# Which allocation rule generates true price signals for the $CO_2$ allowance market?

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## Abstract

The Kyoto Protocol sets national quotas on the global pollutant $CO_2$ and allows for international emissions trading as a way to obtain air quality standards at least costs. The economic efficiency of the system depends on firms being able to deal with permits at competitive prices and to decide on the "best" emissions reducing investment. Here, early and reliable price signals constitute the basis, particularly for energy efficient investment decisions which are of increasing interest for companies under emissions trading. Based on our experimental study (Benz and Ehrhart, 2006), we exclusively investigate the reliability of market price signals generated by different policy-relevant allocation rules for $CO_2$ allowances under the EU emissions trading system (EU-ETS). We consider gratis allocation (grandfathering), auctions, and their combination in so-called hybrid systems. Regarding the auctions, we also inquire for the "appropriate design" for carbon auctions.

Based on a theoretical approach, where agents bid according to their marginal abatement costs, we show that the hybrid system of grandfathering and a one-sided auction (which is taken into account in the EU-ETS) does not generate reliable price signals, which should reflect the actual market scarcity of the allowances. This requirement, however, is met, if in the hybrid system the one-sided auction is replaced by a double auction or if a one-sided auction is used exclusively. The results of a laboratory experiment persuasively support our theoretical findings with respect to correct price signals.

## Introduction

In January 2005 the EU-wide $CO_2$ emissions trading system has formally entered into operation.[1] The EU-ETS requires a cap-and-trade program whereby the right to emit $CO_2$ becomes a tradable commodity.[2] The economic efficiency of the system bases on firms being able to abate emissions at different prices and to buy and sell permits relatively easily, with incidental transactions costs and at competitive prices. Hence, the emissions trading system creates incentives for obliged firms to invest in emissions reducing technologies, e.g. technologies that increase the grade of energy efficiency since the emissions generating "use" of energy causes additional costs for firms under emissions trading.[3] Here, the application of an allocation process which creates reliable market price signals at an early stage may be one of the most important regulatory issues for a successful implementation of the system. Reliable price signals, which reflect the "true scarcity" of the emission allowances, constitute the basic requirement for participants to take investment decisions for more innovative and energy efficient technologies, particularly in the energy sector where temporal aspects play an important role with respect to plan-

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[1] The agreement on a common position was reached in December 2002 and passed the EU-parliament's second reading in the summer of 2003 (EU, 2003). The European Commission had already published a proposal for a Directive in October 2001 (COM, 2001).

[2] The most prominent example of already existing emissions trading systems is the $SO_2$ allowance trading scheme under the Clean Air Act (Stavins, 1998; Joskow et al., 1998; Burtraw, 1996)

[3] Please note that in this context energy-efficiency addresses a strict technological (equipment-based) concept. Hereby a technology is considered to be more energy-efficient if it reduces the intensity of energy inputs by keeping the output level constant. The provision of technologies, which reduce energy at least cost are not considered in this concept.

ning and realising abatement measures. These emissions reduction projects are often characterised by high costs and long implementing times. This will require an investment appraisal in order to evaluate advantages and disadvantages of the projects.[4] Since a company has to decide whether to invest in abatement measures or to buy emission allowances, the costs of the new technology must be made comparable to the market price for emission allowances which is unknown and can only be estimated at the time of investing.[5] Therefore, reliably and early market price signals are indispensable objectives of the allocation rule for $CO_2$ allowances since they provide a basis for cost efficient investment, i.e. $CO_2$ is abated where it is cheapest.

Two allowance allocation alternatives are discussed by authorities: auctioning and gratis allocation in proportion to historical emissions (*grandfathering*).[6] In the pilot-period 2005-2008 the National Allocation Plans (NAPs I) of most of the participating countries exclusively applied grandfathering. Only four countries used the possibility to allocate 5% or less of their total amount of initial allocation (ET-budget) via auctioning: Denmark (5 %), Hungary (2.5 %), Lithuania (1.5 %) and Ireland (0.75 %). At present, the ETS-Directive is concerned with the question of how to improve the allocation process of the pilot-period for the first commitment period 2008-2012 in the NAPs II and beyond. When considering auctions as allocation mechanism, their creation of correct revelation incentives, allocation efficiency and of reliable early price signals for the actual scarcity in the market is of capital importance.

In this paper we are looking for an allocation mechanism in the EU-ETS that complies with these requirements. We conduct an experiment where we compare several policy-relevant allocation rules. We focus on grandfathering, auctioning and their combination. As auction formats we chose dynamic one-sided as well as dynamic double auctions. A static version of the former is considered by the ETS-Directive and is already applied by the aforementioned countries whereas the latter is applied, also statically, in the US market for $SO_2$ allowances. With the mechanism dynamic "double auction" we refer to an institution in which participants can act as buyer and seller with the pricing and activity rule of a Japanese auction, i.e. the auctioneer continuously raises the current price until demand meets supply. Participants must signal at every price level their willingness to stay in the auction and to pay (receive) the current price for their demanded (offered) quantity.[7]

## Literature Overview

Though the experimental economics literature of emissions trading schemes is comprehensive, the initial allocation rule has not been analyzed extensively. To our knowledge, there are no experimental studies with respect to the EU-ETS. Early studies are concerned with the question whether tradable emission schemes should be implemented or not by studying the performance of different trading institutions compared to command and control instruments. In these studies, the initial allocation rule is always treated as a fixed parameter. Later, the attention is focused on how trading schemes should be implemented with respect to the initial distribution of allowances among participants when grandfathering is applied (Ehrhart et al., 2006) or to a ban on banking of allowances, see e.g. Godby et al. (1997), Cronshaw and Brown-Kruse (1999) or Cason et al. (1999). Except of the work by Ehrhart et al. (2006), none of the studies captures the unique institutional design of the EU-ETS. Looking at the literature that specialises on the $SO_2$ trading scheme, the work by Cason (1993, 1995) is more useful. He studies the sulphur allocation process where the Environmental Protection Agency (EPA) conducts annual sealed bid/sealed offer auctions with the auction rule of a "low-offer-to-high-bid" matching system. In a theoretical model and in a later experiment he demonstrates that because of the discriminatory price rule, sellers and buyers have an incentive to misrepresent their true values of the emission permits (costs for emissions control) and state in the auction lower asking and bid prices as this increases their trading priority.[8] Conducting an experiment for testing the EPA auction with uniform pricing Cason and Plott (1996) get a higher efficiency level, more truthful revelation of underlying values and costs and thus more accurate price information. However, as mentioned, in the experimental literature that studies allocation rules for emissions permit trading, subjects do not acquire permits in order to produce or to satisfy any exogenously imposed compliance cap. The papers employ a simplified, abstract trading commodity environment; however they ignore the opportunity of a resale market after the initial allocation process. Studying $CO_2$ permit allocation mechanisms, our intention is to analyze the trading market as a whole, with the interaction of all its components: initial allocation, trading and abatement decision. We use the experimental set-up of Benz and Ehrhart (2006) which creates a realistic trading situation where subjects act as profit-maximising firms that have to decide on strategies in a simplified trading environment which is geared to the EU-ETS.

The remainder of the paper is organised as follows. Section 2 formulates theoretical considerations and price hypotheses with respect to the use of auctions in the carbon market. Using an example, we show that a one-sided uniform auction combined with grandfathering is expected to generate too high market price signals, whereas a double uniform auction with grandfathering or the exclusive use of a one-sided, uniform auction provide reliable prices. Section 3 describes the experimental set-up. Section 4 presents and interprets the results of the experimental analysis in which we concentrate on market prices and bidding strategies of the participants. Section 5 concludes.

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[4] One may think of an energy company that is considering the replacement of a coal-fired power station by installing a hydroelectric power station or a wind park.

[5] Likewise, excess allowances, which result from such investments may be sold at a profit at the market.

[6] A third allocation option is the use of benchmark emission rates (e.g. Bode, 2004).

[7] Please note that our definition differs from Friedman (1991). He defines the double auction market as institution in which participants continually can make and accept public offers to buy (bids) and to sell (asks).

[8] The lower the stated bid the less likely it is that any other seller has a lower bid, which increases the probability of winning, i.e. sellers' bids only determine their probability of winning.

## Theoretical Considerations and Hypotheses

Consider a company that is obliged to participate in emissions trading and that is able to (costly) reduce its emissions volume by activating abatement measures. Then company's valuation for emission allowances is determined by the company's costs for abating its emissions; i.e. company's marginal abatement costs (MAC). Since companies' MACs are different and private information, emission allowances should be assigned to the class of goods characterised by so-called private values. Hence, by analyzing a single auction or trading scheme for allowances the private-values framework (e.g. McAfee and McMillan, 1987) seems to be the appropriate approach. Although it is well known that players' bidding or trading behaviour (e.g. bid shading) depends on the auction or trading format, private-values settings have in common that players' bids base upon their private valuations, i.e. a company with high MAC is induced to submit higher bids than a company with low MAC. Consider the following example: a (small) company needs the quantity $q$ of allowances and therefore takes part in a multi-unit auction, which is assumed to be the only way to receive emission allowances, i.e. there is neither grandfathering nor trading. Thus, our company's willingness to pay (WTP) in the auction is determined by its MAC. If, for example, the uniform price rule is applied and many other companies participate in the auction, our company is induced to submit bids according to its MAC (e.g. Ausubel and Cramton, 2002), what facilitates company's participation in the auction. Let us assume for simplicity that company's MAC are constant and equal to $c$. Our company then demands quantity $q$ in the auction by submitting bids (approx.) equal to its MAC $c$. As a result, if the auction price $p_A < c$, our company receives its demanded quantity $q$ and has to pay the price $p_A$ for each allowance. In case of an auction price $p_A > c$, our company receives nothing and, thus, has to abate the emissions volume $q$, which is in this case less expensive for the company than buying allowances in the auction. Finally, if all companies behave in this way, the auction has an efficient outcome and the auction price $p_A$ is a reliable signal for the true scarcity of emission allowances, which is given by the "scarcity price", denoted by $p^*$. Thus, $p_A = p^*$.

If one, however, considers the whole emissions trading system including grandfathering, auctioning, trading, abatement decisions, and submitting allowances, things become more complex. This is caused by the fact that there are interdependencies and time lags between the aforementioned components of the system. Let us consider a stylised model of an emissions trading scheme, where companies are first allotted with allowances via grandfathering, followed by an auction for additional allowances, then emissions trading takes place, and finally companies have to submit allowances for cancellation corresponding to their emissions. For the realistic case that an auction is followed by trading on the market and finally by the obligation to hand in allowances (the moment companies actual need their allowances), companies' WTP in the auction is crucially depend on their expectations of the trading price and less on their MAC. Furthermore, if all companies are risk-neutral price-takers and their price expectations are based on the same distribution (common beliefs), each company' WTP is equal to the expected trading price and, hence, is independent of its individual MAC. In this respect, emissions allowances become the character a common value good, which has the same uncertain value for everyone (Benz and Ehrhart, 2007).

In this context, let us consider a one-sided auction, in which companies can only buy additional allowances, and let us assume that at the time of the auction companies already possess allowances (e.g. via grandfathering or banking). If in a uniform price auction all companies bid according to their MAC, the auction price is then expected to exaggerate the scarcity price: $p_A > p^*$. Hence, the auction price $p_A$ is no longer a truthful signal. Illustrating this finding, we study an explicit example. In this example the auction supply $S$ is equal to 100 tons of $CO_2$ (100 allowances) and we have five participating companies $V$, $W$, $X$, $Y$, and $Z$, each initially allotted with 600 allowances. If each firm's emissions quantity is assumed to be equal to 660 tons of $CO_2$, each company demands for 60 tons of $CO_2$, i.e. the difference between firm's emissions and its stock of allowances. Furthermore, each company disposes of one abatement measure, which can be activated in order to reduce company's emissions volume up to a maximum quantity of 300 tons of $CO_2$ (Potential Abatement Volume) at a certain price per abated ton of $CO_2$, given by company's (constant) MAC. Companies' characteristics are summarised in *Table 1*.

If in the uniform price auction (with the price rule that the auction price $p_A$ is determined by the lowest fulfilled bid) all companies ask their individual demanded quantity of 60 tons by bidding their MAC, we get an auction price $p_A = 40$ EUR/ton. The auction supply of 100 tons is allocated to firm $V$ (60 tons) and firm $W$ (40 tons) as $V$ submits the highest bid (50 EUR/ton) and $W$ the second highest bid (40 EUR/ton). The scarcity price $p^*$, however, lies between 10 and 20 EUR/ton and, hence, is much lower than the auction price $p_A$. The scarcity price $p^*$ is efficiently achieved when company $Z$, which has the cheapest abatement measure, abates 300 tons of $CO_2$ in order to cover its own demand of 60 tons and to sell 60 tons to each of the others companies, which are willing to pay more than 10 EUR/ton. Note, if company $Y$ and $X$ consider $p_A$ as a correct market price signal, both firms have an incentive to abate, what would prevent from cost-efficiency.

*Figure 1* demonstrates the relationship between the scarcity price $p^*$, the price $p_A$ in a one-sided uniform price auction, and

**Table 1: Companies' individual characteristics in the example**

| Company | Demand [tons $CO_2$] | Potential Abatement Volume [tons $CO_2$] | MAC [EUR/ton $CO_2$] |
|---|---|---|---|
| **V** | 60 | 300 | 50 |
| **W** | 60 | 300 | 40 |
| **X** | 60 | 300 | 30 |
| **Y** | 60 | 300 | 20 |
| **Z** | 60 | 300 | 10 |

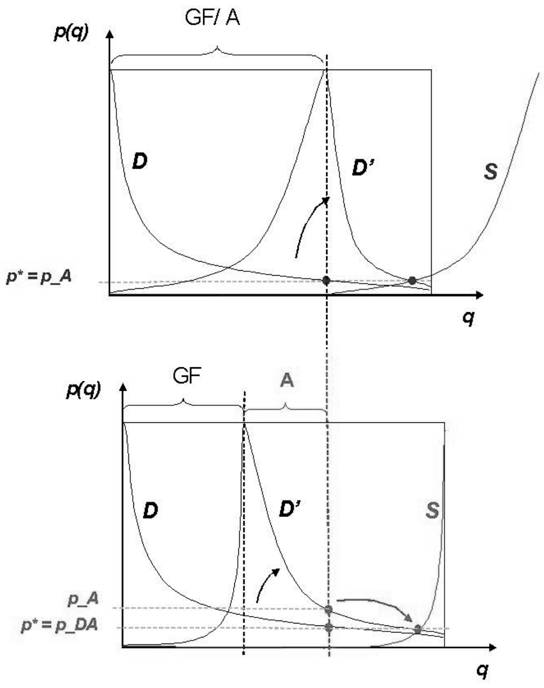

*Figure 1: Upper panel: allocation mechanism GF and A. Lower panel: allocation mechanism GF+A and GF+DA*

the price $p_{DA}$ in a double uniform price auction, when all companies bid according to their MAC. For sake of simplicity, we assume (infinitely) many marginal $CO_2$ emitting installations and abatement measures with different MAC, which are assumed to be constant for each abated ton of $CO_2$. By aggregating these values, we get the demand curve $D$ which represents the participating companies' WTP for allowances before the allowance allocation. The quantity of allocated allowances $Q$ is given exogenously. The amount of grandfathered allowances is denoted by $GF$, which is assumed to be the same for each installation. The amount of auctioned off allowances is denoted by $A$. Please note that all our following statements also apply in case of weaker assumptions, like non-marginal installations, non-constant abatement costs, as well as different demanded and grandfathered quantities. We consider the following four initial allocation rules:

1. Only grandfathering ($Q = GF$).[9]
2. Only one-sided uniform auction ($Q = A$).
3. Grandfathering with a one-sided uniform auction ($Q = GF+A$).
4. Grandfathering with a double uniform auction (Q = GF+A).

In all four cases the scarcity price is given by $p^*$, which is given by the intersection of the original demand curve $D$ with the vertical dashed line, which reflects the total amount of initial allowances $Q$, regardless of the applied allocation method. Whenever grandfathering is involved, $D$ is shifted to $D'$, which indicates the missing allowances after grandfathering. Besides we get the supply function $S$, which is determined by companies that offer their grandfathered allowances at a price higher than their MAC (upward sloping supply curve).[10] Remember, we assume that in the auctions the companies set their demand and supply bids according to their MAC. Figure 1 depicts the four allocation rule. Note, quantity $Q$ is in both figures the same. This graphic illustrates the following statement:

**Proposition 1** *If companies submit their (supply and demand) bids according to their MAC, the following auction prices result:*

- *Only one-sided auction ($Q = A$): auction price is equal to scarcity price, $p_A = p^*$,*
- *Grandfathering and one-sided auction ($Q = GF+A$): auction price is higher than scarcity price, $p_A > p^*$,*
- Grandfathering and double auction (Q = GF+A): auction price is equal to scarcity price, $p_{DA} = p^*$.

Looking at hybrid allocations (rule 3 and 4) with respect to reliable price signals, a double auction has to be considered as superior to a one-sided auction because rule 4 generates the better price signal than rule 3. In this context, a one-sided auction format is only expected to yield good price signals if at the time of the auction, companies do not possess any allowances, i.e. no grandfathering (and also banking) is applied. Based on these findings, we experimentally investigate the four allocation rules in combination with a succeeding trading phase in order test the following hypothesis, where $p_T$ denotes the trading price:

**Hypothesis 1** *In an emissions trading system with initial allocation via*

- *grandfathering ($Q = GF$): trading price is equal to scarcity price, $p_T = p^*$,*
- *a one-sided uniform price auction ($Q = A$): auction price is equal to trading and scarcity price, $p_A = p_T = p^*$,*
- *grandfathering followed by a one-sided uniform price auction ($Q = GF+A$: auction price is higher than trading and scarcity price, $p_A > p_T = p^*$,*
- *grandfathering followed by a double uniform price auction ($Q = GF+A$): auction price is equal to trading and scarcity price, $p_{DA} = p_T = p^*$.*

## Experimental Design

We conduct four different variations of one treatment variable – the initial allocation procedure at the beginning of each period. All variants are based on the same trading game, which is described below.

### TRADING GAME

Instead of designing a game, where allowances of a pollutant can be traded, we use a neutral language to prevent that decisions may be influenced by ethical aspects which are attached

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[9] This situation imitates the allocation process for the pilot-period in the most countries.

[10] In case of non-marginal firms, the curves are step functions indicating the price intervals between the MAC at which companies are willing to buy or sell allowances. As mentioned before, our results remain true if we use these functions.

to environmental terms. We replace a firm's carbon commitment by a delivery commitment of a given quantity of units of product *X* which can be traded among participants. Introducing the initial allocation process, we give each company either an initial endowment of units, which is analogous to grandfathering, and/or conduct an auction where units can be only bought or both bought and sold. Capturing the possibility of carbon abating, each company can also produce units of *X* by himself at individual production costs *c* per unit. These costs are equivalent to the MAC in the emissions trading game.

Hence, the framed emissions trading game captures the main features of the EU-ETS with some simplifications to prevent the system becoming too complex for a controlled experiment. The main characteristics of the game are:

- Length: Five periods, which are independent of each other during the game.
- Players: Six individual players, each representing a company. In each period a company is characterised by a given level of **delivery commitment** equal to 200 units of the good *X*, and a **baseline money endowment (**measured in ExCU[11]) increases from period to period (see Table 3).
- Allocation: In each period, a company either disposes of an **initial endowment of units** of the good *X* or has the possibility to buy units of *X* in an auction or both.
- Trading: In each period, there is one trading date at which units of *X* may be purchased or sold. The trading date is organised as a dynamic uniform double auction. For a detailed description of the double auction design we refer to the appendix or to Benz and Ehrhart (2006). The market is modelled as a closed system: market prices and trading volumes result exclusively from the players' market interaction.
- Self-production: at the end of each period if the players do not have sufficient units of the good *X* to cover their delivery commitment, they automatically produce the missing units by themselves at their individual production costs *c* per unit of the good *X*, which models the case of constant MAC.
- Information structure: Players' characteristics are private information. However, all players know the number of periods and players, the total delivery commitment in each period, the total initial endowment of units (if there is one), the exogenous given auction supply (in case that auctions are involved), and the distribution of the individual productions costs *c*. Players' characteristics (i.e. initial endowment of units, money endowment and production costs *c*) change in each period.[12]
- Objective: Maximisation of total profits. A player's profit per period is given by the baseline money endowment minus (plus) the value of the units of the good *X* purchased (sold) in the trade and/or auction process minus production costs. Note that excessive units become worthless at the end of the period. A player's total profit in the game is determined by the sum of his profits in all five periods.

### PLAYERS' CHARACTERISTICS AND TREATMENTS

The experiment consists of four treatments. The treatments differ with respect to the key treatment variable, the allocation process of a exogenously given initial quantity of units of the good *X* (see Tables 2 and 3):

- In the Treatments *GF+A* and *GF+DA*, at the beginning of every period the initial quantity of units of *X* is allocated by a combination of grandfathering and an auction. I.e. in the framed trading game at the beginning of every period there is a fixed initial endowment of units of *X* for each player and either a one-sided uniform price auction (*GF+A*), where players can only buy units or a double auction (*GF+DA*), where players can sell or buy units.
- In the Treatments *GF* and *A*, at the beginning of every period the initial quantity of units of *X* is completely allocated by grandfathering (*GF*) or by a one-sided uniform price auction (*A*) only. The implementation for the framed trading game is analogue to the Treatments *GF+A* and *GF+DA*.

For all treatments, the players exhibit the following common characteristics (see *Tables 2, 3, and 4*):

- Players' initial situation: All six players of a group have a constant delivery commitment of 200 units of *X* in each period, i.e. the total delivery commitment in each period is equal to 1200 units of *X*.
- Distribution of production costs *c*: During an experimental session, all six players of a group face the same known distribution of production costs *c* per unit of *X*. The exact costs distribution is shown in the appendix.
- Total allocated quantity Q: At the beginning of each period a fixed quantity of units of *X* is allocated to the six players via grandfathering and/or an auction. This quantity starts with Q = 1110 units in the first period and decreases by 120 units in each period, i.e. in the fifth (last) period there are Q = 630 units of *X* to allocate.

Since the total delivery commitment and total allocated quantity of units of *X* in each period are the same for all treatments, the requirements for comparability are satisfied. The calibration of the experimental design and the instructions can be found in Benz and Ehrhart (2006).

### ORGANISATION OF THE EXPERIMENT

We ran the experiment at the University of Karlsruhe, Germany, where students from various disciplines were randomly selected. 18 subjects participated in each session. Thus, for each treatment, we ran three sessions with three groups each. The experiment was computerised. The subjects received common written instructions, which were also read aloud by an instructor. Before the experiment started, each subject had to answer several questions at his computer terminal with respect to the instructions. At the end of a session, the subjects were paid in cash according to their profits.

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[11] ExCU stands for Experimental Currency Unit.

[12] This information structure basically enables participants to calculate bidding and self-production behavior in the cost minimum, i.e. according to the theoretical reference point.

**Table 2: Characteristics of the treatments I**

| Treatment | Number of groups | Number of companies in each group | Allocation process |
|---|---|---|---|
| ***GF+A*** | 6 | 6 | Grandfathering followed by a one- sided uniform price |
| ***GF+DA*** | 6 | 6 | Grandfathering followed by a double uniform price auction |
| ***GF*** | 6 | 6 | Grandfathering |
| ***A*** | 6 | 6 | One-sided uniform auction |

**Table 3: Characteristics of the treatments II**

| Treatment | Indiv. money endowment from first to last period [ExCU per unit of *X*] | Delivery commitment in each period [units of *X*] | Indiv. initial endowment from the first to last period [units of *X*] | Exogenous total auction supply from the first to last period [units of *X*] |
|---|---|---|---|---|
| ***GF+A, GF+DA*** | 800, 1200, 1600, 2000, 2400 | 200 | 160, 140, 120, 100, 80 | 150 |
| ***GF*** | 300, 700, 1100, 1500, 1900 | 200 | 185, 165, 145, 125 105 | – |
| ***A*** | 800, 1200, 1600, 2000, 2400 | 200 | – | 1110, 990, 870, 750, 630 |

**Table 4: Basic characteristics for all treatments**

| | Average Prices [ExCu per unit of *X*] | | | Deviations from $p^*$ [ExCU per unit of *X*] | |
|---|---|---|---|---|---|
| **Treatment** | Scarcity $p^*$ | Auction | Trade $p_T$ | Auction | Trade $p_T$ |
| ***GF+A*** | 6.6 | 10.27 | 8.13 | **3.67** | 1.53 |
| ***GF+DA*** | 6.6 | 6.6 | 7.80 | 0.00 | 1.20 |
| ***GF*** | 6.6 | - | 7.63 | - | 1.03 |
| ***A*** | 6.6 | 6.8 | 7.50 | 0.20 | 0.90 |

### THEORETICAL REFERENCE POINTS

In our experimental emissions trading game the sequence of the scarcity price $p^*$ is shown in *Table 5* and *Figure 2*. For all four treatments we expect these prices in the trading process and, according to Hypothesis 1, also in the auctions of the Treatments *A* and *GF+DA*. In Treatment *GF+A*, however, we expect higher auction prices $p_A$ which are also shown in Table 5. Note that the price $p^*$ is also connected with a cost-efficient outcome where the cheapest abatement measures are activated in order to reach the emissions target.

## Experimental Results

In the statistical analysis of the data we focus on auction and trading prices.[13] We compare the observations of the auction and trading prices with the scarcity price $p^*$. In the following, we take a closer look at the experimental results, focusing on the:

- market prices that are generated in auctions and trading,
- bidding behaviour of players according to their individual productions costs c and scarcity of units of *X*.

### MARKET PRICES

Figure 2 presents the sequence of the average market prices for each treatment. A glance at the graphic suggests that the data are in line with Hypothesis 1. An evident deviation from the scarcity price trajectory $p^*$ can only be recognised in Treatment *GF+A*. Obviously, the auction price generated by the one-sided uniform auction exaggerates the scarcity price $p^*$. Trading prices of all treatments stay relatively close to the sequence of $p^*$. Table 6 specifies for all treatments the average scarcity price $p^*$ and the average observed auction and trading prices with their average deviations from $p^*$. These deviations serve as a measure for the (in)efficiency of allocation rules in terms of generating correct price signals.

The average auction prices in the Treatments *GF+DA* and *A* seem to be really good predictors for the scarcity price $p^*$: the average auction price in *GF+DA* exactly meets $p^*$ and there is only a marginal deviation of 0.2 ExCU in Treatment *A*. In Treatment *GF+A*, however, we observe a significant positive deviation from $p^*$ of 3.67 ExCU.[14] If we additionally compare the price deviations of the treatments, we get significant higher auction prices in Treatment *GF+A* than in Treatment *GF+DA* as well as in Treatment *A*.[15]

Looking at trading prices, we observe significant deviations from the scarcity price $p^*$ in all treatments, except of Treatment

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[13] A level of significance of 5 % is required for all tests.

[14] Sample sizes of six units per Treatment, Wilcoxon rank-sum test.

[15] Sample sizes of six units per Treatment, U-test.

**Table 5: Sequence of the scarcity price, expected auction and trading prices in the treatments**

| Period | 1 | 2 | 3 | 4 | 5 |
|---|---|---|---|---|---|
| Scarcity price $p^*$ | 3 | 6 | 6 | 9 | 9 |
| Expected trading price $p_T$ in all treatments, expected auction price $p_A$, $p_{DA}$ in *A* und *GF+DA* | 3 | 6 | 6 | 9 | 9 |
| Expected auction price $p_A$ in *GF+A* | 9 | 12 | 15 | 15 | 15 |

**Table 6: Average prices and price deviations from the scarcity price $p^*$ of all treatments**

| | Average Prices [ExCu per unit of *X*] | | | Deviations from $p^*$ [ExCU per unit of *X*] | |
|---|---|---|---|---|---|
| **Treatment** | Scarcity $p^*$ | Auction | Trade $p_T$ | Auction | Trade $p_T$ |
| ***GF+A*** | 6.6 | 10.27 | 8.13 | **3.67** | 1.53 |
| ***GF+DA*** | 6.6 | 6.6 | 7.80 | 0.00 | 1.20 |
| ***GF*** | 6.6 | - | 7.63 | - | 1.03 |
| ***A*** | 6.6 | 6.8 | 7.50 | 0.20 | 0.90 |

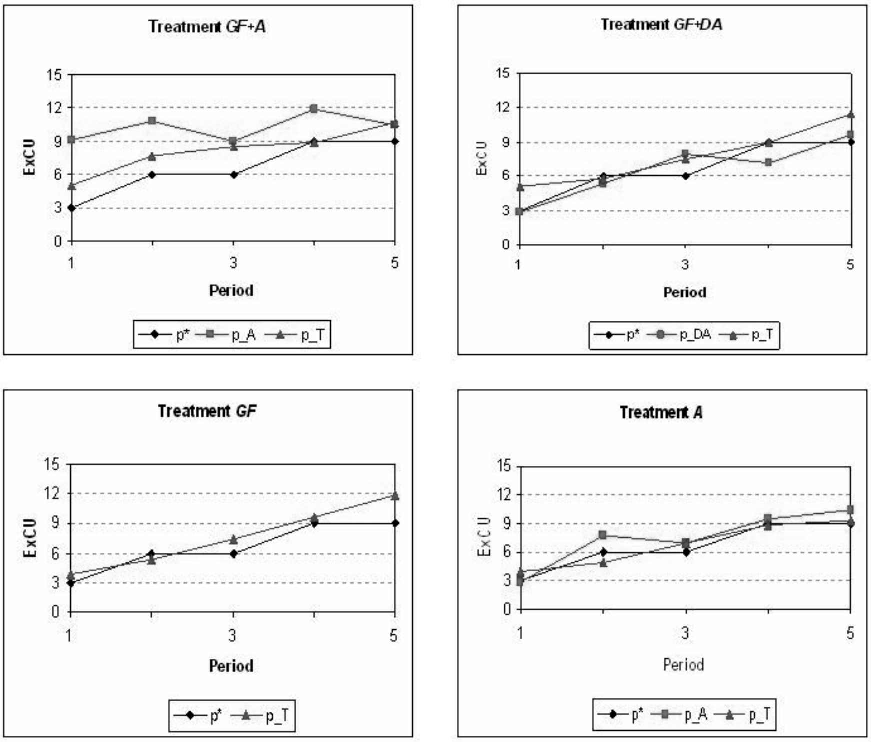

*Figure 2: Observed auction prices $p_A$, $p_{DA}$ and trading prices $p_T$ and the scarcity price $p^*$ for each treatment*

*GF+DA*.[16] However, compared to the auction price deviation in *GF+A*, these deviations are quite small (1.53 for *GF+A*, 1.03 for *GF* and 0.90 for *A*). Moreover, in all three cases the trading volume is rather small so that the trading results should not be overestimated.[17] We do not observe significant different trading prices in our four treatments.[18]

Hence, with respect to the observed prices we formulate the following result which is in line with our Hypothesis 1:

**Result 1** *The auction design matters with respect to correct market price discovery:*

- *Treatment GF+A generates significantly higher auction prices than the theoretical scarcity price.*
- *Treatments GF+DA and A both generate scarcity prices in the auction.*
- *Treatment GF+A generates significantly higher auction prices than Treatments GF+DA and A.*
- *In all treatments we observe trading prices being (a little bit) higher than the scarcity prices.*

## BIDDING STRATEGIES

We now investigate players' bidding behaviour in the auction and trading process. Based on the result of Schleich et al. (2006), i.e. players take their individual abatement costs as

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[16] Sample sizes of six units per Treatment, Wilcoxon rank-sum test.

[17] For a detailed analysis of the trading activity we refer to Benz and Ehrhart (2006).

[18] Sample sizes of six units per Treatment, U-test.

**Table 7: Number of purchases with respect to bid price *p* and individual production costs *c***

| | Buyers | | | | | |
|---|---|---|---|---|---|---|
| | Auction | | | Trading | | |
| **Treatment** | $p < c$ | $p = c$ | $p > c$ | $p < c$ | $p = c$ | $p > c$ |
| ***GF+A*** | 57 | 9 | 12 | 75 (72) | 12 (11) | 0(0) |
| ***GF+DA*** | 80 | 13 | 3 | 37 (36) | 8(8) | 3(3) |
| ***GF*** | - | - | - | 93 (93) | 5 (5) | 3 (3) |
| ***A*** | 95 | 14 | 19 | 53 (50) | 3(3) | 1(1) |

**Table 8: Number of selling bids with respect to bid price *p* and individual production costs *c***

| | Sellers | | | | | |
|---|---|---|---|---|---|---|
| | Auction | | | Trading | | |
| **Treatment** | $p < c$ | $p = c$ | $p > c$ | $p < c$ | $p = c$ | $p > c$ |
| ***GF+A*** | - | - | - | 15 (8) | 7 (6) | 54 (52) |
| ***GF+DA*** | 27 | 5 | 38 | 22 (4) | 3(2) | 36 (31) |
| ***GF*** | - | - | - | 15 (0) | 3 (0) | 53 (0) |
| ***A*** | - | - | - | 32 (6) | 5 (5) | 25 (22) |

reference point for their bids, we analyse if buying and selling strategies are geared to either market prices, or the individual production costs *c* and to individual scarcity of *X*. Hereby for each observation, we analyse if bidders behave cost-oriented, that is to sell units of *X*, when the market price is above their individual production costs *c* and to buy units of *X*, when the market price is below the individual production costs *c*. First, we consider the buyers and then the sellers' side in the auction and trading. Furthermore, we are interested at which price level buyers decide to leave the auction and trading.[19]

### BUYERS IN THE AUCTION AND TRADING

The entries in *Table 7* display the number of satisfied demand bids, separated into auction and trading. We are interested in the price *p* at which players actual buy units of *X* and differentiate between three cases: observations where players buy at a price *p* that is below, equal or above their individual production costs *c*. The figures in brackets in Table 7 show the number of purchases of those players who actual require units of *X* when taking the buyers-position in the trading process.

Obviously, in the auction and trading most of the players act cost-oriented and submit bids at a price below or equal their individual production costs *c*. Comparing the number of bids that are higher than *c*, we find much more in the auction than in trading. Note that after the auction players again have the possibility to resell surplus units in the trading process, whereas after trading surplus units become worthless. Thus, we may consider submitting bids in the auction at a higher price level than the individual costs *c* as strategic bidding. Looking at the number of demand bids in the trading process, we see that almost all demanding players actual require units of *X*. Hence, we state the following result:

**Result 2** *After the auction process buyers align their bidding strategies with their individual production costs and individual scarcity of units of X*.

### SELLERS IN THE AUCTION AND TRADING

*Table 8* presents the number of supply bids in the auction (only possible in Treatment *GF+DA*) and trading. As before, we are interested in the relationship between the individual production costs *c* and price *p* at which players submit a selling offer for the first time. Analogously, the figures in brackets display the number of offers of those sellers who still require units of *X* when entering the trading process.

Obviously, the majority of the players decide to submit selling offers at a price above or equal their individual production costs *c*, independent of the number of units they possess. Note that players who sell at a price above their production costs ($p > c$) are able to fulfil their delivery commitment by the more profitable alternative of self-production. We notice, however, that in all treatments many players start to submit offer bids at a price level below their individual production costs *c*. In order to shed some light on this phenomenon, we additionally differentiate between trading-sellers who still require units of *X* for their delivery commitment (figures in brackets in Table 8) and those who don't (difference between the number and the number in brackets in Table 8). Here, we get a clear picture: most of the sellers who offer at a price below their production costs ($p < c$) possess more units than they actual need. Since these units become worthless after trading, these players have a strong incentive to sell them at what price ever, even at a price that is lower than their production costs *c*. We can state the following result:

**Result 3** *Players who still require units of X after the auction (only) sell units of X in the trading at a price above or equal their individual production costs c. Players who sell at a price below their production costs already have fulfilled their delivery commitment after the auction and, thus, try to minimise their losses by offering their surplus allowances at lower prices than their individual production costs.*

### DROPOUTS IN THE AUCTION AND TRADING

We further investigate the point of time (price level) when players decide to drop out of the auction and trading respectively. As a player – having once taken a seller position – cannot leave the processes anymore, this analysis focuses on the buyers only.

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[19] As reminder, the activity rule says that for a seller it is not possible any more to leave the auction. Once having submitted a selling offer, it is valid until the process is finished.

**Table 9: Number of buyer dropouts with respect to dropout price *p* and individual production costs *c***

| | Buyers-Dropouts | | | | | |
|---|---|---|---|---|---|---|
| | Auction | | | Trading | | |
| Treatment | $p < c$ | $P = c$ | $p > c$ | $p < c$ | $p = c$ | $p > c$ |
| ***GF+A*** | 26 | 46 | 30 | 37 (19) | 38 (38) | 18 (17) |
| ***GF+DA*** | 39 | 28 | 17 | 88 (19) | 33 (32) | 11 (9) |
| ***GF*** | - | - | - | 23 (23) | 37 (37) | 19 (19) |
| ***A*** | 11 | 22 | 19 | 70 (30) | 38 (35) | 15 (13) |

As dropouts we count players who never submit a demand bid, players who leave the auction from the buyer position, and those players who switch from the buyer to the seller position in the course of the auction or of the trading. As before, we analyse the dropout behaviour with respect to individual production costs *c*. The cost-oriented strategy for a player is to drop out when *c* equals the price of the current auction or trading round. At this price, a player is indifferent with respect to his costs between buying and producing his required amount of *X*. Results are displayed in *Table 9*. Again, the figures in brackets in Table 9 give the number of dropouts of players who still require units of *X*.[20]

In the trading, most of the players who submit demand bids at a higher price than their individual production costs *c* (i.e. they drop out too late), still require units of *X*. Hence, we assume that individual scarcity is again an important indicator for the subjects. In Treatments *GF+DA* and *A*, we observe that the number of dropouts at a price below individual production costs *c* is much higher in the trading than in the auction. We attribute this observation to the fact that many of the players who dropout in the trading do not require any units of *X* after the auction. As a consequence, the majority of these players do not submit any demand bid at all in the trading. This is due to the large auction supply in these two treatments, which the auction process then allocates to the players with high production costs and, thus, trading becomes less important.

## Conclusion

In our paper we compared two alternative approaches for allocating $CO_2$ emission allowances, allocation according to historical emissions (grandfathering) and auctioning. We focused on the design of correct carbon auctions. We have shown that the combination of grandfathering and an one-sided uniform auctions, where market participants only act as buyers and bid according to their marginal abatement costs, is not expected to generate correct market price signals reflecting the true market scarcity. Only if firms are also allowed to sell allowances in the auction (i.e. double auction), will the price be expected to meet the correct market scarcity price. We have stressed the importance of these results with respects to energy efficiency, i.e. the generation of correct market incentives for investment decisions in more energy efficient technologies.

Economists almost unanimously recommend more auctioning. Political as well as institutional parties postulate using only auctions as alternative to grandfathering. Especially the industry sector claims that the application of auctions would create less distortion of competition among the participating sectors, avoid windfall profits, and generate an outcome that may be perceived as “fair” because - in contrast to a free allocation of allowances – the “polluter pays” principle holds (Betz et al., 2006). Not surprisingly, vested interests (electric utilities, coal, and oil companies) are lobbying that the allowances be allocated to them gratis and according to historical output as they have been equipped very generously with allowances in the pilot-period. In general, compared to grandfathering, auctioning off allowances would result in simpler, more transparent and efficient NAPs as they avoid problems and distributional aspects when designing allocation rules that account for e.g. early action, expected growth, the treatment of new installations and closures (Harrison and Radov, 2002) or the split between different sectors (Sijm et al., 2002). Despite all the academic recommendations (see also Hepburn et al., 2006; Crampton and Kerr, 2002), auctioning in emission trading systems is today the exception rather than the rule.

## Appendix

### DOUBLE AUCTION DESIGN

Players simultaneously submit their demand or supply of units in the form of a quantity bid at an initial price $p = 1$ ExCU. If the total demand bids exceed the total supply bids, the current price is increased by 1 ExCU and a new bidding round starts. The bidding continues until total demand is less or equal than total supply. The units are then allocated at the price of the last or the round before last. This depends on whether total demand in the last round was equal or smaller than total supply. Those buyers are rationed who reduced their quantity in the last round. The activity rule is that each buyer cannot increase and each seller cannot decrease his quantity as the price rises. Hereby we already equip subjects with monotone bidding strategies which help to bid rationally and prevent from absurd bidding. During the trading process a buyer can always switch to a seller position or drop out completely from the trading process whereas this is not possible for the seller position. Once a selling bit is submitted it is valid until the trading process is over.

### CALIBRATION

To prevent from learning effects in the course of the experiment, in every period we change the players’ characteristics, those are the quantity of the initial individual endowment of units (only relevant when grandfathering is applied, i.e. for Treatment *GF+A*, *GF+DA* and *GF*) and rotate the set of

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[20] As reminder, in Treatment GF the number of purchases is equivalent to the number of observations that require units of X in the trading process as there is no auction involved.

**Table 10: Distribution of production costs *c* [ExCU per unit of *X*] for all treatments**

| Period\Company | 1 | 2 | 3 | 4 | 5 | 6 |
|---|---|---|---|---|---|---|
| 1 | 9 | 12 | 15 | 18 | 3 | 6 |
| 2 | 6 | 3 | 18 | 15 | 12 | 9 |
| 3 | 18 | 15 | 12 | 9 | 6 | 3 |
| 4 | 3 | 6 | 9 | 12 | 15 | 18 |
| 5 | 15 | 18 | 3 | 6 | 9 | 12 |

production costs *c* across subjects, with *c* being in the interval [0, 20].[21] The distribution of *c* is chosen in such a way that all players have approximately the same total production costs for the five periods in order to receive approximately the same profit in the theoretical overall cost minimum. Hence, every player is in profitable situations with relatively cheap as well as with relatively expensive production costs, which is less profitable. *Table 10* displays the distribution of production costs *c* throughout the experiment.

The companies' money endowment (see Table 3) are calculated in such a way that at the beginning of every period all companies are able to satisfy their initial individual demand of units *X* by themselves, i.e. only by self-production at the maximal possible production price of 20 ExCU and without taking part in the trading and, if applied, in the auction process.

## References

Ausubel, L., Cramton, P., 2002. Demand reduction and inefficiency in multi-unit auctions. Working paper.

Benz, E., Ehrhart, K.-M., 2006. The Initial Allocation of $CO_2$ Emission Allowances: An Experimental Study. Working paper.

Benz, E., Ehrhart, K.-M., 2007. Auctions and Secondary Markets. Working paper.

Betz, R., Rogge, C., Schleich, J., 2006. An Early Assessment of National Allocation Plans for Phase 2 of EU Emissions Trading. Working paper sustainability and innovation, no. s1 2006, Centre for Enrgy and Environmental Markets (CEEM) at University of Wales, Sydney, Australia; Fraunhofer Institute Systems and Innovation Research, Karlsruhe, Germany.

Bode, S., 2004.Multi-period emission trading in the electricity sector winners and loosers. HWWA Discussion Paper 268.

Burtraw, D., 1996. Cost Savings Sans Allowance Trades? Evaluating the $SO_2$ Emissions Trading Program to Date. Discussion Paper 95-30-REV.

Cason, T. N., 1993. Seller Incentive Properties of EPA's Emission Trading Auction. Journal of Environmental Economics and Management 25, 177–195.

Cason, T. N., 1995. An Experimental Investigation of the Seller Incentives in EPAs Emission Trading Auction. American Economic Review 85, 905–922.

Cason, T. N., Elliott, S. R., Van Boening, M. R., 1999. Speculation in Experimental Markets for Emission Permits. Research in Experimental Economics 7, 93–119.

Cason, T. N., Plott, C. R., 1996. EPAs New Emissions Trading Mechanism: A Laboratory Evaluation. Journal of Environmental Economics and Management 30, 133–160.

COM, 2001. Proposal for a Directive of the European Parliament and of the Council Establishing a Framework for Greenhouse Gas Emissions Trading within the European Community and Amending Council Decision 96/61/EC. http://www.europa.eu.int/comm/environment/climat/emission.htm.

Crampton, P., Kerr, S., 2002. Tradable Carbon Allowance Auctions: How and why to auction not grandfather. Energy Policy 30, 333–345.

Cronshaw, M. B., Brown-Kruse, J., 1999. An Experimental Analysis of Emission Permits with Banking and the Clean Air Act Amendments of 1990. Research in Experimental Economics 7, 1–24.

Ehrhart, K.-M., Hoppe, C., Schleich, J., 2006. Banking and distribution of allowances an experimental exploration of EU emissions trading. Working paper, University of Karlsruhe.

EU, 2003. Directive Establishing a Scheme for Greenhouse Gas Emission Allowance Trading within the Community and Amending Council Directive 96/61/EC, provisional text available at http://europa.eu.int/comm/environment/climat/030723provisionaltext.pdf. European Commission.

Friedman, D., 1991. A simple Testable Model of Double Auction Markets. Journal of Economic Behavior and Organisation 15.

Godby, R. W., Mestelman, S., Muller, R. A., Welland, J. D., 1997. Emissions Trading with Shares and Coupons when Control over Discharges is Uncertain. Journal of Environmental Economics and Management 32, 359–381.

Harrison, D., Radov, D., 2002. Evaluation of Alternative Initial Allocation Mechanisms in a European Union Greenhouse Gas Emissions Allowance Trading Scheme. Nera economic consulting, prepared for dg environment, European Commission.

Hepburn, C., Grubb, M., Neuhoff, K., Matthes, F., Tse, M., 2006. Auctioning of EU ETS phase II allowances: how and why? Climate Policy (6), 137–160.

Joskow, P., Schmalensee, R., Baily, E., 1998. The Market for Sulfur Dioxide Emissions. American Economic Review 88 (4).

McAfee, R., McMillan, J., 1987. Auction and bidding. Journal of Economic Literature 35, 699–738.

Schleich, J., Ehrhart, K.-M., Hoppe, C., Seifert, S., 2006. Banning Banking in EU Emissions Trading. Energy Policy 34 (1), 112–120.

Sijm, J., Smekens, K., T., K., Boots, M., 2002. Economic Effects of Grandfathering $CO_2$ emission Allowances. Ecn c-02-022.

Stavins, R. N., 1998. What can we learn from the Grand Policy Experiment? Lessons from $SO_2$ Allowance Trading. Journal of Economic Perspectives 12 (3), 69–88.

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[21] This mechanism is almost equivalent to a uniform distribution of the production costs c on the interval [0,20].