costs, and marginal abatement costs coincide for all firms.

2.2 The decentralized economy

Next, we consider the decentralized economy in which firms can trade their emissions allowances and output on competitive markets. The competitive firm i maximizes its

[3] This reflects concrete policy concerns that the European emissions trading system might not be linked with trading schemes from other signatory countries under the Kyoto Protocol or allow for using credits obtained from Joint Implementation (JI) or Clean Development Mechanism (CDM) projects. Such a recognition of allowances and credits from other schemes (the world market) is now envisaged as a further development of the Directive. Clearly, the openess of the system is a prerequisite for achieving emission reduction at lowest costs. However, there can be serious reasons for closing the system, such as concerns on environmental effectiveness due to loopholes in satellite systems.

two-period stream of profits

$$\max \sum_t [p_t q^{it} - c^{it}(q^{it}, e^{it})] - \sigma_1(e^{i1} - \bar{e}^{i1}) - \sigma_2(e^{i2} - [\lambda_0^i + \lambda_q^i q^{i1} + \lambda_e^i e^{i1}])$$

leading to first-order conditions

$$p_1 + \sigma_2 \lambda_q^i = c_q^{i1} \quad (3)$$
$$p_2 = c_q^{i2} \quad (4)$$
$$\sigma_1 - \sigma_2 \lambda_e^i = -c_e^{i1} \quad (5)$$
$$\sigma_2 = -c_e^{i2} \quad (6)$$

As in the case of the social planner problem, conditions (4) and (6) imply efficient production and emission plans in period 2: Marginal production and abatement costs equal the prices for the consumption good and emissions allowances, respectively. Comparison with (1) and (2) yields

$$\sigma_2 = \sigma_2^*$$

and, thus, second period allocation does not depend on the grandfathering scheme $G = (\lambda_0^i, \lambda_q^i, \lambda_e^i)_i$.

In period 1, however, the grandfathering rule, G, drives a wedge between nominal prices and marginal costs (conditions (3) and (5)). If $\lambda_q^i > 0$, the consumer price in period 1, p_1, is smaller than the implicit producer price $p_1 + \sigma_2 \lambda_q^i$. The allocation rule therefore provides implicit production subsidies $\sigma_2 \lambda_q^i$. Analogously, emission subsidies are given by $\sigma_2 \lambda_e^i$. The nominal first period emission price, σ_1, is given by σ_1^{WM}, for the open emission trading system while it depends on the grandfathering scheme for the closed system.

In general, the first period equilibrium is given by (4) and (6) together with $\sigma_1 = \sigma_1^{\mathrm{WM}}$ for the open, and $\sum_i e^{i1} = \bar{E}^1$ for the closed system. The solution is denoted by $((q^{i1}(G), e^{i1}(G))_i, \sigma_1(G))$.

For given prices (p_t, σ_t), differentiating (4) and (6), yields $\frac{\partial q^{i1}}{\partial \lambda_0^i} = \frac{\partial e^{i1}}{\partial \lambda_0^i} = 0$, and $\frac{\partial q^{i1}}{\partial \lambda_q^i} = \sigma_2 \frac{c_{ee}^{i1}}{\Delta_c^i} > 0$, $\frac{\partial e^{i1}}{\partial \lambda_e^i} = \sigma_2 \frac{c_{qq}^{i1}}{\Delta_c^i} > 0$, $\frac{\partial q^{i1}}{\partial \lambda_e^i} = \frac{\partial e^{i1}}{\partial \lambda_q^i} = \sigma_2 \frac{-c_{qe}^{i1}}{\Delta_c^i} > 0$, where $\Delta_c^i = c_{ee}^{i1} c_{qq}^{i1} - (c_{qe}^{i1})^2 > 0$. Therefore, increases of λ_q^i, λ_e^i lead to increases of emissions and output.

2.3 The open emissions trading system

Optimal grandfathering schemes for the (small) open emissions trading system are derived from

$$\max_G \quad \sum_i [p_1 q^{i1}(G) - c^{i1}(q^{i1}(G), e^{i1}(G)) - \sigma_1^{\mathrm{WM}} e^{i1}(G)] \tag{7}$$

$$\text{s.t.} \quad \sum_i [\lambda_0^i + \lambda_q^i q^{i1} + \lambda_e^i e^{i1}] = \bar{E}^2 \tag{8}$$

$$\text{and } \lambda_0^i, \lambda_q^i, \lambda_e^i \geq 0 \tag{9}$$

Denoting the Lagrange multipliers by μ_E, μ_0^i, μ_q^i, μ_e^i, respectively, and differentiating by $\lambda_0^i, \lambda_q^i, \lambda_e^i$, we obtain the following first-order conditions (note that $\frac{\partial q^{i1}}{\partial \lambda_0^i} = \frac{\partial e^{i1}}{\partial \lambda_0^i} = 0$):

$$0 = -(\mu_E + \mu_0^i) \tag{10}$$

$$[p_1 - c_q^{i1} + \mu_E \lambda_q^i]\frac{\partial q^{i1}}{\partial \lambda_q^i} - [\sigma_1^{\mathrm{WM}} + c_e^{i1} - \mu_E \lambda_e^i]\frac{\partial e^{i1}}{\partial \lambda_q^i} = -(\mu_E q^{i1} + \mu_q^i) \tag{11}$$

$$[p_1 - c_q^{i1} + \mu_E \lambda_q^i]\frac{\partial q^{i1}}{\partial \lambda_e^i} - [\sigma_1^{\mathrm{WM}} + c_e^{i1} - \mu_E \lambda_e^i]\frac{\partial e^{i1}}{\partial \lambda_e^i} = -(\mu_E e^{i1} + \mu_e^i) \tag{12}$$

Using (3) and (5), conditions (10) - (12) simplify to

$$0 = \mu_E + \mu_0^i \tag{13}$$

$$\lambda_q^i \frac{\partial q^{i1}}{\partial \lambda_q^i} + \lambda_e^i \frac{\partial q^{i1}}{\partial \lambda_e^i} = \frac{\mu_E q^{i1} + \mu_q^i}{\sigma_2 - \mu_E} \tag{14}$$

$$\lambda_q^i \frac{\partial e^{i1}}{\partial \lambda_q^i} + \lambda_e^i \frac{\partial e^{i1}}{\partial \lambda_e^i} = \frac{\mu_E e^{i1} + \mu_e^i}{\sigma_2 - \mu_E} \tag{15}$$

If there are no restrictions to the choice of the allocation scheme G, i.e on λ_0^i, the optimal scheme implies $\mu_E = \mu_0^i = 0$, and hence, $\lambda_q^i = \lambda_e^i = 0$. The levels of λ_0^i, however, are not uniquely determined but satisfy $\sum_i \lambda_0^i = \bar{E}^2$. Thus, we obtain:

Proposition 1 *In a (small) open economy, first-best second-period grandfathering schemes G do not depend on firm-specific decisions in period 1, i.e. $g^i = \lambda_0^i$.*

The reason is that output and emissions choices will be distorted and efficiency losses occur unless $\lambda_q^i = \lambda_e^i = 0$. The first-best therefore coincides with grandfathering rules that are independent of first period emissions and output. Grandfathering to firm i is a lump-sum transfer of wealth $\sigma_2\lambda_0^i$.

For political reasons, however, it might not be possible to use second period allocation schemes that are not linked to firms' performance in period 1.[4] At least, possibly not all allowances can be allocated lump-sum, i.e. $\sum_i \lambda_0^i < \bar{E}^2$. Solving (14) and (15) for λ_q^i and λ_e^i gives

$$\lambda_q^i = \left[[\mu_E q^{i1} + \mu_q^i]\frac{\partial e^{i1}}{\partial \lambda_e^i} - [\mu_E e^{i1} + \mu_e^i]\frac{\partial q^{i1}}{\partial \lambda_e^i}\right] \frac{\Delta_c^i}{(\sigma_2)^2[\sigma_2 - \mu_E]} \tag{16}$$

$$\lambda_e^i = \left[[\mu_E e^{i1} + \mu_e^i]\frac{\partial q^{i1}}{\partial \lambda_q^i} - [\mu_E q^{i1} + \mu_q^i]\frac{\partial e^{i1}}{\partial \lambda_q^i}\right] \frac{\Delta_c^i}{(\sigma_2)^2[\sigma_2 - \mu_E]} \tag{17}$$

We can reformulate this system using (cross) price elasticities: $\eta_{ee}^i = -\frac{\partial e^{i1}}{\partial \sigma^i}/\frac{e^{i1}}{\sigma^i}$, $\eta_{qq}^i = \frac{\partial q^{i1}}{\partial p^i}/\frac{q^{i1}}{p^i}$, $\eta_{qe}^i = -\frac{\partial q^{i1}}{\partial \sigma^i}/\frac{q^{i1}}{\sigma^i}$, $\eta_{eq}^i = \frac{\partial e^{i1}}{\partial p^i}/\frac{e^{i1}}{p^i}$ (note that $\eta_{qe}^i p^i q^{i1} = \eta_{eq}^i \sigma^i e^{i1}$) where $\sigma^i = \sigma_1 - \sigma_2\lambda_e^i$, $p^i = p_1 + \sigma_2\lambda_q^i$. Denoting $\Delta_\eta^i = \eta_{qq}^i\eta_{ee}^i - \eta_{qe}^i\eta_{eq}^i = \frac{\sigma^i p^i}{e^{i1}q^{i1}}\frac{1}{\Delta_c^i}$, this leads to

$$\tau_q^i := \frac{\lambda_q^i\sigma_2}{p^i} = \left[[\mu_E + \mu_q^i/q^{i1}]\eta_{ee}^i - [\mu_E + \mu_e^i/e^{i1}]\eta_{qe}^i\right] \frac{1}{\Delta_\eta^i[\sigma_2 - \mu_E]} \tag{18}$$

$$\tau_e^i := \frac{\lambda_e^i\sigma_2}{\sigma^i} = \left[[\mu_E + \mu_e^i/e^{i1}]\eta_{qq}^i - [\mu_E + \mu_q^i/q^{i1}]\eta_{eq}^i\right] \frac{1}{\Delta_\eta^i[\sigma_2 - \mu_E]} \tag{19}$$

which corresponds to a Ramsey-formula of optimal taxation (subsidies).

This formula can be substantially simplified. Note that $\mu_q^i \geq 0$ and $\mu_E \geq 0$ since the necessary distortions and, hence, efficiency losses increase with $\bar{E}^2$.[5] Therefore, (18) and (19) imply:

Proposition 2 *In a (small) open economy, second-best grandfathering schemes G for period 2, are determined by either of the following three Ramsey-rules for firm i:*
(i) if $\eta_{ee}^i \geq \eta_{qe}^i$ and $\eta_{qq}^i \geq \eta_{eq}^i$, then grandfathering is based on both output and emissions according to:

$$\tau_q^i = \frac{\mu_E}{\Delta_\eta^i[\sigma_2 - \mu_E]}(\eta_{ee}^i - \eta_{qe}^i) \qquad \tau_e^i = \frac{\mu_E}{\Delta_\eta^i[\sigma_2 - \mu_E]}(\eta_{qq}^i - \eta_{eq}^i)$$

[4] For example, it is often postulated that grandfathering should account for the size and, therefore, for future expansion and shrinkage of firms. As an extreme case, a firm should not perpetually receive allowances although it already dropped out off the market.

[5] If $\bar{E}^2 = 0$, one can choose $\lambda_q^i = \lambda_e^i$, which would yield first-best in period 1. The larger $\bar{E}^2$, the larger λ_q^i, λ_e^i have to be chosen which results in increased efficiency losses.

(ii) if $\eta^i_{qq} < \eta^i_{eq}$, then grandfathering is exclusively based on output:

$$\tau^i_q = \frac{\mu_E}{\sigma_2 - \mu_E}\frac{1}{\eta^i_{qq}} \qquad \tau^i_e = 0$$

(iii) if $\eta^i_{ee} < \eta^i_{qe}$, only past emissions determine the number of grandfathered allowances:

$$\tau^i_e = \frac{\mu_E}{\sigma_2 - \mu_E}\frac{1}{\eta^i_{ee}} \qquad \tau^i_q = 0$$

The proof is given in the appendix.

Note that Proposition 2 implies that optimal grandfathering schemes $(\lambda^i_q, \lambda^i_e)$ can substantially differ across firms: It could be optimal to grandfather to one firm exclusively based on emissions while another should be grandfathered based on a combination of output and emissions. In general, a firm i with more elastic output (less elastic emissions) gets a smaller fraction of grandfathered allowances related to output and a smaller fraction connected to its emissions level. The differences between firms are the larger, the larger $\frac{\mu_E}{\sigma_2 - \mu_E}$ is. Thus, differences between firm-specific grandfathering rules increase in μ_E, i.e. in the aggregate number $\bar{E}^2$ of allowances to be grandfathered in period 2, and decrease in the second period emissions price σ_2.

Grandfathering should be based on either output or emissions if the respective cross-price elasticities exceed the price-elasticities. Here, the relative subsidies are inverse to the price-elasticity of output (emissions). In this case it would even be efficiency-increasing to negatively correlate grandfathering with the other factor, i.e. to choose $\lambda^i_e < 0$ or $\lambda^i_q < 0$. Such an outcome, however, is ruled out by the (realistic) assumption that grandfathering schemes must be monotonic in both emissions and output.

If, cross-price elasticities are small, optimal grandfathering is based on both emission and output levels, i.e. $\lambda^i_q, \lambda^i_e > 0$. Then,

$$\frac{\tau^i_q}{\tau^i_e} = \frac{\lambda^i_q \sigma_2 / p^i}{\lambda^i_e \sigma_2 / \sigma^i} = \frac{\eta^i_{ee} - \eta^i_{qe}}{\eta^i_{qq} - \eta^i_{eq}}$$

which is the standard implication of the Ramsey rule for relative subsidies on output and emissions in proportion to the respective producers prices: (i) The higher the elasticity of emissions with respect to the emissions price, the smaller the relative subsidy on emissions, and (ii) the more elastic output reacts to a price increase, the smaller the relative subsidy on output is. Interpreting $c^{it}(q,e)$ as the costs of an aggregate input to produce (q,e), one can easily transform the formula into a Corlett-Hague type relationship (Corlett and Hague 1953). The (intuitive) interpretation then is straightforward: The better substitutable the aggregated input is to emissions, the larger the subsidies on emissions compared to those on output.

We illustrate proposition 2 by the following simple examples for the two-firms-case:

Example 1
Assume that $\eta^i_{qe} = \eta^i_{eq} = 0$. Then, as long as all price elasticities $\eta^i_{xx} > 0$ $(x = q, e)$, $\lambda^i_x > 0$ for all i, x, and optimal relative subsidies are given by the inverse elasticity rule: $\tau^i_x = \frac{\mu_E}{\sigma_2 - \mu_E}\frac{1}{\eta^i_{xx}}$.$\square$

Example 2
Assume that $c^{i1}(q,e) = q^{\alpha^i}e^{-\beta^i}$ $(\alpha^i - \beta^i > 1)$. This yields $q^{i1}(p,\sigma) = \gamma^i_q p^{\eta^i_{qq}}\sigma^{-\eta^i_{qe}}$ and $e^{i1}(p,\sigma) = \gamma^i_e p^{\eta^i_{eq}}\sigma^{-\eta^i_{ee}}$, where

$$\eta^i_{qq} = \frac{1+\beta^i}{\alpha^i - \beta^i - 1}, \quad \eta^i_{eq} = \frac{\alpha^i}{\alpha^i - \beta^i - 1}, \quad \eta^i_{ee} = \frac{\alpha^i - 1}{\alpha^i - \beta^i - 1}, \quad \eta^i_{qe} = \frac{\beta^i}{\alpha^i - \beta^i - 1}$$
$$\gamma^i_q = \frac{(\beta^i)^{\eta^i_{qe}}}{(\alpha^i)^{\eta^i_{qq}}}, \quad \gamma^i_e = \frac{(\beta^i)^{\eta^i_{ee}}}{(\alpha^i)^{\eta^i_{eq}}}$$

Therefore, in this case, $\eta^i_{qq} - \eta^i_{eq} < 0$, and Proposition 2 implies that emissions must not be subsidized, i.e. $\lambda^i_e = 0$, whereas the optimal grandfathering rule λ^i_q for firm i is given by $\tau^i_q = \frac{\mu_E}{\sigma_2 - \mu_E}\frac{1}{\eta^i_{qq}}$.$\square$

2.4 The closed emissions trading system

If the emissions trading scheme is closed, i.e. $\sum_i e^{it} = \bar{E}^t$, first period equilibrium again depends on the specific grandfathering rule and is given by (4) and (6). Instead of solving the social welfare maximization problem explicitly, the social optimum, which is given by (1) and (2), can be achieved without relying on lump-sum transfers. To see this, note that if

$$\lambda^i_q = 0, \, \lambda^i_e = \lambda^j_e =: \lambda_e$$

the equilibrium conditions (4) and (6) simplify to

$$p_1 = c_q^{i1} \quad (20)$$

$$\sigma_1 - \sigma_2^* \lambda_e = -c_e^{i1} \quad (21)$$

Given that $\sum_i e^{i1} = \bar{E}^1$, the comparison of (20) and (21) with the social optimum (1) and (2) yields:

$$\sigma_1 = \sigma_1^* + \sigma_2^* \lambda_e \quad (22)$$

i.e. the effective price of allowances, $\sigma_1 - \sigma_2^* \lambda_e$, is independent of λ_e. Thus, for any given λ_e we can achieve first-best in period 1, $((q^{i1*}, e^{i1*})_i, p_1^*, \sigma_1^*)$. We determine λ_e from the grandfathering condition $\sum_i [\lambda_0^i + \lambda_e e^{i1*}] = \bar{E}^2$:

$$\lambda_e = \frac{\bar{E}^2 - \sum_i \lambda_0^i}{\bar{E}^1}$$

To summarize, even if lump-sum transfer of allowances are not feasible, i.e. $\lambda_0^i = 0$, social optimality is not jeopardized.

Proposition 3 *In a closed emissions trading system, first-best second-period grandfathering schemes G consist of an assignment proportional to emission in period 1 plus a term which does not depend on firm-specific decisions, i.e.*

$$g^i = \lambda_0^i + \lambda_e e^{i1}$$

Proposition 3 states that efficient grandfathering schemes must not depend on firms' output levels but are linear in the first-period emission levels. Although the equilibrium allocation and therefore efficiency is independent from the specification of $G = (\lambda_0^i, \lambda_e)_i$, different lump-sum transfers λ_0^i clearly have distributional impacts. From a practical policy point of view, it is important to note that the flexibility to account for distributional (equity) concerns without efficiency trade-offs shrinks with the number of permits that can be allocated in a lump-sum way ($\sum_i \lambda_0^i < \bar{E}^2$). In the extreme case, where $\lambda_0^i = 0$, there is only one grandfathering scheme that guarantees efficiency.

Corollary 4 *If lump-sum transfers are ruled out ($\lambda_0^i = 0$) in a closed emissions trading system, the sole grandfathering scheme that warrants efficiency assigns allowances proportional to first-period emissions. The proportionality factor is given by the targeted contraction factor of aggregate emissions, i.e. $\lambda_e = \bar{E}^2 / \bar{E}^1$.*

2.5 Policy implications

A major policy claim in the debate on allocation schemes is that an installation (firm) should not perpetually receive transfers via the grandfathering rule although it has already been shut down. Otherwise unilateral abatement might provide strong incentives for multinational companies to relocate production activities to non-abating regions while reaping allowance credits for closed installations in regions that form part of the abatement regime. The allocation rule could meet such concerns by choosing $\lambda_0^i = 0$, i.e. by using the discussed second-best allocations rules. Then, if a firm is closed in period 1 ($e^{i1} = q^{i1} = 0$), it receives no emissions allowances in period 2 (as well as in subsequent periods which are not modelled here). In the closed system, economic efficiency, i.e. the decision to maintain or drop the installation, will not be affected since the effective costs of holding emission allowances do not depend on the choice of λ_e. In the open system, however, efficiency requires $\lambda_e^i = \lambda_q^i = 0$ unless there are firms which produce or emit infinitely inelastic. Hence, there is a trade-off between economic efficiency ($\lambda_e^i = \lambda_q^i = 0$) and addressing the concerns of perpetual transfers ($\lambda_0^i = 0$).

Another key issue in the set-up of allocation schemes is the treatment of new market entrants. If the latter are not grandfathered, there is a distributional bias towards incumbent firm. The distributional bias becomes the more severe, the higher λ_e^i and λ_q^i. In other words, a dynamic grandfathering rule, exacerbates the distributional bias in favor of incumbent firms. This problem can be dealt with by holding back free allowances for new entrants. Note again that for the open system there is a potential conflict between efficiency ($\lambda_e^i = \lambda_q^i = 0$) and political acceptance of the system by firms which frequently argue that allocation should reflect output and emission levels .

3 Conclusions

From 2005, the EU will have the first international trading system for greenhouse gas emission allowances. Until then, Member States must have developed national allocation plans for emission allowances across large installations of energy-intensive firms. Obviously, a core requirement to such allocation plans is that they preserve the cost-saving potential of emission trading. In this paper, we have studied first- and second-best allocation rules for dynamic grandfathering schemes with concretions to an open or a closed trading system. In the open system, first-best requires lump-sum allocation while second-best rules correspond to a Ramsey-formula and are generally based on a combination of output and emission levels. In the closed system, however, efficient grandfathering requires *independence* of the allocation of previous output levels, i.e. the initial allocation must be linear in past emission levels.

In real practice, implementation of even second-best rules across EU Member States may not be possible due to various reasons. Allocation rules typically addressed in the policy debate are either based on emissions or output. For concrete policy advice, it may therefore be crucial to quantify the magnitude of efficiency losses associated with alternative policy-relevant allocation schemes.

Appendix

Proof of proposition 2:
We first rewrite (18) and (19) as:

$$\tau_q^i = \frac{\lambda_q^i \sigma_2}{p^i} = \left[[\mu_E + \mu_e^i / e^{i1}](\eta_{ee}^i - \eta_{qe}^i) + [\mu_q^i / q^{i1} - \mu_e^i / e^{i1}]\eta_{ee}^i \right] \frac{1}{\Delta_\eta^i [\sigma_2 - \mu_E]} \quad (23)$$

$$\tau_e^i = \frac{\lambda_e^i \sigma_2}{\sigma^i} = \left[[\mu_E + \mu_e^i / e^{i1}](\eta_{qq}^i - \eta_{eq}^i) - [\mu_q^i / q^{i1} - \mu_e^i / e^{i1}]\eta_{eq}^i \right] \frac{1}{\Delta_\eta^i [\sigma_2 - \mu_E]} \quad (24)$$

(i) Let us that $\tau_q^i = \tau_e^i = 0$. Then, (23) and (24) reduce to

$$\begin{pmatrix} \eta_{ee}^i - \eta_{qe}^i & \eta_{ee}^i \\ \eta_{qq}^i - \eta_{eq}^i & \eta_{eq}^i \end{pmatrix} \begin{pmatrix} \mu_E + \mu_e^i / e^{i1} \\ \mu_q^i / q^{i1} - \mu_e^i / e^{i1} \end{pmatrix} = \begin{pmatrix} 0 \\ 0 \end{pmatrix}$$

The determinant of the matrix is $-\Delta_\eta^i < 0$, therefore the only solution of the system were $\mu_E + \mu_e^i / e^{i1} = 0$, $\mu_q^i / q^{i1} - \mu_e^i / e^{i1} = 0$ which implies $\mu_E = 0$. That is, only if first-best can be obtained, $\lambda_e^i = \lambda_q^i = 0$. Hence, for $\mu_E > 0$, at firm i will be grandfathered based on past emissions or output.

(ii) Assume that $\tau_q^i, \tau_e^i > 0$, and therefore $\mu_q^i / q^{i1} = \mu_e^i / e^{i1} = 0$. Then, (23) and (24) lead to

$$\tau_q^i = \frac{\mu_E}{\Delta_\eta^i [\sigma_2 - \mu_E]} (\eta_{ee}^i - \eta_{qe}^i) \qquad \tau_e^i = \frac{\mu_E}{\Delta_\eta^i [\sigma_2 - \mu_E]} (\eta_{qq}^i - \eta_{eq}^i)$$

which requires $\eta^i_{ee} > \eta^i_{qe}$, and $\eta^i_{qq} - \eta^i_{eq} > 0$.

(iii) Assume that $\tau^i_q = 0$, and therefore (from (i)) $\tau^i_e > 0$ and $\mu^i_e/e^{i1} = 0$. Here, (23) implies that $\mu^i_q/q^{i1} = -\frac{\eta^i_{ee}-\eta^i_{qe}}{\eta^i_{ee}}$. Since $\mu^i_q \geq 0$, this implies $\eta^i_{ee} - \eta^i_{qe} < 0$, on the one hand, and, with (24), $\tau^i_e = \frac{\mu_E}{\sigma_2-\mu_E}\frac{1}{\eta^i_{ee}}$.

(iv) The remaining case, $\tau^i_e = 0$, follows the same line of reasoning as (iii).□

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