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CO2 Allowance Price Dynamics and Stock Markets in EU Countries: Empirical Findings and Global CO2-Perspectives

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Summary:

The European Union uses an emissions certificate trading system (the EU ETS) with coverage of both industry and the energy sector CO2 emissions which is based on an EU-wide emissions cap that declines over time. Firms that have an excess stock of CO2 emission permits can sell surplus certificates at the current market price and have to record the value of the excess emission permits as an asset on the balance sheet of the respective company so that the stock market price of companies with an excess supply of certificates should increase while that of firms which have to purchase a considerable amount of additional emissions permits – beyond any initial free allocation by the EU emission trading system – could face a decline in the value of their respective stock market price. An AR-GARCH approach shows the behaviour of the EU stock market oil and gas subindex (STOXX Europe 600 Oil & Gas Producers (SEOG) index) and of the overall stock market index – with somewhat lower empirical impact findings – with regard to positive and negative shocks in terms of the allowance price dynamics. Results indicate that the oil and gas stock index responds asymmetrically to positive and negative price shocks from the CO2 allowance market: The coefficient of the shock dummy is negative and significant, while that of a positive shock dummy is not significant. There is no Granger causality in the direction from CO2 allowance price dynamics to stock market price dynamics, there is, however, a significant Granger causality running from stock markets to CO2 allowance markets in the EU – with a negative sign. The analysis has wide-ranging implications for climate policy and financial market dynamics in the EU, the US and Asia in the long run.

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1. Introduction

Global warming has become an increasingly important research topic for economists as well as climate researchers and policymakers have undertaken several policy initiatives aimed at fighting climate problems. The Paris climate convention of 2015 is a major step forward, although the US has withdrawn under the Trump Administration from the resultant agreement in 2019. In that year, the G20 held a meeting in Japan in which part of the political focus was on global warming and the same holds true for the first meeting of G20 environmental ministers – which also took place in Japan. Various policy options can be envisaged to achieve CO2 mitigation and this is important since CO2 and other greenhouse gas emissions are considered to be the main drivers of global warming. A crucial role of CO2 emissions is related to fossil fuel energies used in OECD countries and Newly Industrialized Countries (NICs) including China, India and Indonesia as key countries in Asia. The instruments available for CO2 mitigation are regulations, CO2 taxes and CO2 emission certificates.

Energy producers and industrial firms in several OECD countries which are using an Emissions Trading System (ETS) have to purchase CO2 allowances in order to be able to produce the desired quantities of output. CO2 allowances could in time become a financial instrument in its own right globally, but to date usage of an ETS is rather limited primarily to the EU, where an ETS was implemented in 2005 as a pioneering approach, later followed by California (from 2013; with an enlarged CO2 coverage in 2015), the Republic of Korea, Switzerland and China. The latter had regional pilot systems for several years, but there is a nation-wide system for the energy sector as of 2020. Japan has only two regions where an ETS is applied. In the Tokyo region (the other region covered is Saitama), the ETS is mandatory for industry and commercial buildings where the annual reduction for industry is 6%, for commercial buildings 8%.

Since 2005 the number of countries or regions with CO2 emissions certificate trading has increased continuously worldwide. That year, the EU member countries became the starter group where coverage of the EU ETS was for 45% of CO2 emissions, namely energy and industry – enlarged to include intra-EU commercial flights in 2012. Among the countries and regions which have followed the EU are California in 2013 which raised coverage up to 85% in 2015 and which has implemented a 3% annual reduction path for the overall emission cap. By contrast, the EU has an annual reduction rate of 1.74% until 2020, as of 2021 the reduction rate for the EU cap will be 2.2%. China has used regional pilot projects over several years and has started a national ETS in 2020 – with the coverage limited to the energy sector. Japan's ETS approaches are regional, namely in the Tokyo area where ETS is mandatory for big commercial buildings and for industry while in neighboring Saitama province firms are only invited to participate in a combined Tokyo-Saitama ETS (ARIMURA, 2018). California's ETS is linked with the Canadian province of Quebec.

The allowance price dynamics in the EU were considerable in the beginning since the early price was close to €25/ton CO2, later followed by a strong decline in 2007-2017; only in 2018/19 had the price recovered to about €26/ton CO2. The fourth emission trading period relating to 2021-2030 will offer fewer free allowances and thus the market mechanics should fully apply.

At the same time it is remarkable that the allowance price in California in recent years in was much lower than that in the EU which is an important aspect to be considered in the final policy section. One may point out that from a theoretical perspective the price of allowances should reflect the marginal CO2 abatement cost which, in turn, should be equal to the marginal damage cost of CO2. This raises the question as to the extent to which there are consistent pricing systems in Europe and worldwide; for example, the Swiss CO2 tax, which is imposed outside the framework of the CO2 ETS, was close to €100/ton at the end of 2019, while in Sweden the national CO2 tax (also outside the EU ETS) was close to €120/ton. These CO2 taxes are clearly much higher than CO2 allowance prices; one may note that the Swiss ETS will be linked to that of the EU by 2021. Whether governments use CO2 ETS or CO2 taxation, it is clear that CO2 pricing in either form should stimulate CO2-mitigation innovations. Such innovations require green R&D and entrepreneurship which is devoted to sustainability and climate challenges in a Schumpeterian way (AUDRETSCH, 2019).

With CO2 taxation and CO2 emission trading systems there is a new price dynamic for CO2 emissions; in the case of ETS in the EU, this will refer CO2 allowance prices – typically daily prices. If CO2 allowance prices behave similarly to other financial markets, certain GARCH or related statistical approaches should be useful in analysis. The simplest approach is a GARCH model where, besides the return Rt (t is the time index) of a financial market price, the variance Vt is modeled by lagged variance and squared error terms in order to deal with a possible heteroscedasticity in the time series. Subsequently, various approaches, including an EGARCH model, will be considered.

Depending on the intensity of sectoral value-added, there could be considerable pressure from ETS both on the cost side and on the market price of the respective products, while from a theoretical perspective, one may therefore expect that, for example, energy sector firms in the stock market – read: oil and gas companies - should be particularly exposed to stock market price changes linked to ETS price changes. There is, however, a caveat which concerns the free allocation of an initial stock of CO2 allowances by government in some sectors (in the first two trading periods of emission certificates in the EU, exporting companies have obtained a certain endowment of certificates for free as governments did not want to undermine their international competitiveness). If the market price of tradable CO2 permits is rising, this amounts to an asset valuation gain and hence higher profits so that this should go along with higher sectoral stock market prices of the respective firms.

In a broader analytical perspective, there are links between various financial markets of crucial importance for portfolio investors and the investment decisions of firms; the volatility is also part of macroprudential supervision in OECD countries. In the EU, since 2010, the newly created European Systemic Risk Board (ESRB) is the relevant institution which, however, seems to limit its analytical focus to traditional financial markets while the price dynamics of emission certificate prices for which a large EU-wide market exists are not considered. Naturally, the links between these price dynamics and stock market dynamics are of particular importance. Any excess supply of emission certificates form part of the respective company’s assets and have to be considered in the balance sheet – a rising market price of certificates thus will raise the stock market value of a company quoted on the stock market, whereas a declining market price should translate into a lower stock market value if expected net profits are the basis of stock market valuation. From this perspective and for other reasons – including potential speculation in emission certificates - the market dynamics of emission certificate pricing and stock market prices should economically be linked; this could affect both current and future prices in the respective financial market.

As the EU ETS includes about 45% of value-added, namely industry and the energy sector, the spillovers between certificate prices and stock market price indices of EU countries could be limited on the one hand; on the other hand, the leading stock price indices typically include the biggest companies in both the energy sector and industry. To the extent that certificate prices raise electricity prices, one may expect that profitability in both the electricity sector and in industry – with all firms using electricity as an input – will be affected by changes in certificate prices. Companies which develop innovative CO2-reducing technologies should, in turn, record higher profits and hence higher stock market prices; typically, the innovative firms come from the manufacturing industry. Higher emission certificate price volatility is expected to translate into higher stock market price volatility.

A first empirical analysis on the link between the EU emission certificate price (EU ECP) and the stock market prices of electricity companies was undertaken by OBERNDORFER (2008) where the EU ECP was indeed found to affect stock market prices of electricity companies; notably, however, the sign of the results differed across Western EU countries. As regards the efficiency of the certificate trading market, it was found to increase over time (SATTARHOFF/GRONWALD, 2018) which suggests that this politically created emission certificate asset market should be a consistent part of overall financial market dynamics in the EU and in other countries/regions with emission certificate trading (WELFENS ET AL., 2017).

The broader picture of climate protection analysis and policy, respectively, is rather complex and there are certainly issues regarding international coordination and cooperation. If, for example, all OECD countries plus China would have an ETS with a broad coverage of CO2, then emission leakage effects will no longer play a prominent role, namely the fact that firms facing an ETS – say in the EU – have an incentive to relocate production of the whole product, or of intermediate products, to countries without an ETS. At the same time, one should not ignore the potential positive link between ETS and induced innovation dynamics – in line with the general approach of PORTER (1998), according to which pressure makes diamonds and hence reinforces the role of innovative firms: Firms facing a considerable and rising relative CO2 allowance price might come under pressure to become more innovative over time so that ETS in the medium term could reinforce the international competitiveness of the countries considered. One may also raise the question as to what extent national – or supranational – framework conditions which encourage green innovations affect the link between financial markets in general and the performance of companies with a strong sustainability orientation (e.g. as measured through an adequate sustainability rating index – for example, see the relevant Dow Jones subindex).

In a wider perspective, one may consider CO2 allowance markets as being part of broader financial markets. If there is short-term speculation on rising stock market prices, this will drain liquidity from other financial markets, including CO2 allowance markets, so that a negative link between price dynamics in stock markets and CO2 allowance price dynamics could be observed. Financial markets, including CO2 allowance markets, and stock markets, respectively, will react to the various impulses from the real economy and the political system, respectively.

The following analysis places an initial focus on crucial new theroetical links between CO2 allowance pricing, oil prices and stock market price dynamics (Section 2) before the attention is turned to empirical links between allowance price changes – price shocks - and stock market price indices/subindices in selected sectors in the EU and on an explanation of stock market price volatility in an environment with CO2 ETS; there is also a particular interest in Granger causality and in volatility analysis (Section 3). Section 4 presents some conclusions for economic policymakers and calls for a global integration of national/regional ETS.

The empirical evidence presented puts the focus on daily data related to an EU stock market energy subindex and the EU ETS' CO2 pricing. EU stock markets in the oil and gas subsector show an asymmetric reaction to positive and negative CO2 allowance price shocks; Granger causality analysis suggests that the link runs from the stock market to the pricing of CO2 allowances. Moreover, volatility links are also considered. While an extension of CO2 emission trading in the G20 and worldwide can clearly be recommended, one should be aware that certain minimum regulations for financial markets and CO2 ETS are required if major instabilities are to be avoided.

2. CO2 Emission Certificate Trading and Stock Market Dynamics

Publicly quoted stock companies can be expected to face a link between stock market dynamics and allowance price developments in the EU. The relatively large stock markets might dominate allowance price dynamics in EU countries or in other countries and regions with CO2 allowance trading.

With the Paris Agreement of 2015, 196 countries have pledged to contribute towards achieving the so-called 2 degrees goal, namely that the rise in terms of the average global termperature should not exceed 2 degrees by 2050. From this perspective it is clearly important to gain a deep understanding of the CO2-mitigation options and to carefully consider CO2-reduction options through various mechanisms. One important aspect concerns financial market dynamics and also the potential link between stock markets and progress towards CO2 reduction. As regards the relative role of stock markets in financial markets, there are considerable differences across OECD countries (and Newly Industrialized Countries).

CO2 allowance prices raise the cost of production and thus could reduce the profitability of the respective firms. An analysis with a focus on companies quoted in the stock market could thus be useful. One may emphasize that part of the literature has provided rather surprising findings in the sense that a higher CO2 allowance price goes along with a higher stock market price of the respective firm; and this is explained, in a theoretical perspective, by the fact that the log of output prices could increase more in the firms considered than the log of costs, hence the profitability of firms in an ETS environment could increase (BUSHNELL/CHONG/MANSUR, 2013); the authors look at the EU ETS market and the Eurostoxx, and the positive empirical evidence is based on an analysis which looks at the

50% fall of the CO2 allowance price which occurred in April 2006. This view is not really convincing and a more consistent approach is presented subsequently: It will be shown that a rise of the relative price of CO2 allowances reduces the relative oil/energy price and this, of course, should increase the profits of firms quoted in the stock market so that higher (expected) CO2 allowance prices would go along with a higher stock market price index (WELFENS, 2019); there is, of course, a trade-off, namely that firms face higher CO2 prices which means a rise in costs, but the induced fall of the relative oil price will amount to a cost reduction and, in many sectors, the net effect could amount to lower total costs of production. Part of the effect could be related to higher mark-ups over costs, if higher CO2 prices put pressure on firms in certain sectors to merge and higher mark-ups could also raise the stock market prices of firms in those sectors.

As regards the broad links between CO2 pricing and the oil price – and hence energy price dynamics which were still dominated by fossil fuels in the EU in the period 2000-2019 – one may refer to an extended Hotelling rule approach (WELFENS, 2019b): The assumption is that the owner of an oil/gas extraction site is maximizing profits and considers at the margin the profits resulting from taking out one unit of the natural resource in the current period t or leaving that unit in the ground until a later date which will bring a profit of dP''^E/dt where P''^E is the expected oil price and t is the time index. Extracting the marginal unit in the current period earns the product of the nominal interest rate i times the cash flow P”-H (where P” is the oil price, H is the unit cost of production; all in $ or € and i is the US interest rate or the Eurozone interest rate, as the oil/gas firms of both OPEC and OECD countries are assumed to invest in Western banks). Hence the standard optimization condition is given by

(1) $$i\left(P''-H\right)=dP''^{E}/dt$$

Several extension are considered in WELFENS (2019), namely technological progress in future oil production (with an exogenous progress rate of Z”); it is also assumed that the real unit cost of production H/P is proportionate to oil output Q (P is the aggregate price level). Demand for oil is supposed to be a negative function of the relative oil price P”/P and the amount of renewable energy R used in the economy which, in turn, is positively affected by the relative CO2 allowance price (P’/P; P’ is the CO2 allowance price). Real subsidies S’ for fossil fuels raise the demand for oil as does the aggregate real gross domestic product Y. A higher real oil price should raise profits in the fossil energy sector and thus the sub-index for the energy sector stocks should increase. However, a rise of the relative oil price (P”/P) should dampen the relative overall stock market price index (and hence a rise of P” should dampen the overall stock market price index) due to lower profits in the overall economy which is assumed to be characterized by firms still using mostly fossil fuels and energy based on fossil fuels such as gas and oil. Based on WELFENS (2019), the following set of equations are considered where the nominal interest rate (i; the real interest is denoted by r) was considered carefully since $i= r + \pi^E$. (π^E is the expected inflation rate where the relevant price index consists of oil/energy as well as non-oil goods). The inflation rate π can in turn be written as $\pi = V\pi' + (1-V)\pi''$ where V is the weight for non-oil goods, π' is the non-oil goods inflation rate and π'' the oil price inflation rate.

Subsequently we will additionally consider that real unit production costs H’ is proportionate to oil production Q so that there are rising marginal costs (H’=v’Q; positive cost parameter is v’). Moreover, the availability of renewable energy – quantity is denoted as R - will be considered in the demand equation for the oil market and R is considered to be a positive function of the relative allowance price p':=P'/P where P' is the price of CO2 allowances and P the general price level. Thus we can determine the market-clearing price of oil (or other natural resources).

Hence we have the following equations (WELFENS, 2019):

(1') $$i\left(P''-H\right)=\left(dP''^{E}/dt\right)\left(1+Z''\right)$$

The oil price can be assumed to be denoted in \$ and hence H also is expressed in \$. The relevant nominal interest rate is that of the US if one assumes that OPEC oil producers and US oil producers will invest in US financial markets. Under perfect foresight we have after dividing by P":

(2) $$i\left(1-H''\right)=\pi''\left(1+Z''\right)$$

Let us define H":= H/P"; H"= (H/P)(P/P")= H'(P/P"); p':= P/P"; p":= P"/P. Positive marginal cost of oil production are indicated in the next equation which then is inserted in the modified Hotelling rule.

(3) $$H'=v'Q$$

(4) $$i\left(1-v'p'Q\right)=\pi''\left(1+Z''\right)$$

(5) $$\frac{\left(r+V\pi'+(1-V)\pi''\right)}{\pi''}=\frac{\left(1+Z''\right)}{1-v'p'Q}$$

for v'p'Q close to zero one can write as an approximation:

(6) $$\frac{\left(r+V\pi'+(1-V)\pi''\right)}{\pi''}=(1+Z'')(1+v'p'Q)$$

(7) $$\frac{r}{\pi''}+\frac{V\pi'}{\pi''}+1-V-1-Z''=(1+Z'')v'p'Q$$

In equilibrium, the oil price inflation rate and the non-oil price inflation rate have to be equal, so that we get as the relevant supply curve for an equilibrium analysis here:

(8) $$Qs=((r/\pi'')-Z'')(P''/P)/(v'(1+Z''))$$

It may be assumed that the demand for oil is a positive function of Y (Y is world GDP; V' is a positive parameter) and a negative function of p", as well as a negative function of renewable energy R where R' is a positive parameter and R is assumed to be a positive function of the relative allowance price P'/P. Subsidies – in real terms - for fossil fuels (here, oil) are denoted by S' and s" is a positive parameter. The global subsidization of fossil fuels was already identified as a major problem by the leaders of the G20 at the 2009 G20 summit in Pittsburgh; in 2018, however, the relevant subsidies worldwide still stood at about 6% of world GDP (COADY ET AL., 2019).

(9) $$Qd = V'Y - h''P''/P - R'R(P'/P) + s''S'$$

(10) $$Qd = V'Y - h''p'' - R'R''P'/P + s''S'$$

Thus the equilibrium price ratio can be determined in a rather simple way from the equilibrium condition in the oil market:

(11) $$((r/\pi'') + V(\pi'/\pi'') - V - Z'')p''/(v'(1+Z'')) = V'Y - h''p'' - R'R''P'/P + s''S'$$

(12) $$((r/\pi'') + V(\pi'/\pi'') - V - Z'' + h''(1+Z''))p'' = (V'v'Y - R'R''(P'/P) + s''S')(1+Z'')$$

One should note that equilibrium requires $\pi'=\pi''$ and hence the equilibrium relative oil price is given by:

(13) $$p'' = (V'v'Y - R'R''(P'/P) + s''S')(1+Z'')/((r/\pi'') + h'' - Z'')$$

The equilibrium price p" thus is

- a positive function of the cost parameter v', the real subsidies (S') for fossil fuel demand, and the expected technological progress parameter Z";
- a negative function of the relative CO2 allowance price P'/P, the real interest rate r, and the non-oil price inflation rate (the latter would largely be determined by the growth rate of the money supply in the US; and if there is monetary policy interdependency in the behavior of the US Federal Reserve System, the European Central Bank and the National Bank of China, the growth rate of the US money supply could partly be influenced by the Eurozone and China).

To the extent that a reduction of the relative price p" leads to a rise of the general stock market price index – through a lower cost of production and higher profits, respectively – all factors that lead to a lower p" imply a rise of the stock market price index. From a theoretical perspective, it should be noted that the interplay of higher CO2 allowance prices and declining oil prices matters for the overall impact of CO2 allowance prices on the stock market price index. Empirical analysis has to show how the joint impact of direct and indirect CO2 allowances prices affects stock market price indices.

This index has to be distinguished from the energy (oil & gas) sector sub-index where the sign of the impact of those variables could be opposite. Empirical analysis has to show which way the (Granger) causality goes between the two markets, namely the CO2 allowance market and the stock market, respectively.

In a broader analytical perspective, the possible links between CO2 pricing and the stock markets could go both ways: One key aspect of stock market dynamics with an impact on CO2 mitigation – and hence on the CO2 allowance pricing – is from DE HAAS/POPOV (2019) who have analyzed the link between finance and CO2 mitigation. The key finding of their empirical analysis is that countries with relatively large stock markets have stronger CO2 per capita reductions than countries with a rather small stock market: Investors in stock markets apparently put strong pressure on the managers of publicly quoted firms to implement CO2-efficiency improvements and hence push the economy towards lower CO2-intensity production. Moreover, if the relative role of stock markets in overall financial markets is reinforced, the authors find evidence that firms' R&D engagement is geared more towards CO2 mitigation technologies where CO2-light progress is measured through relevant green patents. This is clearly an important innovation perspective which would imply that capital market dynamics in general – and certainly stock markets in particular - play a crucial role on the way to a climate neutral economy. From this perspective, there are also new options for adequate policy reforms in both the OECD countries and G20 countries, respectively. It is, however, obvious that the depth of financial markets, for example, in EU28 countries or in the OECD (or in the G20) differs across countries; the potential for institutional catching up in an international perspective could be considerable.

The DE HAAS/POPOV (2019) approach has suggested that deeper stock markets go along with more green innovativeness. This in turn brings a lower relative demand for CO2 allowances. Moreover, more anticipated green innovativeness could help oil and gas companies by reducing the political pressure to phase out the use of oil and gas in the transportation and energy sector and this would suggest a negative link between oil & gas stock market price dynamics and the CO2 allowance price in the EU.

As regards links between the allowance market and the stock market one has to consider several points:

- On the one hand, the relatively small CO2 allowance markets could affect current and future profitability oil and gas firms and of firms using fossil fuels in a direct and indirect way for transportation, heating or electricity generation. As the oil and gas stock market price index indicates expected discounted future profits one has to also consider in principle that short term interest rate changes could affect stock market price indices – actually in all sectors. Additionally, a decreasing interest rate could lead to higher stock prices, higher production and thus to higher demand for CO2 certificates. That way, the link between allowance price developments and stock market price dynamics could be positive.
- On the other hand, the much larger EU stock markets – with size measured in terms of market capitalization or daily, weekly, monthly or annual turnover figures – could affect the CO2 markets: If investors anticipate high innovation dynamics and hence higher (gross) profits – gross profits means profits net of payments for CO2 certificates – and thus stock market prices are high, the need to invest in more CO2 allowances could reduce. While rising output would per se raise CO2 emissions of the company considered, the same company's strong green innovation dynamics would reduce the need to invest more in CO2 allowances; one may have to consider that those firms which are generally innovative are also the firms which show a good performance in green innovation dynamics. If the innovation perspectives dominate the picture, the link between allowance price developments and stock market price dynamics could be negative.

3. Empirical Analysis of CO2 Pricing Dynamics and Stock Markets

Data

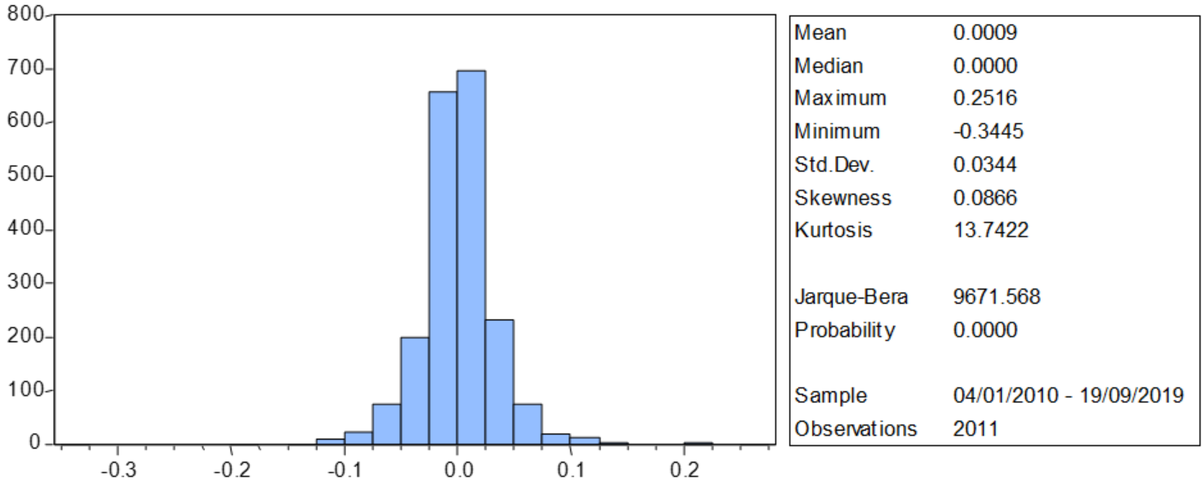
Focusing on the link between the EU ETS and the stock market index, it is adequate to consider the overall Stoxx Europe index and a relevant oil and gas sector sub-index, namely for a period after the Great Recession in 2008/09. Since the EU ETS covers all 28 EU member countries (and additionally Liechtenstein, Iceland and Norway), European stocks are considered for the empirical part of this research. The Stoxx Europe 600 index, which includes 600 large, medium and small capitalization companies for 17 European countries, provides a broad range in terms of sector diversity. It follows the Industry Classification Benchmark (ICB) sector division, in which the following sectors could be related to the EU ETS: Oil & Gas Producers, Chemicals, Forestry & Paper, Industrial Metals & Mining, Mining, Construction & Materials, Aerospace & Defense Industrial Transportation, Automobiles & Parts, Travel & Leisure (or subsector Airlines) and Electricity. In order to reveal the link between stock markets and the CO2 allowance market, we limit the empirical evaluation to the STOXX Europe 600 Oil & Gas Producers (SEOG) index. For the time series of the SEOG and Stoxx Europe 600 indices, which are retrieved from the financial portal *onvista.de*, we calculate the daily growth rates for the period January 04, 2010, to September 19, 2019. For the same time period, the allowance prices of the EU ETS are retrieved from *markets.businessinsider.com* from which we also calculate daily growth rates. Since the time series of the allowance prices shows some data gaps, we matched both indices and the allowance price series by excluding days without data.

Basically one can look at various frameworks of linkages:

- The whole of the EU versus the Eurozone, so that relevant STOXX indices have to be considered. Looking at Eurozone Stoxx figures means largely avoiding particular exchange rate dynamics which affect non-Euro countries in the EU.
- The oil & gas sub-index can be analyzed with respect to CO2 allowance price shocks – or an overall index is considered so that a comparison of the overall index and the chosen sub-index reveals some information about the economic relevance of CO2 allowance price dynamics.

Some descriptive statistics – including tests on normal distribution of CO2 allowance price changes – are shown subsequently (see Table 1) for the period covered.

Table 1: Descriptive statistics for the daily growth rates of the CO2 allowance price



Source: Own calculations

To identify the possible distinct behavior of the stock market in relation to positive and negative allowance price shocks, we derive dummy variables based on the magnitudes of the allowance price growth rates:

- Dummy variable $D_{+,20}$ takes the value of one on all days where a positive allowance price growth rate is - in absolute terms - higher than the average of the absolute growth rates of the previous 20 trading days.
- Dummy variable $D_{-,20}$ takes the value of one on all days where a negative allowance price growth rate is - in absolute terms - higher than the average of the absolute growth rates of the previous 20 trading days. 20 trading days roughly represents the financial dynamics of one month and may be considered to be a relevant time period for many institutional investors active in stock markets; thus the dummy variables stand for a pragmatic approach in financial market analysis.

The EGARCH approach is considered subsequently.

CO2 Pricing Dynamics and Stock Markets

Since financial data often contain serial correlations, an AR(m)-EGARCH(p,q,s) model is adopted for the growth rates of the prices as follows:

$$R_{SEOG,t} = \sum_{\mathrm{i}=1}^{m} \beta_{\mathrm{i}} R_{SEOG,t-i} + \gamma R_{CO2,t} + \varepsilon_t \tag{14}$$

with $\varepsilon_t \sim N(0, \sigma_t^2)$

$$\ln(\sigma_t^2) = \alpha_0 + \sum_{i=1}^{p} \alpha_i \left| \frac{\varepsilon_{t-i}}{\sigma_{t-i}} \right| + \sum_{j=1}^{s} \theta_j \frac{\varepsilon_{t-j}}{\sigma_{t-j}} + \sum_{k=1}^{q} \delta_k \sigma_{t-k}^2 \tag{15}$$

where on the left-hand side of the mean equation (14), $R_{SEOG,t}$ represents the growth rate of the SEOG index price at time t and on the right-hand side $R_{CO2,t}$ is the growth rate of the EU

ETS CO2 allowance price at time t. The error term ε_t is assumed to follow a normal distribution. To account for fat tails in the error distribution, we compute heteroskedasticity consistent covariances by using the method of BOLLERSLEV/WOOLRIDGE (1992). On the left-hand side of the variance equation (15), $\ln(\sigma_t^2)$ is the logarithm of the conditional variance of the exchange rate returns and is modelled by the symmetric ARCH $\left[\sum_{i=1}^{p} \alpha_i \left|\frac{\varepsilon_{t-i}}{\sigma_{t-i}}\right|\right]$, the asymmetric ARCH $\left[\sum_{j=1}^{s} \theta_j \frac{\varepsilon_{t-j}}{\sigma_{t-j}}\right]$, and the generalized ARCH $\left[\sum_{k=1}^{q} \delta_k \sigma_{t-k}^2\right]$.

The following table presents the result of the AR(1)-GARCH(1,1,1) model and shows that the coefficient of the CO2 allowance price growth rate R_{CO2} is significant at the five percent level. Evidently, there is a positive link between both stock market and CO2 allowance price dynamics.

Table 2: AR(1)-EGARCH(1,1,1) approach for the growth rate R_{SEOG} using R_{CO2} as regressor

Mean Equation, dependent variable: R_{SEOG}				
Variable	Coefficient	Std. Error	z-Statistic	Prob.
R_{CO2}	0.015741	0.006262	2.513781	0.0119
AR(1)	0.039832	0.024138	1.650201	0.0989
Variance Equation				
α_0	-0.282897	0.064707	-4.371966	0.0000
Symmetric ARCH	0.128337	0.026948	4.762350	0.0000
Asymmetric ARCH	-0.082389	0.017055	-4.830899	0.0000
GARCH	0.979585	0.005872	166.8207	0.0000

Source: Own calculations

Using the same AR-GARCH approach while using dummy variables $D_{+,20}$ and $D_{-,20}$ in lieu of R_{CO2}, the distinct behavior of the stock market towards positive and negative shocks in the allowance price dynamics are revealed. The results for this approach, which are presented in the following table (Table 3), indicate that the stock market behaves asymmetrically towards positive and negative price shocks from the CO2 allowance market:

- The coefficient of the negative shock dummy is negative and significant
- The coefficient of the positive shock dummy is not significant.

Table 3: AR(1)-EGARCH(1,1,1) approach for the growth rate R_{SEOG} using $D_{+,20}$ and $D_{-,20}$ as regressors

Mean Equation, dependent variable: R_{SEOG}				
Variable	Coefficient	Std. Error	z-Statistic	Prob.
$D_{-,20}$	-0.001841	0.000593	-3.105933	0.0019
$D_{+,20}$	0.000457	0.000524	0.873647	0.3823
AR(1)	0.039108	0.024104	1.622473	0.1047
Variance Equation				
α_0	-0.253863	0.059054	-4.298866	0.0000
Symmetric ARCH	0.118848	0.025648	4.633724	0.0000
Asymmetric ARCH	-0.080439	0.016586	-4.849933	0.0000
GARCH	0.981843	0.005291	185.5846	0.0000

Source: Own calculations

Causality of CO2 Pricing dynamics and Stock Market dynamics

The results indicate a consistent link between the EU ETS CO2 allowance price dynamics and stock price dynamics. However, the causal relationship of this link is not yet shown. To tackle this issue, an ordinary least squares (OLS) estimation in use of heteroskedastic-autocorrelation consistent (HAC) variance-covariance estimator proposed by NEWEY/WEST (1987) is applied for both R_{SEOG} and R_{CO2} separately. To model R_{SEOG}, only lagged R_{Carbon} are used as regressors and vice versa:

$$R_{SEOG,t} = \sum_{\mathrm{i}=1}^{p} \beta_i R_{CO2,t-i} + \varepsilon_t \qquad (16)$$

$$R_{CO2,t} = \sum_{\mathrm{i}=1}^{p} \beta_i R_{SEOG,t-i} + \varepsilon_t \qquad (17)$$

That way, the causality (in the sense of Granger) can be tested by applying a Wald-test for the sum of the coefficients as null hypothesis:

$$\beta_1 + \beta_2 + \cdots + \beta_p = 0 \qquad (18)$$

In case that the calculated test statistic, which follows a $\chi 2$-distribution, indicates a significant joint impact as calculated with equation (18), one can proceed on the assumption that (Granger) causality is present. The number of maximum lags p is set to five days, whereas the Akaike Information Criterion (AIC) is considered as model selection criteria.

For R_{SEOG}, the lowest AIC value has the model with p=1:

$$R_{SEOG,t} = \underbrace{0.0004}_{(0.0080)} R_{CO2,t-1} + \hat{\varepsilon}_t \qquad (19)$$

where estimated Newey-West standard errors are in parenthesis. The coefficient is not significantly different from zero at any significance level, indicating that there is no causality in the sense of Granger in the direction from CO2 allowance price dynamics to stock market price dynamics.

For R_{CO2}, the AIC has the lowest value in *p*=2:

$$R_{CO2,t} = \underbrace{-0.0844}_{(0.0554)} R_{SEOG,t-1} - \underbrace{0.1224}_{(0.0666)} R_{SEOG,t-2} + \hat{\varepsilon}_t \tag{20}$$

The cumulative impact of the lagged regressors equals -0.2068 and is, according to the Wald-test, significant at the five percent level (Wald-statistic = 4.9404; p-value = 0.0262). This result indicates that there is a Granger causal relationship in the direction from the stock market to the CO2 allowance market. It is crucial to note that in the previous section we estimate a positive link between the - unlagged - price growth rates.

It is, however, noticeable that the overall stock market rate of return – see equation 21 - also affects CO2 allowance price dynamics:

$$R_{CO2,t} = \underbrace{-0.0809}_{(0.0735)} R_{STOXX,t-1} - \underbrace{0.1930}_{(0.1024)} R_{STOXX,t-2} + \hat{\varepsilon}_t \tag{21}$$

The cumulative impact of the lagged regressors is somewhat higher, namely 0.2739, but according to the Wald-test only significant at the ten percent level. Since short-term, upward stock market dynamics raising the rate of return in the stock market also absorb liquidity that otherwise could go into other markets, including the CO2 allowance market, this finding is not surprising.

Empirical Analysis of CO2 Pricing Volatility and Stock Market Volatility

To investigate the link between the volatilities of both markets, the previously described AR-EGARCH model is used again. Since the focus here lays on the variance of the predicted factor, the predictor is inserted in the variance equation (15):

$$R_{SEOG,t} = \sum_{\mathrm{i}=1}^{m} \beta_{\mathrm{i}} R_{SEOG,t-i} + \varepsilon_t \tag{22}$$

$$\text{with } \varepsilon_t \sim N(0, \sigma_t^2)$$

$$\ln(\sigma_t^2) = \alpha_0 + \sum_{i=1}^{p} \alpha_i \left| \frac{\varepsilon_{t-i}}{\sigma_{t-i}} \right| + \sum_{j=1}^{s} \theta_j \frac{\varepsilon_{t-j}}{\sigma_{t-j}} + \sum_{k=1}^{q} \delta_k \sigma_{t-k}^2 + \gamma R_{CO2,t}^2 \tag{23}$$

$R_{CO2,t}^2$ is a proxy for the variance of the CO2 allowance price, whereas γ is its coefficient. In case that the coefficient γ is significantly different from zero, the volatility link between both markets would be considered. Note that the benefit of the EGARCH is that the conditional variance is in natural logs, so that the coefficients are able to have negative signs.

The result of this approach is presented in the following table and show that the coefficient of the squared CO2 price growth rates γ is negative and significantly different from zero at the five percent level. According to this finding, a higher volatility in the CO2 allowance market is related with lower stock market volatility.

Table 4: AR(1)-EGARCH(1,1,1) approach for the growth rate R_{SEOG} using R^2_{CO2} in the variance equation as regressor

Mean Equation, dependent variable: R_{SEOG}				
Variable	Coefficient	Std. Error	z-Statistic	Prob.
AR(1)	0.038156	0.024119	1.582007	0.1136
Variance Equation				
α_0	-0.287935	0.063180	-4.557402	0.0000
Symmetric ARCH	0.123396	0.025604	4.819327	0.0000
Asymmetric ARCH	-0.084563	0.017077	-4.951988	0.0000
GARCH	0.977975	0.005926	165.0299	0.0000
$R^2_{CO2,t}$	-4.655657	1.965285	-2.368948	0.0178

Source: Own calculations

To have a closer look into the linkage, we insert next the "shock" dummies $D_{+,20}$ and $D_{-,20}$ into the variance equation instead of R^2_{CO2}. The following table indicates the result of this approach, which shows, that at the significance level of five percent, negative price shocks are related with higher stock market volatilities, whereas the coefficient of the positive price shocks is not significant. Like at the mean-level, market participants apparently behave asymmetrically towards negative and positive price shocks in terms of the volatility.

Table 5: AR(1)-EGARCH(1,1,1) approach for the growth rate R_{SEOG} using $D_{+,20}$ and $D_{-,20}$ in the variance equation as regressors

Mean Equation, dependent variable: R_{SEOG}				
Variable	Coefficient	Std. Error	z-Statistic	Prob.
AR(1)	0.041115	0.023736	1.732207	0.0832
Variance Equation				
α_0	-0.346731	0.074468	-4.656119	0.0000
Symmetric ARCH	0.134252	0.027792	4.830578	0.0000
Asymmetric ARCH	-0.086434	0.017711	-4.880133	0.0000
GARCH	0.975501	0.006362	153.3369	0.0000
$\boldsymbol{D_{-,20}}$	0.088574	0.037439	2.365830	0.0180
$\boldsymbol{D_{+,20}}$	0.027390	0.037879	0.723086	0.4696

Source: Own calculations

Negative shocks from the CO2 pricing volatility raise the stock market price volatility in the oil and gas sector in the EU. Moreover, as argued by DASKALAKIS/PSYCHOYIOS/MARKELLOS (2009), high volatilities and the presence of discontinuities in carbon prices have counter-productive effects on the emission allowance derivatives, shrinking the (risk) hedging ability of market stakeholders. Thus, one can only warn policymakers in the EU against organizing the ETS in such a way that it brings unnecessarily high CO2 pricing volatility, which would also hamper the sustainability of the carbon allowance market regarding liquidity and market efficiency. As regards the overall stock market price index, the results are also quite interesting with respect to volatility. The following tables show the results for the Stoxx Europe 600 index. It is apparent that the coefficient of the squared CO2 price growth rates γ is not significantly different from zero. Using the "shock" dummies $D_{+,20}$ and $D_{-,20}$, the results indicate that – similar to the previous findings – only the coefficient of negative price shocks in the CO2 allowance market is significantly different from zero at the one percent level and has a positive sign.

Table 6: AR(1)-EGARCH(1,1,1) approach for the growth rate R_{STOXX} using R^2_{CO2} in the variance equation as regressor

Mean Equation, dependent variable: R_{STOXX}				
Variable	Coefficient	Std. Error	z-Statistic	Prob.
AR(1)	0.029807	0.026677	1.117324	0.2639
Variance Equation				
α_0	-0.501917	0.081982	-6.122296	0.0000
Symmetric ARCH	0.169947	0.038730	4.387958	0.0000
Asymmetric ARCH	-0.157630	0.026343	-5.983631	0.0000
GARCH	0.960429	0.008519	112.7440	0.0000
$\boldsymbol{R^2_{CO2,t}}$	-0.798046	3.527536	-0.226233	0.8210

Source: Own calculations

Table 7: AR(1)-EGARCH(1,1,1) approach for the growth rate R_{STOXX} using $D_{+,20}$ and $D_{-,20}$ in the variance equation as regressors

Mean Equation, dependent variable: R_{STOXX}				
Variable	Coefficient	Std. Error	z-Statistic	Prob.
AR(1)	0.034282	0.024955	1.373763	0.1695
Variance Equation				
α_0	-0.571879	0.082307	-6.948090	0.0000
Symmetric ARCH	0.162035	0.039297	4.123374	0.0000
Asymmetric ARCH	-0.162349	0.027589	-5.884623	0.0000
GARCH	0.956937	0.007340	130.3762	0.0000
$\boldsymbol{D_{-,20}}$	0.154775	0.054415	2.844317	0.0045
$\boldsymbol{D_{+,20}}$	0.046564	0.051754	0.899721	0.3683

Source: Own calculations

A special problem concerns the potentially disturbing role of BREXIT and the United Kingdom's EU referendum of June 23, 2016. It is interesting to make a sample split at this date. Subsequently, the regression results for the period January 4, 2010, to June 23, 2016, are shown; the results of this split are very similar to the previous results so that BREXIT does not seem to have affected the links between the CO2 allowance markets in the EU and the EU stock markets.

Table 8: AR(1)-EGARCH(1,1,1) approach for the growth rate $\boldsymbol{R_{SEOG}}$ using $\boldsymbol{R^2_{CO2}}$ and $\boldsymbol{R^2_{USD/EUR}}$ in the variance equation as regressor. Sample: 04/01/2010 – 23/06/2016

Mean Equation, dependent variable: R_{SEOG}				
Variable	Coefficient	Std. Error	z-Statistic	Prob.
AR(1)	0.052100	0.026368	1.975881	0.0482
Variance Equation				
α_0	-0.424699	0.102156	-4.157379	0.0000
Symmetric ARCH	0.116395	0.026436	4.402842	0.0000
Asymmetric ARCH	-0.124001	0.019246	-6.442988	0.0000
GARCH	0.964285	0.009841	97.98626	0.0000
$R^2_{CO2,t}$	-4.137590	2.033723	-2.034490	0.0419
$R^2_{USD/EUR}$	561.2865	243.4963	2.305113	0.0212

Source: Own calculations

Table 9: AR(1)-EGARCH(1,1,1) approach for the growth rate $\boldsymbol{R_{SEOG}}$ using $\boldsymbol{D_{+,20}}$, $\boldsymbol{D_{-,20}}$ and $\boldsymbol{R^2_{USD/EUR}}$ in the variance equation as regressor, sample: 04/01/2010 – 23/06/2016

Mean Equation, dependent variable: R_{SEOG}				
Variable	Coefficient	Std. Error	z-Statistic	Prob.
AR(1)	0.041115	0.023736	1.732207	0.0832
Variance Equation				
α_0	-0.489312	0.111945	-4.370989	0.0000
Symmetric ARCH	0.127281	0.028652	4.442367	0.0000
Asymmetric ARCH	-0.127852	0.020309	-6.295294	0.0000
GARCH	0.961539	0.010225	94.04214	0.0000
$\boldsymbol{D_{-,20}}$	0.083823	0.044723	1.874288	0.0609
$\boldsymbol{D_{+,20}}$	0.034478	0.048530	0.710450	0.4774
$R^2_{USD/EUR}$	645.4791	273.1364	2.363211	0.0181

Source: Own calculations

As regards the US, the rather limited ETS system of California and smaller regional ETS systems for approximately a dozen US states means that the US has a rather limited CO2 allowance market. Hence the links between CO2 allowance pricing and stock market price dynamics should be rather small in the United States. Only if the US adopts a broader regional or national comprehensive ETS would US financial markets benefit from CO2 allowance pricing.

4. Policy Implications

Looking at the EU ETS CO2 allowance and oil and gas stock market price dynamics, we find clear evidence for links on both levels: mean and variance. The estimates show a positive relation between both price growth rates. Moreover, market participants behave asymmetrically on both levels: negative price shocks are related to lower price growth rates and higher price volatilities in the case of the oil and gas stock market.

The EGARCH approach revealed that higher volatilities in the CO2 market are linked to lower volatilities in the oil and gas stock market. Since higher volatilities reflect increasing risk and uncertainty, this outcome is, from a theoretical perspective, unintuitive.

We also find some evidence for the causality of this link, namely that the oil and gas stock markets are Granger-causal for the CO2 allowance market dynamics. The results illustrate that political decision-makers have to take into account that stocks (and also other assets such as commodities) are likely linked to the CO2 allowance market. Thus, policy changes in the ETS can have major impacts on both the financial and real economy, and vice versa.

An efficient transition to climate neutrality will require extending the current coverage of the EU ETS and it would also be useful to have a broad ETS within a decade in all G20 countries. Such developments would help to reduce the relative oil price in world markets and should thus help to phase out oil and gas production. One cannot rule out that for a transition period there could indeed be a so-called "Green Paradox", namely that after a fall of the world market price of oil and gas, poor developing countries as well as OECD countries could start increasing fossil fuel consumption again so that this would counteract the progress already achieved with regard to climate neutrality adjustment steps. A rise of the CO2 allowance price will not only help to bring down the relative price of fossil fuel but could also be a major driver of rising stock market indices worldwide. This then amounts to a rise of Tobin's Q and therefore higher global investment which is a welcome perspective considering the difficult transition to climate neutrality.

As regards future research questions, there are many important challenges. One aspect concerns the issue of fossil fuel pricing in the new international environment of energy substitution in the sense that the share of renewable energy is rising over time compared to the share of fossil fuels. Further research will be needed in the crucial field of financial markets, oil markets and CO2 allowance pricing. More than a dozen of countries – which have existing or are initiating CO2 ETS – will all be eager to understand the new findings and the crucial implications here.

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