Incentive Regulation and Initial Allocation in Emission Permit Trading Systems

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WORK IN PROGRESS - DO NOT QUOTE

Abstract

Free initial allocation of permits in emission trading schemes can pose considerable problems both regarding efficiency and distributionary issues. Initial allocation tied to variables at the discretion of the firms usually results in inefficient outcomes due to incentives for distorted output, input and abatement decisions. In addition, any free allocation comprises a potentially huge wealth transfer thus fostering lobbying activities. In this paper, I apply results from the theory of incentive based regulation under asymmetric information to design optimal initial allocation schemes. Asymmetric information is an issue regarding true abatement and production costs and future emissions. Designing schemes extracting part of this information helps to optimise initial allocation as it prevents firms from lobbying for as many free permits as possible and sets incentives to reveal the firms' true needs for free permits. Such schemes may have the potential to mitigate the problem of over-allocation to the sectors covered by the EU-ETS as information on the true situation of the industry regarding overall competitiveness and potential bankruptcies can be extracted.

Key words: emissions trade, permit trading system, initial allocation, incentive regulation, asymmetric information
JEL: D82, H21, H23, L51, Q50

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1 Introduction

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↬ **Attention** ↫

Currently, I have derived various properties of the optimal contracts I investigate, but the viability of the model depends on some assumptions that have to be discussed in detail. Furthermore, for the existence of this solution, some convexity condition still has to be established.

Thus, the model either can be formulated consistently - what would be an important contribution to the discussion of initial allocation in permit trading systems - or a consistent formulation is not possible. This would however provide interesting insights in the underlying mechanics and in the limits of the formalism of incentive based regulation.

From my preliminary results, it is not yet clear if a consistent formulation is possible without imposing overly restrictive assumptions on the general model. This is tied to the presence of variables at the discretion of the firm that do not enter the contracts (e.g. output sold in a competitive market when only abatement effort and some lump sum payment (initial allocation of free permits) enters the contract).

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In this paper, I try to identify optimal initial allocation methods in emission permit trading systems (ETS). Allocation methods are systematically described and analysed in Sterner and Muller (2006). Basically, initial allocation can take place via an auction or via a set of free allocation methods that are tied to historic ("grandfathering") or current ("current allocation") values of output, input or emissions. An intermediate scheme is "updating", tying initial allocation to some past but updated (i.e. the previous) period. Updating has distortionary effects on output, input or abatement levels and such distortion may also creep in with grandfathering in case the baseline is somewhen updated for later periods. These distortions can be avoided if the free allocation takes place without reference to any variable the firms can influence (i.e. grandfathering) or if no gratis allocation system is implemented at all and firms acquire all permits needed via an auction. The main difference between these systems is then distributionary, as the firms have to pay for all emission permits in the latter case only, while in the first case, the permits are distributed for free. The rents due to the emission permits are thus captured by the firms in the former and by the state in the latter case. This is also the reason that auctions are unpopular with firms and lobbying efforts will work in favour of (updated) grandfathering. Somewhat in-between lies the solution to the initial allocation problem by Ahman et al. (2007), who suggest to allow for updating with a considerable delay (e.g. ten years), thus largely destroying incentives for distorted inefficient input, output or abatement choices, as the pay-off of such is small due to discounting.

The design of the allocation system is not only relevant for existing firms, but also for new entrants and closures. New entrants can be obliged to buy all or a part of the credits they need, or they may get all credits for free, what has different effects on their actions. Similarly for closures, where the effects of loosing all credits when closing down operation has very different effects from being allowed to keep credits with closure. Depending on its details, the allocation system thus can foster efficient operation, or work as a subsidy to inefficient production. If, for example, new entrants are generously rewarded with emission permits, social costs are not accounted for and a coal plant may be more profitable than a wind power park. If, however, no such allocation is made, thus truly reflecting total social costs in the firms' business plans, wind-power can be more profitable than coal-based production (Ahman et al. 2007). The system of initial allocation thus has big influence on business decisions and which investments are undertaken and which are not (cf. also Rogge et al. 2006).[1]

A second element relevant for optimal allocation schemes is the presence of asymmetric information regarding firms' abatement costs and future emissions.

This suggests to investigate in application of the theory of incentive based regulation (IBR) under asymmetric information (see e.g. Laffont and Tirole 1993, Macho-Stadler and Perez-Castrillo 2001) to find optimal allocation systems, given the likely impossibility of an auction due to political reasons[2] and given the goal to distribute as few permits as possible for free, resp. to min-

[1] **To be added: Update information on allocation from NAP II!!**
[2] **To be done: update information on the discussion on auctioning....**

imize or avoid the suboptimal effects of updated allocation. The formalism could help to design optimal contracts due to correct incentives for the firms to reveal their true abatement costs and emission projections. Central to the theory of incentive regulation under asymmetric information is the finding that the extraction of information comes at the cost of conceding some rents to the firms that could also be extracted under full information. Such an incentive-based system usually performs worse than the full information case but better than the case where no incentives to truthfully reveal hidden information is set. In an ETS, defining an optimal initial allocation system can thus be expected to result in less rents left with the firms than with current grandfathering tied to past production, emissions or some current emission standard, but also with less rents extracted than it could be the case with an auction or under full information.

Crucial for the endeavor to apply the theory of incentive regulation to initial allocation in an ETS is the translation of the incentive regulation scheme developed in the context of monopoly regulation and firms of different efficiency levels (for concrete examples from electricity distribution regulation, see Shuttleworth (2005) and Hawdon et al. (2005)) to this specific situation in emissions trading, where a monopoly is not present and pure economic efficiency is actually replaced or complemented by some notion of environmental efficiency. In principle, the market for the output and the newly established market for emission permits also already account for achievement of efficient outcomes as each firm undertakes abatement up to the level where marginal abatement costs equal the permit price. This is not in line with the intuition of incentive regulation, where it is key to differentiate firms according to their costs of effort to reach a certain goal, which translates into different abatement costs required for polluting monopolists of different efficiency (Jebjerg and Lando 1997).

One application of incentive based regulation in the context of environmental regulation of non-monopolists is Moxey et al. (1999). However, the free output-market is not included in their model and each firm is implicitly treated as an independent monopolist to be regulated via a contract prescribing the use of environmentally damaging input and offering some lump-sum transfer. Their model has thus basically the same structure as the standard model and does not add further insight for my case.

Thus, approaches not tied to marginal cost differentiation have to be developed to adapt the theory of incentive regulation to the problem of initial allocation in permit trade. Not marginal cost conditions but rather shut-down conditions of firms newly subjected to an ETS should be focused on. This is however not that far from incentive based regulation, as the participation condition usually part of such formalisms actually is a shut-down condition. Kling and Zhao (2000) give a short and exemplary discussion taking up the point of closures. They investigate how the regulation of total emissions resp. of the number of firms needs to be discerned under certain conditions regarding the types of the polluting firms. On the other hand, marginal cost differentiation may not totally leave the scene, as in case of emission based allocation, permit prices and thus abatement costs incurred can actually differ for different firms subject to an ETS (Sterner and Muller 2006). This could offer some other lever to tie incentive based initial allocation to.

The organisation of the paper is as follows. Section 2 shortly introduces the basic formalism of incentive based regulation and then presents how it could be implemented in an ETS, first discussing the issues related to shut-down conditions (section 2.2) and then assessing the potential of this approach for emission-based initial allocation (section 2.3). Section 3 compares the optimal contract solution to other regulatory schemes and the final section 4 concludes.

2 The Model

In this section, I first present the classical model of incentive regulation under asymmetric information for a monopolist (the agent), regulated by the state (the principal). The same model applies to a principal contracting a firm for a certain task, etc. In the second part, I adapt this formalism to the problem of initial allocation in an ETS as motivated above in section 1.

2.1 The Basic Model of Incentive Regulation Under Asymmetric Information

Consider the following adverse selection problem (for details, see Macho-Stadler and Perez-Castrillo 2001). A principal has a task to be done with a certain set of possible outcomes $\{x_i, i = 1, ..., n\}$, measured as monetary payments, for example. For some wage w, the principal contracts an agent for this task and the agent has to exert some effort e to achieve it, where the probability of each possible outcome x_i depends on the effort exerted: $p_i(e)$. The expected profit is thus $\Pi(e) := \sum_{i=1}^{n} p_i(e)x_i$. The adverse selection enters trough the presence of two types of agents, G and B, between which the principal cannot distinguish. The agent gets some utility $u(w)$ from the wage w and incurs some disutility of effort exerted, which is $v(e)$ for type G and $kv(e)$ for B, where $k \geq 1$. G stands for "good" and B for "bad", as the principal has to pay more to the latter than to the former to have the same level of effort exerted, i.e. to compensate for the disutility incurred by the agent from exerting effort e. The agents' utilities thus are $U^G(w, e) = u(w) - v(e)$ and $U^B(w, e) = u(w) - kv(e)$, with $k > 1$, while the principals utility is $\Pi(e) - w$.[3]

Given full information, the principal can calculate the optimal combination of wage and effort for each type (such a combination of wage and effort is called a "contract"), such that the agents just realise their reservation utility $\underline{U}$, which they want to earn at minimum (this reflects that the agent does not accept the contract if the utility from participating is lower than $\underline{U}$). This optimal contracts shall be denoted by (e^{B*}, w^{B*}) and (e^{G*}, w^{G*}), with $U(e^{B*}, w^{B*}) = \underline{U} = U(e^{G*}, w^{G*})$. Due to asymmetric information, though, the principal cannot offer the optimal contracts, as in this case, both types B and G would chose the contract for B (as $k > 1$): $U^G(e^{B*}, w^{B*}) = u(w^{B*}) - v(e^{B*}) > u(w^{B*}) - kv(e^{B*}) = \underline{U}$.

The principal thus has to follow a different strategy. Assuming the distribution of types is given by the probability ν for G, $\nu \in [0, 1]$ and thus by $1 - \nu$ for B, the principal faces the following utility maximisation problem, where the first two conditions are the participation constraints for the agents, reflecting the condition that they have to realise at least their reservation utility. The third and fourth constraints are self-selection or incentive compatibility conditions, which state that the contract designed for a certain type has to give higher utility to this type than the contract designed for the other: by choosing this optimal contract, the agent thus reveals its true type.

$$\begin{aligned}
\max_{(e^G, w^G), (e^B, w^B)} \quad & \nu[\Pi(e^G) - w^G] + (1 - \nu)[\Pi(e^B) - w^B] && (1)\\
\text{s.t.} \quad & u(w^G) - v(e^G) \geq \underline{U} && (2)\\
& u(w^B) - kv(e^B) \geq \underline{U} && (3)\\
& u(w^G) - v(e^G) \geq u(w^B) - v(e^B) && (4)\\
& u(w^B) - kv(e^B) \geq u(w^G) - kv(e^G). && (5)
\end{aligned}$$

The menu of contracts $\{(e^G, w^G), (e^B, w^B)\}$ that solves this problem is characterised by the following conditions (derived by solving this standard

[3]**To discuss: is it promising/necessary to include some "shadow costs of public funds" variable? - Cf. Moxey et al. (1999).**

constrained maximisation problem, see also Macho-Stadler and Perez-Castrillo 2001):

$$\begin{aligned} u(w^G) - v(e^G) &= \underline{U} + (k-1)v(e^B) && (6) \\ u(w^B) - kv(e^B) &= \underline{U} && (7) \\ \Pi'(e^G) &= \frac{v'(e^G)}{u'(w^G)} && (8) \\ \Pi'(e^B) &= \frac{kv'(e^B)}{u'(w^B)} + \frac{\nu(k-1)}{1-\nu}\frac{v'(e^B)}{u'(w^G)}. && (9) \end{aligned}$$

Important properties of the solution are the following (Macho-Stadler and Perez-Castrillo 2001): The effort required from G is bigger than the effort required from B - as it is more valuable for the utility of the principal - , the contract for G is efficient (i.e. the effort level required is the same as the effort required under full information), while the one for B is not (the effort required from B is lower than under full information), and the utility of type G is strictly bigger than its reservation utility, while it is equal to this for B. This model with two discrete types of agents generalises similarly to a continuum of types (Macho-Stadler and Perez-Castrillo 2001).

Incentive regulation under asymmetric information thus succeeds in designing optimal contracts for this situation. The basis is a set of contracts that are self-selecting, i.e. it is not advantageous for a firm of a certain type to chose a contract designed for another type. For this to work, some rents have to be ceded to more efficient types (while no rents have to be given to the least efficient type), while a suboptimal level of effort is required from less efficient types (but the optimal level is required for the most efficient type: "no distortion at the top"). Finally, I mention that the presence of the reservation utility could be seen as a "no bankruptcy"-condition for the contracts offered.

2.2 Application to Initial Allocation in ETS - Shutdown Conditions

Incentive regulation solves the problem of asymmetric information as good as possible by means of a wisely designed contract. In permit trade, many aspects of asymmetric information actually pose no problem, as the establishment of a market accounts for this. This is the case for marginal abatement and production costs under efficient initial allocation, i.e. via an auction or grandfathering, where the firms cannot influence initial allocation by their actions and thus have no incentives for distorted input, output or abatement decisions. In such a case, the new market accounts for hidden information on abatement costs and prospective emissions and decisions are efficient, i.e. marginal costs equal marginal benefits, i.e. prices.

The situation is different for initial allocation based on variables the firms can influence, as it is the case with current allocation and updating. This potentially distorts marginal abatement and production costs and thus offers a possibility to apply the type of contracts designed for incentive regulation, as they are based on varying marginal costs (i.e. varying "costs of effort"). This case will be discussed below in section 2.3. Here, I will first discuss a second issue, where incentive based contracts may be applied in permit trade. This is the question of bankruptcy. While bancruptcy is accounted for via the reservation utility in incentive based contracts, it is no explicit issue in the theoretical formulation of an ETS. But implementation of such a system actually makes production more expensive by internalising the external costs of pollution. The competitiveness of single firms subject to the ETS becomes an issue in case the costs increase is high enough and abatement at reasonably low costs is not possible.

Depending on the goals of the establishment of an ETS, bankruptcies of dirty and too expensive (after internalisation of external costs) firms can be a welcome effect. On the other hand, there may be reasons to hedge against bankruptcies under permit trade, as long as the emissions are brought down.

Such hedging policies can be implemented via the initial allocation of permits. If no free permits are allocated initially, all firms have to pay for the total external costs and where total costs are too high after their inclusion, shut-down will follow. The other extreme would be allocation at the level of 100% of actual emissions, equivalent to no regulation and no inclusion of any external costs, thus not changing the industry.

There may also be reasons for such hedging in case of an economy with several sectors whereof only a part is subjected to the ETS, the economy as a whole faces an emission cap and lower or even missing reductions incurred in the sectors subject to trade could be compensated by increased reductions in the other sectors, e.g. via an emission tax. Such hedging usually will be inefficient, however, but one could imagine lobbying activities strong enough to lead to their implementation. This situation can be observed in the initial allocation of permits for the European Union ETS - the National Allocation

Plans, both for period I and II, where allocation to the sectors subject to trading are generally too generous (Ellerman and Buchner 2006, Rogge et al. 2006).

Any free allocation, however, sets incentives for potentially inefficient outcomes regarding shut-down (closures) and new entrances. Here, I use shut-down or closure to refer to both firms that are too expensive in production due to the introduction of the ETS, i.e. due to the inclusion of external costs, and thus cannot survive in a competitive environment after introducing the ETS, and to closures of firms or production units at any time in an ETS already under operation, due to various reasons, such as antiquated physical capital.

In the following, I focus on initial allocation and distortions of shut-down decisions. With any ETS newly introduced and featuring free initial allocation, lobbying for larger shares of permits sets in (Rogge et al. 2006, Sterner and Muller 2006) and the total monetary amounts involved can be huge.[4] Arguments for generous initial allocation usually are the threatened competitiveness of a sector or single firms.

In the long run, a firm in a competitive environment shuts down as soon as the production costs are higher than the output price. In the short run, differentiation between fixed and variable costs is in place and the firm shuts down as soon as the price is lower than the average variable costs - if it is lower than average total costs but higher than average variable costs the firm still operates although incurring losses (but less than if it would close down). A firm arguing that the introduction of an ETS makes its operation uncompetitive thus argues that the costs of permits adds that much to the production costs that the price finally realized for the output is in the end lower than the variable production costs (including emission prices). Facing a variety of firms differing by production and abatement costs, these costs and thus the difference between the output price and costs are private information. Under full knowledge of this difference, the principal would know how much permits are necessary for the firm to not go bankrupt. Under private information, the firm has incentives to claim more free permits than it actually needs, resp. to claim bankruptcy threats at lower emission costs than would actually be possible to incur without shutting down.

[4] Each year, about two billion permits are distributed in the EU-ETS, what comprises a decent sum already for low permit prices of 10 €.

Incentive regulation could thus be brought in here, trying to define contracts for initial allocation that extract truthful information on production and abatement costs, and prospective emissions, resp. on profits realised before the implementation of the ETS. It thus would not aim at implementing the optimal marginal operation decisions, as this is accounted for by the market for the output and the newly introduced permit market, but to extract the correct information on the firms' situation regarding competitiveness in principle. That means extracting information on the firms' ability to afford to pay for permits without going bankrupt. This would allow for a more informed system of initial allocation that has not to rely on potentially exaggerated claims from the industry, and thus would avoid distributing the wealth represented by the free permits according to lobbying power rather than according to actual need due to the true cost structure.

This intuitive reasoning can be captured in a formalism inspired by the standard formalism presented in the previous subsection 2.1. Assume the presence of two types of firms $\beta = D, C$ in the economy, D with relative frequency $\nu \in [0,1]$, C with $1-\nu$, with heterogeneous production (output q) and abatement (emissions reductions a) costs $c^{\beta}(q,a)$ and emissions $e^{\beta}(q)-a$ ($e^{\beta}(q)$ are the unregulated emissions of type β producing output q): for the same levels of q and a, I assume $c^{C}(q,a) > c^{D}(q,a)$ and $e^{C}(q) < e^{D}(q)$ - abatement thus is more costly for C than for D (but C emits less for the same amount of output than D; this reflects the situation of an already quite clean production unit with high costs for further abatement in contrast to a dirty unit with low abatement costs - with respect to this is D the "more efficient" type). Such heterogenities can pertain also in an otherwise competitive situation due to specific policies (e.g. subsidies to keep the work force in operation for a certain part of a sector) or due to scarcity or quality rents (e.g. of the coal beds exploited for coal-fired power plants on the site), for example. The concrete reasons why heterogeneities are present is however not important for the following discussion. The firms are subjected to a newly introduced ETS with an overall cap $\bar{E}$. The output of each firm q is sold on an international competitive market for a fixed price p not at the discretion of the firms subjected to the ETS, and emissions permits are also sold on a competitive market at a price p^e that neither can be influenced.

After introduction of permit trade, total costs are $c^{\beta}(q,a)+p^{e}(e^{\beta}(q)-a^{\beta})$. Given free allocation of permits takes place, firms will lobby for bigger shares as they can result in a considerable wealth-transfer and, more important, as they can change a potentially disadvantageous relation of average variable costs to output prices (i.e. the former are higher than the latter). In case bankruptcy should be avoided - and this can be done by the free initial allocation - the exact amount of wealth transfer necessary for a certain firm to survive should be known to implement such a strategy optimally. That is, $c^\beta(q,a) + p^e(e^\beta(q) - a^\beta)$ should be known for optimal free allocation. This is not the case in general and this thus comprises a classical asymmetric information problem to the state handing out permits for free to a firm that has an incentive to overstate its needs for free permits.

In order to formulate this problem in the incentive regulation framework, the goal of the state (i.e. the utility function to be maximised), the type of the firms, the effort and wage payments to the firm and observable outcomes have to be identified. I assume the goal of the state to be avoidance of bankruptcies after regulation (i.e. to assure production of the output q), reductions of emissions and both at lowest cost, i.e. ceding as few free permits to the firms as possible. I assume that the firms, after initial allocation, will take optimal (for them) decisions on abatement and production, i.e. abatement takes place up to the level where its marginal costs equal the permit price (accounting for potential distortions due to suboptimal allocation methods as described in e.g. Sterner and Muller (2006), resp. distortions caused by the contract accepted). Asymmetric information is due to production and abatement costs and also future emissions that are private information of each firm. The state thus has no information on how many permits each firm actually needs to survive. Information on actual emissions and output, however, is public and can enter a contract. The state thus faces the following optimization problem ("effort" is measured via abatement, resp. via the remaining amount of emissions, "costs of effort" are abatement costs and "wage" is captured by the free initial allocation of permits $\bar{e}^\beta$):

$$\begin{aligned}
\max_{(a^D,\bar{e}^D),(a^C,\bar{e}^C)} \quad & \nu[\Pi(q^D,a^D) - p^e\bar{e}^D] + (1-\nu)[\Pi(q^C,a^C) - p^e\bar{e}^C] && (10)\\
\text{s.t.} \quad & pq^\beta - c^\beta(q^\beta,a^\beta) - p^e[e^\beta(q^\beta) - a^\beta - \bar{e}^\beta] \geq 0 \\
& \qquad\qquad\qquad\qquad \text{for} \quad \beta = C, D && (11)\\
& pq^D - c^D(q^D,a^D) - p^e[e^D(q^D) - a^D - \bar{e}^D] \geq \\
& \qquad pq^{D+} - c^D(q^{D+},a^C) - p^e[e^D(q^{D+}) - a^C - \bar{e}^C] && (12)\\
& pq^C - c^C(q^C,a^C) - p^e[e^C(q^C) - aC - \bar{e}^C] \geq \\
& \qquad pq^{C+} - c^C(q^{C+},a^D) - p^e[e^C(q^{C+}) - a^D - \bar{e}^D], && (13)
\end{aligned}$$

where the firm faces contracts prescribing abatement levels a^β and fixed amounts of free permits $\bar{e}^\beta$, and chooses its output q^β, and in consequence also its emissions accordingly, maximising individual utility (i.e. q^D is optimal for type D for the contract $(a^D, \bar{e}^D)$, q^{D^+} is optimal for type D for the contract designed for C, and similarly for q^C and q^{C^+}). As above, the first condition captures the "no-bankruptcy" condition for both types and the second and third conditions capture incentive compatibility, i.e. that the contract designed for type β is actually optimal for this type.

By assumption, c and e have the following common properties (in the following, I sometimes drop the superscript β if the notation stays unique or if it does not matter): $c'_a > 0$, $c''_{aa} \geq 0$, $c'_q > 0$, $e'_q > 0$ (the primes indicate derivatives with respect to the variables in the sub-script). I also assume that abatement costs increase slower with abatement than the costs of emissions $p^e(e - a)$ come down with it (i.e. first abatement steps come at low costs). In this case, $c'_a - p^e < 0$ for small a. Furthermore, the following proposition holds (because $c''_a \geq 0$):

$$\text{if } c'_a - p^e > 0 \text{ for } a = a_1, \text{ then } c'_a - p^e > 0 \text{ for all } a > a_1. \tag{14}$$

Thus, abatement will take place only in the case when $c'_a - p^e < 0$ (up to the efficient level where $c'_a - p^e = 0$). For a firm with $c'_a - p^e > 0$, abatement does not pay off. Thus, $v^\beta(q, a) := c^\beta(q, a) - p^e a$ shall denote the disutility of "effort" (i.e. of abatement) for the type β, which decreases for any firm that abates below the efficient abatement level. As $c^C(q, a) > c^D(q, a)$ we have $v^C(q, a) > v^D(q, a)$ for identical output and abatement levels. The utility of "wage", the free permit allocation, is $u(\bar{e}) := p^e\bar{e}$. As in the standard case described above in section 2.1, the function v depends on the type, while u does not. Similarly to the standard case, I assume a relation between v^C and v^D, via abatement costs: $c^C(q, a) \stackrel{!}{=} kc^D(q, a)$ with $k > 1$. In the following, I thus drop the superscript on c and write $c(q, a)$ and $kc(q, a)$. The most important difference with respect to the standard case, however, arises from the presence of the revenues from the free output market. This adds the terms $\pi^\beta(q^\beta) = pq^\beta - p^e e^\beta(q^\beta)$ to the firms' profit function. As $e^C(q) < e^D(q)$, we thus have $\pi^C(q) > \pi^D(q)$ for identical levels of output. Using this notation, the maximisation problem reads as follows:

$$\max_{(a^D,\bar{e}^D),(a^C,\bar{e}^C)} \nu[\Pi(q^D,a^D) - p^e\bar{e}^D] + (1-\nu)[\Pi(q^C,a^C) - p^e\bar{e}^C] \tag{15}$$

s.t.

$$\pi^\beta(q^\beta) - v^\beta(q^\beta,a^\beta) + u(\bar{e}^\beta) \geq 0 \text{ for } \quad \beta = C, D \tag{16}$$

$$\pi^D(q^D) - v^D(q^D,a^D) + u(\bar{e}^D) \geq \pi^D(q^{D+}) - v^D(q^{D+},a^C) + u(\bar{e}^C) \tag{17}$$

$$\pi^C(q^C) - v^C(q^C,a^C) + u(\bar{e}^C) \geq \pi^C(q^{C+}) - v^C(q^{C+},a^D) + u(\bar{e}^D). \tag{18}$$

From the definition of q^{D+} as the optimal value for q for a firm of type D given the contract (q^C, a^C), we have that the r.h.s. of (17) is larger than $\pi^D(q^C) - v^D(q^C,a^C) + u(\bar{e}^C)$. Using $v^D(q^C,a^C) < v^C(q^C,a^C)$, this is larger than $\pi^D(q^C) - v^C(q^C,a^C) + u(\bar{e}^C)$. Assuming[5] identical revenues for D and C, $\pi^D = \pi^C =: \pi$, this equals $\pi(q^C) - v^C(q^C,a^C) + u(\bar{e}^C)$. This is larger than zero (use (16) for $\beta = C$) and I have thus established that (16) for $\beta = D$ follows from (16) for $\beta = C$ and (17), and can thus be dropped. The reservation utility condition for the more efficient type D is thus not necessary. This is one characteristic property of incentive based contracts.

Furthermore, adding the l.h.s. and r.h.s., respectively, of equations (17) and (18), replacing q^{C+} and q^{D+} on the right side by q^D and q^C, respectively, which again reduces the right side by definition of $q^{\beta+}$, cancelling terms $\pi(\cdot)$ and $u(\cdot)$, and employing the definition of v gives $c(q^D,a^D) \geq c(q^C,a^C)$. This gives $a^D \geq a^C$.[6] This is the other characteristic property of incentive based contracts: more effort is required from the more efficient type. A further characteristic of standard IBR contracts is that the abatement required by the contracts offered truly differ, i.e. that it is not optimal to require the same abatement from both types. This is also true in my model: Assume the same abatement was required from both types, then (17) and (18) lead to the condition that also $\bar{e}^D = \bar{e}^C$ (employ again the definition of $q^{\beta+}$ and that replacing it with q^β reduces the r.h.s of (17) and (18)). Employing the first order conditions (see below) from the optimisation (15) then leads to a contradiction thus proofing my claim.[7]

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[5] **MOTIVATE/DISCUSS/REPLACE THIS ASSUMPTION**

[6] Four cases can be discerned: $a^D > a^C$ and $q^D > q^C$ is compatible with $c(q^D,a^D) \geq c(q^C,a^C)$. If $a^D < a^C$, then necessarily $q^D > q^C$ **(IS IT POSSIBLE TO EXCLUDE THIS CASE - USING FOCs MAYBE??)** , and if $q^D < q^C$, then we necessarily have $a^D > a^C$. Not possible is $a^D < a^C$ and $q^D < q^C$.

[7] **GIVE DETAILS ON USING THE FOCs TO ESTABLISH THAT EQUAL a AND EQUAL e LEAD TO A CONTRADICTION!!!**

I now state the first order conditions for the constrained maximisation[8]:

$$\begin{aligned}
\nu\Pi'_{a^D} &+ \nu\Pi'_{q^D}{q^D}'_{a^D} \\
&+\lambda_2\pi'_{q^D}{q^D}'_{a^D} - \lambda_2{v^D}'_{q^D}{q^D}'_{a^D} - \lambda_2{v^D}'_{a^D} \\
&-\lambda_3\pi'_{q^{C+}}{q^{C+}}'_{a^D} + \lambda_3{v^C}'_{q^{C+}}{q^{C+}}'_{a^D} + \lambda_3{v^{C+}}'_{a^D} = 0
\end{aligned} \tag{19}$$

$$-\nu p^e + \lambda_2 u'_{\bar{e}^D} - \lambda_3 u'_{\bar{e}^D} = 0 \Leftrightarrow \lambda_2 - \lambda_3 = \nu \tag{20}$$

$$\begin{aligned}
(1-\nu)\Pi'_{a^C} &+ (1-\nu)\Pi'_{q^C}{q^C}'_{a^C} \\
&+\lambda_1\pi'_{q^C}{q^C}'_{a^C} - \lambda_1{v^C}'_{q^C}{q^C}'_{a^C} - \lambda_1{v^C}'_{a^C} \\
&-\lambda_2\pi'_{q^{D+}}{q^{D+}}'_{a^C} + \lambda_2{v^D}'_{q^{D+}}{q^{D+}}'_{a^C} + \lambda_2{v^D}'_{a^C} \\
&+\lambda_3\pi'_{q^C}{q^C}'_{a^C} - \lambda_3{v^C}'_{q^C}{q^C}'_{a^C} - \lambda_3{v^C}'_{a^C} = 0
\end{aligned} \tag{21}$$

$$\begin{aligned}
-(1-\nu)p^e &+ \lambda_1 u'_{\bar{e}^C} - \lambda_2 u'_{\bar{e}^C} + \lambda_3 u'_{\bar{e}^C} = 0 \\
&\Leftrightarrow \lambda_1 - \lambda_2 + \lambda_3 = 1 - \nu
\end{aligned} \tag{22}$$

It follows from (20) and (22), that $\lambda_1 = 1$ and that the participation constraint (16) for D binds. As Lagrange multipliers are non-negative, it follows further from (20) that $\lambda_2 > 0$ and the corresponding condition (17) thus binds as well. These binding conditions (17) and (16) combine to[9]

$$\begin{aligned}
\pi(q^D) &- v^D(q^D, a^D) + u(\bar{e}^D) && (23)\\
&= v^C(q^C, a^C) - v^D(q^{D+}, a^C) + \pi(q^{D+}) - \pi(q^C) \\
&= \pi(q^{D+}) - v^D(q^{D+}, a^C) + u(\bar{e}^C) - \pi(q^C) + v^C(q^C, a^C) - u(\bar{e}^C) \\
&\geq \pi(q^C) - v^D(q^C, a^C) + u(\bar{e}^C) - \pi(q^C) + v^C(q^C, a^C) - u(\bar{e}^C) \\
&= v^C(q^C, a^C) - v^D(q^C, a^C) \geq 0 && (24)
\end{aligned}$$

which corresponds to (6), while the binding participation condition for C corresponds to (7). I have thus established the first two conditions characterising optimal IBR contracts in the context of initial allocation in an ETS.

[8] λ_1 is the Lagrange multiplier for condition (16) for C, λ_2 for (17) and λ_3 for (18), and condition (19) refers to a^D, (20) to (22) to $\bar{e}^D$, a^C and $\bar{e}^C$; q^D and q^{C+} are functions of a^D, q^C and q^{D+} of a^C. Also use $u(\bar{e}) = p^e\bar{e}$.

[9] Use the definition of q^{D+}.

The interpretation is the same as in the standard case: Type C just "earns its reservation utility", i.e. in this case, where this is zero, C just does not shut down, while type D earns a strictly higher utility. To derive the analogues to the other two conditions, (8) and (9), I first rearrange (19) and (21), using $\lambda_1 = 1$:

$$\begin{aligned} \nu\Pi'_{a^D} &+ \nu\Pi'_{q^D}{q^D}'_{a^D} = \\ &= -\lambda_2(\pi'_{q^D}{q^D}'_{a^D} - {v^D}'_{q^D}{q^D}'_{a^D} - {v^D}'_{a^D}) \\ &\quad +\lambda_3(\pi'_{q^{C+}}{q^{C+}}'_{a^D} - {v^C}'_{q^{C+}}{q^{C+}}'_{a^D} - {v^{C+}}'_{a^D}) \end{aligned} \tag{25}$$

$$\begin{aligned} (1-\nu)\Pi'_{a^C} &+ (1-\nu)\Pi'_{q^C}{q^C}'_{a^C} = \\ &= -\pi'_{q^C}{q^C}'_{a^C} + {v^C}'_{q^C}{q^C}'_{a^C} + {v^C}'_{a^C} \\ &\quad +\lambda_2(\pi'_{q^{D+}}{q^{D+}}'_{a^C} - {v^D}'_{q^{D+}}{q^{D+}}'_{a^C} - {v^D}'_{a^C}) \\ &\quad -\lambda_3(\pi'_{q^C}{q^C}'_{a^C} - {v^C}'_{q^C}{q^C}'_{a^C} - {v^C}'_{a^C}) \end{aligned} \tag{26}$$

Proceeding further is more complicated than in the standard case, as λ_3 need not be zero, as it has not yet been established that (18) cannot bind, due to the presence of the q-terms. To nevertheless proceed, I assume that (18) does not bind[10] and we thus have $\lambda_3 = 0$ and, in consequence, $\lambda_2 = \nu$. Equation (25) then reads (assuming $\nu \neq 0$, i.e. that there is a positive probability for each type to occur)

$$\nu\frac{\mathrm{d}\Pi}{\mathrm{d}a^D} - \nu\frac{\mathrm{d}v^D}{\mathrm{d}a^D} + \nu\pi'_{q^D}{q^D}'_{a^D} = 0 \Leftrightarrow 1 = \frac{\frac{\mathrm{d}\Pi}{\mathrm{d}a^D}}{\frac{\mathrm{d}v^D}{\mathrm{d}a^D} - \pi'_{q^D}{q^D}'_{a^D}}. \tag{27}$$

From the definition of u, we have $1 = \frac{p^e}{u'(\bar{e}^D)}$, and combining this and the previous equation gives

$$\frac{\mathrm{d}\Pi}{\mathrm{d}a^D} = \frac{\frac{\mathrm{d}v^D}{\mathrm{d}a^D} - \pi'_{q^D}{q^D}'_{a^D}}{u'(\bar{e}^D)/p^e} = \frac{\mathrm{d}v^D}{\mathrm{d}a^D} - \pi'_{q^D}{q^D}'_{a^D}, \tag{28}$$

which is equivalent to the efficiency condition (8) from the standard case. The independence from the wage $\bar{e}$ reflects the risk-neutral agent ($u(\bar{e})$ is proportional to $\bar{e}$); also in the standard case, this efficiency condition is independent of the wage for risk-neutral agents. As the agent maximises its

[10]**MOTIVATE/DISCUSS/REPLACE THIS ASSUMPTION**

profits given the contract accepted, this shows that the abatement level optimal under full information is realised for type D (as for the standard case with risk-neutral agents, see Macho-Stadler and Perez-Castrillo (2001)). We then have $\frac{\mathrm{d}v^D}{\mathrm{d}a^D} - \pi'_{q^D} {q^{D}}'_{a^D} = 0 = \frac{\mathrm{d}\Pi}{\mathrm{d}a^D}$, which characterises the optimal level. This is again the principle of "no distortion at the top".

Similarly, equation (26) leads to

$$\frac{\mathrm{d}\Pi}{\mathrm{d}a^C} = \Big(\big[\frac{\mathrm{d}v^C}{\mathrm{d}a^C} - \pi'_{q^C} {q^{C}}'_{a^C} \big] - \nu \big[\frac{\mathrm{d}v^D}{\mathrm{d}a^C} - \pi'_{q^{D+}} {q^{D+}}'_{a^C} \big] \Big) \frac{1}{1-\nu}, \tag{29}$$

which corresponds to condition (9) from the standard case for risk-neutral agents. As for B, the optimal full information abatement level for C fulfils $\frac{\mathrm{d}v^C}{\mathrm{d}a^C} - \pi'_{q^C} {q^{C}}'_{a^C} = 0 = \frac{\mathrm{d}\Pi}{\mathrm{d}a^C}$. If this were true here, $\frac{\mathrm{d}v^D}{\mathrm{d}a^C} - \pi'_{q^{D+}} {q^{D+}}'_{a^C} = 0$ would thus hold as well, which cannot be true, as this is the condition for optimal abatement for D and the optimal value for a^D necessarily being different from optimal a^C (see above) thus cannot fulfil this as well. Abatement required from C is thus sub-optimal. As in any case $a^C < a^D$ (see above), $\frac{\mathrm{d}v^D}{\mathrm{d}a^C} - \pi'_{q^{D+}} {q^{D+}}'_{a^C} < 0$ as an increase in a^C would reduce the total costs (including rewards from output-sales) for D as it would approach its optimal abatement level. Thus, we always have $-\nu\big(\frac{\mathrm{d}v^D}{\mathrm{d}a^C} - \pi'_{q^{D+}} {q^{D+}}'_{a^C}\big) > 0$. Assume a^C being higher than it s optimal level. Then $\frac{\mathrm{d}v^C}{\mathrm{d}a^C} - \pi'_{q^C} {q^{C}}'_{a^C} > 0$ as a further increase in abatement would increase costs for C. The right hand side of (29) is thus positive and in consequence the l.h.s is positive as well: $\frac{\mathrm{d}\Pi}{\mathrm{d}a^C} > 0$. This however is a contradiction, as for a^C being bigger than the optimal level, we have $\frac{\mathrm{d}\Pi}{\mathrm{d}a^C} < 0$, as a further increase would reduce the regulators returns. I have thus established that the contract requires abatement strictly lower than the optimal level for C. This is again the same result as in the standard IBR case. I have thus established the four conditions that characterise the optimal IBR contract for the case of initial allocation in an ETS under certain assumptions.

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TO BE DONE FOR THIS SECTION:

CHECK CONDITIONS FOR THE APPLICABILITY OF THE STANDARD SOLUTION PROCEDURES FOR THE MAXIMISATION PROBLEM - ARE THERE SOME CONVEXITY RESTRICTIONS, etc.? PROVIDE A PROOF FOR THE EXISTENCE

OF A SOLUTION.

TRY TO PROOF A FURTHER PROPERTY OF STANDARD IBR: (18) DOES NOT BIND!!! - OR PROOF THAT IT BINDS!

AND TRY TO GET RID OF THE ASSUMPTIONS ON IDENTICAL REVENUES FOR THE TWO TYPES

DISCUSS THE VARIOUS FOOTNOTES ABOVE CONTAINING SOME RESTRICTIONS/ASSUMPTIONS. TRY TO REMOVE THEM.
****

2.3 Application to Initial Allocation in ETS - Emission Based Allocation

Yet to be done, similar to the previous section:

- motivate the model intuitively
- translate into formalism - state maximisation problem plus boundary conditions
- solve; FOCs, rearrange to get a form of the standard equations 6-9 again
- some interpretation of the results

3 Additional Issues

May simulate such optimal contracts as described in the sections above in comparison with other regulations (similarly to the simulations in Moxey et al. (1999)).

4 Conclusions

5 References

Åhman, M., Burtraw, D., Kruger, J. and Zetterberg, L., 2007, A Ten-Year Rule to Guide the Allocation of EU Emission Allowances, Energy Policy

35(3): 1718-1730.

Ellerman, D. and Buchner, B., 2006, Over-Allocation or Abatement? A Preliminary Analysis of the EU-ETS Based on the 2005 Emissions Data, FEEM Working Paper, SSRN Electronic Paper Collection: http:// ssrn.com/ abstract= 946091 (20.11.06).

Hawdon, D., Hunt, L.C., Levine, P. and Rickman, N., 2005, Optimal Sliding Scale Regulation: An Application to Regional Electricity Distribution in England and Wales, CEPR Discussion Paper No. 4934, February 2005, Centre for Economic Policy Research, London.

Jebjerg, L. and Lando, H., 1997, Regulating a Polluting Firm Under Asymmetric Information, Environmental and Resource Economics 10: 267-284.

Kling, C.L. and Zhao, J., 2000, On the Long-run Efficiency of Auctioned vs. Free Permits, Economics Letters 69: 235-238.

Laffont, J.-J. and Tirole, J., 1993, A Theory of Incentives in Procurement and Regulation, Cambridge, Mass., MIT Press.

Macho-Stadler, I. and Perez-Castrillo, J., 2001, An Introduction to the Economics of Information, 2nd ed., Oxford, UK, Oxford University Press.

Moxey, A., White, B. and Ozanne, A., 1999, Efficient Contract Design for Agri-Environment Policy, Journal of Agricultural Economics 50(2): 187-202.

Rogge, K., Schleich, J. and Betz, R., 2006, An Early Assessment of National Allocation Plans for Phase 2 of EU Emission Trading, Working Paper Sustainability and Innovation No. S1/2006, ISI Karlsruhe.

Sterner, T. and Muller, A., 2006, Output and Abatement Effects of Allocation Readjustment in Permit Trade, RFF Discussion Paper 06-49, Resources for the Future, Washington DC (submitted to Climatic Change).

Shuttleworth, G., 2005, Using Incentives to Inform Regulatory Decisions, NERA Energy Regulation Insights Issue 25, August 2005, NERA Economic Consulting, London.