THE INITIAL ALLOCATION OF CO_2 EMISSION ALLOWANCES: A THEORETICAL AND EXPERIMENTAL STUDY

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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 buy and sell permits, with incidental transactions costs and at competitive prices. We study the reliability of prices 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.

In 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.

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Keywords: Tradable CO_2 Emission Allowances; Initial Allocation Process; Grandfathering; Auctions.

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1 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 a particular amount of 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. Therefore, 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. Two allowance allocation alternatives are discussed by authorities: *auctioning* and gratis allocation in proportion of historical emissions (*grandfathering*).[3] 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 the total amount of their 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 initial allocation mechanism in the EU-ETS that comply with these requirements. We conduct an experiment where we compare several policy-relevant allocation rules. Hereby we focus on grandfathering, auctioning and their combination. As auction formats we chose dynamic one-sided as well as dynamic double auctions.[4] A static version of the former ones 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.

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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; Burtraw, 1996; Joskow et al., 1998).

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

[4] 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. Hence, 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).

2 Literature Overview

Though the experimental economics literature of emissions trading schemes is comprehensive, the initial allocation rule as a treatment variable 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. Hereby, 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 specializes 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 lower asking and bid prices as this increases their trading priority.[5] 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, in the mentioned 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 ignore the opportunity of a resale market after the initial allocation process. Studying CO_2 permit allocation mechanisms we want to analyze the trading market as a whole with the interaction of all its components: initial allocation, trading and abatement decision. We create a realistic trading situation where subjects act as profit-maximizing 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 organized as follows. Section 2 formulates theoretical considerations and price hypotheses with respect to the use of auctions in the carbon market. Motivated by 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 only use of a one-sided uniform auction provide reliable price discov-

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[5] 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.

ery. Section 3 describes the experimental setup. 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.

3 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. 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' MAC are different and private information, emission allowances should be assigned to the class of goods characterized 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 behavior (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 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 $p_A > c$, 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 scarcity of emission allowances, i.e. $p_A = p^*$, where p^* denotes the "true scarcity price".

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 stylized 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 cancelation 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 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 base 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 respect thereof, emissions allowances become a common value good, which has the same uncertain value for everyone (Benz and Ehrhart, 2006).

Illustrating this finding, we study an explicit example. 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, as before, the uniform price rule is applied and companies bid according to their MAC, the auction price is expected to exaggerate the true scarcity price (i.e. $p_A > p^*$) and, hence, the auction price is no longer a truthful signal. In the example the auction supply S is equal to 100 tons of CO_2 (100 allowances) and we have four participating companies W, X, Y, and Z. Each company has a demand of allowances for 60 tons CO_2 and disposes of one abatement measure, which reduces company's emissions up to a maximum quantity (Potential Abatement Volume) at a certain price per abated ton of CO_2 which is given by company's (constant) MAC. Table 1 summarizes the companies' individual situations:

Table 1:
Companies' individual situations for the example

Company	**Demand [tons CO_2]**	**Potential Abatement Volume [tons CO_2]**	**MAC [EUR/ton CO_2]**
W	60	100	40
X	60	100	30
Y	60	100	20
Z	60	300	10

If all companies ask their individual demanded quantity of 60 tons by bidding their MAC, we get an auction price $p_A = 30$ EUR/ton with firm W receiving 60 tons and X getting 40 tons as W submits the highest and X the second highest bid according to their MAC. However, the true scarcity price p^* lies between 10 and 20 EUR/ton and, hence, is much lower than p_A. Price p^* is efficiently achieved when company Z, which has the cheapest abatement measure, abates 240 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. Furthermore, if company Y

considers p_A as a correct market price signal, Y has 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 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:

- Only grandfathering ($Q = GF$).[6]
- Only one-sided uniform auction ($Q = A$).
- Grandfathering with a one-sided uniform auction ($Q = GF + A$).
- Grandfathering with a double uniform auction ($Q = GF + A$).

In all four cases the true scarcity price is reflected by p^*. It is the intersection point of the original demand curve D with the vertical dashed line, which reflects the total amount of initial allowances to allocate Q, regardless of the applied allocation method. Whenever grandfathering is involved, D is shifted to D', which indicates the still missing allowances after grandfathering. Besides we get the supply function S, which is determined by companies, which sell their grandfathered allowances only at a price that is higher than their MAC (upward sloping supply curve).[7] Remember, we assume that in the auctions the companies set their demand and supply bids according to their MAC. Figure 1 depicts the allocation rule 1 to 4. 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:*

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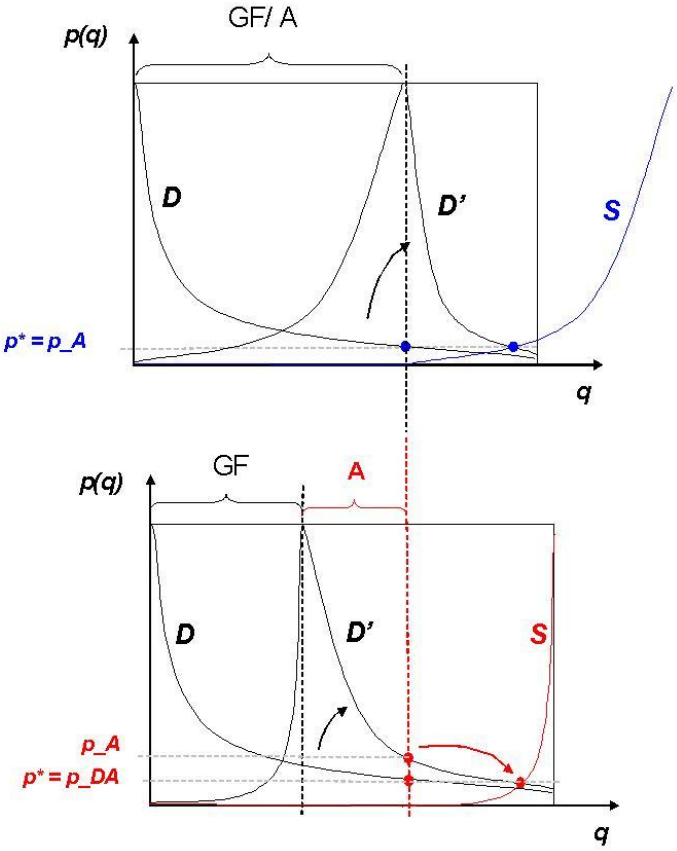
[6] This situation imitates the allocation process for the pilot-period in the most countries.

[7] 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.

Figure 1:
Upper panel: Allocation mechanism 1 and 2
Lower panel: Allocation mechanism 3 and 4



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

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 (p_T denotes the trading price):

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

1. *grandfathering* ($Q = GF$) *we expect* $p_T = p^*$,
2. *a one-sided uniform price auction auction* ($Q = A$) *we expect* $p_A = p_T = p^*$,
3. *grandfathering followed by a one-sided uniform price auction* ($Q = GF + A$) *we expect* $p_A > p_T = p^*$,
4. *grandfathering followed by a double uniform price auction* ($Q = GF + A$) *we expect* $p_{DA} = p_T = p^*$.

4 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.

4.1 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 to environmental terms. We replace a firm's carbon commitment by a delivery commitment of a given quantity of units of a 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 analogue 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 characterized by a given level of delivery commitment equal to 200 units of the good X, and a baseline money endowment (measured in ExCU[8]) which increases from period to period.

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[8] ExCU stands for Experimental Currency Unit.

- 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 organized as a dynamic uniform double auction. For a detailed description of the double auction design we refer to the appendix. The market is modeled 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.

- Information Structure: the players' characteristics are private. However, all players know the number of periods and players, the total delivery commitment in every 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 productions costs c. Players' characteristics, i.e. the initial endowment of units, money endowment and c change in each period.[9]

- Objective: maximization 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. Excessive units become worthless at the end of the period. A player's total profit is determined by the sum of his profits in all five periods.

4.2 Players' Characteristics and Treatments

Our experiment has 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 Table 2):

- In Treatment $GF+A$ 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.

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[9] 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

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

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 of units of X from the first to last period**	**Exogenous total auction supply [units of X]**
$GF + A$, $GF + DA$	800, 1200,..., 2400	200	160, 140,..., 80	150
GF	300, 700, ..., 1900	200	185, 165,..., 105	-
A	800, 1200,..., 2400	200	-	1110, 990,..., 630

Table 3:
Basic characteristics for all treatments

Period	**1**	**2**	**3**	**4**	**5**
Total delivery commitment [units of X]	1200	1200	1200	1200	1200
Total allocated quantity [units of X]	1110	990	870	750	630
Total required self-production (abatement quantity) [units of X]	90	210	330	450	570

- In Treatment GF and A, at the beginning of every period the initial quantity of units of X is only 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 and 3):

- Players' initial situation: All six players of a group have in each period a constant delivery commitment of 200 units of X, i.e. the total delivery commitment in each period is 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 and 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 the Appendix.

4.3 Organization 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 every treatment, we ran three sessions with three groups each. The experiment was computerized. 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.

4.4 Theoretical Reference Points

In our experimental emissions trading game the sequence of the true scarcity price p^* is shown in Table 4 and Figure 2. For all four treatment we expect these prices in the trading process and, according to our Hypothesis 1, also in the auctions of the Treatments $GF + DA$ and A. In Treatment $GF + A$, however, we expect higher auction prices p_A which are also shown in Table 4. Moreover, 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.

Table 4:
Sequence of the true scarcity price p^* and of the expected price p_A in the one-sided auction of $GF + A$

Period	**1**	**2**	**3**	**4**	**5**
p^*	3	6	6	9	9
p_A	9	12	15	15	15

5 Experimental Results

In the statistical analysis of the data we focus on auction and trading prices.[10] We compare the observations to the true scarcity prices 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 behavior of players according to their individual productions costs c and scarcity of units of X.

5.1 Market Prices

Figure 2 presents the sequence of the average market prices in each treatment. A glance at the graphic suggests that the data are in line with Hypothesis 1. An evident deviation from the true scarcity price trajectory p^* can only be recognized in Treatment $GF + A$. Obviously, the auction price generated by the one-sided uniform auction exaggerates p^*. Trading prices of all treatments stay relatively close to the sequence of p^*. Table 5 specifies for all treatments the average true 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 Treatment $GF + DA$ and A seem to be really good predictors for p^*: the average auction price in $GF + DA$ exactly meets p^* and there is only a marginal deviation of 0.20 ExCU in Treatment A. In Treatment $GF + A$, however, we observe a significant positive deviation from p^* of 3.67 ExCU.[11] If we additionally compare the price deviations of the treatments, we get significant higher auction prices in Treatment $GF + A$ than in Treatment $GF + DA$ and than in Treatment A.[12]

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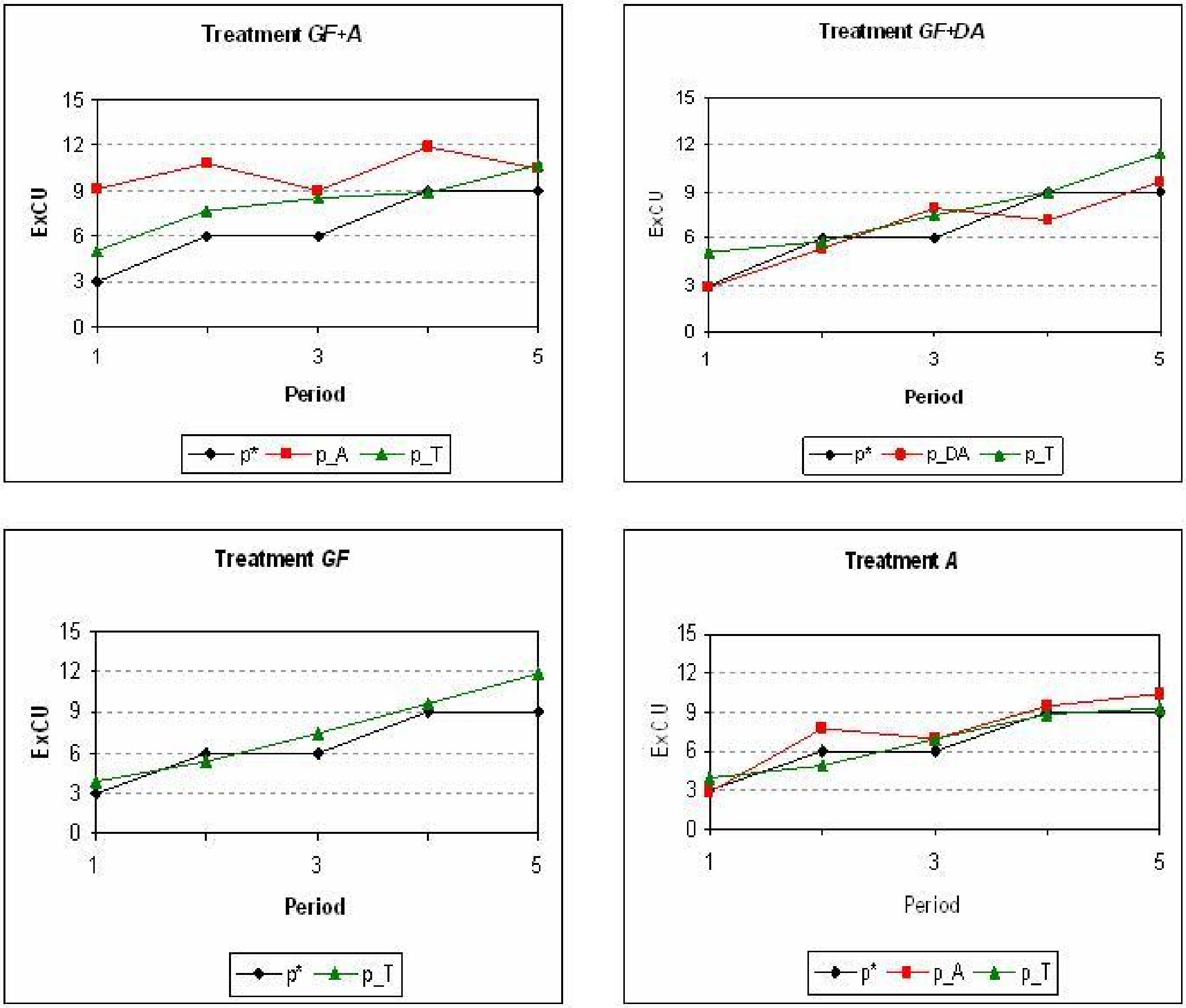
[10] A level of significance of 5% is required for all tests.

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

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

Figure 2:
Sequence of auction and trading prices together with the true scarcity prices p^*



Looking at trading prices, we observe significant deviations from p^* in all treatments, except of Treatment $GF + DA$.[13] 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 should not be overestimated. We do not observe significant different trading prices in our four treatments.[14]

Hence, with respect to market prices we formulate the following results which are in line with our Hypothesis 1:

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

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

Table 5:
Average prices and price deviations from the true scarcity price of all treatments

	Average Price [ExCu per unit of X]			**Deviation from p^* [ExCU per unit of X]**	
Treatment	p^*	**Auction**	**Trade**	**Auction**	**Trade**
$GF + A$	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

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

- *Treatment $GF + A$ generates significantly too high auction prices.*
- *Treatments $GF + DA$ and A both generate true 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 true scarcity prices.*

5.2 Bidding Strategies

We now investigate players' bidding behavior in the auction and trading process. Based on the result of Schleich et al. (2006), that is players take their individual abatement costs as reference point for their bids, we analyze 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 analyze 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.[15]

5.3 Buyers in the Auction and Trading

The entries in Table 6 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

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[15] 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 6:
Number of **purchases** with respect to 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)

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 6 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.*

5.4 Sellers in the Auction and Trading

Table 7 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 posses. Note that players who sell at $p > c$ are able to fulfill their delivery commitment by the more profitable alternative of self-production. We notice, however, that in all treatments many players start to

Table 7:
Number of **selling** bids with respect to 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 (-)	3 (-)	53 (-)
A	-	-	-	32 (6)	5 (5)	25 (22)

submit offer bids at a price level below their 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) and those who don't (difference between the number and the number in brackets). We get a clear picture: most of the sellers who offer at a price below their production costs c possess more unit 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 minimize their losses.*

5.5 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. 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 analyze the dropout behavior with respect to 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 8. Again, the figures in brackets give the number of dropouts of players who still require units of X.[16]

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[16] 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 8:
Number of buyer dropouts with respect to 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)

In the trading, most of the players who submit demand bids at a higher price than 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 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.

6 Conclusion

In our paper we compare the two alternative approaches, allocation according to historical emissions and auctioning allowances. We hereby focus on the design of correct carbon auctions. We have shown that grandfathering with normal one-sided uniform auctions, where market participants only act as buyers, do not automatically generate correct market price signals. Only the possibility of also selling allowances in a double auction brings the price back towards the correct market scarcity price. Economists almost unanimously recommend more auctioning. Political as well as institutional parties postulate to only use 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 are allocated to them gratis and according to historical output as they have been equipped quite well 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 the exception rather than the rule.

A 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.

B 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 production costs c across subjects, with c being in the interval [0, 20].[17] 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 9 displays the distribution of production costs c throughout the experiment.

The companies' money endowment (see Table 2) 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

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

Table 9:
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

of 20 ExCU and without taking part in the trading and, if applied, in the auction process.

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