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Output and abatement effects of allocation readjustment in permit trade

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Abstract In permit trading systems, free initial allocation is common practice. A recent example is the European Union Greenhouse Gas Emission Trading Scheme (EU-ETS). We investigate effects of different free allocation schemes on incentives and identify significant perverse effects on abatement and output employing a simple multi-period model. Firms have incentives for strategic action if allocation in one period depends on their actions in previous ones and thus can be influenced by them. These findings play a major role where trading schemes become increasingly popular as environmental or resource use policy instruments. This is of particular relevance in the EU-ETS where the current period is a trial-period before the first commitment period of the Kyoto protocol. Finally, this paper fills a gap in the literature by establishing a consistent terminology for initial allocation.

1 Introduction

More and more ecosystem resources are regulated through pricing or instruments such as permit trading. To appease the opposition to regulation from vested interests and facilitate the adoption of more stringent environmental goals, it has become

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common practice for the regulator to give out free permits (or tax-exemptions) to groups of (influential or needy) resource users (polluters). Giving away the permits free of charge means that potential efficiency gains from using these revenues to finance public spending are foregone. This so called "revenue recycling effect" could be quite significant (Goulder et al. 1999) but if the political resistance from vested interests is strong enough to oppose important environmental reforms then this may be a necessary sacrifice since instruments that benefit some economic agents may diffuse the opposition from business (see for instance Fredriksson and Sterner 2005). Distributing the permits for free can also be seen as compensation for sunk costs due to changes in the business environment (Haites and Hornung 1999). In this paper, we do not further discuss this background but focus instead on differences among various ways of allocating permits for free.

This issue has become relevant in a very significant way due to the launching of the European Union Greenhouse Gas Emission Trading Scheme (EU-ETS) in 2005, the largest permit trading scheme ever (IEAT 2005). We are now in a pilot phase I (2005–2007) which is to be followed by phase II (2008–2012) corresponding to the First Commitment Period of the Kyoto Protocol. This is supposed to lead to emission reductions of 5% (for the industrialised and transition economies). For this to have sufficient impact on the climate, it must be followed by more Commitment Periods with ever more stringent emission targets (and thus likely rising costs of abatement). The total number of permits allocated annually in phase I of the EU-ETS is about two billion, representing a large monetary value, even at a low permit price of 10 €. Thus the principles for permit allocation and the readjustment of the allocations for each new period are of great importance and interest to those affected.

In any permit trading system, the state needs to set criteria for the initial allocation, both for existing plants when a trading scheme is established or a new accounting period begins, and for new entrants or closures. One popular method has been to allocate the permits in proportion to historic resource use. This is often and somewhat loosely referred to as "grandfathering" and in Europe, where permit allocation is fairly new, it is commonly perceived that this is the "American" way to allocate permits (following the sulfur trading and some other policies in the USA). For our purposes this is not sufficiently precise and we believe there are some important differentiations that need to be made.

The linchpin of this issue is that allocation is actually a repeated game since permits tend to be allocated several times over the life of a long program and it may become somewhat unclear what is to be meant by "historic use." The method of allocation has major importance for perceived fairness, political acceptability and economic efficiency: If firms can affect future allocations in any way by their actions today, they have incentives to act strategically and in general, this implies a deviation from the efficient resource allocation. As we will show below, this can for example result in overproduction and sub-optimal abatement effort. For *this* reason, economists emphasize the virtue of using truly *historic* data for calculating permit allocations. We will reserve the term "grandfathering" for allocation indexed to a base year that *remains fixed* throughout the whole life of the environmental program under discussion. Grandfathering builds on leaving untouched the property- or use-rights once handed out. The firms are then not tempted to act strategically to influence the number of permits they get in future rounds of allocation.

We are convinced that there is a real risk that suboptimal allocation schemes leading to inefficient outcomes will be used. With tough competition between countries for new investments, it will be very difficult for countries not to give new entrants permits – particularly as long as some of their competitors do so. In addition, if new entrants are given special permits then also existing firms are likely to argue that they too, should be "compensated" if they expand through new investments. We will illustrate this with the allocation procedures in the EU-ETS and its treatment of new entrants and closures (Section 3).

Below, we develop a model to investigate the different allocation schemes and their incentives for strategic action. We also establish a rigorous and consistent terminology for initial allocation schemes, as this is missing up to now. We knowingly deviate somewhat from the terminology used in Raymond (2003), but only by using fewer and broader terms (thus, our "grandfathering" subsumes his grandfathering, "intrinsic" and "instrumental allocation"). This is so, as the terminology we propose is more in line with the partly established use in academic and applied environmental, resource and regulatory economics literature, as it is simple and as it is differentiated enough for the analysis of incentives in various initial allocation schemes, focusing on economic rather than on legal and legal-philosophical concepts.

The next two sections present some legal and historical background for allocation schemes and discuss some examples. Section 4 introduces the model, which is applied in Section 5 to analyse various initial allocation schemes. Section 6 concludes.

2 Legal and historic background

Permit allocation creates a form of property rights[1] and we have distinctly different legal traditions in different parts of the World. Increasingly, hitherto free resources such as the greenhouse gas absorption capacity of the atmosphere become scarce and valuable by incorporating them into the economic system. Rights to such new resources may be allocated in different ways: to owners of related property, for example, as mineral rights belong to land owners in some countries such as the USA. Another prominent principle is so-called "prior appropriation" which gives rights to the first user. This can be seen as rights established by use almost like the "facts on the ground" that conquering nations use to establish by colonizing and developing territory taken in war. A similar principle of favouring vested interests governs water allocation in the Western parts of the USA, for example, or allocation of quotas to fishermen in many fisheries.[2]

[1]These rights are not always property rights in the most encompassing sense including all the exclusivity, stability and security aspects that come with those (see Raymond 2003). Sometimes, they are of only restricted form and the state keeps considerable power – this is the case for the permits in the US sulfur trade, for example (EPA 1990).

[2]For a discussion of property rights in relation to policy instruments see Sterner (2003), Chap. 5, and Raymond (2003) for a detailed discussion of different types of private rights to public resources.

A "rights-based" perspective building on prior appropriation provides a solid foundation for grandfathering. According to this view, the rights are established by use and when codified they are then essentially perpetual and thus their base year never changes. Grandfathering can thus be attractive to some socio-legal and cultural traditions that will promote it politically.

If grandfathering is applied consistently, new entrants get no permits but firms do keep their rights even when they close. To some, this might seem inappropriate or impossible: how can closed enterprises be given rights? However with a "rights-based" perspective as laid out above, this is no more odd than the fact that firms closing down a plant still own the land, patents and machines. Like the latter, the rights to carbon emissions can simply be sold if they are not to be used.

There are however other views. For instance people may view new rights as essentially belonging to the state that defines them (as for instance mineral rights in Sweden, Spain, and Mexico e.g. Meyer and Sherman 1979). According to this view, the agents in the economy may still be allocated rights but somehow there has to be a further reason or principle than prior use through which the agents earn this – delegated – right.[3] One way to earn such rights is through socially useful production — and this is the basis for allocation based on current output or possibly some other variable such as current fuel input multiplied by some ("fair" or "normal") emission factor.[4] We call such a scheme "current allocation," indicating that allocation is based on a measure of activity in the current period.

In addition to these two (pure) principles for free[5] allocation, there is a third intermediate category. It is characterized by the use of neither historic nor current periods of time but by values from some intermediate preceding period. We thus call it "updating." In later periods of a program, the original historic baseline may appear to be very much "out of date": We believe that, at least in Europe, the logic of absolute grandfathered rights is not well established and instead the social norms will favour updating or even current allocation. To make this case we will exemplify our model with the EU-ETS and its rules for the treatment of new entrants and closures.

3 The European union greenhouse gas emission trading scheme

Looking at the existing trading schemes, a heterogeneous picture arises (cf. also Raymond 2003). Grandfathering is, broadly speaking, the manner in which rights were allocated in the famous US sulfur trading program and closing firms keep their permits while new entrants do not get permits for free (EPA 1990, Title IV, Sec. 403(a); Joskow and Schmalensee 1998; Raymond 2003). In the EU-ETS however,

[3] Or "licensed property," as Raymond (2003) terms "...a private legal right that provides a significant degree of security and exclusivity to resource users but remains unprotected from future government adjustment or cancellation without compensation."

[4] Sometimes this is called "benchmarking" and we suggest to reserve this term for technology specific policies such as technology-specific emission rate standards or regulations in support of "best-in-class" technologies; currently, the term is used very inconsistently and we decided not to use it at all for our general taxonomy in this paper.

[5] A further alternative is of course not to allocate permits freely but sell them in an auction.

while allocation to existing plants takes place via grandfathering based on historic emissions, with some small amount to be auctioned (less than 5% for the first, less than 10% for the second phase) in some countries (Egenhofer et al. 2006), firms exiting loose their permits and new entrants gain permits in most countries (albeit sometimes less generous than the allocation to existing firms). According to Egenhofer et al. (2006) only the Netherlands and Sweden allow firms to keep their allowances upon exit, and then this only extends through the end of the first period. Thus essentially the grandfathering rule that rights are permanent is *not* respected.[6] Both allocation for new entrants and the "use-or-lose" rule for closures may appear to have some "common-sense appeal" but both introduce a relationship between output and allocation. They thus both act as a subsidy to production. The "use-or-lose" rule can similarly be seen as a tax on exit. These mechanisms foster strategic action by the firms in the permit trading scheme.[7]

According to Åhman and Holmgren (2006) all countries set aside some allowances for new entrants but the percentage varies enormously from 0,6% of all permits in Germany to 12% in Latvia. Numbers vary not only in aggregate but also for different plant designs. One plant design studied would receive no permits in Sweden, permits for 100% of its emissions in a number of countries and for 105% in Germany. Germany furthermore guarantees that the permits will be allocated for 14 years which seems very generous considering that the current trading is only planned up to 2012. Permit allocation also involves high values, e.g. 18 to 27% of expected revenues or 70 to 105% of fixed costs for new capacity for new entrants in the energy sectors of Denmark, Finland, Germany and the Baltic states (Åhman and Holmgren 2006).

Recent assessments of the National Allocation Plans (NAPs) for phase I consistently reveal significant over-allocation. Egenhofer et al. (2006) point out that "[...] several member states have allowed their covered sectors to increase emissions by as much as 10 or 20%, although they are on a trajectory that will not enable them to meet the Kyoto Protocol targets." Similarly, Kolshus and Torvanger (2005) find overallocation in some countries, based on simulations of the effects of the NAPs and what would be needed to be on track with the Kyoto targets (in total +13% with respect to the base year, and, for single countries, up to +60% with respect to the Kyoto targets). Differentiation by sectors exposed and nonexposed to international competition reveals particularly generous allocation to the former in most countries.

Grandfathering is perceived as unfair especially in the case that new firms have lower emissions than older ones since it implies that "dirty" firms, which get more generous allocations, are favoured at the expense of "cleaner" ones. The movement away from grandfathering in Europe seems to show that the ideology of prior appropriation rights is not so deeply rooted there. Possibly the mechanism is less well understood or the differences in legal traditions and political economy account for the different attitudes in the USA and in Europe. One factor is that the smaller

[6]There are also a couple of countries that allow some form of complex and temporary transfer of rights within a firm from a closed plant to a new one, but this does not modify the broad picture.

[7]These problems would not arise for an "upstream" regulation, e.g. on the level of fossil fuel producers based on the carbon dioxide released by the use of their products. They can only abate via reducing output and inefficient output or abatement decisions due to strategic actions are less likely. The EU-ETS, however, regulates "downstream" industries and the potential problems identified above thus arise.

the political constituency making an allocation the greater may be the temptation to consider the effects on local employment and the more distant is the overall cohesion of the program. Such concerns at a local level can also be observed in the USA.[8]

We are now in the midst of the pilot phase in the EU-ETS. The emission inventories of the member countries were published April 2006 and permit prices fell from about 30 to 10 €, at least partly because massive overallocation became manifest (EU 2006). At the time of writing (mid-2006), the national allocation principles for the next period 2008-2012 are just being established and many issues are not yet clear, such as monitoring, sanctions and other institutional features like the availability of a banking option for this and potential subsequent periods. On the other hand, much has already been achieved: For the first time, the EU-ETS has created a price signal for carbon emissions that applies across Europe and that is being closely watched at the global scale.

4 The model

Consider the second period of a system where new entrants have received some allocation: why should an old firm that has expanded its production not also be rewarded with more permits? If the expansion were legally a separate entity, then there would be an extra allocation for the "new entrant." Plants that expand will argue that it is unfair that they are awarded permits purely based on historic values (before their expansion). Thus elements of allocation based on current values or at least updating may creep into the scheme even if it was originally intended to be grandfathered.

At a more general level, if grandfathering were to become the standard in all resource and environmental policy (e.g. quotas for fisheries, logging and new types of pollution) then the relevant agents would learn and adapt their behaviour: It would be profitable for them to increase resource use or pollution in order to get a good baseline in future rounds of allocation. Experience has shown that firms will expend considerable rent-seeking efforts to acquire permits (see e.g. Joskow and Schmalensee 1998) and this may become quite unwieldy in a system which implies a massive free hand-out of over two billion permits per year.

We address these issues in a model designed to show the basic underlying incentive structure in different allocation schemes. As an input to the ongoing discussions on trading systems, especially in the climate and EU-ETS context, it is also worthwhile to present these underlying mechanisms in a short, direct and easily accessible form, as this is missing in the prior literature. A number of related models exist. Fischer and Fox (2004), for example, include the presence of industries with different emission intensities, of leakage (i.e. the possibility of sectors or regions without emission reduction goals), and the interaction with the existing tax system, just to name a few. Strategic action in the face of allocation of a renewable resource based on prior use has been modeled in the context of fisheries, for example, explicitly incorporating the resource dynamics (Bergland et al. 2002). Dewees (2001) addresses the differences

[8] See e.g. Joskow and Schmalensee (1998) for political economy issues related to the US sulfur trading program.

between output- and emissions based allocations and shows that the former leads to a relative increase in output compared to the optimum. He employs a simulation based on the specific situation of pollution regulation for electricity production in the USA and Canada. Burtraw et al. (2002) and Burtraw and Palmer (2006) discuss the effects of allowance allocation on the asset value of electricity utilities. These models contain details allowing the authors to address trade-offs between different schemes in the presence of multiple market failures or in specific existing situations.

We investigate an economy with n periods of time $t \in \{1, ..., n\}$, with a firm producing quantities q_t of one good employing two inputs h_t and x_t at costs $c_t(q_t, h_t, x_t, a_t)$, where a_t is abatement and emissions are $e_t(q_t, h_t, x_t, a_t)$. c and e are assumed to be differentiable.

Input h stands for "heat input" as many initial allocation schemes relate to the heat input in the fuel used in production processes. h is understood to correlate highly with emissions e. x stands for any other type of input that is not related to energy use and emissions. This discrimination of inputs allows to capture potential effects of allocation schemes on the relative factor use in the production process.

Output is a function of the inputs: $q_t = q_t(h_t, x_t)$. We further assume that the relationship between q and h is well-behaved so that it can be inverted and expressed as $h_t = h_t(q_t, x_t)$. This also allows us to write an input- or output-focused formulation of the cost- and emissions-function:[9] $c_t(q_t, h_t, x_t, a_t) = c_t(q_t, h_t(q_t, x_t), x_t, a_t) \overset{\text{def.}}{=} \hat{c}_t(q_t, x_t, a_t)$ and $c_t(q_t, h_t, x_t, a_t) = c_t(q_t(h_t, x_t), h_t, x_t, a_t) \overset{\text{def.}}{=} \tilde{c}_t(h_t, x_t, a_t)$, and similarly for the definition of $\hat{e}$ and $\tilde{e}$.

The firm is a price taker in the competitive market where the good is sold at the price p_t. The overall discount rate in this model is r.[10] $f'_{k,w}$ denotes the derivative of the function f_k with respect to w: $f'_{k,w} \overset{\text{def.}}{=} \frac{\partial}{\partial w} f_k$. For the rest of the paper, we often omit the arguments of the functions to keep the formulae simpler. We assume the common properties for costs and emissions: For each time period t, the costs c increase with increasing output q and also with increasing abatement a, and in both variables at an increasing rate. The emissions e increase with increasing output q and decrease with increasing abatement a, at a decreasing rate. Costs increase with increasing inputs h and x and emissions increase with increasing h while they are independent of changes in x: $\hat{e}'_{t,x_t} = \tilde{e}'_{t,x_t} = 0$.

Emissions are regulated through a tradable permit scheme which gives $\bar{e}_t$ permits to the firm at the beginning of each period t. The firm can comply with this goal either by abatement or by buying additional allowances at a price p^e_t on a permit market, where it is a price-taker. In case emissions are lower than the permit allocation, the firm can sell the additional unused allowances on the market. In this model, there is no banking or borrowing of permits.[11] The firm maximizes the total profit over the n

[9]The notion "$\overset{\text{def.}}{=}$" indicates a definition.

[10]Given the focus of this paper, we will not specifically discuss the role of the discount rate in the models below.

[11]We do not include banking or borrowing in the model since it would obscure the basic mechanisms of initial allocation and distorted company incentives on which we focus.

periods, which is captured by the following two equivalent maximisation problems, relating to an output- or input-focus of firm choices:

$$\max_{\substack{q_1, ..., q_n, \\ x_1, ..., x_n, a_1, ..., a_n}} \sum_{t=1}^{n} \frac{1}{(1+r)^{t-1}} \Big(p_t q_t - \hat{c}_t(q_t, x_t, a_t) + p_t^e \left[\bar{e}_t - \hat{e}_t(q_t, x_t, a_t) \right] \Big) \quad (1)$$

$$\max_{\substack{h_1, ..., h_n, \\ x_1, ..., x_n, a_1, ..., a_n}} \sum_{t=1}^{n} \frac{1}{(1+r)^{t-1}} \Big(p_t q_t(h_t, x_t) - \tilde{c}_t(h_t, x_t, a_t) + p_t^e \left[\bar{e}_t - \tilde{e}_t(h_t, x_t, a_t) \right] \Big) \quad (2)$$

subject to $a_t \geq 0$, $h_t \geq 0$, $x_t \geq 0$ and $q_t \geq 0$ for all $t \in 1, ..., n$.

5 Readjustment of allocations

In a static (single-period) model, the initial allocation of permits $\bar{e}$ can take three different basic forms. Permits can be sold to the firms, e.g. by an auction ('AU'), or they can be allocated for free by grandfathering ('GF') based on some historic value of emissions, input or output, i.e. independently of any current actions of the firm, or in proportion to actual input or output ('CA': current allocation).[12] With CA, each unit of current output or input gives entitlement to ϵ or η units emissions, respectively, corresponding to some best practice or norm, which basically implies the regulation of output or input emissions intensity rather than total emissions, unless an aggregate cap is imposed.[13]

In a multiple period model there are more possible allocation methods. The allocation for the second (and subsequent) periods may either change or continue to depend on the same baseline used in the first period. The latter is grandfathering since it continues to depend on something the firms cannot influence. If the allocations are to change they may either depend on actual values for input or output, reflecting the CA scheme again, or on the values for some previous intermediate period, e.g. $t-1$. The general form for the free permit allocation is thus $\bar{e}_t = \bar{e}_t(q_t, q_{t-1}, h_t, h_{t-1}, e_{t-1})$ where q and h are related as discussed in the previous section and e_{t-1} is itself a function of q_{t-1}, h_{t-1} and a_{t-1}.[14] Not having x_t explicitly as

[12] Allocation cannot be tied to actual emissions since this clearly does not make sense.

[13] We discuss some of the aspects of a cap below, after Table 1.

[14] This is sufficient to study the basic incentive structure of the readjustment schemes. Initial allocation depending on earlier periods, $t-k, k>1$ or on combinations of variables referring to different periods, e.g. the average of some past periods' emissions, does not add qualitatively new insights.

Table 1 Number of free permits $\bar{e}_t$ according to the different options for allocation

Scheme	Time	Allocation criterion		
		Output (q)	Input (h)	Emissions (e)
Grand-fathering (GF)	t_0	ϵq_0	ηh_0	αe_0
Updating (UP)	$t-1$	ϵq_{t-1}	ηh_{t-1}	αe_{t-1}
Current Allocation (CA)	t	ϵq_t	ηh_t	n.a.
Auction (AU)		0	0	0

ϵ and η denote output and input emissions intensities, respectively, and we require $\alpha \in [0, 1]$

an argument in $\bar{e}$ reflects the distinction we want to make by specifying two inputs: h, one input ("heat input") that emissions regulation may be tied to (e.g. fossil fuel input), and x, an input that is not directly subject to such regulation (e.g. labour). In the multi-period model we thus have the options for the initial allocation $\bar{e}_t$ in period t as displayed in Table 1.

The columns of the table correspond to the three different variables that can be chosen as the "key" for allocation.[15] Including the auction, we have thus defined nine different prototype allocation schemes, AU; GFq,h,e; UPq,h,e and CAq,h[16], where we refer to the non-auction allocations by combining the abbreviations for the schemes and the key-variables. Thus GFe means grandfathering based on historic emissions.

Depending on the details of the system and institutional framework, there might or might not be a strictly enforceable aggregate cap on emissions. For an auction the aggregate cap is naturally fixed. For GF and UP a cap is fairly easy to apply, while for current allocation it is a little more difficult since the values of the key vaiable are not known ex ante. Without cap, these allocation mechanisms result in an emission intensity regulation (basically equivalent to a tradable performance standard, see e.g. Fischer 2001), but with a cap, emission intensities have to be adjusted. For CAq, this allocation mechanism is sometimes termed a "generation performance standard" (Burtraw et al. 2002).[17]

The results regarding incentives to curb emissions for the various options in the static, one period case are well known (e.g. Sterner 2003). The derivation is similar to the derivation of the multi-period results we present below. We briefly state these results before deriving the more general case. In principle, three channels for emission reduction can be identified, corresponding to the variables the firm can

[15] One could also think of allocations differentiated by types of outputs or inputs in case the firms produce several outputs or employ several heat inputs. This is in fact not uncommon, but it is a completely straightforward extension with different values of η or ϵ for say oil or coal fired plants and does, again, not add new qualitative insights to the analysis. The emission intensities could in principle also change over time. They could for instance fall gradually to zero if a scheme is to transit from free to auctioned allocation. We omit this here as well as it neither adds qualitatively to the issues we explore.

[16] As already mentioned above, CAe does not make sense.

[17] It is equivalent to setting each firms share of initial emission allowances equal to the firms current share in production.

influence to maximise its profits: output, input and abatement (see also Goulder et al. 1999). In the one period case the incentives for abatement are the same for all the mechanisms – marginal abatement costs are equal to the permit price. But the incentives for reduction of output or input are different. For auctioned and grandfathered permits there is an (optimal) incentive to reduce production since the output price includes the cost of extra permits needed to cover the marginal pollution caused by marginal production. Similar reasoning applies for inputs. If permit allocation is based on *current* output or input (CAq,h), however, this mechanism is missing. This implies an incentive for excessively high output or input use. From an efficiency viewpoint the main disadvantage is that the output or input effect, i.e. the incentive to reduce emissions by reducing output or input is foregone. There is a significant literature on this (see e.g. Goulder et al. 1999; Burtraw et al. 2002; Fischer 2003). However, the use of CAq may still be warranted in cases when an output effect is not wanted, i.e. when one only wants to affect technology of production and not its volume. Examples include the small open economy (when other countries have no corresponding policy), when only a subsector of polluters is targeted, under oligopolistic competition or if the polluters are too powerful and lobby against policy makers (Fischer 2001; Sterner and Höglund Isaksson 2006; Fredriksson and Sterner 2005; Gersbach and Requate 2004; Gersbach 2002). CAq has also been implemented in a number of cases (e.g. the phase-out of lead from gasoline in the USA (Hahn 1989)).

Much of the discussion concerning permit allocation is based on this simple static model and the received wisdom is therefore that grandfathering, as opposed to CA, is a sound principle. Although it does not generate revenue like auctioning it does have correct output incentives at the margin. We now study the effects of the mechanisms in the multi-period model. Assuming initial allocation as presented in Table 1, i.e. dependent on current, updated or historic values of q, h or e, the first-order conditions (FOCs) from Eqs. 1 and 2 for q_t, h_t, x_t and a_t give, in a general form[18, 19]

$$\frac{1}{(1+r)^{t-1}}\left(p_t-\hat{c}'_{t,q_t}+p^e_t\left[\bar{e}'_{t,q_t}-\hat{e}'_{t,q_t}\right]\right)+\frac{1}{(1+r)^t}p^e_{t+1}\bar{e}'_{t+1,q_t}=0 \tag{3}$$

$$\frac{1}{(1+r)^{t-1}}\left(p_t q'_{t,h_t}-\tilde{c}'_{t,h_t}+p^e_t\left[\bar{e}'_{t,h_t}-\tilde{e}'_{t,h_t}\right]\right)+\frac{1}{(1+r)^t}p^e_{t+1}\bar{e}'_{t+1,h_t}=0 \tag{4}$$

$$\frac{1}{(1+r)^{t-1}}\left(p_t q'_{t,x_t}-\tilde{c}'_{t,x_t}+p^e_t\left[\bar{e}'_{t,x_t}-\tilde{e}'_{t,x_t}\right]\right)+\frac{1}{(1+r)^t}p^e_{t+1}\bar{e}'_{t+1,x_t}=0 \tag{5}$$

$$\frac{1}{(1+r)^{t-1}}\left(-\tilde{c}'_{t,a_t}-p^e_t\tilde{e}'_{t,a_t}\right)+\frac{1}{(1+r)^t}p^e_{t+1}\bar{e}'_{t+1,a_t}=0. \tag{6}$$

The terms proportional to $\frac{1}{(1+r)^t}$ capture the effects of strategic action by firms that take into account the value of future permit allocations due to current decisions.

[18] Use Eq. 1 to derive the FOCs for q_t, Eq. 2 for h_t and x_t, and both equivalently for a_t.

[19] We omit the Kuhn–Tucker term from the boundary conditions $q_t, h_t, a_t \geq 0$. These lead to additional terms in the Lagrangian, $\lambda^0_a(a_t)$, with $\lambda^0_a \neq 0$ only if $a_t = 0$, i.e. if one sits on the boundary of zero abatement. The same applies for the q- and h-term. We discuss these terms only in one case where they are of particular interest.

Table 2 Output effects of the various allocation schemes

	Output (q)	Input (h)	Emissions (e)
Grand-fathering (GF)	$p_t = \hat{c}'_{t,q_t} + p^e_t \hat{e}'_{t,q_t}$	$p_t = \hat{c}'_{t,q_t} + p^e_t \hat{e}'_{t,q_t}$	$p_t = \hat{c}'_{t,q_t} + p^e_t \hat{e}'_{t,q_t}$
Updating (UP)	$p_t = \hat{c}'_{t,q_t} + p^e_t \hat{e}'_{t,q_t} - \frac{\epsilon}{1+r} p^e_{t+1}$	$p_t = \hat{c}'_{t,q_t} + p^e_t \hat{e}'_{t,q_t} - \frac{\eta}{1+r} p^e_{t+1} h'_{t,q_t}$	$p_t = \hat{c}'_{t,q_t} + p^e_t \hat{e}'_{t,q_t} - \frac{\alpha}{1+r} p^e_{t+1} \hat{e}'_{t,q_t}$
Current allocation (CA)	$p_t = \hat{c}'_{t,q_t} + p^e_t \hat{e}'_{t,q_t} - \epsilon p^e_t$	$p_t = \hat{c}'_{t,q_t} + p^e_t \hat{e}'_{t,q_t} - \eta p^e_t h'_{t,q_t}$	n.a.

Inserting the expressions from Table 1 for the initial allocation $\bar{e}_t$ in Eq. 3 gives the effects on output in period t listed in Table 2. For this, h is understood as a function of q, as for this case q, x, and a are the variables the firm bases its decisions on.

Table 2 shows, as expected, that all allocations except GF have a suboptimal price or output effect in comparison to the (first best) efficient solution implemented by an auction: The scarcity implied by the regulation is not fully incorporated into product prices. Thus the general equilibrium effects of the higher product price are missing. With UPe, the intuition is that due to the revenue from increased allocation in period $t+1$, emissions in period t get relatively cheaper. The cost of an additional unit of emission due to increased output changes from p^e_t to $p^e_t - \frac{\alpha}{1+r} p^e_{t+1}$. This makes production cheaper. Seen differently, UPe increases the unit revenue for output from p_t to $p_t + \frac{\alpha}{1+r} p^e_{t+1}$. For UPq, there is a similar effect but it applies to directly increasing current output and thus acts as an output subsidy. The prospect of increased permit allocation for period $t+1$ makes output in period t more valuable – per unit of output the revenue rises from p_t to $p_t + \frac{\epsilon}{1+r} p^e_{t+1}$. Similarly, output decisions are distorted by heat input based allocation if output and input h correlate (i.e. if $h'_{t,q_t} > 0$), as for example in fossil fuel fired power plants where h may stand for fossil energy input. Corresponding results, but within one period hold for CAq,h.

Proceeding in the same way, employing Eq. 4, we get the heat input effects of the various allocation systems (Table 3). Here q is treated as a function of h as the firm decides on h, x and a. Deviations from the optimum again occur for all allocation methods except GF. The mechanisms influencing incentives are the same again – UPe makes emissions due to increased inputs at t relatively cheaper and UPh and CAh directly act as input subsidies reducing the marginal costs of increased input. Due to the relation between q and h, output-based allocation distorts heat input decisions as well.

Table 3 Heat input effects of the various allocation schemes

	Output (q)	Input (h)	Emissions (e)
Grand-fathering (GF)	$p_t q'_{t,h_t} = \tilde{c}'_{t,h_t} + p^e_t \tilde{e}'_{t,h_t}$	$p_t q'_{t,h_t} = \tilde{c}'_{t,h_t} + p^e_t \tilde{e}'_{t,h_t}$	$p_t q'_{t,h_t} = \tilde{c}'_{t,h_t} + p^e_t \tilde{e}'_{t,h_t}$
Updating (UP)	$p_t q'_{t,h_t} = \tilde{c}'_{t,h_t} + p^e_t \tilde{e}'_{t,h_t} - \frac{\epsilon}{1+r} p^e_{t+1} q'_{t,h_t}$	$p_t q'_{t,h_t} = \tilde{c}'_{t,h_t} + p^e_t \tilde{e}'_{t,h_t} - \frac{\eta}{1+r} p^e_{t+1}$	$p_t q'_{t,h_t} = \tilde{c}'_{t,h_t} + p^e_t \tilde{e}'_{t,h_t} - \frac{\alpha}{1+r} p^e_{t+1} \tilde{e}'_{t,h_t}$
Current allocation (CA)	$p_t q'_{t,h_t} = \tilde{c}'_{t,h_t} + p^e_t \tilde{e}'_{t,h_t} - \epsilon p^e_t q'_{t,h_t}$	$p_t q'_{t,h_t} = \tilde{c}'_{t,h_t} + p^e_t \tilde{e}'_{t,h_t} - \eta p^e_t$	n.a.

Table 4 Abatement effects of the various allocation schemes

	Output (q)	Input (h)	Emissions (e)
Grand-fathering (GF)	$\tilde{c}'_{t,a_t} = -p^e_t \tilde{e}'_{t,a_t}$	$\tilde{c}'_{t,a_t} = -p^e_t \tilde{e}'_{t,a_t}$	$\tilde{c}'_{t,a_t} = -p^e_t \tilde{e}'_{t,a_t}$
Updating (UP)	$\tilde{c}'_{t,a_t} = -p^e_t \tilde{e}'_{t,a_t}$	$\tilde{c}'_{t,a_t} = -p^e_t \tilde{e}'_{t,a_t}$	$\tilde{c}'_{t,a_t} = -p^e_t \tilde{e}'_{t,a_t} + \frac{\alpha}{1+r} p^e_{t+1} \tilde{e}'_{t,a_t}$
Current allocation (CA)	$\tilde{c}'_{t,a_t} = -p^e_t \tilde{e}'_{t,a_t}$	$\tilde{c}'_{t,a_t} = -p^e_t \tilde{e}'_{t,a_t}$	n.a.

Again proceeding similarly, employing Eq. 5 and treating q as a function of x, we get the effects of the various allocation systems on input x. According to our assumption $e'_{t,x_t} = 0$, distortions only arise for UPq and CAq, due to the term $\bar{e}'_{t,x_t}$, which is proportional to q'_{t,x_t} and thus not necessarily equal to zero. Due to assumed independence of h and x, there are no distortions on x from h-based allocation. Comparison with Table 3, however, shows that h-based allocation distorts the relative use of the two inputs h and x as the former becomes relatively cheaper.[20]

Finally, Table 4 gives the effects on abatement by inserting $\bar{e}_t$ from Table 1 in Eq. 6. All allocation methods except updating based on emissions (UPe) give the same (optimal) incentives for abatement technology, i.e. abatement takes place up to the level where its marginal costs equal the marginal payments for emissions. Emission based updating (UPe), however, discourages abatement. Again, increased allocation in period $t+1$ makes the costs of emissions in period t relatively cheaper: $p^e_t - \frac{\alpha}{1+r} p^e_{t+1}$. In case the period $t+1$ permit price p^e_{t+1} is large enough with respect to the price in the preceding period, $\frac{\alpha}{1+r} p^e_{t+1}$ can be the same order of magnitude as p^e_t and $p^e_t - \frac{\alpha}{1+r} p^e_{t+1}$ can reach zero, implying that the incentive for abatement may be small or even missing.[21] Instead of abating now and saving the cost of current permits, the firm inflates current emissions in order to increase allocation of valuable permits in the subsequent period.[22] Table 5 collects all these results:

Table 5 Summary of the suboptimal effects of the various allocation schemes

Suboptimal effects for	Allocation scheme
q	All but GF
h	All but GF
x	UPq, CAq
a	UPe

[20]Here, q expands with increased use of h while x is not changed – but in a situation of fixed q, substitutability assumed, h would expand at the expense of x.

[21]The omitted Kuhn–Tucker term accounts for the case where the combined coefficient of e'_{t,a_t} is larger than zero and the equation has no solution. a_t will then be chosen equal zero.

[22]This is however not necessarily true if banking were allowed.

Simulations from the literature indicate that the changes in abatement and output effects due to different allocation mechanisms can indeed be very significant. Burtraw et al. (2001), for example, model the welfare effects of different allocation schemes for a regulation of the electricity generating sector and identify a large output-effect for CAq with respect to AU and also GF. For a policy with 6% reduction of carbon emissions, output decreases by less than 0.4% for CAq and by 1.0 and 1.4% respectively for GF and AU. Burtraw et al. (2006) simulate the Regional Greenhouse Gas Initiative among Northeast and Midwest Atlantic US States with regard to these issues. They find that deviations from grandfathering can reduce the output effect by 50%, and that they could lead to a doubling of permit prices. Goulder et al. (1999) and Parry and Williams (1999) also contain simulation results illustrating the significance of cost differences (and thus also of differences in the abatement and output effects) of quota systems, performance standards, etc. to achieve a certain reduction.

In a system with strictly enforced aggregate caps, the effects of readjustment as described above would not be to increase overall emissions but rather raise their price (cf. e.g. Fischer 2001; Burtraw et al. 2002). If firms do little abatement they would all bid for a bigger share of the same amount of permits and the price of current permits would rise thereby restoring incentives for abatement. Due to differences between the firms this would likely lead to some redistribution, but it would not affect the overall environmental effect. However, it may nevertheless accelerate introduction of new technologies. On the other side, the output effect of updating, respectively the corresponding implicit subsidy on production and the reduction in variable costs are still present for readjustment with strict caps and lead to considerable welfare losses (Burtraw et al. 2001).

If however there is no aggregate cap or if enforcement of the system is likely to be lax – and we focus on these cases here – with UPe, there will be reduced abatement and higher emissions. The other schemes are only distorted in quantity (both input and output) and not in abatement. This, however, will indirectly lead to higher emissions as well.

Although enforcement was largely successful in the classical regional or national US trading schemes (Sulfur, Lead, RECLAIM, see Tietenberg 2006), enforcement of the system is a major uncertainty in the case of the EU-ETS. Many details such as penalties for non-compliance have been decided at some level of generality,[23] but it is still fair to say that there is quite some uncertainty concerning actual implementation and enforcement in practice. Maybe the strongest source of this uncertainty is the inability of the EU to enforce its macroeconomic stability pact (EU 1997). This pact is one of the pillars of macroeconomic policy in the EU in the last decade (it was adopted in 1997) and a very important part of the common currency policy. In fact this pact, which concerns the budget discipline of the member countries, is quite essential for the stability of the Euro. Originally Germany was one of the countries that was most sceptical to the budget discipline of other member countries and therefore as a prerequisite for a common currency, all countries are required to keep government deficits below 3% of GDP. France and Germany itself broke

[23] Penalties for non-compliance are at 40€/t CO_2eq for the first phase period and 100€/t CO_2eq for the second. These fees do not absolve from the obligation to acquire the necessary certificates (EU 2003a).

this rule in 2003 and consequently were placed in an excessive deficit procedure by the ECOFIN Council. However due to their considerable power within the EU, the two countries managed to persuade other members not to vote to sanction and fine them in the European Union's Council of Ministers (EU 2003b). The European Commission (the executive part of the EU) then brought the case in the European Court of Justice. Enforcement of the pact was decided there, but no fine has been paid up to now – and no one is expecting it to be paid (Feldstein 2005). When such a high-level, prominent and clear system is allowed to break down then this implies that the ability of politicians to commit to any form of sanctions in other agreements including the Kyoto Protocol and ETS is strongly compromised. This view may be supported by the current difficulties in getting the member states to file the NAPs for phase two in time (Euractiv 2006).

6 Conclusion

We have built as simple a model as possible to show that the readjustment schemes for permit allocation can result in reduced abatement activity, quite opposite to the overall goal of permit trade. This or a similarly unwanted output or input effect occur if the allocation can be influenced by actions of the firms, i.e. if the allocation depends on emissions (inputs or output) in the previous (or current) period.

Free allocation of valuable permits is bound to create problems. The very reason for giving them out free rather than reaping the efficiency benefits of revenue recycling, is the existence of powerful vested interests that the policy maker wishes to appease. Thus the stage is set for considerable infighting and rent-seeking. From the viewpoint of efficiency the least damage is done by sticking to a once and for all allocation that we have referred to as grandfathering. As soon as the allocation mechanisms are updated, new rounds of rent-seeking will be set in motion and incentives will be created for excess pollution, production or input. See Smith (2006) on plans to build eleven new coal-fired power plants in Texas that seem to provide a bold example of such speculation to get a bigger share of permits in a potential future carbon regulation expectedly based on grandfathering.

As mentioned in preceding sections, we believe that there are strong forces that will push us in the direction of updating and output based current allocation both in the case of climate policies in the various commitment periods of the Kyoto Protocol or whatever international agreement succeeds it. Correspondingly, this can also happen for new areas of environmental regulation (e.g. newly regulated fisheries) where firms that learn that grandfathering will most likely be used for all resource and environmental problems try to affect initial allocation of user rights by rapacious over utilization of the resource to be regulated.[24]

The EU-ETS first period which is explicitly said to be a "trial" period, involves countries that have little experience with permit schemes and in some cases little interest in the whole scheme. They also have a recent history of allowing themselves to break rules such as the stability pact. It is thus fairly likely that enforcement will be

[24]Not only firm action may push for such a development. Allocation schemes with implicit subsidies can also be attractive as transition policies to protect regulated industries that have to compete in an open economy with unregulated competitors.

lax. In this situation the individual countries' industries lobby organizations may well be successful in acquiring a very large number of permits for each member state's industrial sector. This happened for the pilot period of the EU-ETS, as the national allocation plans and the publication of the emission inventories for the member states showed. They reveal heavy overallocation to the industries subject to the trading system. Such issues pose an excess burden to achieve reductions on the sectors not regulated under the EU-ETS (such as transport and households) and will make it difficult to meet Kyoto targets for the whole economy which will further lower the credibility of the whole agreement.

Thinking about improvements of the current greenhouse gas emissions regulations, one could clearly take up the discussion on price vs. quantity measures (cf. e.g. Nordhaus 2005). With a global harmonized carbon tax, the problematic issue of initial allocation would not arise. The pros and cons of these different approaches, however, have to be seen against the background of the already existing quantity regulation within the Kyoto-protocol and how this might shape future discussions. Furthermore, strategic actions and political economy terms could be expected to influence the design of a global carbon tax as well (e.g. Dijkstra 1999; Svendsen et al. 2001) and may lead to similarly sub-optimal solutions regarding incentives for abatement (e.g. via some type of refunded emission payments or tax exemption schemes) to gain support from industries and to avoid deadlock of the discussions on a global regulation.[25]

The best way for improvement may well be to announce a gradual transition to an auctioned system. Åhman et al. (2007) describe such a system for an existing trading scheme and one reasonable mechanism to enlarge it towards a global system would be to allow this transition to depend on the rate of expansion of climate targets throughout the World Economy. When all (major) economies are included in the same agreement, there is no longer any carbon leakage argument in favor of limiting the burden to domestic industries.

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References

Åhman M, Burtraw D, Kruger J, Zetterberg L (2007) A ten-year rule to guide the allocation of EU emission allowances energy policy. Energy Policy 35(3):1718–1730

Åhman M, Holmgren K (2006) Harmonising allocation to new entrants in the nordic energy sectors, Working paper, The Swedish Environmental Research Institute IVL

Bergland H, Clark DJ, Perdersen PA (2002) Rent-seeking and quota regulation of a renewable resource. Resour Energy Econ 24(3):263–279

Burtraw D, Palmer K (2006) Compensation rules for climate policy in the electricity sector. Resources for the Future

[25]In the light of political economy issues in environmental policy making, it is likely that trying to implement an auction of all credits in the first phase of the EU-ETS would have led to heavy opposition.

Burtraw D, Palmer K, Bharvirkar R, Paul A (2001) The effect of allowance allocation on the cost of carbon emission trading. RFF Discussion Paper 01-30, August 2001, Resources for the Future, Washington DC

Burtraw D, Palmer K, Bharvirkar R, Paul A (2002) The effect on asset values of the allocation of carbon dioxide emission allowances. Electr J 15(5):51–62

Burtraw D, Kahn D, Palmer K (2006) CO_2 allowance allocation in the regional greenhouse gas initiative and the effect on electricity investors. Electr J 19(2):79–90

Dewees DN (2001) Emissions trading: ERCs or allowances? Land Econ 77(4):513–526

Dijkstra B (1999) The political economy of environmental policy. Edward Elgar, Cheltenham

Egenhofer C, Fujiwara N, Åhman M, Zetterberg L (2006) The EU ETS: taking stock and looking ahead, ECP Report 2, May 2006

EPA (1990) Clean Air Act. U.S. Environmental Protection Agency. http://www.epa.gov/ttn/oarpg/gen/caa-pdf.Pdf (8.8.2006)

EU (1997) Council regulation (EC) No 1466/97 of July 1997 on the strengthening of the surveillance of budgetary positions and the surveillance and coordination of economic policies. http://eur-lex.europa.eu/smartapi/cgi/sga_doc? smartapi! celexapi! prod! CELEXnumdoc &lg=EN &numdoc= 31997R1466 &model= guichett (17.7.2006). See also 'The stability and growth pact', http://ec.europa.eu/economy_finance/about/activities/sgp/sgp_en.htm (17.7.2006)

EU (2003a) Directive 2003/87/EC of the European Parliament and of the Council of 13 October 2003 establishing a scheme for greenhouse gas emission allowance trading within the Community and amending Council Directive 96/61/EC. http://europa.eu.int/eur-lex/pri/en/oj/dat/2003/l275/l27520031025en00320046.pdf (29.4.2005)

EU (2003b) Implementation of the Stability and Growth Pact', European Council – ECOFIN Meeting, 25 November 2003. http://www.eurotreaties.com/stabpactend.pdf (17.7.2006)

EU (2006) EU emissions trading scheme delivers first verified emissions data for installations. http://europa.eu/rapid/pressReleasesAction.do?reference=IP/06/612 (18.7.2006)

Euractiv (2006) CO_2 quota plans: EU threatens legal action against latecomers. Euractiv EU News & Policy Positions. http://www.euractiv.com/en/sustainability/co2-quota- plans-eu- threatens-legal- action-latecomers/article-157019 (28.7.2006)

Feldstein M (2005) The Euro and the stability pact. Talk at the American Economic Association. http://www.nber.org/feldstein/eurostabilitypact.pdf (17.7.2006)

Fischer C (2001) Rebating environmental policy revenues: output-based allocations and tradable performance standards. RFF Working Papers 01-22, July 2001, Resources for the Future, Washington, DC

Fischer C (2003) Combining rate-based and cap-and-trade emissions policies. Climate Policy 3S2: S89–S109. Related RFF Discussion Paper: 03–32

Fischer C, Fox A (2004) Output-based allocations of emissions permits: efficiency and distributional effects in a general equilibrium setting with taxes and trade. RFF Discussion Paper 04-37, December 2004, Resources for the Future, Washington, DC

Fredriksson P, Sterner T (2005) The political economy of refunded emissions payments programs. Econ Lett 87(1):113–119

Gersbach H (2002) How to get firms to invest: a simple solution to the hold-up problem in regulation. Rev Econ Des 7(1):45–56

Gersbach H, Requate T (2004) Emission taxes and optimal refunding schemes. J Public Econ 88(3–4):713–725

Goulder L, Parry I, Williams III R, Burtraw D (1999) The cost-effectiveness of alternative instruments for environmental protection in a second-best setting. J Public Econ 72(3):275–288

Hahn RW (1989) Economic prescriptions for environmental problems: how the patient followed the doctor's orders. J Econ Perspect 3:95–114

Haites E, Hornung R (1999) Analysis of options for gratis distribution of allowances. National Round Table on the Environment and the Economy, Canada

IEAT (2005) State and trends of the carbon market 2005. International Emissions Trading Association and World Bank, Washington, DC, May 2005

Joskow P, Schmalensee R (1998) The political economy of market-based environmental policy: the U.S. acid rain program. J Law Econ XLI: 37–83

Kolshus H, Torvanger A (2005) Analysis of EU member states' national allocation plans. CICERO Working Paper 2005:2

Meyer MC, Sherman WL (1979) The course of mexican history. Oxford University Press, New York

Nordhaus W (2005) Life after kyoto: alternative approaches to global warming policies. NBER Working Paper Series WP 11889

Parry IWH, Williams III RC (1999) A second-best evaluation of eight policy instruments to reduce carbon emissions. Resour Energy Econ 21:347–373
Raymond L (2003) Private rights in public resources: equity and property allocation in market-based environmental policy. RFF Press, Washington, DC
Smith R (2006) Burning debate: as emission restrictions loom, texas utility bets big on coal. Wall Street Journal 26.7.2006
Sterner T (2003) Policy instruments for environmental and natural resource management. RFF Press, Washington, DC
Sterner T, Höglund Isaksson L (2006) Refunded emission payments theory, distribution of costs, and Swedish experience of NOx abatement. Ecological Economics 57(1):93–106
Svendsen GT, Daugbjerg C, Hjollund L, Pedersen AB (2001) Consumers, industrialists and the political economy of green taxation: CO2 taxation in the OECD. Energy Policy 29:489–497
Tietenberg T (2006) Emissions trading – principles and practice. RFF Press, Washington, DC