Institut für Wirtschaftsforschung Halle
Halle Institute for Economic Research

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February 2010 No. 4

IWH-Diskussionspapiere
IWH Discussion Papers

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Stochastic Income Statement Planning and Emissions Trading[*]

Abstract

Since the introduction of the European CO_2 emissions trading system (EU ETS), the development of CO_2 allowance prices is a new risk factor for enterprises taking part in this system. In this paper, we analyze how risk emerging from emissions trading can be considered in the stochastic profit and loss planning of corporations. Therefore we explore which planned figures are affected by emissions trading. Moreover, we show a way to model these positions in a planned profit and loss account accounting for uncertainties and dependencies. Consequently, this model provides a basis for risk assessment and investment decisions in the uncertain environment of CO_2 emissions trading.

Keywords: CO_2, emissions trading, EU ETS, risk, stochastic business planning

JEL classification: D81, G32, L59, Q54, Q56, Q58

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[*] We gratefully acknowledge funding of the project underlying this paper by the German Federal Ministry for Education and Research (BMBF). The responsibility for the content of this publication rests with the authors.

Stochastische Unternehmensplanung und der Emissionshandel[*]

Zusammenfassung

Dieses Papier behandelt die Frage, wie durch den CO_2-Zertifikatehandel verursachte Risiken in der stochastischen Gewinn- und Verlustplanung von Unternehmen Berücksichtigung finden können. Es wird zunächst diskutiert, welche Plangrößen durch den Zertifikatehandel betroffen sind. In einem weiteren Schritt werden Möglichkeiten aufgezeigt, wie diese Positionen unter Einbeziehung von Unsicherheiten sowie Abhängigkeiten in einer Plan-Gewinn- und Verlustrechnung modelliert werden können. Das vorgestellte Modell stellt eine Basis für Risikobewertungen und Investitionsentscheidungen im unsicheren Umfeld des CO_2-Zertifikatehandels dar.

Schlagwörter: CO_2, Emissionshandel, EU ETS, Risiko, stochastische Unternehmensplanung

JEL-Klassifikation: D81, G32, L59, Q54, Q56, Q58

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[*] Das diesem Bericht zugrunde liegende Vorhaben wurde mit Mitteln des Bundesministeriums für Bildung und Forschung (BMBF) gefördert. Die Verantwortung für den Inhalt dieser Veröffentlichung liegt bei den Autoren.

1 Introduction

In 1997, with the Kyoto Protocol an international agreement was met to reduce global greenhouse gas emissions. Under this protocol, Europe committed itself to reduce its emissions about eight percent between 2008 and 2012 compared to the base year 1990. To achieve this goal as cost-effectively as possible, the European Union introduced the pan-European CO_2 emissions trading system (EU ETS) in 2005. Emissions trading is a market-based instrument of environmental policy. It is used for the politically motivated quantity control and hence for the reduction of Europe's CO_2 emissions. Emission allowances are allocated free of charge, sold or auctioned off in the future to affected firms and can be traded freely thereafter. Emissions trading in its effect is equal to the introduction of prices on the emission of CO_2 and is a new cost factor for the companies concerned.

Because of these new costs, CO_2 avoiding investment projects are coming to the focus of an enterprise. These projects have to be evaluated both in terms of their desirability in relation to alternatives such as the purchase of necessary certificates on the market and in terms of ability of the company to implement such projects. Both in terms of advantage as well as to the feasibility by the company the risk associated with the investment plays a decisive role. Projects with a too large probability of loss may be inconsistent with the risk policy of a company and are therefore rated unfavorable. A number of individual projects can increase the capital requirements of the company to the extent that they cannot be implemented due to lack of risk-bearing capacity.

An essential risk driver in this context is the price of CO_2 allowances. In the literature various models evaluating the price risk are discussed.[1] However, there are few models that show how this CO_2 price risk can be included in any investment decision, taking account of interdependencies with other investment risks in decision making. An exception is Yang and Blyth (2007) as well as IEA (2007). They, for example, refer explicitly to correlations between CO_2 certificate prices and commodity prices such as oil. There are also software providers, whose programs generate a so-called CO_2 footprint or promise help in the management of CO_2 emissions. However, systems to support investment decisions in the context of CO_2 emissions trading are scarce. Moreover, risk-bearing capacity constraints are neglected in this connection. The

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[1] See e.g. Yang and Blyth (2007), Benz and Trück (2009), Paolella and Taschini (2008) as well as Dannenberg and Ehrenfeld (in press).

latter results from the fact, that equity capital can be a scarce resource in a non-perfect capital market. This problem does not occur with the classical methods of evaluating investment alternatives, such as the internal rate or net present value method, since the perfect capital market is assumed here where capital is not scarce (Adam 1997, p. 3). However, in particular the financial crisis in the years 2008 and 2009 shows that the ability to bridge a period of time with liquidity or capital reserves may be decisive for the advantages of an investment option. If there is not enough risk buffer available and insolvency occurs, transaction costs inherent with such an event generally mean that an investment option turns out to be disadvantageous.

Dannenberg (2009) shows an example of how investment decisions can be made taking risk-bearing capacity constraints into account. A prerequisite of such a decision making is the modeling of future profit and loss accounts (income statement) of a company. In this paper an approach is presented, which allows the modeling of the income statement considering CO_2 emissions trading. This model thus represents a basis for investment decisions, including risk-bearing capacity constraints and emissions trading.

In the following section we will show first which positions of the profit and loss statement (P&L) are affected by emissions trading. For these positions we then describe how they can be modeled taking emissions trading into account. The article closes with a brief summary.

2 Positions to be modeled in the income statement

The stochastic modeling of the profit and loss account or any part of the balance sheet is already well established in risk management (see e.g. Bemmann 2007 or Gleißner 2005). The advantage of this approach is that at first autonomous models for the individual items of the income statement or balance sheet can be developed independently of each other. They form the basis for the description of the respective positions. In a further step, dependencies and interactions between the different positions can be included - if necessary even across periods. By aggregation of individual items, for example by Monte Carlo simulation, characteristic numbers usable for company management can be determined. The advantage of such an approach is that one has not to assume that the management of an enterprise is due to its experience in a position to identify risk distributions for all crucial indicators influenced by several interacting factors. Such an assumption is unrealistic in practice, as often already the description of an isolated individual risk by a probability distribution is a challenge for the management. The goal should be therefore to first develop models for individual risks and then take care of interactions and dependencies between different risk positions. Certainly, even such an approach represents a significant challenge to the management, as also the modeling of individual risks can be very complex. In particular, the evaluation of dependencies between the individual risks will require a lot of experience. Nevertheless, the distributions derived from such models are better established than those assumed to be known by the management.

Next, we show how the risk associated with emissions trading can be included in the planning of the income statement. The focus here is not on an accounting treatment of allowances but on the stochastic planning of ETS-related costs and revenues. Companies taking part in the emissions trading system can get emission allowances free of charge by allocation or by buying. For each calendar year the actual amount of CO_2 emitted has to be determined, for which the company has to deliver the equivalent quantity of allowances to the Emissions Trading Authority (e.g. the German DEHSt) by the end of April of the following year. Within a trading period (e.g. the so-called "Kyoto-period" 2008-2012) allowances allocated for the current year can also be submitted for the emissions of the past year (borrowing). Excess allowances can be transferred into the following year (banking). While borrowing is only allowed within a trading period, banking probably will be allowed via the term border. The amount of acquired or marketable certificates therefore depends both on the amount of free allocation and consumption, and hence on the production respectively sales volume.

Because, depending on the competitive situation, the certificate costs can be passed on to the customer in whole or in part, one must also consider that the sales prices of the company depend on the price of CO_2 allowances. Next, the price of CO_2 allowances can be correlated with various commodity prices, especially with prices of electricity or fuels like oil, gas or coal (see e.g. Mansanet-Bataller, Pardo and Valor 2007). Therefore, when modeling commodity costs such dependencies must be contained. It has also to be included in a model that commodity costs correlated with the CO_2 prices can be passed on wholly or partially. Because of this relationship

CO_2 prices also influence the sales price. So it must be asked as well to what extent a company can pass on commodity costs to its customers, which in turn depends on each individual competitive environment. Furthermore, it should be considered that companies can achieve speculative gains and losses by trading certificates. These depend on the strategy chosen by the company. Therefore, different trade policies must also be taken into account when planning.

3 Price modeling

3.1 CO_2 allowance price

In the previous section it became clear that a crucial component in the stochastic modeling of the income statement is the price of CO_2 allowances. In the literature different approaches for modeling CO_2-prices are discussed.[2] In the practical implementation, basically every pricing model can be used which appears appropriate to the respective management. As the planning of the income statement has in general a more long-term nature (one or more years into the future), the approach of Dannenberg and Ehrenfeld (in press) appears to be particularly suitable, since it puts a focus on long-term uncertainties. In particular, special attention is given to price shifts, which are essential for the long-term risk planning. This pricing model is briefly outlined below.

Within a trading period, a certain amount of CO_2 allowances is available to a company. Companies in the ETS can consume their allocated allowances for their own emissions and acquire missing allowances on the market or sell surplus allowances. For a company investing in CO_2-avoiding technologies it pays off when the pollution rights saved hereby are traded on the market at a higher price. If the costs of avoiding emissions are higher than the price of the pollution allowances, then it is worthwhile for a company not to invest. Instead, the company will purchase allowances on the market. Since all market participants are faced with this decision, the permit price of a given period reflects the “make or buy”-decisions of all market participants. The allowance price of a trading period is therefore determined by the last and therefore most expensive unit to save CO_2 emissions. These costs are referred to as marginal

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[2] See e.g. Seifert, Uhrig-Homburg and Wagner (2008), Benz and Trück (2009), Daskalakis, Psychoyios and Markellos (2009).

abatement costs. The current market price should therefore equal the (possibly discounted) marginal abatement costs for the period.

Since at the current time the exact marginal abatement costs are not known, market participants act on the basis of expectations. The variety of expectations about the marginal abatement costs of a period is reflected in the current market price. This processes all available information and projections. Thus, the market price represents the best estimate of the period's marginal abatement costs at the current time. For the allowance price it would therefore be expected that it randomly fluctuates around the marginal abatement costs expected by the market. Therefore, it makes sense to model the CO_2 allowance price based on a so-called mean reversion process.

But, within a trading period additional information can emerge, leading to a fundamental reassessment of the expected marginal abatement costs by the market. For this reason, sudden shifts in the price level are conceivable, which cannot be attributed solely to stochastic fluctuations. This behavior can be mapped by a modification of the mean reversion process. Here the level of this process is not regarded as a constant any more but as a random variable. This means that the reversion level moves with a certain probability. The extent of price correction is stochastic and is therefore described by a probability distribution. Dannenberg and Ehrenfeld (in press) model the possible change of reversion levels by a mixed Bernoulli-PERT distribution. This means that at any simulated point of time it is determined on basis of a Bernoulli distribution, whether a reversion level changing information enters the market. If this is the case, the jump height is assigned based on the PERT distribution. The PERT distribution was chosen because even in the presence of price limits it can be constructed in such a way that the expected value equals (nearly) the old reversion level. This means that in the simulation only information which is also actually available are processed.

In Section 2 we already pointed out that the prices of CO_2 allowances and energy sources can be correlated. It therefore appears necessary also to provide energy pricing models. In the following section, some approaches to the modeling of energy commodities are described. Here, for reasons of illustration, we focus on the oil price.

3.2 Commodity price

Early models such as, for example, Brennan and Schwartz (1985) used the Brownian motion for stochastic modeling of commodity prices. Here, the underlying assumption was that the prices follow a random walk. Later models made increased use of the mean reversion process. The use of the mean reversion process is here also theoretically well founded (Andersson 2007, p. 769): If for a commodity a price jump occurs, this probably will be temporary. The higher price attracts new businesses. The supply increases. Thus, in the longer term the price moves again in direction of the production costs as a result of the competition in the market. Therefore, the price should decrease after some time. So, the price exhibits short-term fluctuations but moves back again towards its "normal" level. Dias and Rocha (1999) also argue here with the role of OPEC, which has an interest in establishing a long-term, profit-maximizing price.

Bessembinder, Coughenour, Seguin and Smoller (1995) investigate the price of oil over the period 1982 to 1991 and come to the conclusion that 44 percent of oil price shocks are compensated over the following eight months. They find that the mean reversion process is well suited to model the price of oil. Pilipovic (1998, Table 4-9, p. 87) identifies the mean reversion model with logarithmic prices as the best model in her investigations. Pindyck and Rubinfeld (1991, p. 462f.) conduct a Dickey-Fuller unit root test for the price of crude oil during the period from 1870 to 1987 and may reject the random walk hypothesis (Geometric Brownian motion). Pindyck (1999) examines the behavior of oil, coal and natural gas by up to 127 years and concludes that the prices of these commodities show mean reverting behavior, but the mean reversion speed is very low. Further, he finds that the mean reversion level itself fluctuates over time. Al-Harthy (2007) examines various stochastic processes in their application to the oil price and the effects of model choice on the capital value of investment projects. Three pricing models are compared: the geometric Brownian motion (GBM), the mean reversion process (MR) and a mean reversion process with jumps. Al-Harthy gives the following results: First, the MR process with jumps in the simulation provides the largest span for the capital values. Second, if the decision is made on the basis of volatility, the GBM is not a good basis for decisions.

The models of Laughton and Jacoby (1993, 1995), Schwartz (1997), and Cortazar and Schwartz (1997) are members of the class with only one mean reversion parameter. In the aftermath, models with two (e.g. Gibson and Schwartz 1990, Schwartz 1997, and Schwartz and Smith 2000) or three (e.g. Cortazar and Schwartz 2003, Schwartz 1997) parameters were introduced. These models were made to map a rather more realistic behavior. Bernard, Khalaf, Kichian and McMahon (2008) compare a number of ARCH, GARCH and EGARCH models with the model of Schwartz and Smith (2000). The authors analyze the price development of commodities on the example of aluminum prices and may not reject the hypothesis of a unit root for their time series of spot and futures prices. Nevertheless, the mean reversion model with stochastically modeled convenience yield provided by far the best result in terms of the mean square forecast error. Bernard et al. (2008) refer in this context to a known problem of unit root tests in the presence of structural breaks.[3]

Hence, the mean reversion process appears to be suitable to model the price of oil and finds frequent application in the literature. However, the decision in what way commodity prices are modeled is finally subject to the user. For reasons of manageability we specify the oil price behavior using a one factor model which is based on a mean reversion process. In the following section, the price models for CO_2 and oil are parameterized first. Then we briefly depict how dependencies among the prizes can be included.

3.3 Parameterization of the pricing models and consideration of dependencies

The CO_2-price model is parameterized according to Dannenberg and Ehrenfeld (in press). There, as outlined above, a mean reversion process with variable reversion level for the CO_2 price is proposed. The model has the following form:

$$\Delta S_{CO_2,t+1} = \alpha_{CO_2}(S^*_{CO_2,t+1} - S_{CO_2,t}) + u_{CO_2,t+1}$$

$$\text{with } S^*_{CO_2,t+1} = \begin{cases} S^*_{CO_2,t} & \text{if } J(p) = 0 \\ H & \text{if } J(p) = 1 \end{cases} .$$

$S_{CO_2,t}$ denotes the current allowance price, and $S_{CO_2,t+1}$ the price of the next day. The difference between the two prices is $\Delta S_{CO_2,t+1}$. The term $J(p)$ indicates a Bernoulli-distributed random variable, which is parameterized by the jump probability p. $J(p)$

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[3] For this see also Perron (1989, 1993).

can take the values one and zero. If it takes the value one, a shift to the new reversion level of height H will occur. The shift is modeled by a random variable that is described by a PERT distribution: $H \sim \text{PERT}(H_{\min}, H_{\text{mod}}, H_{\max})$. This distribution is parameterized by the smallest possible ($H_{\min}$), the most likely (H_{mod}), and the maximum possible reversion level ($H_{\max}$) after the jump. The mean reversion speed is denoted by α_{CO_2}. Stochastic shocks between time points t and $t+1$ are included by the normally distributed error term $u_{t+1} \overset{i.i.d}{\sim} N(0, \sigma^2_{CO_2})$ with variance $\sigma^2_{CO_2}$. On basis of the historical price development Dannenberg and Ehrenfeld (in press) suggest a parameterization of this model as follows: $p = 2\%$, $H_{\min} = \max(S_{\min}\,;\, 0.7\, S^*_t)$, $H_{\max} = \min(S_{\max}\,;\, 1.3\, S^*_t)$, $H_{\text{mod}} = \frac{6S^*_t - H_{\max} - H_{\min}}{4}$, $\sigma_{CO_2} = 0.0194$ and $\alpha_{CO_2} = 0.3071$. $S_{\min}$ indicates the absolute minimum, and $S_{\max}$ the absolute upper limit for the reversion level after a shift. The lower limit arises because the surplus allowances of any period may be transferred to the subsequent period. Therefore, the current price level cannot fall below the (discounted) price level of the next period. The upper price limit arises because at the end of a trading period missing certificates must be submitted in the following period plus an additional penalty of currently 100 EUR. In a trading period the expected price level will then be maximal the price level of the following period plus the penalty. The price level of the subsequent period could be derived from the next period futures (if already traded). If these are not yet available, e.g. if due to lack of policy framework no futures market has been established for the demanded period, historical price levels of futures prices could give an indication for long-term marginal abatement costs. For example, in the first trading period (2005-2007) the futures prices were on average about 20 EUR for the second period (2008-2012).

However, Dannenberg and Ehrenfeld (in press) point out that the jump probability will be slightly underestimated, because small shifts in historical data cannot be measured but are contained in the model. Therefore, a slight increase in the shift probability to about 2.5% seems appropriate. It should also be noted that the parameters of the model like the mean reversion speed and volatility are subject to changes over time. An extension of the model to these uncertainties may therefore be useful. Furthermore, Dannenberg and Ehrenfeld (in press) refrain from the consideration of interest rates. For this reason, the price limits within a trading period are constant there. Including interest rates would result in increasing price limits during the period.

For the oil price mechanism we select a one factor model based on the mean reversion process with the following form:

$$\Delta S_{oil,t+1} = \alpha_{oil}(S^*_{oil} - S_{oil,t}) + u_{oil,t+1}.$$

Analogous to the parameters in the CO_2-price model $S_{oil,t}$ is called the spot price at time point t, $\Delta S_{oil,t+1} = S_{oil,t+1} - S_{oil,t}$ the expected price change, S^*_{oil} the mean reversion level, α_{oil} the mean reversion speed and σ_{oil} the volatility. To estimate parameters for the oil price mechanism, logarithmic daily data for the spot-market price of oil from the U.S. Department for Energy are evaluated. For the period January 1999 to January 2009, 2502 observations are available. To test whether the oil price can be modeled as a stationary process, Augmented Dickey-Fuller tests (ADF) were run. For the described period, the null hypothesis of a unit root can be rejected (p-value = 0.0359). Thus, the price of oil can be assumed to be stationary over this period, confirming the use of a mean reversion process for the oil price modeling. For the mean reversion speed $\alpha_{oil} = 0.0035$ was estimated, which approves the observation of Pindyck (1999), that oil prices exhibit a very low mean reversion speed. For the logarithmic mean $S^*_{oil} = 3.67$ is calculated, which corresponds to an equilibrium price of 39.25 EUR. For the volatility σ_{oil} the analysis yields a value of 0.0252.

Based on the presented price models for CO_2 and oil the historical correlation between the error terms u_{t+1} of the two time series can be determined. Here, it was calculated to be $\rho = 0.271$.[4] Since the error terms of each series are taken as standard normal, the joint distribution of the error terms is described by a bivariate standard normal distribution with correlation coefficient ρ. During the simulation correlated standard normal random numbers can be drawn from this distribution.[5]

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[4] The calculation was performed for the periods investigated by Dannenberg and Ehrenfeld (in press). For these periods the stationarity of the CO_2 price was shown.

[5] The modeling of correlated standard normal random variables can be done for example by multiplying (here two) independently drawn standard normal random variables with the Cholesky-decomposed correlation matrix (see Martin, Reitz and Wehn 2006, p. 201f.). The method can also be applied in the multidimensional case (see e.g. Cherubini, Luciano and Vecchiato 2004, p. 181).

4 Pass-through of the costs to the selling price

Besides the pricing models presented for the certificate price and the price of oil, approaches for any other raw materials and supplies may be established and integrated into the enterprise model. In addition to these supply prices, sales prices also play a crucial role for business success. Since this may depend on the ability to pass on the costs, this relationship is taken into account. Here, we restrict to the ability to pass on oil and CO_2 certificate prices.

In a first step, we develop a model for the sales price. Since the pass-through should be explicitly modeled, the selling price is initially predicted on the assumption that commodity or certificate costs cannot be shifted. To include planning uncertainties, it is useful to describe the sales price with a distribution.

The determination of the markup on the sales price caused by the price pass-through may be done in different ways. One possible approach is the pass-through of an average price. This is calculated as the average of all the simulated prices of a year. Alternatively, the average purchasing prices of a company could be used. This seems more suitable to very narrow, hence oligopolistic or monopolistic markets, because only here one can expect that a single firm has an impact on the pass-through of prices in its market. When a company, based on its experience, assesses the ability to pass on only 50% of the price to the customers at a given competitive situation, a price premium of half the respective CO_2 price will result. One reason for the incomplete pass-through of prices to the customer may be the use of other technologies by competitors. When a competitor emits less CO_2 per final product, because of having made a CO_2 emissions-reducing investment, he gains a competitive advantage at a CO_2 price increase. For simplicity it can be assumed that only the sales prices depend on changes of input prices. Basically, it must also be assumed that a change of input costs and therefore selling prices, result in changes of sales volumes. This connection could also be considered in a model. However, it is likely that the evaluation of this effect in the corporate practice represents a challenge. The portion of the sales price, which can be attributed to the CO_2 emissions trading will be relatively low in many industries. We assume that the volume effect is negligible in many cases. Therefore, this aspect is disregarded in the following.

Also, the specification of an overall pass-through-factor is a simplification. So it seems plausible to assume another pass-through at an average CO_2 price of e.g. 10

EUR than at a price of e.g. 50 EUR. The pass-through therefore also depends on the price elasticity of demand and thus on the shape of the demand function. Again, this relationship is not considered here for simplicity's sake. A pass-through of energy or other costs can be explicitly modeled in the same way as described for the CO_2 price.

5 Modeling of sales volume and certificate amount

In addition to the sales price and input costs, the sales volume represents an important component of business planning under carbon emission risks. Since selling prices and sales volume are influenced by the same external factors (e.g. economic situation), it is advisable to include such dependencies in a model. A method considered appropriate to include such effects can e.g. be Look-Up Tables (see Vose 2008, p. 391f.). At this point dependencies between sales price and sales volume could also be included in a model. For reasons of simplification they are not further treated here. Thereby, it should be noted that depending on the economic situation, different price elasticities of demand should be modeled accordingly.[6] The forecast of sales volume takes place at the enterprise level. Here, it is also reasonable to describe it by a distribution.

Given a company-specific technology, a factor expressing the quantity of CO_2 emitted per end product is determined by the management. This factor can be calculated from the fuel consumptions per unit of output and the so-called emission factors[7]. The emissions caused by a product in a certain period can then be generated by multiplying the simulated sales volume with this factor. For simplicity reasons, a year's sales volume could be set equal to the production volume. Basically, also stock variations could be modeled. This approach is applicable to all other kinds of variable costs as well.

The costs associated with a simulated amount of emissions depend on at what prices the company purchases the missing certificates. That is, these costs are affected by both the allowance price development and the chosen trading strategy. A company which forms a certificate buffer at the beginning of a trading period has therefore a

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[6] So it is conceivable that customers respond more price-sensitive in times of crisis.

[7] E.g. from the EU Monitoring Guideline (EU Commission Decision 2007/589/EC).

different chance and risk profile than a company that clears its emissions account at the very last day of the trading period. In the following section we show how certificate costs can be simulated considering trading strategies.

6 Modeling of emissions allowance and commodity costs

The certificate shortage or surplus of a year depends on the stock at the beginning of the year, the allowances allocated free of charge and the consumption. We suggest recording this shortage or surplus for one point of time a year. Basically, also shorter intervals could be considered. Now, we outline the case in which the certificate stock will be determined at the end of the year. Table 1 shows various trade options that can be included in a simulation.

The purchase of certificates can be done independently of the price whenever a shortage is obvious. Also, a strategy can be chosen in which missing allowances are only bought when the price is below a certain threshold. Such a trading strategy involves the chance to buy missing certificates at a later date at lower cost. So, one speculates on falling prices. However, the risk exists that the predetermined threshold is exceeded no more until the end of the period. Then the missing allowances have to be purchased at even higher prices. Consequently, such a strategy also exhibits significant loss potential. This potential loss can thus be limited by restricting the value of missing certificates at a definable threshold during the simulation.

In addition to purchasing missing allowances, buying allowances in advance can also be a strategic option. That is, it can be speculated on rising prices. It can also be a business goal to consider potential market volume increases by keeping an allowances reserve. The stockpiling can be dependent or independent of the simulated certificate price. Excess allowances can also be sold independently of the price immediately. However, there is also the opportunity to speculate on rising prices and to maintain the certificates until the price excesses a certain threshold or the value of the allowances strides a given amount. To avoid conflicts between stockpiling and the sale of allowances the priorities of the various strategies have to be determined.

Table 1: Trading strategies of emissions allowances.

1. Buy EUAs		
1.1	independent of price	yes/no
1.2	if price is less than	…………..€
1.3	if missing value is more than	…………..€
2. Buy EUAs on reserve		
2.1	hold on reserve	EUAs
2.2	independent of price	yes/no
2.3	if price is less than	…………..€
3. Sell surplus EUAs		
3.1	independent of price	yes/no
3.2	if price is above	…………..€
3.3	if value of surplus EUAs is more than	…………..€
3.4	priority of selling higher than holding on reserve?	yes/no

While the shortfall or surplus of allowances may be recorded only at the end of each year, trading could take place on a daily basis. This means that buy and sell conditions are checked at each trading day. One should also keep in mind that the allocation of free allowances is scheduled for late February. So, within one year a surplus of allowances can emerge, which is sold depending on the trading strategy. At the beginning of a year a company has a certificate stock, which can possibly be negative, since the lack of certificates from the year before can be compensated with free allocated allowances for the current period.[8] The opening stock is increased by allowances allocated for free and buying. It decreases with sale or consumption. At the end of the period the certificate stock results as:

$$\text{closing stock} = \text{opening stock} + \text{free allocation} + \text{purchase} - \text{sell} - \text{consumption}.$$

Beginning and ending inventory are appraised at the allowance prices on the valuation date. The difference between initial and final value plus the cost of allowances buys, less the revenue from purchases and sales of certificates reflects the outcome of the enterprise's allowance trade. Typically, this will be negative if due to the emissions caused more allowances have to be delivered to the Emissions Trading Authority

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[8] One exception is that at the end of a trading period shortages can only be offset by borrowing at the price of a penalty (currently 100 EUR per certificate). Therefore, in the model a compensation of the shortages takes place at the end of the period. The case in which shortfalls at the end of the year may be greater than the amount of free allowances allocated in the following year is not considered here.

than were allocated for free. Where a company has received more free allowances than needed, a return can be generated. In addition, by including opening and closing stocks, speculation losses and gains can find evaluation in a plan period.

The result of the allowance trade can be directly considered in the income statement as profit or as loss. Alternatively, costs per certificate can be derived. Therefore, the total cost must be divided by the number of the certificates used. With the cost per certificate, for example, gross margins for individual products can be determined in a multiproduct company. The calculation of the cost per certificate presented here does not take into account that the total costs are influenced by speculation losses and gains. For contribution accounting it could be useful to split off this effect first and allocate it to the financial result.

Energy costs can be modeled similar to certificate costs. That is, therefore trading strategies can also be developed and considered in the model. One can assume, however, that companies taking part in emissions trading have relatively high energy consumptions. In many cases therefore a variety of deliveries are carried out per year. The average price a company has to pay within a year will therefore approximately be equal to the average of all the simulated prices. Thus, for simplicity, energy cost can be calculated as the product of the average of all simulated prices and the consumption.

7 Summary

In this article, we developed models for different positions of the income statement affected by CO_2 emissions trading. On this basis, planning of a future profit and loss account can incorporate risks associated with emissions trading. Here, only the positions of the profit and loss statement were highlighted, for which a connection to allowance trading was identified. Of course, in business planning other variables have to be considered and corresponding models have to be developed for them. These can be introduced stepwise in the model discussed here. Respectively, the approaches presented here can complement existing models.

References

Adam, D. (1997): Investitionscontrolling. 2nd ed. München, Wien: Oldenbourg.

Al-Harthy, M. H. (2007): Stochastic Oil Price Models: Comparison and Impact. In: *The Engeneering Economist* 52, pp. 269–284.

Andersson, H. (2007): Are commodity prices mean reverting? In: *Applied Financial Economics* 17, pp. 769–783.

Bemmann, M. (2007): Entwicklung und Validierung eines stochastischen Simulationsmodells für die Prognose von Unternehmensinsolvenzen. Dresden: TUDpress Verlag der Wissenschaften.

Benz, E. A. and S. Trück (2009): Modeling the price dynamics of CO_2 emission allowances. In: *Energy Economics* 31, pp. 4–15.

Bernard, J.-T., L. Khalaf, M. Kichian, and S. McMahon (2008): Forecasting commodity prices: GARCH, jumps, and mean reversion. In: *Journal of Forecasting* 27, pp. 279–291.

Bessembinder, H., J. F. Coughenour, P. J. Seguin, and M. Smoller (1995): Mean Reversion in Equilibrium Asset Prices: Evidence from the Futures Term Structure. In: *Journal of Finance* 50.1, pp. 361–375.

Brennan, M. J. and E. S. Schwartz (1985): Evaluating natural resources investments. In: *Journal of Business* 58.2, pp. 135–157.

Cherubini, U., E. Luciano, and W. Vecchiato (2004): Copula Methods in Finance. Chichester: John Wiley & Sons.

Cortazar, G. and E. S. Schwartz (1997): Implementing a real option model for valuing an undeveloped oil field. In: *International Transactions in Operational Research* 4.2, pp. 125–137.

Cortazar, G. and E. S. Schwartz (2003): Implementing a Stochastic Model for Oil Futures Prices. In: *Energy Economics* 25.3, pp. 215–238.

Dannenberg, H. (2009): Investitionsentscheidung unter Berücksichtigung von Risikotragfähigkeitsrestriktionen. In: *Zeitschrift für Controlling & Management (ZfCM)* 53.4, pp. 248–253.

Dannenberg, H. and W. Ehrenfeld (in press): "A Model for the Valuation of Carbon Price Risk." In: Proceedings of the 5th Research Workshop on Emissions Trading and Business.

Daskalakis, G., D. Psychoyios, and R. N. Markellos (2009): Modeling CO_2 emission allowance prices and derivatives: Evidence from the European trading scheme. In: *Journal of Banking & Finance* 33, pp. 1230–1241.

Dias, M. A. and K. M. Rocha (1999): Petroleum Concessions with Extendible Options: Investment Timing and Value Using Mean Reversion and Jump Processes for Oil Prices. Working Paper. SSRN.

Gibson, R. and E. S. Schwartz (1990): Stochastic convenience yield and the pricing of oil contingent claims. In: *The Journal of Finance* 45.3, pp. 959–97.

Gleißner, W. (2005): Kapitalkosten: Der Schwachpunkt bei der Unternehmensbewertung und im wertorientierten Management. In: *Finanz Betrieb* 2005.4, pp. 217–229.

International Energy Agency (IEA) (2007): Climate Policy Uncertainty and Investment Risk. Paris: IEA Publications.

Laughton, D. G. and H. D. Jacoby (1993): Reversion, timing options, and long-term decision-making. In: *Financial Management* 22.3, pp. 225–240.

Laughton, D. G. and H. D. Jacoby (1995): "The effects of reversion on commodity projects of different length." In: Real options in capital investments: Models, strategies, and applications. Ed. by L. Trigeorgis. Westport: Praeger Publisher, pp. 185–205.

Mansanet-Bataller, M., A. P. Tornero, and E. Valor (2007): CO_2 Prices, Energy and Weather. In: *The Energy Journal* 28, pp. 73–92.

Martin, M. R. W., S. Reitz, and C. S. Wehn (2006): Kreditderivate und Kreditrisikomodelle - Eine mathematische Einführung. Wiesbaden: Vieweg.

Paolella, M. S. and L. Taschini (2008): An Econometric Analysis of Emission-Allowance Prices. In: *Journal of Banking and Finance* 32, pp. 2022–2032.

Perron, P. (1989): The great crash, the oil price shock, and the unit root hypothesis. In: *Econometrica* 57, pp. 1361–1401.

Perron, P. (1993): Erratum: the great crash, the oil price shock, and the unit root hypothesis. In: *Econometrica* 61, pp. 248–249.

Pilipovic, D. (1998): Energy risk - valuing and managing energy derivatives. New York: McGraw-Hill.

Pindyck, R. S. (1999): The Long-Run Evolution of Energy Prices. In: *The Energy Journal* 20.2, pp. 1–27.

Pindyck, R. and D. Rubinfeld (1991): Econometric models and economic forecasts. 3rd ed. New York: McGraw-Hill.

Schwartz, E. S. (1997): The stochastic behavior of commodity prices: Implications for valuation and hedging. In: *The Journal of Finance* 52.3, pp. 923–973.

Schwartz, E. S. and J. E. Smith (2000): Short-term variations and long-term dynamics in commodity prices. In: *Management Science* 46, pp. 893–911.

Seifert, J., M. Uhrig-Homburg, and M. W. Wagner (2008): Dynamic Behavior of CO_2 Spot Prices. In: *Journal of Environmental Economics and Management* 56.2, pp. 180–194.

Vose, D. (2008): Risk Analysis - A Quantitative Guide. 3rd ed. Chichester: Wiley & Sons.

Yang, M. and W. Blyth (2007): Modeling Investment Risks and Uncertainties with Real Options Approach. Working Paper. IEA.