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# The emissions trading paradox

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ABSTRACT

This article considers the price history of $CO_2$ allowances in the EU Emission Trading Scheme. Since European Emissions Trading started in 2005, the prices of allowances have varied between less than one and thirty Euro per ton of $CO_2$. This previously unpredicted volatility and, more notably, a significant price crash in May 2005 led to the hypothesis that electricity producers might use their market power to influence the prices of allowances. Besides market power, the combination of information asymmetry and price interdependencies (between prices of primary goods – especially electricity – and allowances) plays an important role in explaining the emissions trading paradox. The model presented will show that banking can lead to such a price crash if market participators act rationally. Furthermore, in such a scenario banking can be profitable for sellers at the cost of buyers.



## 1. Introduction

The results of the Intergovernmental Panel of Climate Change's Fourth Assessment Report "Climate Change 2007" show the urgency for future agreements on the reduction of greenhouse gas emissions (IPCC, 2007). A basis for further negotiation might be the Kyoto protocol, which defined greenhouse gas emissions cuts for all annex I countries and was ratified by 136 countries (Kyoto, 1997). In Europe, the Kyoto protocol allowed burden sharing between the 15 EU countries with a total emissions reduction target of 8% compared to the emission level of 1990. Until 2020 the reduction target of the European Union is 20%.

In order to meet these goals, the European Union Emissions Trading Scheme was introduced, which works as follows. There are three periods (2005–2007, 2008–2012, and the Post-Kyoto period) of emissions trading. At the beginning of each period, each country has to present a national allocation plan which defines how many emissions allowances[1] each (major) emitter will get in this period (Georgopoulou et al., 2006). For all emissions produced each year of a given emissions trading period, a company must have the corresponding allowances by March 31 of the following year. Superfluous allowances may be sold to other companies that lack allowances. If a company cannot present sufficient allowances, it is fined 40 Euro (first trading period) or 100 Euro (second trading period) for each extra ton of carbon dioxide. Banking within a trading period is allowed, i.e. allowances are valid in every year of the trading period but not in a different trading period. It can be expected that emissions trading will play an important role in the Post-Kyoto process which aims for further reductions of greenhouse gas emissions.

The first phase of EU emissions trading was characterized by the generous allocation of emission allowances to enterprises in emission-intensive industries according to the grandfathering principle (Bhringer and Lange, 2005). Despite the generous allocation and many opportunities to elude the trading system, the prices in the first seventeen months were much higher than initially forecasted. Most forecasts before the start of the trading system ranged between one and three Euro per ton of carbon dioxide for the first trading period (Alberola et al., 2008). After the presentation of the national allocation plans, even lower prices were expected. However, after a steep increase, the price per ton peaked at 30 Euro in April 2006 and fell to a level of a few cents by the end of the trading period in December 2007. The increase and decrease of prices hardly supports the assumptions of existing models and approaches explaining price fluctuations. Since electricity markets in most countries are of oligopolistic nature and European-wide models (Fichtner, 2005) for optimization of carbon dioxide emissions (as a response to different allowance prices levels) exist and their results are well-known by companies, it is very unlikely that the peak level of allowance prices is purely the result of unexpected occurrences (e.g. weather turbulences) as claimed by some market players. Another speculative argument is that unexpected technological progress (technology learning) reduced the emission abatement costs and therefore led to a sharp fall of allowance prices. However, as Barreto and Kypreos (2004) argue, technological

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[1] In order to compare the volume of different greenhouse gases emitted, each gas was rated with a weight (global warming potential) indicating the potential of damage compared to the one of carbon dioxide. Thus, emissions are often simply referred to carbon dioxide.

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learning is not unexpected and happens over longer time periods. Even if there would be a breakthrough in the technological development of one or more basic technologies (e.g. solar power, efficiency of coal power plants), it would take years until these new technologies would be embedded in most installations and subsequently decrease greenhouse gas emissions. Likewise, the assumption that old installations were replaced by technologically-superior facilities does not explain the allowance price development. Since allowances can be either used in the year they were allocated, or banked within the entire 2005–2007 period, it would not be rational to bank allowances if the enterprises already knew that their emissions would decrease due to newer installations. Furthermore, investment planning in the electricity industry is usually performed at least two years before the final installation. Hence, the investors can plan their expected emission reduction several months before it occurs. Despite this fact, many companies actually banked their allowances instead of selling them for the high prices in the first 17 months of emissions trading.

Comparing the results of the existing models and arguments leads to the conclusion that the actual market development is not only unexpected, but is paradoxical. Furthermore, it questions the efficiency of emissions trading as argued in many publications (Egenhofer, 2007; Langniss and Praetorius, 2006). However, the objective of this article is to explain this paradox. By applying dynamic and game theory models, this article shows that the market behaviour (at least from the perspective of the electricity producers) is highly rational and that both the increase of allowance prices in the first half and the decrease in the second half of the trading period can be well explained. The results of the different models explained here also suggest how defective behaviour of market players can be more efficiently than it was during the first trading period.

To explain the emissions trading paradox, the paper is structured as follows. Section 2 gives an overview of the existing literature with an emphasis on different emissions trading models, the forecasting of allowances' prices and structural factors like banking, market power, information asymmetry and price interdependencies. Also discussed is how allowance costs are included in planning systems and how they affect planning results and costs calculation. Research results that illuminate technology substitution and consequences for the electricity industry are summarized. Section 3 will broaden existing models to further investigate the relation between emissions trading and electricity price and will combine both issues from the perspective of electricity producing companies. First, the situation of a monopolistic buyer and seller is considered. The second model analyzes the situation under the assumption that the buyer and seller of emission allowances cooperate. The last and most comprehensive model illuminates the situation where the opportunity to bank allowances exists by applying a dynamic model approach. The three models give clear evidence that there is logic behind the "emissions trading paradox" which was not included in previous models of emissions trading. Finally, Section 4 analyzes future research opportunities and shows which adjustments existing models need to better represent the actual situation.

## 2. Literature review and existing models

Emissions trading as originally described by Dales (1968) is seen as a market-based instrument to efficiently reduce greenhouse gas emissions. On the one hand, a ceiling for emissions quantities can be set which can be applied to an entire industry, country, or a set of countries. Companies that participate in an emissions trading scheme will obtain emissions allowances via grandfathering or auctioning. If companies want to emit more/fewer emissions than covered by their allowances, they can either buy or sell allowances. As market theory proposes, the companies will adjust their buying and selling behaviour according to their marginal abatement costs (Klepper and Peterson, 2006; de Brauw, 2006). If marginal abatement costs are higher than the price of allowances, companies will buy additional allowances; if they are lower, it is beneficial to sell allowances or to buy fewer. Therefore, emissions trading is seen as a market-based and efficient instrument of environmental policy favoured by many economists and politicians. This judgement is based on the assumption of a perfect market and rational behaviour by all market players. As we will see, this assumption does not hold in practice and leads to serious market failures described later as the emissions trading paradox.

Surprisingly, only a small number of recent publications deal with the issue of the price mechanism for emissions allowances. Most older publications include equilibrium models which suggest that marginal abatement costs determine the allowance's market price (Montgomery, 1972). Klepper and Peterson (2006) showed that the energy price level, first and foremost, influences the abatement costs, and therefore, the allowance's price might vary over time. Fischer and Morgenstern (2006) concluded that there is a wide range of carbon abatement costs that makes accurate forecasts of the allowance's price extremely difficult. Christiansen et al. (2005) saw policy and regulatory issues, market fundamentals, and technical indicators as price determinants in the EU emissions trading scheme. With the perspective of different market settings (which can highly influence trading behaviour and the reduction of carbon dioxide) they emphasized macroeconomic aspects without highlighting behaviour of single companies and their strategic interests. As a result, Christiansen et al. (2005) showed that estimating and forecasting $CO_2$ production, the impact of weather, emissions-to-cap, credits from CDM, the role of fuel switching to all be fundamental market parameters. Additionally, Alberola et al. (2008) pointed out that the disclosure of emissions data might cause structural breaks in the pricing of emissions allowances. These statistically significant structural breaks can be traced back to unanticipated temperature changes and heterogeneous anticipations of market players. However, these points cannot explain the disruptive fall of allowance prices in April 2006, as illustrated in Fig. 1. Therefore, further analysis is needed.

In the case of most greenhouse gas emissions, especially carbon dioxide, it does not matter where and when in a time interval of a given number of years the emissions actually occur. Consequently, companies involved in emissions trading are allowed to bank the emissions allowances that are not needed within a year and can transfer them to the following year (Boemare and Quiron, 2002). From an economic standpoint, banking should make emissions trading even more efficient, e.g. abatement costs cannot only be minimized during the course of a single year, but also, in a more dynamic approach, in a time period of several years (Kling and Rubin, 1997; Schleich et al., 2006). However, in terms of information asymmetry, when accurate emissions data are not publicly available (Saarinen, 2003), banking offers the opportunity to hide the actual level of emissions without wasting the allowances. This could lead to strategic behaviour, harmful to competitors or customers. This potential disadvantage is particularly relevant when markets are imperfect.

Several authors consider information asymmetry and market power as important key factors for market functionality. On a general level, the groundbreaking works of Weitzman (1974), White and Wittman (1983) analyze the instruments to reduce negative environmental impacts, namely quantity approaches, taxation of emissions and liability rules taking into account imperfect information (information asymmetry). As a result, costs to obtain information, the costs of polluters and the "pollution victims", as well as the market structure, play an important role in choosing the right

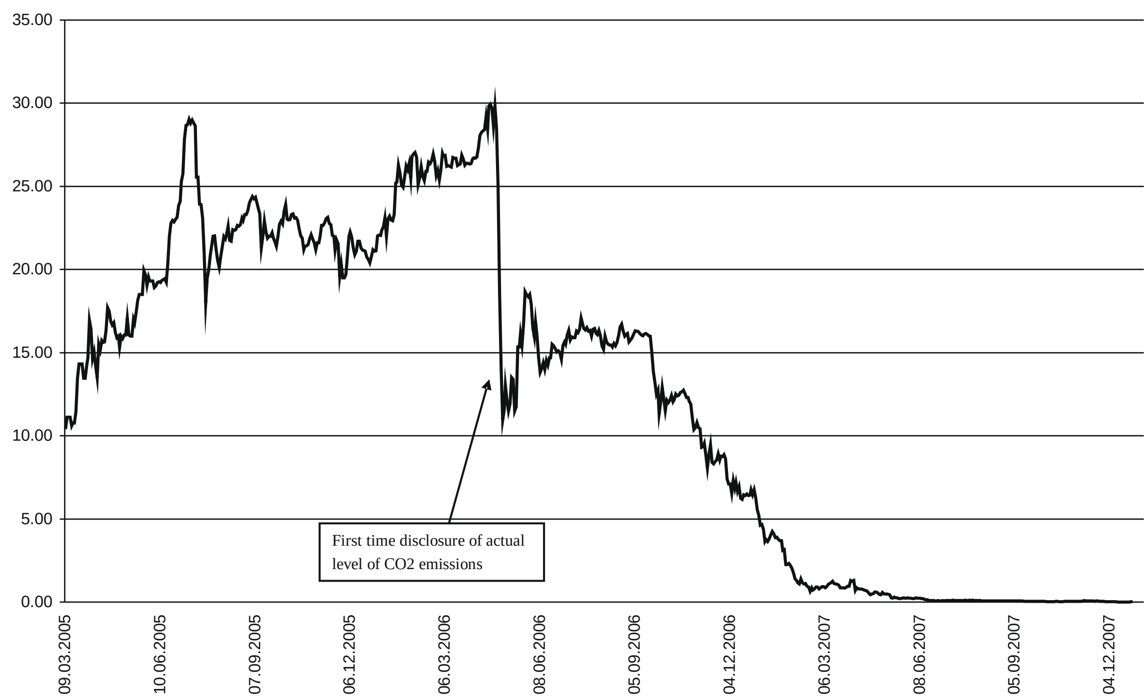


**Fig. 1.** Price history in Euro for $CO_2$ allowances (data taken from www.eex.com).

instrument. More specifically to emissions trading, Eshel (2005) showed in a rigorous analysis that combined market power with information asymmetry can lead to social welfare losses if the allocation of pollution rights will allocate allowances to dominant firms (firms with a high amount of market power) too generously. Due to lobbyism, this is exactly what happened in the subperiod 2005–2007. Basically the same results were confirmed by Cason et al. (2003) in a laboratory experiment. Hagem et al. (2006) showed that even countries like Russia, as a large supplier of natural gas, might use market power in the emissions trading market to influence gas prices to its own advantage. Since gas has a relatively low $CO_2$ emission coefficient, high allowance prices could be favourable to boost demand for natural gas. Though they find only a small, but non-negligible impact on the optimal level of Russian gas exports, their findings clearly support the connection between market power and interdependent demand of $CO_2$ allowances and natural gas. Other country interests leading to strategic behaviour and potential market failure due to varying institutional setups of emissions trading are discussed by Klepper and Peterson (2005).

Considering the previous arguments, emissions trading is highly relevant for decisions on the firm level. In the short term, it might influence both the firms' product mix and the use of different installations (Letmathe and Balakrishnan, 2005; Liao et al., 2009). If companies can pass the costs of allowances to customers, it also affects pricing decisions. In this case, firms may have an interest in high allowance prices if this creates opportunities for additional profits. This argumentation also holds when allowances are distributed according to the grandfathering principle and therefore no cash-relevant costs occur (Bode, 2006).

In the long run, emissions trading will lead to the deployment of more efficient technologies and to an increased availability of renewable energy (Barreto and Kypreos, 2004; Fichtner, 2005; Rong and Lahdelma, 2007; Klingelhöfer, 2009). New technology deployment can be beneficial for existing firms as well as for new companies entering existing markets. This development can be accelerated, especially when green certificates foster renewable energy development (Kunsch et al., 2004). The full potential of influencing carbon dioxide emissions by firm strategy is shown by an article covering the internal emissions trading scheme of BP (previously known as British Petroleum) (House and Victor, 2006). After starting internal emissions trading in 1998, total carbon dioxide emissions fell from 94.4 in 1998 to 80.5 million tons in 2001. Assuming the current EU allowance price of 12.5 Euro/ton (April 2009, see www.eex.com) this would translate into annual cost savings of over 170 million Euros.

Several articles cover the impact of emissions trading on firms in the electricity industry. In line with our previous argumentation, Kara et al. (2008) estimated that energy prices will increase when allowances' prices go up. The authors argue that the electricity companies in Finland will have large windfall profits, whereas the metal industry and private consumers will be most affected by electricity price increases. Currently, this estimation seems to be highly accurate. These results were confirmed by van Asselt and Biermann (2007), Lund (2007), who forecast disadvantages for energy-intensive sectors in Europe. Other empirical studies, as well as models, consistently show that the energy sector will profit from emissions trading at the cost of more downstream industries and private consumers (Bode, 2006; Lee et al., 2008). Again, opportunity costs of allowances can be seen as a major cause of this development. If opportunity costs are included in product prices, both markets – the emissions trading market and the primary product market – are linked to each other (which could lead to market failure as first empirical studies show for the electricity market in the UK (Bunn and Fezzi, 2007)). Nevertheless, quantitative models to explain resulting structural breaks in the emissions trading market do not yet exist.

The total impact of emissions trading on firm behaviour and market outcomes highly depends on the allowances' prices. The initial range of price estimations for the second trading period 2008–2012 was between 4 and 70 Euro/ton (Fichtner, 2005; Springer, 2003). In his insightful review, Springer (2003) categorized different emissions trading models and the main influencing factors. Distinguishing integrated assessment models, macroeconomic models, energy system models, and emissions trading models, Springer described the construction of the different model types and showed the main outcomes, especially with respect to the forecasted allowance price per ton $CO_2$. Additionally, Springer and Varilek (2004) saw transaction costs, limited sectoral coverage, the exercise of market power, and imperfect foresight as important factors that are not fully reflected in current models.

There are only few attempts of explaining the unusually fast price decline observed at the European Emissions Trading Scheme, to which we refer to as the Emissions Trading Paradox. In this paper we present a new approach that takes certain particularities of this market into account. Firstly, it was noticeable that the national allocation plans favoured large companies with significant market power, especially electricity producing companies (Gilbert et al., 2004). With this comes an information asymmetry as the large companies, which are also main emitters, have better information of the total scarcity of allowances. Secondly, notable was that especially the electricity-producing companies argued for high selling prices of their product due to the high price of allowances. However, when the price for allowances collapsed, those companies somehow "forgot" to reduce their product selling price.

We consider these peculiarities and present a two-player model that shows that it is plausible that electricity-producing companies have a rational interest in hoarding and forfeiting allowances instead of selling them. Therefore, the presented model will include market power, information asymmetry and price interdependencies, which, in combination, all had a crucial impact on allowances' prices in the first emissions trading period 2005–2007.

## 3. Emissions trading paradox

In order to explain the emissions trading paradox, we present a general model that describes e.g., the situation faced by an electricity-producing company (referred to as "seller") and another emissions trading company (referred to as "buyer"). We exogenously describe a situation with sellers and buyers in order to display the European Emissions Trading Scheme in which some market players were favoured over others concerning the allocation of allowances (Gilbert et al., 2004).

We consider a market with two players, namely seller and buyer. Each player produces an amount of good $x^S \in \mathbb{R}^+$ or $x^B \in \mathbb{R}^+$, respectively, that can be sold for a (market) price $p^S \in \mathbb{R}^+$ or $p^B \in \mathbb{R}^+$, respectively. Neither goods influence each other in terms of market price, demand, etc. There are no further restrictions on the kinds of goods which could be the same or different. The players furthermore face costs for each unit they produce, described by a continuous, monotonically increasing, and convex function $K : \mathbb{R}^+ \to \mathbb{R}^+, K' > 0$, and $K'' > 0$. The production of $x^S$ and $x^B$ leads to emissions that can be calculated by a continuous, monotonically increasing, convex, and bijective functions $e^S, e^B : \mathbb{R}^+ \to \mathbb{R}^+$ with $e^{B\prime} > 0$, $e^{B\prime\prime} > 0$, $e^{S\prime} > 0$, and $e^{S\prime\prime} > 0$. We assume $e^S$ and $e^B$ to be convex, which is based on the idea that a player uses its best production possibilities (concerning emissions) first. The amount of emissions each player may produce is restricted by a certain number of allowances. However, superfluous allowances can be sold to the other player at market price $\tau \in \mathbb{R}^+$. The players aim to maximize profits (to be described below). In order to do so, they act rationally which implies that they only produce if a profit is made.

In this model, we assume that the seller's optimal production quantity $x^{*S}$ leads to emissions that do not exceed his amount of allowances, i.e., if the seller's amount of allowances is denoted by $e^A \in \mathbb{R}^+$, then $e^A = e^S + \tilde{e}$ with $e^S := e(x^{*S})$ and sold allowances $\tilde{e} \geqslant 0$ holds. On the other hand, the buyer's given allowances are not sufficient by any means. Thus, the buyer has to purchase allowances from the seller. Without loss of generality, we assume that the buyer has no assigned allowances so that he has to exclusively buy them. In other words, we assume that the buyer has already used his given allowances and has to buy further allowances.

The assumption that the seller has superfluous allowances reflects the fact that although the total amount of distributed allowances is scarce, electricity-producing companies received allowances for more emissions than needed by using their current technologies.

We furthermore assume that the seller's product price $p^S$ is positively correlated with the allowance price $\tau$, i.e. a higher market price for the allowances leads to a higher sales price for the seller. We assume this correlation to be described by a function $m$ of the type $p^S = m(\tau)$ with $m(0) = p$, $m(\infty) = p + \alpha$, $m' > 0$, where $p > 0$ describes the market price without emissions trading and $\alpha \in \mathbb{R}^+$ is a given constant. That means that an increasing $\tau$ always leads to an increasing $p^S$, but $p^S < p + \alpha$ holds. This assumption is based on the observation that purchase prices (in this case the allowance price) are often passed on to the consumer. However, as many goods of public value are to some extend regulated, an arbitrary increase of selling price $p^S$ caused by increasing $\tau$ seems to be unrealistic.

If we merge the above mentioned attributes, we get the buyer's profit function

$$\pi^B(x^B) = p^B \cdot x^B - \tau \cdot e^B(x^B) - K(x^B) \tag{3.1}$$

as well as the seller's profit function

$$\pi^S(x^S) = x^S \cdot p^S + \tau \cdot \tilde{e} - K(x^S). \tag{3.2}$$

The notation used is summarized in Table 1.

### 3.1. Monopolistic seller and buyer without cooperation

First, let us consider a scenario in which both players maximize their own profits and cooperation is prohibited. We refer to this model as *Emissions Trading Problem with no Cooperation (ETPN)*. The seller has perfect information about the buyer, whereas the buyer has no information about the seller, except that he knows the amount of allowances the seller wants to sell. The supply of allowances given to the buyer can be denoted by $\sigma(e^S) := \tilde{e} = e^A - e^S$ with $\frac{d\sigma(e^S)}{de^S} = -1$.

The first order condition of the buyer leads to

$$\frac{d\pi^B(x^B)}{dx^B} = p^B - \tau \cdot \frac{de^B(x^B)}{dx^B} - \frac{dK(x^B)}{dx^B} =: \varphi(x^B|\tau) = 0. \tag{3.3}$$

From this function $\varphi$ we derive the optimal $x^B(\tau)$ in dependency on the emissions price $\tau$. The derivation of $x^B(\tau)$ is negative, which we get from the implicit functions theorem:

$$\frac{dx^B(\tau)}{d\tau} = -\frac{\frac{\partial\varphi}{\partial x^B}}{\frac{\partial\varphi}{\partial\tau}} = -\frac{\tau\frac{d^{(2)}e^B(x^B)}{dx^B} + \frac{d^{(2)}K(x^B)}{dx^B}}{\frac{de^B(x^B)}{dx^B}} < 0. \tag{3.4}$$

**Table 1**
Summary of notation.

| | |
|---|---|
| $x^B$, $x^S$ | Amount of the good produced by the buyer/seller |
| $p^B$, $p^S$ | Price per unit of $x^B/x^S$ |
| $\tau$ | Market price for each unit of allowances |
| $m(\tau)$ | $p^S$ described in dependency on the price for allowances, $p^S = m(\tau)$ |
| $p$ | Minimum of $m(\tau)$, market price without emissions trading |
| $\alpha$ | Least upper bound of $m(\tau)$ |
| $K(x^B)$, $K(x^S)$ | Production costs of the buyer/seller |
| $e^B(x^B)$, $e^S(x^S)$ | Emissions caused by the buyer/seller |
| $e^A$ | Number of allowances owned by the seller before production |
| $\tilde{e}$ | Number of allowances to be sold from seller to buyer |
| $\pi^B$, $\pi^S$ | Buyer's/seller's profit function |

The buyer's demand on allowances can then be described by a decreasing function $\delta(\tau) := (e^B \circ x^B)(\tau)$ in which $\circ$ describes the composition of functions:

$$e^B = \delta(\tau) = e^B(x^B(\tau)) \quad \text{with } \frac{d\delta(\tau)}{d\tau} = \frac{de^B(x^B)}{dx^B} \cdot \frac{dx^B(\tau)}{d\tau} < 0. \tag{3.5}$$

In order to permit market equilibrium, we assume $\delta$ to be bijective and let $\delta^{-1}$ be the inverse function of $\delta$. $\frac{d\delta^{-1}(\sigma)}{d\sigma} < 0$ holds and since $\delta(\tau) = \sigma(e^S)$

$$\tau = \delta^{-1}(\sigma(e^S)). \tag{3.6}$$

The seller's profit function now is subject to some constraints.

$$\begin{aligned} \max_{x^S} \quad & x^S \cdot p^S + \tau \cdot \tilde{e} - K(x^S) \\ \text{s.t.} \quad & p^S = m(\tau), \\ & \tilde{e} = \sigma(e^S(x^S)), \\ & \tau = \delta^{-1}(\sigma(e^S(x^S))). \end{aligned} \tag{3.7}$$

All constraints can be inserted into the objective function. By doing so and defining $f := m \circ \delta^{-1} \circ \sigma \circ e^S$ and $g := \delta^{-1} \circ \sigma \circ e^S$ we get

$$x^S \cdot f(x^S) + g(x^S) \cdot \sigma(e^S(x^S)) - K(x^S). \tag{3.8}$$

From the first order condition we can derive the optimal $x^{S^*}$.

$$\begin{aligned} \frac{d\pi^S(x^S)}{dx^S} &= f(x^S) + x^S \cdot \frac{df(x^s)}{dx^S} + \frac{dg(x^S)}{dx^S} \cdot \sigma(e^S(x^S)) + g(x^S) \\ &\quad \cdot \frac{d\sigma(e^S(x^S))}{dx^S} - \frac{dK(x^S)}{dx^S} \\ &=: \psi(x^S) = 0 \Rightarrow x^{S*}. \end{aligned} \tag{3.9}$$

Thus we obtain $\tau^* = g(x^{S^*})$ and $x^{B^*} = x^B(\tau^*)$.

### 3.2. Monopolistic seller and buyer with cooperation

Let us modify the scenario so that both players have the goal to maximize $\pi^B$ and $\pi^S$ together, referred to as *Emissions Trading Problem with Cooperation (ETPC)*. Since the seller's gain of selling allowances and the buyer's damage of purchasing allowances neutralize each other, both will prefer a high $\tau$. Let us therefore assume $\tau \to \infty$. The objective in this scenario is

$$\begin{aligned} \pi^B(x^B) + \pi^S(x^S) &= p^B \cdot x^B - \tau \cdot e^B(x^B) - K(x^B) \\ &\quad + x^S(p^S + \alpha \cdot m(\tau)) + \tau \cdot \tilde{e} - K(x^S) \\ &= p^B \cdot x^B - K(x^B) + x^S \cdot (p^S + \alpha) - K(x^s). \end{aligned} \tag{3.10}$$

Since the total amount of allowances might be scarce, we have to consider the restriction $e^B + e^S \leqslant e^A$. The optimal solution can then be derived using the first order conditions regarding $x^B$ and $x^S$.

Let us point out that such a scenario of cooperation can hardly be transferred to practice – an exorbitant increase of $\tau$ alone would lead to governmental interactions.

### 3.3. Multiple-period problem

Let us now consider two periods that are equivalent for the buyer, but not for the seller. These two periods correspond to the situation of EU emissions trading between 2005 and 2007. Between 2005 and April 2006 (first period), only few market participators, namely the major electricity-producing companies, had information about the scarcity of allowances. From May 2006 to the end of 2007 (second period), all players have at least seen the actual emissions presented in the break of both periods, which covered the entire year 2005.

The seller may now bank some of his unused allowances in the first period and use them in the second period. That means that in the first period the seller spends all his allowances for production, for sale, and for banking. In the second period he has to use his allowances plus the banked ones for his production and for sale (as far as possible). Although the buyer could also use banking, we do not consider this case since the buyer has no incentive to do banking as he lacks allowances. The amount of allowances to be banked by the seller is denoted by $e^R \geqslant 0$.

In the second period, the seller may furthermore charge a part ($\beta$) of the premium on the product price of the first period. This is based on the observation that a price rise for raw materials or intermediate goods is passed on to the consumer, while in times of falling prices, consumer prices do not fall ($\beta = 1$) or fall minimally ($0 < \beta < 1$). Parameter $\beta$ can be interpreted as a "forgetting-rate".[2] If $\beta = 1$, the consumer totally forgets that a price rise was argued by a high price for allowances and he accepts the price of the previous period. If $\beta = 0$, the consumer only accepts a higher price in the second period argued by a high price for allowances in the second period. In this case, the previous period has no influence on the price. If $0 < \beta < 1$, the situation can be described as a convex combination of the two extremes. Thus we can write

$$p_2^S = \beta \cdot m(\tau_1) + (1 - \beta) \cdot m(\tau_2). \tag{3.11}$$

We call this model *Emissions Trading Problem with Banking (ETPB).*

We use the same notation as before but indexed with $t = 1, 2$ describing the two periods. The buyer's and the seller's profit functions are

$$\pi_t^B(x_t^B) = p^B \cdot x_t^B - \tau_t \cdot e^B(x_t^B) - K(x_t^B) \quad t = 1, 2 \tag{3.12}$$

$$\pi_t^S(x_t^S, e^R) = x_t^S \cdot p_t^S + \tau_t \cdot \tilde{e}_t - K(x_t^S) \quad t = 1, 2 \tag{3.13}$$

with $\tilde{e}_1 = e^A - e^S(x_1^S) - e^R, \tilde{e}_2 = e^A - e^S(x_2^S) + e^R$ and $p_1^S = m(\tau_1), p_2^S = (1 - \beta) \cdot m(\tau_2) + \beta \cdot m(\tau_1)$. Both players are to maximize the sum of their profits of each period without cooperation. Without loss of generality, discounting is not considered.

In the two period model, the buyer might face a different supply of allowances in each period, given by $\sigma_1(e^S(x_1^S)) := \tilde{e}_1 = e^A - e^S(x_1^S) - e^R$ and $\sigma_2(e^S(x_2^S)) := \tilde{e}_2 = e^A - e^S(x_2^S) + e^R$. According to Section 3.1, the first order condition leads to functions $x_t^B(\tau_t)$ and thus we have $\delta(\tau_t) = e^B(x_t^B(\tau_t))$ and

$$\tau_1 = \delta^{-1}(e^A - e^S(x_1^S) - e^R), \quad \tau_2 = \delta^{-1}(e^A - e^S(x_2^S) + e^R). \tag{3.14}$$

Again, $\frac{d\delta^{-1}(\sigma)}{d\sigma} < 0$. The period objective functions of the seller come down to

$$\pi_1^S = x_1^S \cdot f(x_1^S) + g(x_1^S) \cdot (e^A - e^S(x_1^S) - e^R) - K(x_1^S), \tag{3.15}$$

$$\pi_2^S = x_2^S \cdot ((1 - \beta) \cdot f(x_2^S) + \beta \cdot f(x_1^S)) + g(x_2^S) \cdot (e^A - e^S(x_2^S) + e^R) - K(x_2^S). \tag{3.16}$$

**Theorem 3.1.** *Consider the Emissions Trading Problem with Banking. If $\beta = 0$, the seller will not use banking, i. e. $e^R = 0$. The seller will use banking ($e^R > 0$) if $0 < \beta \leqslant 1$.*

**Proof.** From the intertemporal equilibrium condition for the seller we get

$$\frac{\partial \pi_1^S}{\partial x_1^S} = \frac{\partial \pi_2^S}{\partial x_2^S} \tag{3.17}$$

[2] The forgetting-rate is especially relevant in the electricity market because in most regions we find an oligopoly or even monopoly which means that markets are highly imperfect.

with

$$\frac{\partial \pi_1^S}{\partial x_1^S} = f(x_1^S) + x_1^S \frac{\partial f(x_1^S)}{\partial x_1^S} + \frac{\partial g(x_1^S)}{\partial x_1^S}\left(e^A - e^S(x_1^S) - e^R\right) - g(x_1^S)\frac{\partial e^S(x_1^S)}{\partial x_1^S} - \frac{\partial K(x_1^S)}{\partial x_1^S},$$

$$\frac{\partial \pi_2^S}{\partial x_2^S} = (1-\beta)\left(f(x_2^S) + x_2^S \frac{\partial f(x_2^S)}{\partial x_2^S}\right) + \beta f(x_1^S) + \frac{\partial g(x_2^S)}{\partial x_2^S}\left(e^A - e^S(x_2^S) + e^R\right) - g(x_2^S)\frac{\partial e^S(x_2^S)}{\partial x_2^S} - \frac{\partial K(x_2^S)}{\partial x_2^S}.$$

Inserting the stationary solution $x_1^S = x_2^S =: x^S$ under the intertemporal equilibrium condition and simplifying leads to

$$\frac{\partial \pi_1^S}{\partial x_1^S}(x^S) = \frac{\partial \pi_2^S}{\partial x_2^S}(x^S), \tag{3.18}$$

$$\iff \frac{\partial g(x^S)}{\partial x^S}\left(e^A - e^S(x^S) - e^R\right) = -\beta x^S \frac{\partial f(x^S)}{\partial x^S} + \frac{\partial g(x^S)}{\partial x^S}\left(e^A - e^S(x^S) + e^R\right), \tag{3.19}$$

$$\iff e^R = \frac{\beta \cdot x^S \cdot \frac{\partial f(x^S)}{\partial x^S}}{2 \cdot \frac{\partial g(x^S)}{\partial x^S}}. \tag{3.20}$$

Since $\frac{\partial f(x^S)}{\partial x^S} > 0$ and $\frac{\partial g(x^S)}{\partial x^S} > 0, e^R$ is positive whenever $\beta > 0$. □

**Corollary 3.2.** *If $\beta > 0$, then $\tau_1^* > \tau_2^*$.*

**Proof.** Since $\frac{d\delta^{-1}(\sigma)}{d\sigma} < 0, e^A - e^S(x^S) - e^R < e^A - e^S(x^S) + e^R$, and $\tau_1^* = \delta^{-1}(e^A - e^S(x^S) - e^R), \tau_2^* = \delta^{-1}(e^A - e^S(x^S) + e^R)$, thus $\tau_1^* > \tau_2^*$. □

The corollary shows that in the ETPB model, a price crash appears just as it had happened on the emissions trading market. The numerical example in the next section illustrates that prices can fall considerably.

### 3.4. Numerical example

We applied the presented models using certain functions in order to derive market equilibrium. In detail we used the following functions

$$\begin{aligned} p^B &= 1, \quad e^B(x) = \frac{x^2}{100}, \quad x^B = 10\sqrt{e^B}, \quad K(x) = \frac{x^2}{100}, \\ p^S &= 1, \quad e^S(x) = \frac{x^2}{400}, \quad x^S = 20\sqrt{e^S}, \quad e^A = 25, \quad \alpha = \frac{3}{10}. \end{aligned} \tag{3.21}$$

The results of the models are shown in Tables 2–4. In order to get comparable results, for each model two periods are listed. If originally only one period was considered, this period is doubled. In Table 2, the effects of the three models on the buyer are denoted. If the seller may use banking, this especially affects the buyer. The production quantity in the first period is much smaller than in the second, in which the buyer has sufficient allowances. As expected, the buyer gains most in model ETPC. The one-period model ETPN is better for the buyer than ETPB. Note that a scenario with cooperation does not differ if banking is allowed or not. As the consumers are exploited as much as possible, banking leads to no improvements.

**Table 2**
Buyer.

| | $x_1^B$ | $x_2^B$ | $\pi_1^B$ | $\pi_2^B$ | $\pi_1^B + \pi_2^B$ |
|---|---|---|---|---|---|
| ETPN | 35.87 | 35.87 | 17.94 | 17.94 | 35.88 |
| ETPC | 39.62 | 39.62 | 23.92 | 23.92 | 47.84 |
| ETPB | 9.09 | 50.00 | 4.55 | 25.00 | 29.55 |

**Table 3**
Seller.

| | $x_1^S$ | $x_2^S$ | $\pi_1^S$ | $\pi_2^S$ | $\pi_1^S + \pi_2^S$ |
|---|---|---|---|---|---|
| ETPN | 69.66 | 69.66 | 32.11 | 32.11 | 64.22 |
| ETPC | 61.00 | 61.00 | 42.09 | 42.09 | 84.18 |
| ETPB | 56.82 | 56.82 | 42.20 | 38.48 | 80.68 |

**Table 4**
Emission market and total agent gain.

| | $\tilde{e}_1$ | $\tilde{e}_2$ | $e^R$ | $\tau_1$ | $\tau_2$ | $\pi_1^B + \pi_1^S$ | $\pi_2^B + \pi_2^S$ | $\pi^B + \pi^S$ |
|---|---|---|---|---|---|---|---|---|
| ETPN | 12.87 | 12.87 | 0.0 | 0.39 | 0.39 | 50.04 | 50.04 | 100.09 |
| ETPC | 15.70 | 15.70 | 0.0 | – | – | 66.01 | 66.01 | 132.02 |
| ETPB | 0.83 | 25.00 | 16.1 | 4.50 | 0 | 46.75 | 63.48 | 110.23 |

The results concerning the seller are listed in Table 3. The seller highly benefits from the two-period model ETPB. The profit is only slightly below the profit with cooperation ETPC. Thus, the seller has very little interest in a scenario in which cooperation is enforced, e.g. through contracts. As seen above, the profit made by the seller in ETPB is done so highly on the cost of the buyer.

Let us finally take a look at the values concerning the market as denoted in Table 4. Banking leads to two completely different periods concerning the price of allowances, the number of allowances sold, and (at least for the buyer) the profit made. What has happened in the European Union Emissions Trading Scheme corresponds especially to the fall of the price for allowances. At first, the allowances seemed to be so scarce that the price for allowances climbed much higher than had been predicted. Because of such high prices, electricity-producing companies justified higher energy prices. However, as the emissions trading reached an end in 2007, allowances became a penny stock.

Although ETPB leads to a higher total agent gain (110.23) than ETPN (100.09), it is questionable whether this is desired or not. The total agent gain is caused by the seller at the cost of the buyer. Furthermore, we have to point out that the total agent gain only includes buyer and seller, but not the consumer. The consumer is worse off in ETPB because of higher energy costs than in ETPN.

## 4. Summary and conclusions

The price history of the first period of the EU Emissions Trading Scheme was rather paradox, as the price for allowances unexpectedly climbed to 30 Euro and was then reduced to a penny stock. To our knowledge, no model was able to describe or even forecast this paradox. We show that taking into account some peculiarities of the market for allowances delivers a simple model explaining the price crash and its rationality. Strongly favouring some enterprises during the allocation of allowances through grandfathering made it possible that energy-producing companies were especially able to raise their product price in accordance with the price of allowances. As the model in line with empirical data shows, energy-producing companies profit from emissions trading at the expense of (smaller) emitters and electricity consumers. This effect is intensified further if banking is allowed.

Due to these results, emissions trading schemes are related to some potential failures which should be taken into account. Strategic behaviour of some market players may harm other players who are directly or only indirectly related to emissions trading. Strategic behaviour is possible when some market players have significant or even monopolistic power in the emissions trading market. Information asymmetry can further increase the consequences of an unbalanced power situation. Banking can be used to enhance a company's or an industry's strategic situation, especially when allowances are mainly banked to influence current and future allowance's market prices. Allocating allowances due to the grandfathering principles creates windfall profits for companies with high numbers of allowances and a modern technology mix.

What are the lessons from the first trading period and the presented model which brings the most problematic issues to surface? First of all, information asymmetry should be minimized through regular reporting of actual emissions levels. Annual reporting does not seem to be appropriate since inter-seasonal issues (such as weather occurrences and economic developments) make it difficult to forecast if surplus allowances are available. However, transparency alone is not sufficient if market power is unbalanced. Then, even limitations to banking allowances and enforcement of selling surplus allowances might be appropriate to prevent the negative side effects of market failures. This could be done by restricting the validity of allowances to a shorter time period, say one year. Lastly, auctioning instead of allocating allowances according to the grandfathering principle would reduce windfall profits in the electricity sector. In summary, it is another paradox that market failures related to emissions trading can only be moderated though market interventions into free emissions trade. In compliance with that argument, Hagem and Westkog (2008) suggest interventions through adjusting allocations if single agents exercise their market power.

The model in this article gives some insight of emissions trading market failures and shows that empirical paradoxes can be well explained. Even first improvement suggestions can be derived. However, to thoroughly understand all potential shortcomings of emissions trading, especially the influence of unbalanced power, further research and more complex models are required. An explicit consideration of consumers in the model, an accentuation on the fact that there is a group of sellers (oligopoly vs. monopoly), or a closer adjustment of the model to the market framework (e.g. an upper bounded $\tau$) are extensions to the presented model to be considered in future research. Such models might even be used to forecast market developments superior to previous approaches.

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