Prediction of Emission Allowances Spot Prices Volatility with the Use of GARCH Models
Predikce volatility cen emisních povolenek s využitím modelů GARCH

DANIELA SPIESOVÁ

Abstract
For several years, the system of emission allowances trading has been dealing with a crisis mainly due to the falling prices of emission allowances. That said, the partial aim of this paper is to create an overview of EUA trading options and acquaint readers with the development of the emission allowances price. Another partial aim is to predict the volatility of prices of emission allowances with the use of BAU scenario, i.e. without any intervention. ARIMA models are used to model the conditional mean value and linear ARCH or GARCH models are used to model conditional variance. The uniqueness of this paper lies in the fact that there are many expert studies dealing with the prediction of the price of allowance but there are only a limited number of scientific studies concerning the prediction of volatility which is the crucial element for trading with emission allowances on the exchange. Based on these two results the main aim of this article is to show possible malfunction of EU ETS in future based on the price development of EUA in time and on volatility prediction. The results of this study confirm that to predict the conditional variance and then volatility, it is adequate to use the cluster model AR(1,8,12)-GARCH(1, 1) without constant, where in the long-term, the square root of the conditional variance inclines towards stable value. Based on the analysis of EUA prices it is obvious that the system is not efficient and does not fulfill its purpose. These two partial conclusions suggest that in case of non-intervention of the European Commission the whole mechanism may fail.

Keywords
emission allowance; volatility; ARIMA; GARCH; prediction, spot price

Abstrakt
Již několik let se systém obchodování s emisními povolenkami potýká s krizí především kvůli klesajícím cenám emisních povolenek. Dílčím cílem tohoto příspěvku je stručně popsat možnosti obchodování s emisními povolenkami EUA a seznámit čtenáře s problematikou vývoje jejich cen. Druhá část textuje věnována predikci volatility cen emisních povolenek za předpokladu BAU scénáře, tj. bez jakýchkoliv vnějších zásahů. K modelování podmíněné střední hodnoty je využito modelů typu ARIMA, k modelování podmíněného rozptylu pak lineárních modelů ARCH potažmo GARCH. Unikátnost článku spočívá ve skutečnosti, že existuje mnoho odborných studií zabývající se predikcí ceny povolenky, ale vědeckých prací na predikci volatility, která je pro obchodování s emisními povolenkami na burze zásadní, je pouze omezený počet. Hlavním cílem je na základě zkoumání vývoje cen EUA v čase a predikce volatility poukázat na možnou nefunkčnost EU ETS v budoucnu. Výsledky modelování potvrzují, že pro predikci podmíněného rozptylu a následně

i volatility je vhodný sdružený model AR(1,8,12)-GARCH(1,1) bez konstanty, přičemž v dlouhodobém horizontu inklinuje odmocnina podmíněného rozptylu ke stabilní hodnotě. Z analýzy vývoje cen EUA je zřejmé, že systém není efektivní a nesplňuje svůj účel. Z těchto dvou dílčích závěrů vyplývá, že v případě neintervenování Evropské komise může dojít k selhání celého mechanismu.

Klíčová slova
emisní povolenka, volatilita, ARIMA, GARCH, predikce, spotová cena

JEL Codes
C32, C53, Q56, Q58

Introduction

The Emissions Trading system (ETS) was launched by European Union in 2005 to create a tool that motivates the operators of installations emitting greenhouse gases to using more efficient technologies and reduce the amount of emissions. The aim of the EU ETS is to ensure that emissions reduce at the lowest cost by creating and trading emission allowances (EUA - European Emission Allowances). Böhringer and Lange (BÖHRINGER, 2005) indicate that the objectives of economic efficiency and free allocation of emission allowances are incompatible with the harmonized allocation rules to prevent distortions of competition. At the same time also shows that Member States have not implemented the optimal allocation in the first trading period 2005-2007. Therefore, the use of flexible mechanisms of the Kyoto Protocol, an international emissions trading, the Clean Development Mechanism (CDM) and Joint Implementation (JI), becomes an important issue.

In recent years, a number of empirical studies that deal with examining the price of emission allowances mainly from an econometric perspective grows. Among the authors of these studies are e.g. Daskalakis et al. (DASKALAKIS, 2005), and Paolella Taschini (PAOLELLA, 2006); Seifert et al. (SEIFERT, 2008), Uhrig-Homburg and Wagner (UHRIG-HOMBURG, 2006) and others. While Uhrig-Homburg and Wagner (2006) focus mainly on derivatives of emission allowances, Seifert et al. (2008) developed a stochastic equilibrium model to reflect the most important parameters of the EU ETS and analyzed the resulting dynamics of the spot price of CO_2.

There is a number of studies to predict the price of emission allowances for the third period. Daily and Bond-Smith (BOND-SMITH, 2010) summarized most of the existing models for predicting the price of allowances into two categories. The first category, "bottom-up" models, which typically do not provide feedback between developments in individual markets and the rest of the economy and cannot even simulate links between individual markets. Assumption of these models is that the market price of emission allowances equals to the unit cost of emissions reductions in a competitive market.

The second set of models is called a "bottom down", which are models describing the system from the top to the bottom. They are relatively complex, mostly dealing with economy as a whole and are usually based on aggregate sector data. In recent years there have been approaches that try these two methodological approaches to integrate into a single framework of general equilibrium. Böhringer and Rutherford (BÖHRINGER, 2009) first directly integrate "bottom-up" and "top-down" description of the economic system in the so-called hybrid integrated model.

Models of volatility were first described by American economist F. Robert Engle (ENGLE, 1982) in 1982. He devised a model that should characterize the conditional heteroscedasticity of the stochastic process, for which he was awarded the Nobel Prize in economics in 2003. Models of volatility are, unlike other models of time series, dealing with modeling of random component based on the conditional variance. Among the basic linear models are ARCH and GARCH (FEDDERKE, 2003), (POPELKA, 2007). These are further described in the following text.

Benz and Truck (TRUCK, 2009) investigated the prediction of the price of allowance with the use of ARCH or GARCH models by analyzing the prediction from sample data and by comparing the results with alternative approaches. In this model, the conditional variance of time series is represented by the weighted sum of squares from previous observations. At the same time, they use Markov-switching model for the analysis of spot prices of carbon dioxide emissions to capture the heteroscedasticity of the time series. Their findings confirm that AR—GARCH models are effective when modeling the short-time conduct. Another analysis of price and the data of returns from emission allowances were carried out with the use of GARCH model in the study of Taschini and Paolella (PAOLELLA, 7/2007). These authors analyzed spot prices of one ton of SO_2 from 4. 1. 1999 to 16. 5. 2006. The source of the spot price of one ton of SO_2 was the Chicago Climate Exchange. Taschini and Paolella used only with 454 values for CO_2 when working on the study. It is necessary to note that both of these studies were primarily focused on the prediction of prices and not on the volatility issues.

The partial aim of this paper is to create an overview of EUA trading options and the development of the emission allowances price. This will be followed by predicting the volatility of prices of emission allowances with the use of BAU scenario, i.e. without any intervention. Based on that, the main aim of this article is to show possible malfunction of EU ETS in future based on the price development of EUA in time and on volatility prediction

1 EU ETS Trading and its Effectiveness

Emission allowance is an "asset corresponding to the right of the operator to emit one ton of CO_2" (Act no. 383/2012 Coll., § 2, letter t). This emission allowance enables polluters to sell them to each other. All companies (industry and energy) have been receiving emission allowances for free based on historical emissions; in the second trading period 2008-2012 it is a total of 86.8 mil. allowances annually for the Czech Republic. In the third period, ie. since 2013, there is a revision of the system, part of the allowances is allocated to facilities for free (based on benchmarking or on historical emissions) and the remainder is available to buy via auction.

In the years 2013-2020 the Czech Republic will have a total of 645 mil. of allowances; 342 mil. of allowances (54%) will be auctioned and 303 mil. of allowances (46%) will be allocated to the Czech industry for free. By 2020 electricity producers will have received a total of 107.8 mil. of allowances for free, the rest they will have to buy (EUROPEAN COMMISSION, 2012).

Emissions trading can be done in several ways: currently daily futures are the most traded on London's financial and commodity exchange Intercontinental Exchange (ICE), but the emission allowances can also be purchased through forward contracts or direct sales.

ICE is the largest global network of exchanges and clearing houses for financial and commodity markets. ICE owns and manages 23 regulated exchanges. ICE Futures is the main market for emission allowances. ICE Futures products meet the requirements of the European Union Emissions Trading System. In April 2010, ICE acquired the European Climate Exhange (ECX). The first emission allowances were offered by the European Climate Exchange, founded in 2005, which stated emission products trading platform ICE Futures Europe.

The EU ETS was launched in early 2005 in order to control CO2 emissions-intensive sectors (e.g. Electricity generation and heavy industry). System is, however, struggling with inefficiencies due to low prices per ton of discharged greenhouse gases. After its beginning in 2005, the price of an allowance was € 30, which was according to the European Commission (EC) an expected price. The price, however, dropped as soon as possible due to the fact that the states requested an excessive amount of allowances during the preparations. This should have been changed during the second phase of trading (2008-2012). The EC demanded by some states to redo their National Action Plans (NAPs) in which they requested an excessive amount of allowances. Thanks to the price rose above € 20 per allowance. However, the economic crisis of 2008 caused an increase in the amount of allowances and their price dropped again. Currently, the value of allowances is - despite other measures taken by EC- far below the price that would encourage the European Commission to modernize installations emitting greenhouse gases again.

The price of emission allowances is currently around 5 euros per ton. This is much less than originally expected. Predictions in 2015 anticipated the end of last year to levels around 8.50 to 9 euros. Although two partial reforms, which should stabilize the market, were approved the price of allowances remains under pressure and react very strongly to prices of energy commodities. The break of the long-term trend of increasing prices of allowances took place on 11th December last year. After a slow recovery the price was finally closed in 2015 at 8.29 euros. However, in early 2016 a sharp downward trend continued. Since the beginning of this year, the allowance price fell by more than 40%.

There is a number of causes for the sharp price decline including speculators, international politics, or economics. Allowance is also part of the energy complex and as such it is related to the price of oil or electricity, and can be influenced even by such a thing as above-average temperatures as heating plant will not need so many emission allowances to fulfill their legal obligations.

2 Methodology

In this paper, we analyzed the time series of emission allowance spot prices for the period from 1. 1. 2008 to 31. 12. 2013. This period was chosen on purpose as it covers the whole second phase of ETS trading. The data contain values of allowances prices on the stock exchange for trading days, i.e. in the majority of the data set these are mostly prices from Monday to Friday. In total, there are 1521 observations in the data set. The most frequent value (modus) is 12.336 EUR/EUA. The minimal value of the price for the period of observation is 2.7 EUR/EUA and the maximum value is 28.3 EUR/EUA.

Given that financial data are very often characterized by high volatility, it is necessary to test the model for ARCH effect, i.e. presence of conditional heteroscedasticity. Regarding heteroscedasticity, it is a situation where the condition of finite and constant variance of random components is violated. The following model illustrates the conditional heteroscedasticity:

$$(lnX_t - lnX_{t-1})^2 = \alpha + \rho\,(lnX_{t-1} - lnX_{t-2})^2 + u_t \tag{1}$$

where X_t, X_t- represent values in the time series when time t is changed by one unit. The parameter α is calculated by the method of the smallest squares and u_t is a random component. If the parameter ρ (regressive parameter) is equal to zero, we cannot talk about heteroscedasticity.

When constructing the model of ARCH type, we face a major problem of choosing the model order. The common procedure for determining the order of ARCH type models is that at first a model of low order is estimated and then is this model modified for instance according to the results of statistic significance of the parameters or according to the analysis of standardized residuals. In the great majority of cases, low order models are sufficient, for instance: ARCH(1), ARCH(2) or GARCH(1,1), GARCH(2,1) etc.

For some time series, the high order is necessary to model volatility with the use of ARCH model which is generalized by adding the influence from previous volatility values. The resulting model is called GARCH model (GARCH - generalized autoregressive conditional heteroscedastic). GARCH models the movements of the conditional variance of residues and thus the following prediction of volatility is at the same time the prediction of the variance.

By extending the ARCH(1) model by conditional variance in the first delay, the GARCH (1,1) model of the conditional variance is in the form of:

$$h_t = \omega + \alpha_1 \varepsilon_{t-1}^2 + \beta_1 h_{t-1} \tag{2}$$

The conditions $\omega > 0$, $\alpha_1 > 0$ a $\beta_1 \geq 0$ ensure the positive conditional variance. Model (8) is labeled as GARCH(1,1) and it can be used where it would be appropriate to choose ARCH model with many delays.

To describe the idea of GARCH models more closely, we rewrite the equation (2) as follows:

$$h_t = \omega + \alpha_1 \varepsilon_{t-1}^2 + \beta_1 h_{t-1} = \omega + (\alpha + \beta) h_{t-1} + \alpha(\varepsilon_{t-1}^2 - h_{t-1}) \quad (3)$$

The conditional variance in this form is then equal to the weighted sum of the variance h_{t-1} predicted in the previous period and the unexpected previous shock $\varepsilon_{t-1}^2 - h_{t-1}$. The parameter α measures the impact of this shock on the prediction for the next period, $(\alpha+\beta)$ represents the rate at which the shock effect will vanish in the following period. The closer is $(\alpha+\beta)$ to one, the longer time it takes to remove the shock.

If we add ε_t^2 to the both sides of the model (2) and subtract h_t, this model may be rewritten to the form of ARMA(1,1) model:

$$\varepsilon_t^2 = \omega + (\alpha_1 + \beta_1)\varepsilon_{t-1}^2 + \nu_t - \beta_1 \nu_{t-1}, \quad (4)$$

where $\nu t = \varepsilon_{t-1}^2 - h_t$. If $\alpha_1 + \beta_1 < 1$, then it follows from the equation that GARCH(1,1) model is stationary in covariations. The unconditional variance of the process $\{\varepsilon_t\}$ is in the form of:

$$\text{var}(\varepsilon_t) = \omega / (1 - \alpha_1 - \beta_1) \quad (5)$$

It is therefore constant in time and the process $\{\varepsilon_t\}$ is unconditionally homoscedastic.

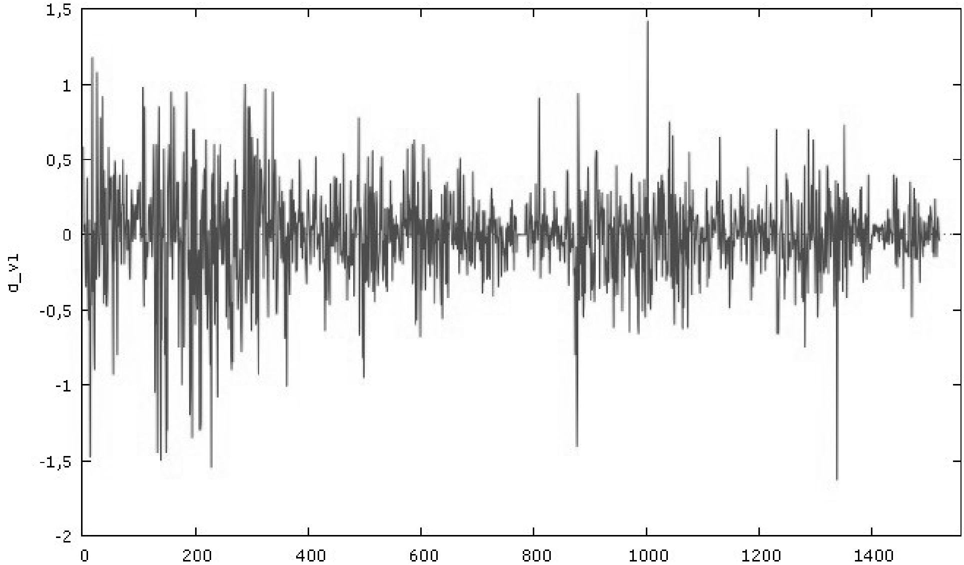
The number of model parameters for GARCH(1,2), GARCH(2,1), GARCH(2,2) can be gradually increased. This procedure is recommended by Tsay (TSAY, 2002). Overall, all GARCH models and their specifications are very efficient in the modeling of volatility.

The final phase of the construction of the volatility model is the verification of the adequacy of the chosen model based on standardized residues. These are obtained by subtracting the diameter from estimated residues and then divide this difference by the standard deviance. Other method of proving the model validity for the specific time series is testing of the non-systematic component – these are specifically tests of autocorrelation and conditional heteroscedasticity (for instance Ljung-Box Q-test, ARCH-LM test or GARCH-LM test.)

3 Prediction of Volatility

The time series of EUA prices was tested for the presence of the unit root with the help of the Dickey Fuller test, which was performed for the scenarios with a constant, without a constant and with a constant and a trend. The model with a constant appears to be the most adequate. Its conclusion is that for the given number of observations and the reliability value, we cannot reject the null hypothesis of the unit root existence, i.e. it is not the stationary time series, in other words, we may assume that the equation is in the first differences (Figure 1). This prerequisite was verified with the help of the autocorrelation and partial-autocorrelation function (ACF and PACF).

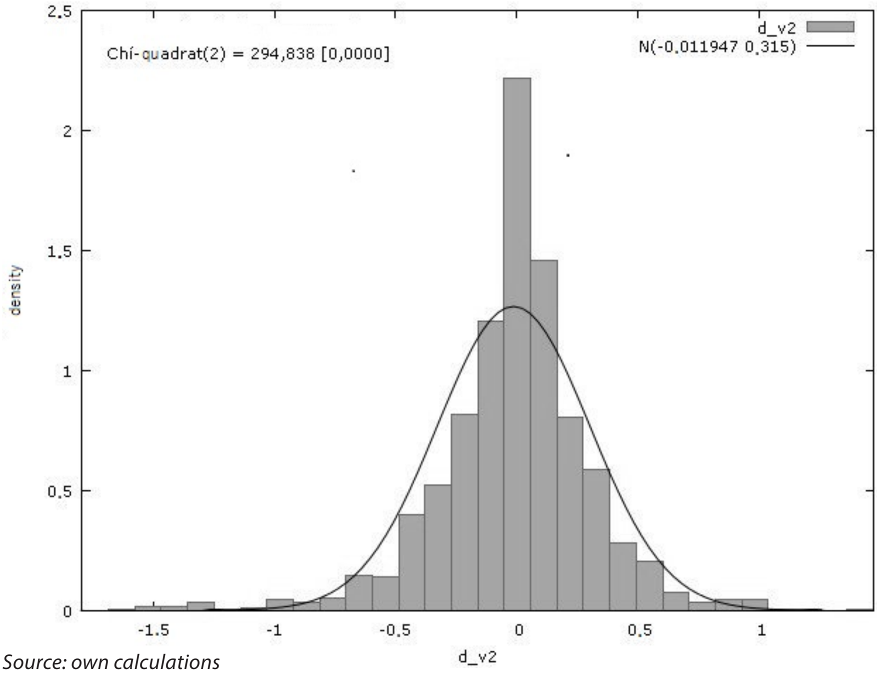
Figure 1: Differentiated time series of EUA (EUR/EUA) prices



Source: own calculations

The prerequisite of the normal distribution of residues is also important for the model. We test this prerequisite in our model. After we differentiated the data, we investigated their empirical distribution (see Figure 2 of the frequency distribution of residues).

Figure 2: Graph of the frequency distribution of residues



Source: own calculations

The data show the leptokurticity. This signifies that there are relatively many observations around the diameter and relatively many observations further from the diameter. The center of the histogram has a high peak and the tails are relatively larger in comparison with the normal distribution, i.e. there is a high probability value on the mean value and not insignificant probability of the remote observations (the distribution with the narrow waist and heavy ends). From above mentioned information follows that the distribution of residues is not in a normal nature, however, due to the sufficient number of observations, it can be assumed, based on the central limit theorem, that the normality prerequisite is fulfilled.

To predict the volatility, it is at first necessary to model the conditional mean value with the use of models AR, ARMA, or ARIMA. Predictions of, for instance financial assets prices, are very often made based on the models of the conditional mean value. In our case, we indentified the ARIMA [(1,8,12),1,1] model without a constant, which met the requirement for the minimum AIC, significant p-value and was then tested by ACF and PACF. The results of the model are shown in Table 1.

Table 1: The output of ARIMA [(1,8,12),1,1] model without a constant

ARIMA [(1,8,12),1,1] model without a constant	**coefficient**	**direct. error**	**z**	**p-value**
phi_1	-0.282922	0.136861	-2.067	0.0387 **
phi_8	0.0788961	0.0244957	3.221	0.0013 ***
phi_12	-0.0881966	0.0251873	-3.502	0.0005 ***
theta_1	0.391545	0.132915	2.946	0.0032 ***
Akaik's criterion	773.1933			

Source: own calculations (SW Gretl)

The detection of heteroscedasticity follows after the initial modeling. **Table 2** confirms the presence of ARCH effect as the p-value is almost zero. We therefore reject the null hypothesis and the heteroscedasticity is thus present in the model. Based on this result we can model the volatility of the time series.

Table 2: Test for ARCH of the 1. order

ARCH of the 1. order	**coefficient**	**direct. error**	**z**	**p-value**
$\alpha 0$	0.0832518	0.00640715	12.99	1.11e-036 ***
$\alpha 1$	0.137696	0.0254225	5.416	7.07e-08 ***
Null hypothesis: There is no ARCH effect Test statistics: LM = 28.8177 **P-value = P(χ2(1) > 28.8177) = 7.95222e-008**				

Source: own calculations

The choice of the ARCH and GARCH model order follows next (Table 3 + Table 4).

Table 3: ARCH models

ARCH(q)	**coefficient**		**z**	**p-value**	**log-likelihood**	AIC
ARCH(1)	α_0	0.0768978	20.87	1.08e-096 ***	-363.0074	732.0149
	α_1	0.251373	5.58	2.31 e-08 ***		
ARCH(2)	α_0	0.0529628	15.39	1.97 e-053 ***	-307.1594	622.3189
	α_1	0.2739	5.82	5.75 e-09 ***		
	α_2	0.266806	6.3	2.97e-010 ***		
ARCH(3)	α_0	0.0459722	14	1.51e-044 ***	-284.7905	579.5811
	α_1	0.168519	4.04	5.33 e-05 ***		
	α_2	0.209461	5.301	1.15 e-07 ***		
	α_3	0.214541	4.56	4.90 e-06 ***		
ARCH(4)	α_0	0.0377719	12.88	6.02e-038 ***	-253.4524	518.9049
	α_1	0.125875	3.535	0.0004 ***		
	α_2	0.173518	4.817	1.46e-06 ***		
	α_3	0.165081	4.103	4.08 e-05 ***		
	α_4	0.202664	5.259	1.45 e-07 ***		

Source: own calculations

According to Gretl calculations, the best model is ARCH (4) with the lowest Akaike's criterion (AIC) and the highest Log-likelihood. Looking at p-values we can see that all of these are significant on the 5% significance level.

Despite this, AIC is too high; therefore we proceed to the next phase where we estimate the conditional variance with the use of GARCH model. We have tested all the possible combinations of GARCH(p,q) if p = 1,2 a q = 1,2, with or without constant. We can conclude that GARCH(1,1) is the best choice, see Table 4. GARCH(1,2), GARCH(2,1) and GARCH(2,2) have higher AIC values and some of their parameters are not significant at all. GARCH with a constant was constructed only for orders p=1, q=1 a p=1, q=2. Due to the fact that in every case the constant was insignificant and the information criteria higher than when modeling without constant, other variations of GARCH order with a constant were not further investigated.

Table 4: GARCH models

GARCH(p,q)	coefficient		z	p-value	log-likelihood	AIC
GARCH(1,1)	α_0	0.001385	3.414	0.0006 ***	-188.4058	384.8117
	α_1	0.115714	6.543	6.01e-011 ***		
	β_1	0.876846	53.63	0.0000 ***		
GARCH(1,2)	α_0	0.001549	3.172	0.0015 ***	-188.0793	386.1586
	α_1	0.095076	3.26	0.0011 ***		
	α_2	0.028903	0.8291	0.4071		
	β_1	0.867491	41.92	0.0000 ***		
GARCH(2,1)	α_0	0.001382	3.133	0.0017 ***	-188.4063	386.8126
	α_1	0.116201	4.404	1.06e-05 ***		
	β_1	0.876533	3.773	0.0002 ***		
	β_2	4.26E-11	2.01E-10	1		
GARCH(2,2)	α_0	0.002797	3.483	0.0005 ***	-186.6285	385.257
	α_1	0.096813	4.654	3.26e-06 ***		
	α_2	0.135699	5.496	3.88e-08 ***		
	β_1	1.13E-12	1.20E-11	1		
	β_2	0.75411	8.307	9.83e-017 ***		
GARCH(1,1) with constant	const.	0.001694	0.2866	0.7744	-188.3648	386.7296
	α_0	0.001385	3.413	0.0006 ***		
	α_1	0.115922	6.549	5.80e-011 ***		
	β_1	0.87668	53.62	0.0000 ***		
GARCH(1,2) with constant	const.	0.002234	0.377	0.7062	-188.0101	388.0202
	α_0	0.001556	3.18	0.0015 ***		
	α_1	0.094413	3.248	0.0012 ***		
	α_2	0.030236	0.8662	0.3864		
	β_1	0.866852	41.79	0.0000 ***		

Source: own calculations

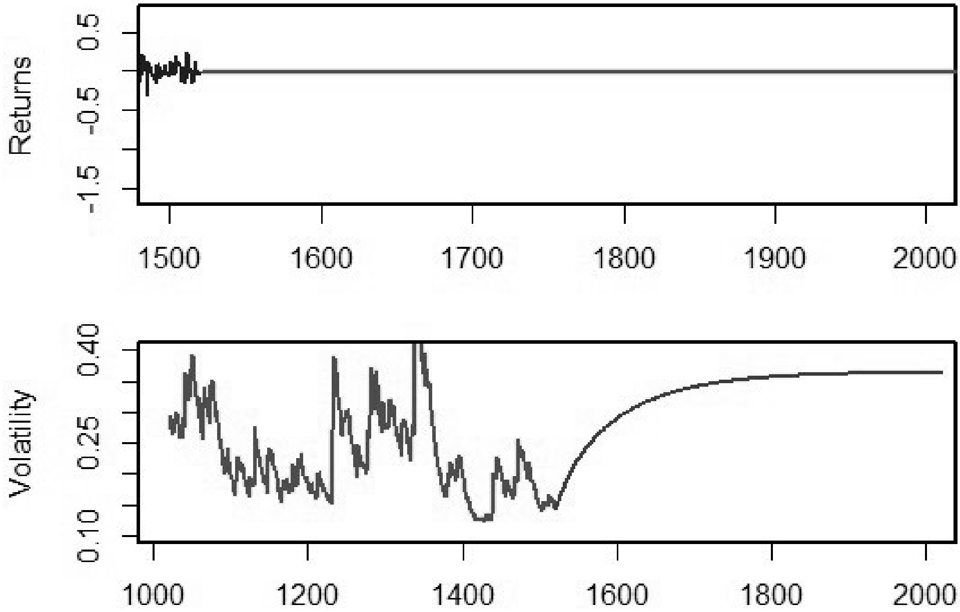
Both the ARCH and GARCH coefficients (0.115714 and 0.876846) are statistically significant.

The sum of these coefficients is 0.99256 which means that the shock to fluctuations affect conditional variations. If $\alpha1 + \beta1$ was equal to 1, we would use the integrated GARCH (1,1), so called IGARCH (1,1).

From the program R for AR(1,8,12)-GARCH(1,1) model application, we obtained the following conditional variation of allowances prices (6). After extraction, we can follow the development of the time series volatility of the prices of emission allowances (Figure 3).

$$h_t = 0.001385 + 0.115714\,\varepsilon_{t-1}^2 + 0.876846 h_{t-1} \qquad (6)$$

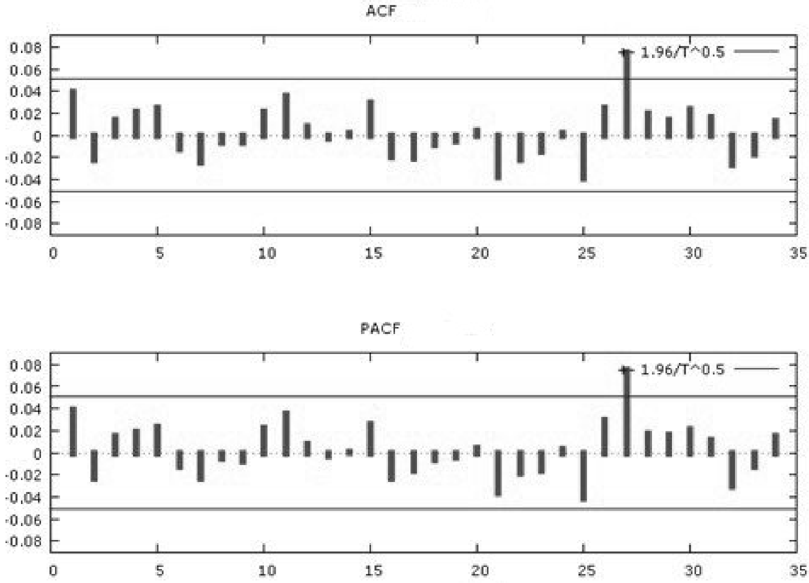
Figure 3: Prediction returns and volatility of emission allowance prices



Source: own calculations (SW RJ)

Given the long-term horizon of the prediction, the allowance price is relatively stable (the analysis is performed through BAU scenario), therefore is its volatility low. Verification (model diagnostics) is performed on the basis of obtained standardized residues. For testing standardized residues, we use the same tests as for the logarithmic returns (ACF, PACF, Box - Pierce and Ljung - Box test a subsequently testing of normality) with the difference of applying these tests on other data, i.e. instead of the logarithmic returns, we apply the data to the standardized residues obtained from parameter estimations. The un-correlation was checked by the selective autocorrelation function of standardized residues.

Figure 4: Testing the autocorrelation: standardized residues ACF and PACF of GARCH (1,1) model



Source: own calculations

From Figure 4 follows that the models of mean value and also of conditional variance were chosen adequately but the conditional heteroscedasticity could not be removed completely. More significant values remain in points of 26 multiples. This fact might be removed by modification of GARCH model to P-GARCH for modeling the seasonality in volatility. This model is discussed by for instance Alan Bester (BESTER, 1999).

Conclusions

The European Emissions Trading System suffers from a long-termexcess of allowances. After complicated and lengthy negotiations a two-phase reform was introduced in order to improve the functionality and stabilize the price. First, in the context of backloading, the volume of EUAs sold at auctions in the years 2014 to 2016 was reduced by 900 million euros. Later, Market Stability Reserve was approved, but the excess of allowances will not begin to be disposed of until 2019.

The second part of this paper contains the methodology of modeling the volatility with the use of ARCH and GARCH models. Then we modeled the cluster model AR(1,8,12)-GARCH(1,1), the output of which is the detection of the conditional variance. The model was verified and we can conclude that model thus identified is adequate for predicting the volatility of the prices of emission allowances.

The results of this study confirm that to predict the conditional variance and then volatility, it is adequate to use the cluster model AR(1,8,12)-GARCH(1,1) without constant, where in the long-term, the square root of the conditional variance inclines towards stable value.

However, we also have to bear in mind that the market with emission allowances is characterized by the fact that it is a market with artificially created demand. It is also important to mention that several artificial shocks caused by the administration occurred during the period examined in this paper which could have some influence on the price of the emission allowances.

The aim of this paper was to assess possible dysfunctions of the system in the future based on examining the effectiveness of the EU ETS and the prediction of volatility in spot prices. The results confirm that for predicting conditional variance and subsequent volatility cluster model AR(1,8,12)-GARCH(1,1) without constant is the most suitable, while the root conditional variance tends to lean to a stable value in the long run. Volatility is very low, because the model works with the BAU scenario, where significant shocks are not recorded.

However, from the viewpoint of stability, 5-6 EUR/EUA is not sustainable. We can expect a slight growing of prices, but not sooner than in three years and in the meantime (without the intervention of the Commission), the price will change minimally as stated in the article. This situation could even bring an irreversible destruction of the system.

References

BESTER, C. A. (1999) *Seasonal Patterns in Futures Market Volatility A P-GARCH Approach*. [online]. Duke University Durham, NC. Retrieved from http://public.econ.duke.edu/~get/browse/courses/200E/fall00/PROJECTS/previous/bester.pdf

BÖHRINGER, C. and A. LANGE (2005) Mission impossible? On the harmonization of national allocation plans under EU emission trading directive. *Journal of Regulatory Economics* 27, 2005.

BÖHRINGER, C. and T. RUTHERFORD (2009) The EU 20/20/2020 targets: An Overview of the EMF22 assessment. *Energy Economics.* October, vol. 31, pp. 268-273.

BOND-SMITH, D. (2010) *Carbon Price Forecasts*. Prepared for parliamentary Commissioner for the Environment.

DASKALAKIS, G., D. PSYCHOYIOS and R. MARKELLOS (2005) *Modeling CO_2 emission allowance prices and derivates: evidence from the EEX.* ERIM Report Series.

ENGLE, R. (1982) Autoregressive Conditional Heteroscedasticity with Estimates of the Variance of United Kingdom Inflation. *Econometrica*. vol. 50, issue 4, pp. 987-1008.

EUROPEAN COMMISSION (2012) *COMMISSION STAFF WORKING DOCUMENT Information provided on the function in of the EU Emissions Trading System, the volume sold greenhouse gas emission allowances auctioned and freely allocated and the impact on the surplus if EUA in the period up to 2020.*

FEDDERKE, J. (2003) *Applied Time Series Analysis*. South Africa: University of Cape Town.

PAOLELLA, M. and L. TASCHINI (2006) An econometric analysis of emission trading allowances. Working paper, Swiss Banking Institute.

PAOLELLA, M. and L. TASCHINI (2007) *An Econometric Analysis of Emission Trading Allowances*. Journal of Banking & Finance 32, July.

POPELKA, J. (2007) *Využití lineárních a nelineárních modelů volatility při analýze českých podílových fondů a akcií*. Prague. Disertační práce na Fakultě informatiky a statistiky Vysoké školy ekonomické.
SEIFERT, J., M. UHRIG-HOMBURG and M. WAGNER (2008) *Dynamic behavior of CO_2 spot prices.* Journal of Environmental Economics and Management 56.
TRUCK, S. and E. BENZ (2009) Modeling the price dynamics of CO_2 emission allowances. *Energy Economics*. Vol. 31, pp. 4-15.
TSAY, R. S. (2002) *Analysis of Financial Time Series*. John Wiley & Sons, INC., New York.
UHRIG-HOMBURG, M. and M. WAGNER (2006) *Success changes and optimal design of derivates on CO_2 emission certificates*. Working Paper, University of Karlsruhe.

Contact address

Ing. Daniela Spiesová, Ph.D.
Czech University of Life Sciences Prague, Faculty of Economics and Management, Department of Economic Theories / Česká zemědělská univerzita v Praze, Provozně ekonomická fakulta, Katedra ekonomických teorií
(saolinka@email.cz, spiesova@pef.czu.cz)