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Regime-dependent Assessment of the European Union Aviation Allowances Price Risk**

A b s t r a c t. In this article the European Union Aviation Allowances (EUAA) price risk, associated with the activity of aircraft operators within the European Economic Area (EEA), has been evaluated across the low and high volatility periods occurring on the carbon permits market. It is found that Markov-switching heteroscedasticity models distinguish well between two volatility regimes, as well as three volatility regimes on the EUAA futures market, and that the assessments of EUAA price risk are clearly different in the regimes. These findings may be explained by the European Union Emission Trading Scheme (EU ETS) design and the changes in both the EU climate policy rules and global regulations in the scope of CO_2 emissions by international aviation.

K e y w o r d s: European Union Aviation Allowances; EU Emission Trading Scheme; Markov-switching model; risk.

J E L Classification: C40; G32; L93; Q53.

Introduction

Worrying statistics concerning the over 3% share of CO_2 emission from international aviation bunkers in the total carbon dioxide emission in the EU countries in 2004 and the forecasts concerning an increase in greenhouse gases emission in international aviation by about 70% in 2020 compared with 2005 led the international community to take interest in the issues of

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limiting the negative impact of air transport on the natural environment. In 2008 the European Commission adopted the directive on including civil aviation into the EU Emission Trading Scheme (EU ETS), which refers to the EU's long-term policy aimed at limiting the greenhouse effect, improvement in the environment quality, increased energy efficiency and growth of renewable energy sources share in the energy consumption structure (Directive 2008/101/WE). Aircraft operators that in the given year carry out aviation operations covered by the Attachment 1 to the Directive 2003/87/WE in the territory of European Economic Area have been included into the EU ETS.

The period of civil aviation participation in the EU ETS has been divided into the two settlement periods: the first one of them comprising only the year 2012, the aim of which was to adjust the aircraft operators functioning to the functioning scheme of the remaining sectors in the allowances trading system, and the second one (common for all the sectors covered by the EU ETS) for the years 2013-2020. The EU ETS system operates according to the "cap and trade" principle. A permissible limit of CO_2 emissions in the given period ("cap") has been determined for all aircraft operators included into the system, which is gradually decreased over time. In order to asses this limit, data on average annual CO_2 emission in aviation was used, which covered the reference period of 2004-2006 and came from the European Organisation for the Safety of Air Navigation (Eurocontrol). In the first settlement period the total amount of European Union Aviation Allowances (EUAAs) to be allocated for aircraft operators was 97% of the average calculated from historical aviation emissions in the reference period. In the second settlement period the joint annual number of allowances granted to the aviation sector decreased to 95% of the same average emission. Within the established limit, in the first settlement period 85% of allowances allocated to cover the annual CO_2 emission of civil aviation will be granted to aircraft operators free of charge, and 15% of aviation allowances will be sold in the auctioning system. In the period from 1st January 2013 to 31st December 2020 in turn, 82% of aviation allowances will be allocated free of charge, 15% will constitute allowances purchased at auctions, and 3% will be moved to a special reserve for new aircraft operators. Chin and Zhang (2013) presented mathematical formulas and described in detail the method of emission allowances allocation consistent with the Directive 2008/101/EC and proposed an alternative method of allowances allocation (the Augmented EU ETS), which considers energy efficiency of aircraft operators (Chin and Zhang, 2013). The European Commission Regulation No 601/2012 imposes on aircraft operators the following duties, which result from their participation in the EU ETS system: the necessity to monitor carbon dioxide emission in each year, submitting a verified report on historical carbon dioxide emission to the proper body and its settlement through redemption of a proper amount of emission allowances in the EU Redemption Registry. Aircraft operators may settle their own CO_2 emissions by means of emission allowances assigned to stationary installations (European Union Allowances - EUAs) or aviation allowances (EUAAs). Moreover, aircraft operators should possess a plan to monitor annual emissions, approved by the appointed in the given member country competent body. There are sanctions foreseen that can be applied to operators that fail to settle their CO_2 emissions in the given year, including a prohibition on flights to the European Union. Aircraft operators also has a possibility to apply for allocation of free CO_2 emission allowances for the years 2013–2020 from a special reserve, provided that they complied with the obligation to monitor tonne-kilometres throughout 2014. Such a system of CO_2 emission allowances allocation was supposed to be an incentive to invest in environmentally-friendly technologies and modernise the air fleet against an alternative to incur additional costs of purchasing allowances. The emission allowances trading system was considered by the European Commission to be the most effective and least expensive instrument to limit the emission of greenhouse gases in aviation in the territory of the EU member states, yet, it encountered criticism. This concerned additional costs generated by the EU ETS for the aircraft operators participating in it, which was connected with, among others, purchases of missing EUAAs, new environmentally-friendly investments, administrative costs. The growing fears of aircraft operators included into the EU ETS concerned the loss of their competitive position due to their lower market share, change of entry barriers or lower profits margin (Meleo et al., 2016). The most severe objection concerned imposing additional charges on aircraft operators from outside the EU. The charges resulted from participation in the EU ETS and were imposed without any prior agreements, which was treated as a breach of the Chicago Convention on International Civil Aviation (1944). In response to this the European Commission introduced derogating mechanisms: „stop the clock” derogation (Decision 2013/337/EU), the exclusions mechanism in the scope of aviation operations covered by the EU ETS system (Regulation 2014/421). The abovementioned legislative regulations in the scope of obligations concerning reporting the emission from aviation operations within the EU ETS in the years 2013–2014, postponing the deadline to settle these emissions for 2013 and 2014, delayed the launch of aviation allowances trading in the auctioning system.[1] In addition, they influenced the volatility of EUAAs prices and the volume of EUAAs derivatives trading, as well as the interest of aircraft operators in the use of this type instruments to manage the CO_2 emission risk.

The inclusion of international aviation into the EU Emission Trading Scheme causes that the management of the EUAA price risk is becoming increasingly important for companies covered by the EU ETS. The increase in the price allowances volatility in the secondary market and the reduction of free allowances, which are granted to companies, cause the increase in their exposure to price risk. The aim of this article is to evaluate the EUAA price risk connected with the activity of aircraft operators within the European Economic Area, distinguishing between low and high volatility periods occurring on the carbon permits market. Volatility and downside risk measures are used to assess this type of risk across different regimes of the EUAAs' future prices, which are identified by means of Markov-switching models.

1. Research Methodology

The CO_2 emission allowances price risk from the aircraft operators point of view may result in a danger of not achieving by them the expected returns due to a sale of excessive or purchase of insufficient aviation allowances on the secondary market (neutral risk concept). The aviation allowances price risk may be perceived as a danger of sustaining a loss, which can have significant impact on financial results of the aircraft operator (negative risk concept). Volatility measures are the tools which are most frequently used to measure risk according to the neutral risk concept, while risk measurement in the negative meaning are conducted according to the downside risk measure (Jajuga, 2007). The most frequently determined by practitioners volatility measures include: standard deviation, interquartile range and absolute median deviation. The downside risk measure, which exposes only unfavourable situations for the aircraft operator when the real returns on sale or purchase of aviation allowances was below the average, is semi-standard deviation.

The first volatility measures, which have been estimated on the basis of settlement prices of EUAAs futures contracts, is standard deviation (Kuziak, 2011):

[1] Aviation auctions have been conducted since 1st January 2015.

$$\sigma = \sqrt{\frac{1}{T-1}\sum_{t=2}^{T}(R_t - \overline{R})^2}\ , \tag{1}$$

where: $R_t = \ln(P_t / P_{t-1})*100\%$ – return on sale/purchase of aviation allowance on the secondary market in *t* period; P_t – settlement price of EUAA in *t* period; P_{t-1} – settlement price of EUAA in the period $t–1(t = 2,.., T)$; σ – standard deviation; $\overline{R}_t$ – expected value of EUAA returns.

Coefficient of variation is also used in order to assess how much risk accompanies one unit of profit from the investment in the EUAA futures market. The lower the value of this measure is, the higher the expected profit on sale/purchase of aviation allowances is at the defined risk level or lower risk at the defined level of profit:

$$V_s = \left|\frac{\sigma}{\overline{R}}\right| 100\% \tag{2}$$

where V_s is coefficient of variation.

Asymmetric risk measure is semi-standard deviation, which can be defined in the following way (Booth et al., 2005):

$$SV = \sqrt{\frac{1}{T-1}\sum_{t=2}^{T} d_t^2}\ , \tag{3}$$

for

$$d_t = \begin{cases} 0 & \text{for } \mathrm{R_t} \geq \overline{R} \\ R_t - \overline{R} & \text{for } \mathrm{R_t} < \overline{R} \end{cases}, \tag{4}$$

where SV – semi-standard deviation.

This measure reflects an unfavourable for aircraft operators situation, where the returns on sale/purchase of EUAAs on the secondary market were below their expectations.

Robust volatility estimators in turn are characterized by the fact that present in the sample outliers have little impact on the estimation results (Trzpiot, 2010). This is a very important property for EUAAs return series, where single outliers occur, which confirms extremely high change of aviation allowances price form period to period. The most frequently applied robust volatility estimator is absolute median deviation, which can be described by means of the following relation (Trzpiot, 2010):

$$MAD(R_t) = \underset{t}{median}\{|R_t - \underset{i}{median}\{R_i\}|\}, \tag{5}$$

where $MAD(R_t)$ – absolute median deviation of EUAA returns.
One of the simplest robust volatility estimators is interquartile range (*IQR*), which ignores up to 25% of lowest and largest returns (Trzpiot, 2010):

$$IQR = Q_3(R_t) - Q_1(R_t), \tag{6}$$

where $Q_1(R_t)$ and $Q_3(R_t)$ – respectively the first and third quartile of EUAA returns empirical distribution.
It is worth stressing that risk has been most often measured under the assumption of the worst- scenario in the market, what has been derived from the negative concept of risk and has contributed to the popularization of the downside risk measures. However, this approach may not reflect the change of uncertainty sets with respect to different market environments (e.g. calm and turbulent periods). Following Liu and Chen (2014), in this article Markov regime switching models are used to describe the time-varying uncertainty set of the first and second order moments, which are related to two main characteristics of investments in the EUAA futures, namely expected profits and risk.

As a result, Markov-switching dynamic regression models with *N*-regimes (MS(*N*)-DR(*p*)) have been used to describe the different dynamism of the EUAAs returns series, generated by changing risk factors on the market of CO_2 emission allowances (Hamilton, 1990; Doornik, 2013):

$$\begin{aligned} &R_t = \beta_0(s_t) + \beta_1(s_t)R_{t-1} + \beta_2(s_t)R_{t-2} + \ldots + \beta_p(s_t)R_{t-p} + \varepsilon_t, \\ &\varepsilon_t \sim N(0, \sigma^2(s_t)), \end{aligned} \tag{7}$$

where: $\beta_i(s_t)$ – the parameter describing the influence of delayed by *i*-periods EUAA returns per the current returns ($i=1,2,\ldots,p$), ε_t – the error term, $\sigma^2(s_t)$ - residual variance dependent on the valid at the given moment regime, s_t – non-observable variable modelled as homogeneous Markov chain of *N* regimes and the transition probabilities matrix $\mathbf{P} = \lfloor p_{i|j} \rfloor_{i,j\in\{0,1,\ldots,N-1\}}$.

The elements of stochastic matrix **P**, defining the process probability transition from *j* regime at *t–1* moment to *i* regime at the *t* moment, satisfy the Markov property (Hamilton, 1990):

$$\begin{aligned} p_{i|j} &= P(s_t = i \mid s_{t-1} = j, s_{t-2} = i_{t-2}, \ldots, s_0 = i_0) \\ &= P(s_t = i \mid s_{t-1} = j) \end{aligned}, \tag{8}$$

means that probability of moving to the next regime depends only on the current regime of a system and not on the previous regimes.
Therefore, the transition probability matrix can be defined in the following way (Doornik, 2013):

$$\mathbf{P} = \left(\begin{array}{c|cccc} & s_t = 0 & s_t = 1 & \cdots & s_t = N-1 \\ \hline s_{t+1} = 0 & p_{0|0} & p_{0|1} & \cdots & p_{0|N-1} \\ s_{t+1} = 1 & p_{1|0} & p_{1|1} & \cdots & p_{1|N-1} \\ \vdots & \vdots & \vdots & \vdots & \vdots \\ s_{t+1} = N-1 & p_{N-1|0} & p_{N-1|1} & \cdots & p_{N-1|N-1} \\ \hline \sum & 1 & 1 & \cdots & 1 \end{array} \right), \tag{9}$$

at the conditions that guarantee the stochastic structure of this matrix:

$$\sum_{i=0}^{N-1} p_{i|j} = 1, \qquad \mathrm{p}_{\mathrm{i|j}} \geq 0 \quad \text{for}\, i,j = 0,1,..,N\text{-}1. \tag{10}$$

Stawicki (2004) describing this class of econometric models introduced the concept of a dual stochastic process to emphasize the existence of an unobservable variable that has controlled the changes of regimes in addition to the observable economic variable being the subject of modelling (Stawicki, 2004).
Moreover, on the basis of estimated transition probabilities (elements of stochastic matrix **P**), the further expected duration of the system in a given regime can be determined (Hamitlon, 1990):

$$D_i = \frac{1}{1 - p_{i|i}} \quad (i = 0, 1, \ldots, N\text{-}1), \tag{11}$$

where: D_i – average duration of EUAAs returns in *i*-th regime.
It is also worth stressing that the model (7) considers the heteroscedasticity characteristic for the EUAAs returns through introduction of Markov switching also in the residual variance.

The most frequently applied parameter estimation method of Markov switching model is the maximum likelihood method (ML), which makes use of FSQP algorithm (*Feasible Sequential Quadratic Programming*) (Lawrence and Tits, 2001; Psaradakis and Sola, 1998). A by-product of the Markov-switching model parameter estimation is a sequence of smoothed probabilities $P(s_t = j \mid \Omega_T)$ which make it possible to identify the moment of process switching between the particular volatility regimes. These probability inferences allow to draw conclusions about the EUAA returns process being in a particular regime, although the regime variable s_t is unobserved. On this basis, the time series of the EUAAs returns have been divided into observations generated in different volatility regimes, and then risk measures (1)–(6) have been estimated for each sub-sample.

Additionally, regime classification measure (*RCM*) has been used to determine the number of regimes in Markov switching models (Ang and Bekaert, 2002):

$$RCM(N) = 100 \cdot N^2 \cdot \frac{1}{T}\sum_{t=1}^{T}\left(\prod_{i=0}^{N-1} P(s_t = i \mid \Omega_{t-1})\right), \qquad (12)$$

where: $P(s_t = i \mid \Omega_{t-1})$ – filter regime probabilities series (*i= 0,1,…,N–1* and *t= 1,2,…,T*), Ω_{t-1} – information set available up to time *t–1*.
Alternatively, Ang and Bekaert (2002) suggested to replace the filter regime probabilities by the smoothed probabilities over the entire sample ($P(s_t = j \mid \Omega_T)$) in (12). For the two-regime model the RCM statistics ranges from 0 to 100 and smaller value of this measure means better regime classification. High values of the RCM may indicate that the Markov switching model cannot successfully distinguish between regimes from the behavior of the data. It may point at misspecification of the number of regimes (Ang and Bekaert, 2002).

2. Data and Empirical Results

Intercontinental Exchange Futures Europe in London (ICE Futures Europe), adjusting itself to the changing regulations in the scope of the EU climate policy, introduced into trade the EUAA futures contracts in February 2012. This product was dedicated primarily to aircraft operators as an instrument of CO_2 emission risk management, due to a significant increase in their exposition to this type of risk after civil aviation had been included into the EU ETS. Hedging operations with the use of aviation allowances futures should gain in popularity as the international law provisions are being tightened in the scope of carbon dioxide emission in civil aviation and the principles of the EU ETS functioning towards introducing an auctioning system as a basic form of acquiring emission allowances by aircraft operators. An important stage of CO_2 emission risk management process in the civil aviation sector is the measuring price risk of EUAA futures contracts. In the empirical research two types of risk measures have been used for this purpose: volatility risk measure and downside risk measure, which have been estimated on the basis of weekly returns of EUAAs futures prices listed on the ICE Futures in the period from 04.03.2012 to 01.10.2017.[2] The shaping of weekly settlement prices and returns for constructed benchmark series for EUAAs futures have been presented in Fig. 1.

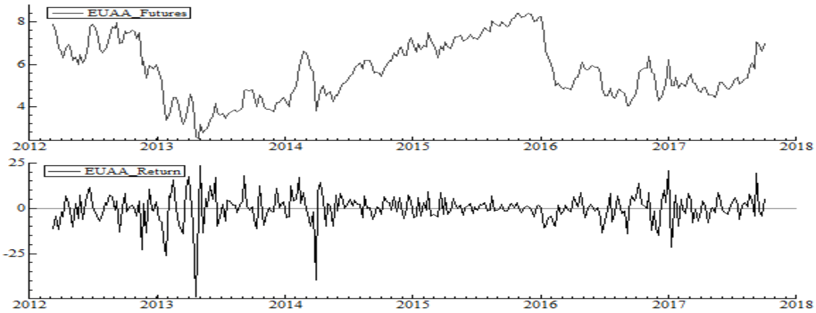

Figure 1. Weekly prices of the EUAA futures [EUR/tCO_2] (upper panel) and their returns [%] (lower panel) quoted in the ICE Futures Europe in the period 4.03.2012 – 01.10.2017

Table 1. MS(N)-AR(4) models for the EUAAs returns

Parameter	MS(2)-DR(4)		MS(3)-DR(4)		
	Regime 0	Regime 1	Regime 0	Regime 1	Regime 2
Constant	0.696	–1.104	0.726	–20.529	0.358
	[0.049]	[0.350]	[0.045]	[0.002]	[0.654]
AR-4	–0.179	–0.129	–0.212	–2.288	–0.050
	[0.019]	[0.234]	[0.013]	[0.001]	[0.546]
sigma	4.113	11.356	3.820	11.089	8.393
	(0.420)	(1.090)	(0.357)	(3.919)	(0.808)
Matrix P	R(0, t)	R(1, t)	R(0, t)	R(1, t)	R(2, t)
R(0, t+1)	0.9349	0.1077	0.9314	0.0000	0.0739
R(1, t+1)	0.0651	0.8923	0.0000	0.2092	0.0470
R(2, t+1)	–	–	0.0686	0.7908	0.8791
D_i (in weeks)	22.38	15.43	22.43	1.40	9.46
Returns assigned to regime	62.37% (179returns)	37.63% (108returns)	54.70% (157returns)	2.44% (7 returns)	42.86% (123returns)

Note: **P** – transition probabilities matrix, standard errors of parameter estimates in parenthesis, p-value in brackets.

Markov switching heteroscedastisity models (MS(N)-DR(p) for N = 2,3 and p = 1, 2, 3, 4) (7) were estimated to describe the dynamism of the EUAAs

[2] The research uses the December prices of EUAA futures quoted on the ICE Futures Europe, presented on the website https://www.quandl.com (access 18.10.2017).

returns series in various volatility regimes. The best results have been presented in Table 1.[3]

Two regimes have been distinguished in the first approach: the low volatility regime (regime 0) that describes the period of calm on the EUAAs futures market and the high volatility regime (regime 1) characterized by turbulent changes on this market, which are generated mainly by changes to the regulations concerning CO_2 emission in the aviation sector. The volatility parameter estimated for the regime 1 (11.356) is almost three times higher than the parameter describing the volatility in regime 0 (4.113). The differences between the regimes can be observed also for the parameter describing the expected profit from the EUAAs futures transactions, which in the low volatility regime is positive and in the high volatility regime negative. Moreover, each of the regimes is rather stable, as the estimated transition probabilities of indicating a chance of EUAAs returns process to remain in the given regime in the next period are relatively high (they amount respectively 0.9349 and 0.8923). Therefore, the low volatility regime on the EUAAs futures market lasts for about 22 weeks, while the high volatility regime lasts on average for over15 weeks.

In the second approach three regimes have been distinguished: the low volatility regime (regime 0), the high volatility regime (regime 2) and „spiky" regime (regime 1) for which the standard deviation of the error term took the highest value (11.089) compared to the low and high volatility regimes (respectively 3.82 and 8.393). The average profit from EUAAs futures transaction is highest in the low volatility regime. The spiky regime is a transitional one, which means that there is a great chance (0.7908) that in the next period it will be replaced by the high volatility regime. Only single EUAAs returns have been assigned to this regime, which indicate extreme changes of EUAAs futures prices connected with the structural changes in the system of aviation allowances trade.

Table 2 shows the results of diagnostic tests on standardised residuals from each model, which allow for positive verification of white noise properties for residuals series. The Akaike information criterion demonstrates the model of three regimes to be better adjusted to the EUAAs returns series,

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[3] Basic descriptive statistics and diagnostic tests verifying the presence of structural break occurrence, autocorrelation, volatility clustering, leptokurtosis effects have been determined for both presented in Figure 1 variables. The results of conducted diagnostic tests justify the use of Markov switching heteroscedastisity models (7) to describe the dynamism of the EUAAs returns series in various volatility regimes. Their results are available upon request from author.

while the Schwarz criterion reaches the lowest value for models of two regimes.

Table 2. Diagnostic tests for scaled residuals from MS(*N*)-AR(4) models

Test	MS(2)-DR(4)	MS(3)-DR(4)
AIC	6.707	6.675
SC	6.809	6.841
B-P(20)	21.120	18.492
	[0.390]	[0.555]
ARCH(1–5)	0.970	1.695
	[0.437]	[0.136]
J-B	5.614	4.009
	[0.061]	[0.135]
LR	80.132	99.299
	[0.000]	[0.000]
RCM	33.547	0.350

Note: B-P(*k*) – Box-Pierce test of serial correlation up to order *k*, ARCH(*1-q*) – Engle's ARCH test for heteroscedasticity up to lag *q*, J-B – Jarque-Bera test for normality, LR – likelihood ratio test for non-linearity, RCM – regime classification measure, AIC – Akaike Information Criterion, SC – Schwarz Information Criterion, p-value in brackets.

It is worth stressing that for both Markov-switching heteroscedasticity models, the Davies (1987) upperbound for the p-value of the LR test of linearity strongly rejects the linear model (Doornik, 2013). The calculated values of the RCM statistics are rather low in the case of each specification of Markov switching model, what indicates the correct classification of regimes in the estimated models.

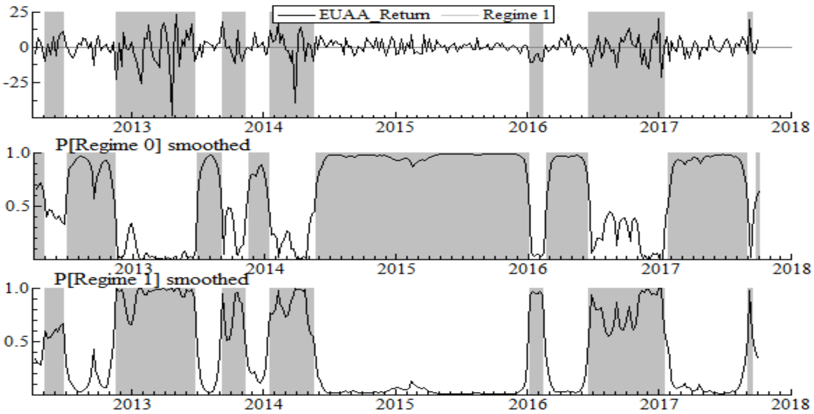

Figure 2. Weekly EUAAs returns (upper panel), smoothed probabilities for regime 0 (middle panel) and smoothed probabilities for regime 1 (lower panel) in the period 4.03.2012 – 01.10.2017

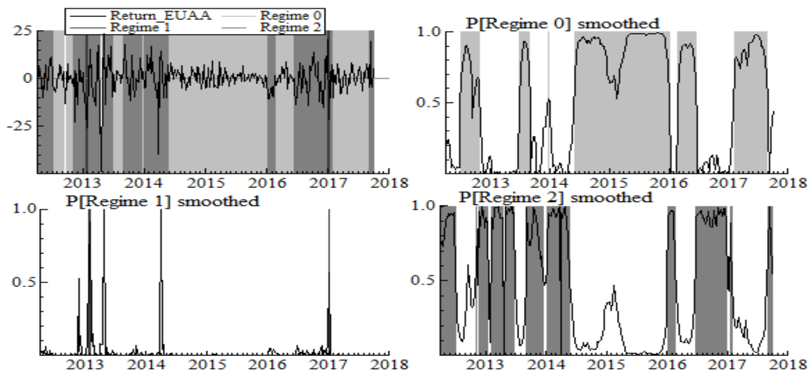

Figure 3. Weekly EUAAs returns and smoothed probabilities for regime 0 (upper panel), smoothed probabilities for regime 1 and regime 2 (lower panel) in the period 4.03.2012 – 01.10.2017

On the basis of obtained in the estimation procedure values of smoothed probabilities, the moments of process switching between particular volatility regimes were estimated. Then, the EUAAs returns series was divided into two sub-samples generated by the low and high volatility regimes (see Fig. 2) or three sub-samples generated by the regimes of low and high volatility and the spiky regime (see Fig. 3). One can observe that in each case the majority of EUAAs returns have been assigned to the low volatility regime (respectively: 62.37% and 54.70%). However, the sub-sample connected with the high volatility regime is relatively numerous, which is a characteristic phenomenon on the CO_2 emission allowance market (Sanin et al., 2015).

In each sub-sample associated with the given volatility regime measures of profit and risk have been determined (1)–(6) (see Table 3). The regime comprising turbulent changes occurring on the market of CO_2 emission allowances in aviation, the source of which is primarily uncertainty accompanying the changes of the EU climate policy and global regulations in the scope of pollutant emission by this sector, is characterized by much higher values of volatility and downside risk measures compared to regime 0. Focusing on the neutral concept of risk, one can see that the ratio between standard deviations estimated in regime 1 and 0 amounts to almost three. Having rejected the outliers in the process of risk measurement, the absolute median deviation in regime 1 is near three times higher than in regime 0. The same ratio is obtained when semi-standard deviations in high and low volatility regimes are compared, according to negative concept of risk. Aircraft operators securing themselves against the EUAAs price risk by means of futures contracts in the high volatility periods could on average lose 0.995% per week, and in the low volatility periods they could on average earn 0.621%.

Table 3. Risk measurement for the EUAAs futures transactions in particular regimes

Statistic	MS(2)-DR(4)		MS(3)-DR(4)		
	Regime 0	Regime 1	Regime 0	Regime 1	Regime 2
Minimum	–13.246	–48.791	–8.049	–48.791	–15.214
Mean	0.621	–0.995	0.710	–22.166	0.421
Median	0.589	–1.017	0.692	–22.816	0.248
Maximum	10.828	23.660	8.701	20.516	23.660
Standard deviation	4.189	11.708	3.995	21.907	8.573
Absolute median deviation	2.701	7.835	2.556	5.776	6.322
IQR	5.291	15.572	4.905	13.684	12.262
Semi standard deviation	2.982	8.874	2.734	12.134	5.835

Note: IQR – Interquartile range, the coefficient of variation is not calculated because of negative values of expected return in some regimes.

In the half of the weeks corresponding with the high volatility regime on the futures market, it was possible to lose at least 1.017%. In the half of the weeks assigned to the low volatility regime, EUAAs returns were not lower than 0.589%. Similar conclusions can be formulated for the 3-regime Markov switching model, when the estimated risk measures were compared for the high and low volatility regime. The risk accompanying the transactions concluded on the derivatives market was very high in regime 1 (21.907% according to the neutral risk concept, 12.134% according to the negative concept). In the spiky regime the volatility estimated with the means of the robust estimator which is absolute median deviation, amounts 5.776% and is significantly lower than other volatility measures. Considering also the average value (–22.166%) and median (–22.816%) one can assume that the majority of observations assigned to regime 1 constitute extremely large, negative EUAAs returns. The results presented in Table 3 indicate significant differences in the level of risk accompanying the transactions concluded on the EUAAs futures market, depending on the presence of the volatility regime in the given period. Therefore, Markov switching models may constitute a useful tool that allows to identify the moment of switching between regimes or determine the average lasting time of particular volatility regimes on the aviation allowances secondary market.

Conclusions

Decisions concerning tightening the EU climate policy in the scope of greenhouse gases emission from aviation and modifying the principles of the

EU ETS functioning will affect competitiveness of aircraft operators performing flights within the European Economic Area in the years 2012–2020. Therefore, it is important that the system of CO_2 emission risk management is adjusted to individual needs of a given aircraft operator and targeted to implement eco-innovations, making it possible not only to comply with legal regulations concerning the size of CO_2 emission but also to earn on the growth of fuel efficiency and transportation process optimization by the operator (Ko et al., 2017). Moreover, the constant control over the CO_2 emissions in order to the maintenance it below the upper allowed threshold and sale at an attractive price the surplus of CO_2 emission allowances leads to strengthening the competitive advantage of aircraft operators. By including civil aviation to the EU ETS system the legislators wanted to implement the principle "polluter pays", yet, the economic practice has shown that similarly to the energy sector, aircraft operators started gradually transfer the cost of participation in the EU ETS on the customers. Thanks to including the cost of CO_2 emission into the price of tickets, despite received free of charge share of aviation allowances, the operators recorded windfall profit. Making use of this option depends on the elasticity of the demand for aviation services, offers of competitive air carriers, state regulations of air transport market in the scope of access to both domestic transports as well as on international markets (concessions, certificates) (Tłoczyński, 2015; Dyduch, 2013). Due to the fact that aircraft operators have to make decisions on the way they use aviation allowances, the measurement of EUAAs price risk on the secondary market is of vital importance in this decision-making process. If the marginal profit from the sale of aviation service is higher than the market value of EUAA allowances, the aviation allowances will be used to cover CO_2 emissions derived from the air operations (Dyduch, 2013).

The paper shows the changes in the EUAAs price risk level depending on the volatility regime in force on the aviation allowances secondary market. On the basis of estimated Markov switching models the Author has identified two or three volatility regimes, for each different risk measures have been determined. The high volatility regime, in which the risk accompanying the sale and purchase transactions of EUAAs futures was several time higher than in the low volatility regime, has been assigned to the periods when important regulations in the aviation sector were introduced. The periods assigned to the high volatility regime corresponded with such events as: the end of the first settlement period for the aviation sector in the EU ETS (2012-11-25–2013-01-13), conducting the first settlement of historical CO_2 emissions in civil aviation for the year 2012 and publishing the decision of the European Parliament and Council on implementing the „stop the clock" mechanism (2013-04-21, 2013-04-28–2013-06-23), publishing the Regulation 421/2014 on further derogation in aviation (2014-04-06–2014-05-25), works on concluding a global agreement regarding implementation of the Carbon Offset and Reduction Scheme for International Aviation, CORSIA) (2016-06-19–2016-12-25). Such an approach makes it possible to measure more precisely the risk that accompanies the sale/purchase transactions of aviation allowances on the secondary market. It also allows diversification of the adopted by aircraft operators strategies of securing themselves against the risk of CO_2 emission allowances price depending on the price volatility regime in force.

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Reżimowo-zależna ocena ryzyka zmian cen unijnych uprawnień lotniczych do emisji CO_2

Z a r y s t r e ś c i. W artykule oszacowano ryzyko zmian cen unijnych uprawnień lotniczych do emisji CO_2, które towarzyszy działalności operatorów statków powietrznych wykonywanej w ramach Europejskiego Obszaru Gospodarczego, w okresach niskiej i wysokiej zmienności występujących na tym rynku. Pokazano, że reżimy zmienności na rynku kontraktów futures na uprawnienia lotnicze zostały prawidłowo zidentyfikowane, zarówno dla dwustanowego, jak i trzystanowego przełącznikowego modelu Markowa, a oszacowane miary ryzyka różnią się w reżimach. Występowanie różnych reżimów zmienności na tym rynku można wyjaśnić modyfikowaniem zasad funkcjonowania europejskiego systemu handlu emisjami oraz wprowadzaniem zmian zarówno w polityce klimatycznej UE, jak i w globalnych regulacjach dotyczących emisji CO_2 przez lotnictwo międzynarodowe.

S ł o w a k l u c z o w e: europejski system handlu emisjami; przełącznikowe modele Markowa; ryzyko; unijne uprawnienia lotnicze do emisji CO_2.