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Impacts of External Factors on EUA Price Volatility in EU Emission Trading System

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Abstract. Responding to the Kyoto Protocol and addressing increasingly severe carbon emission issues, European Union (EU) Emission Trading System (ETS), one of the most effective mechanisms makes significant contributions to the carbon neutral obligations. European Union Allowance (EUA) price which is regarded as a powerful instrument maps the efficiency and effectiveness of decarbonization. EUA prices fluctuate due to several reasons, directly affecting the price prediction and investment decisions. This paper explores the correlation between monthly average volatility of EUA spot prices and external political and economic uncertainties. Monthly standard deviation (SD) based on daily log returns of EUA spot prices is calculated to estimate monthly historical volatility. The time series analysis like Simple Moving Average (SMA), and data analysis like frequency distribution histogram, are combined to measure and quantify historical volatility tendency of EUA prices. In the end, the regular patterns are concluded regarding external factors and volatility during the whole evolution phases of EU ETS.

Key words. Monthly average volatility, EUA spot price, external political and economic uncertainties, time series analysis, data analysis.

1. Introduction

Carbon pricing mechanisms are increasingly prevailing confronted with gradually severe climate conditions and common objective for decarbonization. Carbon tax, carbon emission trading systems (ETS) and combination of former two types jointly constitute carbon price mechanisms [1]. Among them, ETS commercializes European Union allowances (EUA), witnessed as an effective decarbonization strategy [2]. Under the mechanism of ETS, corporations could select to decline CO_2 emissions through low-carbon technologies or fuel switching rather than conducting EUA trading if the cost of EUA trading is more expensive [3]. EU ETS, which is the largest emission trading system in the world, actively responds to the decarbonization policies with application of economic principles [3]. It is founded with multinational approval, participation and action. In EU ETS, EUA is priced through estimating economic cost of damages caused by each ton of carbon emissions. It is one indicator capable of scaling the effectiveness of EU ETS.

Differing ordinary trading market, during the evolution of ETS, changes of policies could cause fluctuations of EUA prices. Since Kyoto Protocol entered into force [4] in 2005, EU ETS has been launched to tackle the joint decarbonization objective. EU ETS is working on the 'cap and trade' mechanism, with gradually declined cap for the tightening confine. The evolution of EU ETS mainly experiences four phases, and currently in its fourth stage. Phase I (pilot phase) was from 2005 to 2007, when all EUAs were allocated to installations of member states obeying free-allocation. On May 15th, 2006 (May incidents), a formal certificate was issued by EU in case of market weaknesses, which was owing to large influx of funds [5]. During the phase II of EU ETS (2008-2012), the proportion of permits adopting grandfathering allocation principle was then reduced to about 90%, with remaining 10% allocated in the form of auction. Emerged on August 9, 2007, the financial crisis began to spiral out of control till September, 2008. During Phase III of EU ETS (2013-2020), auction was regarded as the default form of allocation. The share of auction was raised up to 57% with remaining amount allocated via benchmarking. In particular, EUAs in power sector are allocated all in the form of auction. Implemented since February 2014, back-loading plays a role in postponing allowances auction. It is regarded as a short-term measure response to the imbalance between the supply and the demand. Market Stability Reserve (MSR) was proposed in January, 2014, amended in October, 2015, started up in 2018 and formally operated in 2019. Different from back-loading, it is a kind of long-term strategy used to tackle major shocks through putting a portion of allowances auctioned into reserve [6]. After that, in 2021, entering the Phase IV, the auction proportion maintains the same with the Phase III. However, since 2020, several unforeseen incidents happened like the Pandemic in March 2020. Besides, Russia-Ukrainian War in 2021 and 2022 caused the energy price gouging. Therefore, in response to the economic recession and carbon price reduction during the period, the European Commission released the '€750 billion green recovery plan' in May 2020 [7]. All above external factors involving policy promulgation and unforeseen incidents could lead to the abrupt EUA prices volatility.

Historical volatility is generated owing to the asymmetry between demand and supply, which ultimately depends on uncertainties of economic and political environments. It is an attribute commonly utilized to scale the EUA spot prices instability and market risks, therefore stimulating numerous researchers to target at the orientation [8]. With respect to the pilot phase and Phase II, paper [9] applied Value at Risk (VaR) and Extreme Value Theory (EVT) to measure the economic uncertainties and market risks. Based on GARCH model, the paper explored the volatility of both spot market and futures market considering the economic uncertainties during 2005 to 2009. Similarly, paper [10] further combined the GARCH-MIDAS-RV model to quantify autocorrelation of carbon spot returns fluctuations. The paper also proposed the index called EUEPU to measure the uncertainty of policies. Besides, it constructed GARCH-MIDAS-EUEPU model and GARCH-MIDAS-GEPU model to respectively evaluate the impact of European and global economic uncertainties on volatility from 2005 to 2015. Combining these models, the paper confirmed autocorrelation of volatility. Additionally, it proved that the volatility is more sensitive to global economic uncertainty compared with that in Europe. Paper [11] utilized daily arithmetic return to calculate the monthly standard deviation (SD) of EUA futures in order to reflect the fluctuation circumstances. The paper differentiated the long-term and short-term volatility respectively according to EUA price and monthly volatility from 2009 to 2019. It ultimately summarized and verified the impact of policies implementation on volatility. Paper [12] utilized an analytically tractable simulation model to verify the effect of MSR. It summarized three main parameters consisting of the linear reduction factor, cancellation of allowances stored in the MSR and the intake rate of the MSR will cause similar effects on the increase of carbon price. In addition to normal policies influences, paper [7] targeted at unforeseen incidents like Covid-19. It illustrated that several political factors corresponding to the green recovery plan, oil price, etc. during the pandemic contributes to the stability of carbon price and carbon price structural changes. All papers above reflect the sensitivity of carbon price to external political factors. However, they are limited to the time series restrictions, or just use raw daily returns to reflect volatility during a short session. Besides, there is a lack of detailed depictions on policy timelines for the empirical papers.

Considering deficiencies of empirical research, this paper tends to calculate monthly SD based on log return of EUA daily spot price to estimate the volatility included in the whole phases of EU ETS. Different from harnessing raw daily return, the characteristics of monthly volatility during EU ETS evolution processes can be highlighted. Through resulting data, the regular patterns corresponding to volatility are precisely and holistically depicted and quantified in view of basic time series and data analysis. Moreover, the paper detailed enumerates political incidents and unpredicted events. Therefore, the relationships between monthly volatility of EUA price and external uncertainties can be more intuitive.

The paper is organized as following. Section 2 detailed illustrates the data sources of daily spot prices and methodology utilized. Results of data analysis are presented in Section 3. Discussions about regular patterns according to data and time series analysis are presented in Section 4. In the end, conclusions are drawn in Section 5.

2. Methodology

This section discusses about the methodology used for the data analysis.

A. Data sources

Considering the spot price data on EEX are only presented for the last 45 days, we collect daily EUA spot price during the year 2024 on EEX [13]. EEX is the official trading platform founded since 2002. The data during the period of 2005-2023 are from International Carbon Action Partnership (ICAP) [14], which is a cooperation platform collecting spot prices of EUA all over the world with the execution of ETS. Besides, ICAP tracks the daily spot price on EEX. Based on these platforms [15], daily spot prices of EUA are collected from March, 2005 to January, 2024 for data analysis and comparisons across whole phases.

B. Methodology

The research firstly utilizes the daily spot price of EUA to calculate the monthly average price and volatility in each year.

Secondly, the historical daily log returns of EUA prices are calculated, shown in (1),

$$\mathrm{Re}_i = \ln \frac{P_{EUA_{i+1}}}{P_{EUA_i}} = \ln P_{EUA_{i+1}} - \ln P_{EUA_i} \tag{1}$$

where Re_i is the log return on day i, P_{EUAi+1} and P_{EUAi} indicate the spot price on day i and day $i+1$, respectively. Compared with ordinary daily return analysis, log return is better utilized in the financial market to conduct statistical analysis and modeling due to its better additivity [16].

Thirdly, the monthly SD of log return is calculated via daily log return of EUA to estimate the historical monthly average volatility, as in (2) and (3),

$$\sigma\% = \sqrt{\frac{\sum\left(\mathrm{Re}_i - \overline{\mathrm{Re}}\right)^2}{N-1}} * 100\% \tag{2}$$

$$\overline{\mathrm{Re}} = \frac{1}{N}\sum \mathrm{Re}_i \tag{3}$$

where, σ% is the monthly SD, $\overline{\mathrm{Re}}$ represents the average of log return in each month, and N represents the number of trading days observed in each month. Considering the amount of data is relatively large, all SD of EUA spot price is calculated in MATLAB R2016a.

Fourthly, Simple Moving Average (SMA) is a smoothing and filtering instrument reflecting emergence of new trends, meanwhile removing randomness in data series [17]. Concerning that irrational length averages cannot work effectively, this research adopts two-side moving average

(MA) and selects the number involved in the rolling as 5. Two-side moving average presents advantages in its symmetry. The calculation of SMA is shown in (4) [18],

$$SMA_m = \frac{1}{2k+1}\sum_{j=-k}^{k} V_{EUA_{m+j}} \qquad j \in Z \tag{4}$$

where m is the current month of MA period considered. $2k+1$ represents the number of months included in one moving cycle. j is positions moved from the center month per period. V_{EUAm} is the volatility in month m. In this case, k equals to 2. After one MA cycle, the position of V_{EUAm} moves forward by 1 to replace old moment. Hence, this MA process also called 'rolling' [18]. SMA is computed via 'rolling' function in Python to reflect the integral tendency of monthly volatility. Therefore, according to the principle, there are no values for the first and last two months in the entire time series.

Finally, based on MATLAB R2016a, Skewness and Kurtosis of volatility are respectively calculated during 2005-2007 and 2009-2024. Skewness is commonly used to measure symmetry of data distribution and Kurtosis measures statistical flatness. They are all indexes which can reflect whether data follows a normal distribution or not. The calculation principles of Skewness and Kurtosis are shown in (5) and (6) [19],

$$S = \frac{1}{n}\sum_{m=1}^{n}(V_{EUA_m} - \overline{V_{EUA_m}})^3 \Big/ \left(\frac{1}{n}\sum_{m=1}^{n}(V_{EUA_m} - \overline{V_{EUA_m}})^2\right)^{\frac{3}{2}} \tag{5}$$

$$K = \frac{1}{n}\sum_{m=1}^{n}(V_{EUA_m} - \overline{V_{EUA_m}})^4 \Big/ \left(\frac{1}{n}\sum_{m=1}^{n}(V_{EUA_m} - \overline{V_{EUA_m}})^2\right)^{2} \tag{6}$$

where, S and K represent the Skewness and Kurtosis, respectively. n is the number of observations. Besides, frequency distribution histogram of monthly volatility is constructed, utilized to reflect general frequency distribution situation of volatility. The bin numbers are 10 and 25 respectively during 2005-2007 and 2009-2024. And the bin widths are 4.9 and 0.45 respectively to better scale the frequency distribution characteristics.

3. Results of Data Analysis

According to the methodologies presented in Section 2.B, detailed results of monthly average volatility of EUA price from 2005 to 2024 is shown in Table I, including the data of average volatility of each phase. Besides, Skewness, Kurtosis, Mean and SD of two stages are shown as in Table II. These indexes are presented separately in two stages because of different allocation strategies, that is, full free-allocation was adopted in Phase I, but the proportion of auctions gradually increased in the subsequent stages.

Table II. Indexes of volatility

	2005-2007	2009-2024
Kurtosis	12.29	10.71
Skewness	2.69	2.03
Mean	7.11	2.78
SD	7.14	1.4

The frequency distribution of EUA volatility during 2005-2007 and 2009-2024 are presented in Figure 1 and Figure 2, respectively. The monthly average price of EUA (blue line), monthly average volatility of EUA price (red line) as well as SMA (dotted black line) for different phases are depicted in Figure 3 and Figure 4. Since the volatility in 2008 is relatively large compared to other years for certain reasons (detailed explanation in Section 4), the results of 2008 are presented separately in the right-hand figure of Figure 3, in case that characteristics of volatility in other years are masked.

Table I. Monthly average volatility (%) of EUA price from 2005 to 2023

	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sept.	Oct.	Nov.	Dec.	Ave.
2005	-	-	7.13	6.07	3.85	2.46	5.99	2.00	2.24	1.45	2.35	2.10	7.13 Phase I
2006	2.55	1.61	0.87	9.45	15.56	2.88	1.67	1.85	3.64	2.70	4.11	3.33	
2007	7.90	10.49	7.88	10.65	10.62	10.72	8.69	7.43	11.35	16.79	14.72	38.68	
2008	24.97	29.37	163.47	1.70	1.35	2.36	2.87	1.84	2.41	3.32	3.15	2.86	5.98 Phase II
2009	3.31	5.72	4.48	3.09	2.70	2.48	1.86	1.22	2.18	2.03	1.68	2.90	
2010	2.23	1.49	1.14	1.74	2.70	1.19	1.85	1.21	1.24	0.89	1.28	0.96	
2011	1.10	0.78	2.41	1.22	1.08	3.08	2.34	2.77	2.14	2.30	3.52	5.99	
2012	3.78	4.41	3.41	4.38	2.72	2.80	2.95	1.92	2.53	1.95	4.06	3.91	
2013	5.02	7.99	6.41	11.41	5.96	3.85	2.76	1.52	4.14	4.38	2.51	2.50	3.01 Phase III
2014	2.58	4.11	5.43	4.38	2.64	1.88	2.27	1.53	2.06	1.78	1.64	1.69	
2015	2.75	2.25	2.39	1.72	1.23	1.13	1.23	1.15	1.01	0.85	0.85	1.10	
2016	3.08	4.50	2.14	3.59	2.48	3.44	2.90	2.58	4.14	3.43	3.66	3.70	
2017	5.64	2.41	3.80	3.93	2.50	2.95	2.43	2.13	3.94	2.85	3.01	3.08	
2018	2.37	2.49	3.05	1.94	2.79	2.13	1.30	1.61	6.40	3.85	3.56	2.83	
2019	3.39	4.04	2.66	2.78	2.51	2.01	2.16	2.28	2.45	2.72	1.66	2.75	
2020	1.82	1.88	5.93	4.77	2.36	2.96	3.50	2.46	3.74	2.71	2.21	2.25	
2021	2.70	2.71	2.11	1.44	3.18	1.61	2.62	2.39	1.83	3.39	2.21	5.26	2.56 Phase IV
2022	2.56	3.75	6.26	3.24	3.13	2.45	2.29	2.81	3.83	2.69	2.51	1.79	
2023	3.30	2.01	2.52	1.83	1.81	2.36	1.25	1.49	1.30	1.45	1.68	2.29	
2024	2.77	-	-	-	-	-	-	-	-	-	-	-	

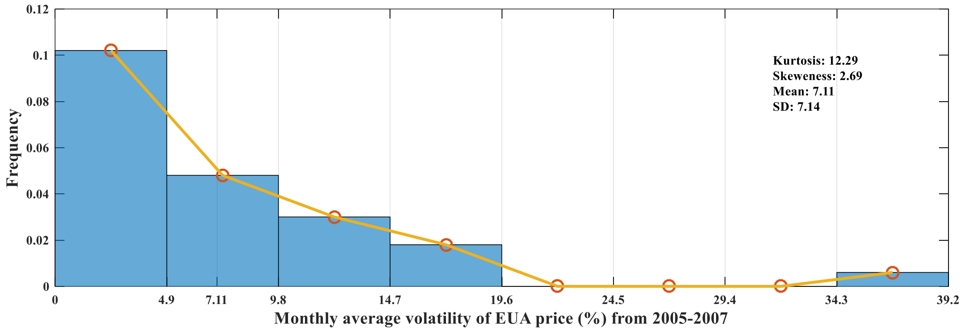

Figure 1. Frequency distribution histogram of monthly average volatility of EUA prices from 2005 to 2007.

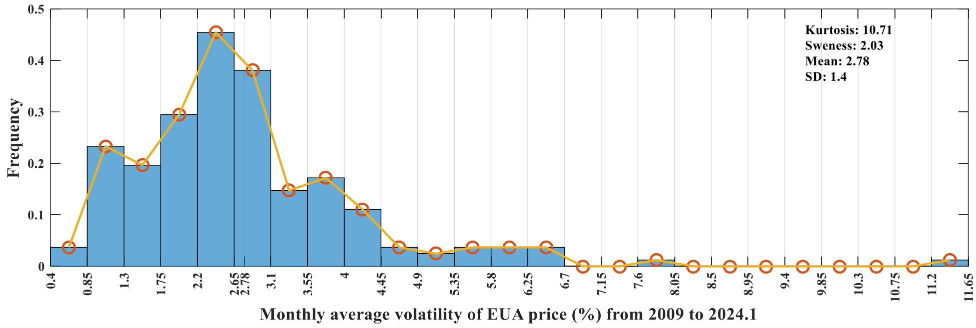

Figure 2. Frequency distribution histogram of monthly average volatility of EUA prices from 2009 to 2024

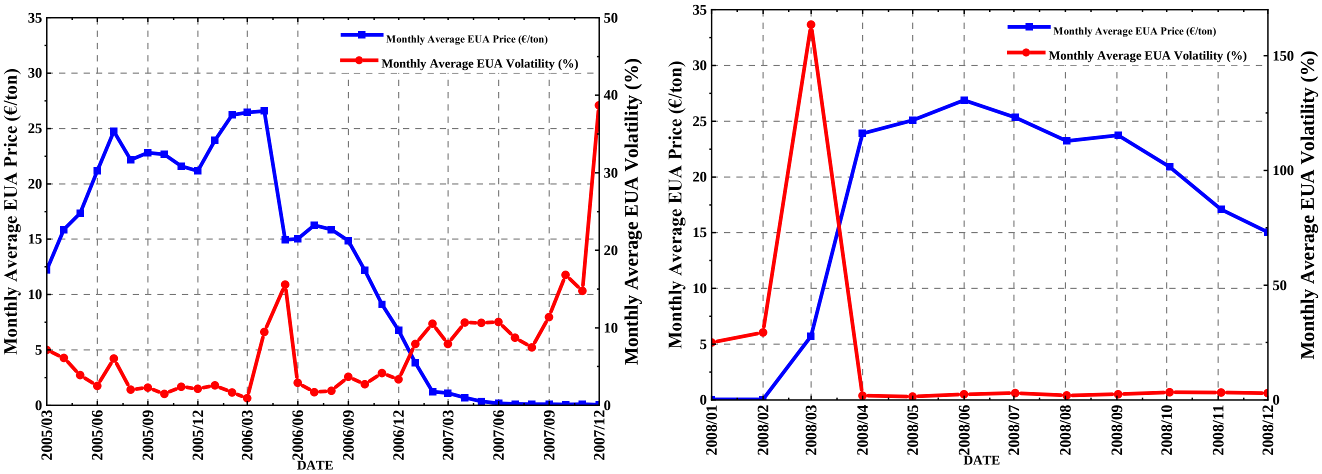

Figure 3. Variation of monthly average EUA volatility (red, %) and monthly average EUA price (blue, €/ton) during Phase I (left) and 2008 (right). The left axis shows the monthly average EUA price (€/ton) and right axis shows the monthly average EUA volatility (%).

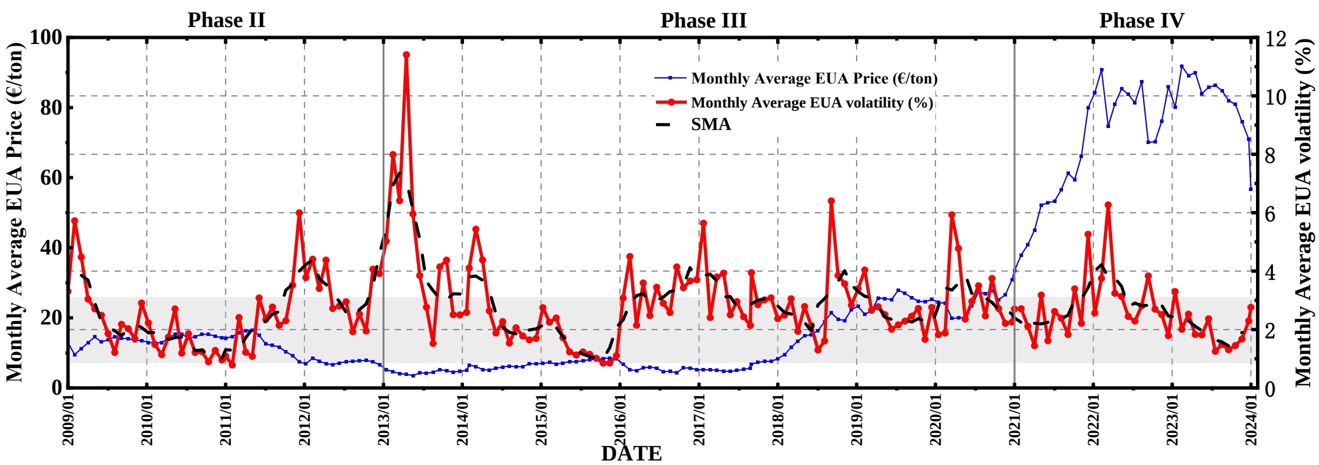

Figure 4. Variation of monthly average EUA volatility (red, %) and monthly average EUA price (blue, €/ton) from 2009 to 2023. The left axis shows the monthly average EUA price (€/ton) and right axis shows the monthly average EUA volatility (%).

4. Discussions

A. *Integral Variation Tendency of Volatility*

According to the result obtained in Section 3, the integral variation tendency of volatility can be witnessed from four aspects, including average volatility of each phase, Skewness and Kurtosis, frequency distribution histogram as well as SMA curve.

It can be obviously observed that average volatility in each phase in Table I shows a decreasing trend, which are 7.13%, 5.98%, 3.01% and 2.56% respectively and the decline rate gradually slows down. In addition, the frequency distribution histograms in Figure 1 and Figure 2 intuitively reflect the volatility of the sample. It can be seen that in the range of 0-5.0% and 0.85-3.1% during the first phase and the following phases respectively, the frequencies are relatively higher. Therefore, it can be considered that the volatility under normal circumstances is within this range. The value above the range is witnessed as larger fluctuations. For better observation from 2009 to 2023, the general ranges of volatility (0.85-3.1%) are marked gray in Figure 4. Compared with normal distribution with Kurtosis being 3 and Skewness being 0, the data present a right-skewed distributions, and both dispersions are higher on the right side of the average. The skewness and kurtosis in 2009-2023 are both lower than those in Phase I, shown in Table II, demonstrating that fluctuation values tend to decrease and become gradually standardized. From SMA curve, shown as the dotted line in Figure 4, the historical tendency of monthly average volatility is gradually stable and levelling off.

B. *Monthly Volatility Characteristics Related to External Uncertainties*

This part is discussed for four phases as following.

1) *Phase I.* Focusing on the monthly average volatility, during the Phase I shown as in Figure 3 when EUA is completely free-allocated, it presents greater volatility like in May 2006 which is 15.56% due to May incident. Even worse, because of the mechanism of free-allocation, the overallocated allowances causes the windfall of industries or companies with intensive carbon emissions. The asymmetry between demand and supply further leads to EUA price collapse, falling to almost zero. However, the volatility gradually rises and almost approaches to 40% in the final stage of Phase I in 2007, for the differences of log return in each day is large.

2) *Phase II.* It can be witnessed that during the initial stage of new policies carrying on, the volatility of the EUA price presents relatively large fluctuations. In the first year of Phase II, 2008, there is an abnormality on the historical volatility of EUA price. Many reasons contribute to the significant fluctuations which increase significantly from 24.97% at the beginning to 163.47% in March. The first reason is that proportion of allocation in the form of auction raised to 10% for the first time. In addition, the crisis in 2008 contributes to oversupply of EUA and sudden drop in demand, further causing an abrupt decline of EUA price below 10 €/ton. After 2008, owing to the recovery of economy, EUA price increases accordingly. Therefore, the volatility in early 2009 presents slightly larger, 5.72% in February and 4.48% in March. After that, the fluctuation maintains at a low level until June, 2011, when German Bundestag announces to gradually and orderly phase out nuclear energy [20] which is a kind of low-carbon energy, after the nuclear disaster in Fukushima on 11 March 2011. The volatility is 3.08% in June 2011, 3.52% and 5.99% in November and December, respectively.

3) *Phase III.* As for the start of the third phase, the monthly average volatility shows an abrupt increase especially in 2013. From the aspect of supply, the proportion of auction rises up to 57% and power sector realizes complete auction of allowances. Besides, the EU Parliament establishes a total of 2,084,301,856 emission allowances (cap) for the entire union, with an annual decrease ratio of 1.73% for the following years' allowances supply [21]. Correspondingly, the volatility of January 2013 shows 5.02%, with the following five months representing 7.99%, 6.41%, 11.41%, 5.96%, and 3.85% respectively, although the monthly average EUA prices maintain at a low level. After that, due to the proposal of MSR and back-loading, the volatility presents relatively high from February to April, 2014 (4.11%, 5.43%, 4.38%). In 2016, UK announces departure from EU, also causing an increase of volatility in February (4.50%). In January, 2017, the first official information concerning the Total Number of Allowances in Circulation utilized for MSR calculations [11] was submitted. Correspondingly, it contributes to the obvious climb of volatility in January 2017 which is 5.64%. The promotion of MSR in 2018 and formal implementation in 2019, both lead to the increase of volatility like the level above 6.00% in September 2018 and 4.04% in February 2019. However, compared with 2018, volatility in 2019 is relatively less noticeable. In the final year of Phase III and shocked by Covid-19, there is an abrupt short-term increase in March and April 2020 (5.93%, 4.77%).

4) *Phase IV.* From SMA curve, it can be witnessed that since 2015, the variation maintains a stable tendency, and the volatility remains within the normal range for most months, except for certain unforeseen periods. Affected by energy crisis during 2021 and 2022, obvious increase of volatility is shown in December 2021 (5.26%) and March 2022 (6.26%). However, the monthly fluctuation is mostly covered within the normal

range, even presenting a decreasing tendency compared with abrupt increases in 2008 and 2013. This phenomenon is corresponding to '€750 billion green recovery plan' proposed in May 2020 to some extent. The plan is specifically issued in response to economic recession during the Pandemic. It can be directly exhibited that monthly volatility gradually reduced since May 2020. Additionally, especially in 2021, which is the first year of Phase IV, the commission readjusts the decrease ramp of the quantity issued to the public in both forms of auction and free-allocation from 1.73% to 2.2% [21]. However, the volatility maintains at a lower level instead between the range of 1.61% and 5.26%, different from 2008 and 2013. These phenomena also prove advantages of short-term strategy of back-loading implemented in 2014 and long-term strategy of MSR formally operated in 2019 as well as the approval of banking and borrowing of EUA since the Phase II.

5. Conclusions

It can be concluded that, due to the proportion increase of auctioned allowances, the EUA price volatility gradually decreases and maintains stable. This is because windfall is always caused owing to free allocation of EUA, especially for corporations with intensive carbon emissions. The phenomenon is attributed to the oversupply of EUA, leading to EUA prices approaching to zero in the final stage of phase I, as well as the large fluctuations of EUA prices.

Additionally, promulgation of policy will cause short-term fluctuations of EUA prices in that year due to uncertainties about the future of new policies by the public. Especially for the initial years of each phase like 2008 and 2013. However, back-loading and MSR are commonly witnessed as shocks and risks hedging tools in the market. They are proved to play certain roles in reducing the volatility, especially confronted with unforeseen incidents like the Covid-19 in 2020 and energy crisis in 2021. MSR is a kind of effective mechanism dealing with oversupply of EUA. It postpones the allowances auctioned by putting certain proportion of EUA into reserve, but not reduce the total amount of EUA distributed. Therefore, it can bring about the rise in EUA price as well as the reduction of volatility.

However, it is still not precise to just evaluate the characteristics of EUA price volatility merely from policy promulgation although certain sensitivity indeed exists. There are also many reasons explaining the indicator, including the discrepancy between demand and supply, the external macroeconomic factors, such as energy price and Gross Domestic Product (GDP) as well as extreme temperature conditions. The orientation regarding determinants of both carbon price and carbon price volatility still deserve further research and exploration.

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