Department of Economics

Carbon price dynamics in the EU ETS

The impact of fuel switching

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Abstract

This paper examines the carbon price dynamics in the European Emission Trading System (EU ETS). It seeks to answer whether these can be explained by marginal emission abatement costs, as stated by theoretical propositions. The primary abatement method, fuel switching, and other potential determinants are examined to test their relative importance in carbon price dynamics. The results from the performed OLS-regressions do not support the hypothesis that fuel switching is a strong indicator of the carbon price movements. The results suggest that the market potentially suffers from inefficiency and/or that the tested model is insufficient to explain the price fluctuations.

Keywords: EU ETS, carbon price, fuel switching, emission abatement cost

Contents

1 Introduction

By ratifying the Kyoto Protocol in 1997, the European Union committed itself to the fight against climate change by setting up emission reduction targets. To meet its targets in the most cost-effective way, the European Union established a cap-and-trade system called the European Union Emission Trading System (EU ETS). With the EU ETS, the EU has aimed to create a market mechanism that determines a price for carbon dioxide (CO_2) emissions and pushes for emission reduction at least cost. Firms covered under the EU ETS must justify their emissions by annually submitting one emission unit allowance (EUA) for every metric ton of CO_2 emitted. The scheme is dominated by firms in the electricity sector, as they account for more than half of the emissions and emission unit allowances on the market. The system's main objective is to encourage the industry's largest emitters to carbon abatement (European Comission, 2015). Thus, achieving the main goal relies on a clear price signal that induces electricity producers to make persisting abatement choices and produce electricity with fewer emissions (European Commission, 2016a).

Under perfect competition, the price of EUAs (carbon price) should reflect the cost of marginal emissions abatement (Montgomery, 1972; Tietenberg, 1985). Therefore, many consider the available abatement options in the dominating electricity sector to be a determining factor in carbon price dynamics (Hintermann, 2010; Delarue et al., 2008; Bertrand, 2012; Chevallier, 2009). Generating electrical power with natural gas produces about half the amount of carbon emissions than generating electrical power with coal. Thus, substituting gas-fired production for coal-fired production has become a way for the electricity sector to achieve emission abatement at a relatively low cost. The ability to switch between the two different fuels is known as fuel switching and has been considered the main short-term emission abatement method under the EU ETS (Bertrand, 2012).

The question of fuel switching has been of growing interest since the establishment of the EU ETS and has given the rise of abundant empirical literature on the first two phases of the system. Although the market has been prone to inefficiencies, previous studies have found fuel switching to be a significant determinant of the carbon price (Mansanet-Bataller et al., 2007; Alberola et al., 2008; Hintermann, 2010; Creti et al., 2012).

The third phase of the EU ETS has just ended, and so it raises the question of whether theory and previous findings hold: Does fuel switching explain the trajectories of the EUA price in the third phase of the EU ETS? Our aim in this paper is to explore the determinants of carbon price movements on the premise that fuel switching is a strong determinant of the price.

To analyse the relative importance of fuel switching in carbon price dynamics, we perform an econometric study where the EUA price regress on a set of explanatory variables, which have proved to be of significance in previous empirical research. In addition to fuel switching, we will test the importance of other energy-related fundamentals, i.e., oil and electricity price, and proxy variables for economic activity. Also, we will investigate potential structural breaks in our time series following institutional and economic events. The results from the empirical study show that fuel switching has not been a significant indicator of the carbon price for the period of Phase III (2013-2020). The other variables, that is, energy-related fundamentals and economic activity proxies, show little explanatory power as well. Exceptions are the electricity price and the coal price by itself. These results contradict a lot of the previous findings for the first two phases of the EU ETS. While there are signs of potential market inefficiencies, it also essential to address the used model's inability to capture any regulatory uncertainty and long-term relationship of the variables. More extensive research is needed on Phase III to explain the actual carbon price drivers fully.

The rest of the paper is organized as follows. Section 2 gives a background on the EU ETS and highlights its key features and design. Section 3 presents (i) the theoretical foundation for the cap-and-trade principle and price formation through fuel switching and (ii) the previous literature on carbon pricing. Section 4 consists of the method, data, and results from the empirical analysis. It also includes a discussion of our findings. Section 5 concludes the paper.

2 Background

The EU ETS was the first large emission trading system globally and remains the biggest (European Comission, 2015). Today the system covers over 11 000 installations and applies to all countries in the European Economic Area. While emissions trading can cover many economic sectors and GHG emissions, the EU ETS focuses on emissions that can be measured, verified, and reported to a high degree of accuracy. Thus, the system is mainly concerned with electrical energy and the major emitters of the industrial sector[1]. As previously mentioned, the electricity sector accounts for more than 50% of total volumes in terms of CO_2 emissions and emission allowances (European Comission, 2015).

The system works on the "cap-and-trade" principle. The total volume that can be emitted each year within the EU ETS is subject to a cap. Within this cap, firms receive or buy emission allowances (EUA). These can be traded on the secondary market if they wish to do so (European Commission, 2016b).

EUAs are the "currency" of the EU ETS, and the cap (limit) on the total volume available gives them a value. For each EUA, the holder is given the right to emit one tonne of carbon dioxide[2]. EUAs can be used only once. Firms are obliged to surrender one EUA for every tonne of CO_2 they emitted in the past year. If they fail to do so, heavy fines are imposed (European Comission, 2015).

By capping overall GHG emissions and reducing the total volume each calendar year, the EU ETS creates an incentive for emission abatement among its participants. The market price of allowances, otherwise known as the EUA price (or the carbon price), is assumed to be growing over time as the regulators progressively shrink the total cap. Following this, the incentive to abate emissions will grow as well (European Comission, 2015).

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[1] Some of the sectors not covered are: transport, households, agriculture and businesses with low carbon intensity

[2] or the equivalent of two other GHGs: nitrous oxide (N2O) and perfluorocarbons (PFCs)

The EU ETS is divided into distinct trading periods, also known as phases (see Figure 1). Throughout each phase, the legislative bodies of the system evaluate the market efficiency and the allowance price signal to adjust for certain shortcomings (European Comission, 2015).

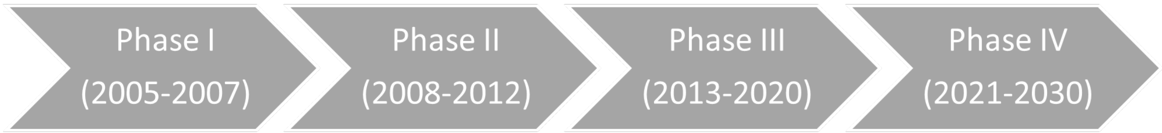

Figure 1: The phases of the EU ETS (European Comission, 2015)

The price of allowances is determined by supply and demand. There has been a challenge in the form of allowance surplus throughout the phases, which has disturbed the price signal and negatively affected the stimulation of emission abatement (European Comission, 2015). During the first phase, all allowances were allocated based on National Allocation Plans (NAPs), where each country estimated their allowance needs. The estimated needs turned out to be excessive, and the over-allocation of allowances caused the price of Phase I EUAs to fall to zero in 2007 (European Commission, 2016b). Similarly, Phase II was affected by the economic crisis in 2008, as firms' production levels rapidly declined, which resulted in another oversupply of allowances. In the short-term, the allowance surplus seen in both Phase I and II risks undermining the proper functioning of the carbon market. In the long-term, excessive supplies could affect the EU ETS' ability to comply with more demanding emission reduction targets cost-effectively since firms are not urged to abate their emissions in an oversupplied allowance market. To account for these shortcomings in Phase III, the legislative bodies imposed two measures: ”back-loading” and a market stability reserve (MSR). These policies aimed to neutralize the negative impacts of any allowance surplus and form an efficient market (European Commission, 2016b).

3 Theory and related works

3.1 Theory

3.1.1 The cap-and-trade principle

Given the undesired price signals and over-allocation of allowances in its two first phases, there have certainly been questions about the credibility of the cap-and-trade system that is the EU ETS (Zetterberg et al., 2014). Yet, as stated in the EU ETS Handbook, there are several theoretical propositions why this structure is favored. Moreover, the EU chose a cap-and-trade structure as the best means of meeting environmental targets on emission reduction at the least overall cost for its participating firms and the economy as a whole (European Comission, 2015). Two other alternatives for regulating greenhouse gas emissions are through the traditional command-and-control approach or a carbon tax. While the first approach may mandate a standard limit per installation, it does not provide flexibility to firms regarding where or how emission reductions occur (Tietenberg, 1985). Second, although a carbon tax would allow the regulator to control the carbon price, the resulting emission level is not known in advance, which causes uncertainty about the environmental outcome (Zetterberg et al., 2014). Thus, the EU policymakers promote emissions trading, as it gives a certain assurance about the environmental outcome.

Thorough examinations of emissions markets as an economic tool to achieve environmental targets date back to Montgomery (1972). As mentioned previously, the basic rationale behind these market-based policy instruments is that the regulator issues (via free allocation or auctioning) a limited number (a cap) of tradable emission allowances and requires that one allowance must be surrendered for each tCO_2 emitted. By doing so, the regulator can limit aggregate emission levels to whatever level is socially desirable. Each participant of the system has the flexibility to use the most effective combination of buying or selling emission allowances, reducing emissions by deploying cleaner technology, or reducing emissions by decreasing production. Thus, the regulator is able to not only limit aggregate pollution to the level it desires but also stimulate efficient emission abatement even if the participating firms have heterogeneous abatement abilities. This follows since every participating firm has a particular incentive to alter its abatement until its marginal abatement cost equals the market price of an emission allowance (Montgomery, 1972). The following result is an achievement of socially optimal aggregate abatement at least cost since every cost-minimizing firm sets the marginal cost of abatement at the same level (see Figure 2 for an illustrative example between two firms). Along these lines, Tietenberg (1985), Cronshaw and Kruse (1996), and Rubin (1996) show that:

$$EUA_t = MC_t \quad \forall t \in [0, T] \tag{1}$$

where EUA_t is the emission allowance price at time t, MC_t is the marginal cost of abatement (reducing one tCO_2) at time t, and T is the end of the distinct trading period (the phase).

The simple relationship stated in Equation (1) constitutes the theoretical framework for the empirical research on EUA price drivers. The main challenge here is to find useful proxies for abatement costs of participating firms. This depends on what emissions reduction alternatives are available to participating firms, as well as on indicators of economic activity, which is the link between production and emissions (Creti et al., 2012).

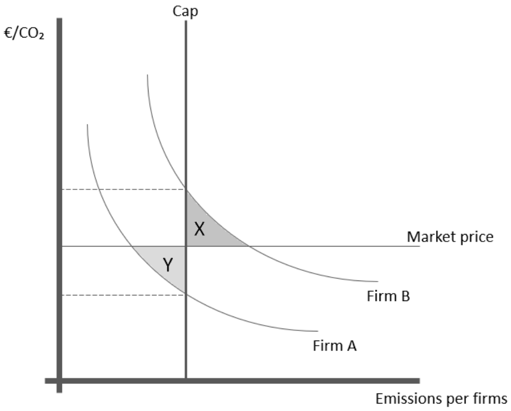

Figure 2: An illustration of the cap-and-trade principle with the marginal abatement cost curves (MACC) of two participating firms, Firm A and B. The regulator has set a cap to limit the total volume of emissions per firm. The positioning of the MACCs shows that Firm B faces a higher marginal cost of emissions abatement than Firm A. Firm A is able to reduce its emissions through abatement methods, creating an internal surplus of allowances (highlighted in area Y). Firm B's cost of abatement is highlighted in area X. For Firm B, it is cheaper to buy allowances for the market price than to abate its emissions internally. Therefore, Firm A is able to make a profit by selling its surplus to Firm B who faces a high cost of abatement. However, in the long run, Firm B will have to abate its emission eventually, since the total cap is decreased each year by the regulator to meet environmental targets.

3.1.2 Fuel switching: The main abatement method

Because of the electricity sector's high share of emissions and allowances in the EU ETS, they are considered the major force on the demand side of the market (European Comission, 2015). Following the theory on marginal abatement cost, their carbon abatement decisions become an important determinant of the EUA price. Moreover, emissions abatement costs from the electricity sector are assumed to be the lowest compared to other sectors in the EU ETS due to the ability to fuel switch from coal to gas (Bertrand, 2012; Delarue et al., 2008). The rationale behind fuel switching is that fuel and EUA prices will determine the demand for emission allowances by setting the composition of electricity generation. Fuel prices and the added cost of emission allowances determine which technology (coal or gas plants) is brought online first, also known as the merit order (Bertrand, 2012).

In particular, the merit order is the ranking of all electrical power plants by the marginal cost of production. The plants are stacked in order of increasing marginal costs of electricity generation (Unger, 2002). If there is no cost of emissions, i.e., the business-as-usual (BAU) scenario, coal plants are usually brought online first because of their lower fuel cost. The second in merit order is gas. However, coal produces about twice the amount of CO_2 emissions per Mega Watt hour ($\sim 0.95tCO_2$/MWh) of electricity produced than gas ($\sim 0.4tCO_2$/Mwh)[3]. For that reason, if a carbon price is introduced, gas plants may become preferable to coal plants due to their lower emission intensity. In the BAU scenario and under the EU ETS, the marginal costs of producing one MWh of electricity with coal and gas plants are defined, respectively, as (Bertrand, 2012):

$$\text{BAU scenario} \begin{cases} MC_c^{BAU} = h_c COAL_t \\ MC_g^{BAU} = h_g GAS_t \end{cases} \tag{2}$$

$$\text{the EU ETS} \begin{cases} MC_c^{EUETS} = h_c COAL + e_c EUA_t \\ MC_g^{EUETS} = h_g GAS + e_g EUA_t \end{cases} \tag{3}$$

Above, e_c and e_g are the coefficients for emission intensity from coal and gas plants, respectively. h_c and h_g denote how much fuel is used to generate 1 MWh of electricity from each plant[4] (Fehr and Hinz, 2006). EUA_t is the price of CO_2, $COAL_t$ is the price of coal, and GAS_t is the price of natural gas, at time t.

The decision to switch between coal and gas is made by a comparison between MC_c^{EUETS} and MC_g^{EUETS}. A fuel switch is redeemed profitable if $MC_g^{EUETS} < MC_c^{EUETS}$ (whereas MC_c^{BAU} could still be lower than MC_g^{BAU}). Moreover, this implies that if the cost of increased emissions with coal plants, $EUA_t(e_c - e_g)$ per MWh of electricity, is higher than the additional fuel cost that comes with the decision of using gas plants, $h_g GAS_t - h_c COAL_t$ per MWh of electricity, then it is cheaper to use gas plants first instead of coal plants. Thus, fuel switching is bound to occur only if $EUA_t(e_c - e_g) > h_g GAS_t - h_c COAL_t$. Finally, this inequality allows

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[3] Values extracted from Refinitiv Datastream (2021)

[4] h = heat and emission rates . See Appendix A for calculations

the derivation of the implicit switching price (Fehr and Hinz, 2006):

$$Switch_t = \frac{h_g GAS_t - h_c COAL_t}{e_c - e_g} \tag{4}$$

$Switch_t$ states the cost of switching from coal to gas to abate one metric ton of CO_2. Moreover, it can also be interpreted as the EUA price that makes gas plants and coal plants equally attractive in terms of marginal cost. So, fuel switching will occur at time t when $EUA_t > Switch_t$.

In summary, the switching price is fundamental to EUA pricing in that the marginal cost of an allowance should follow the switching price. Consider the following scenario: when the EUA price increases enough, electricity producers will end up at the situation $EUA_t(e_c - e_g) > h_g GAS_t - h_c COAL_t$, which implies that firms will be motivated to switch to cleaner fuels. The high degree of fuel switching to natural gas will cause the demand for emission allowances to decrease. This creates a downward pressure that causes EUA prices to stabilize near the implicit switching price (Fehr and Hinz, 2006).

3.2 Related works on carbon price drivers

The price dynamics of the EU ETS and the relative importance of fuel switching have given rise to a large volume of empirical work throughout the years of the system's existence. Most commonly, carbon price dynamics are studied through regressing the EUA price on a set of explanatory variables, including the switching price. Christiansen et al. (2005) conclude that several possible explanatory variables should be considered when addressing EUA price movements in addition to the marginal abatement costs. Besides the switching price, electricity and oil prices are often included to capture additional aspects of energy demand (Alberola et al., 2008; Mansanet-Bataller et al., 2007; Hintermann, 2010). Then, to control for business-as-usual (BAU) emissions, proxies for economic activity are used (Koch et al., 2014; Mansanet-Bataller et al., 2007; Creti et al., 2012). Also, to account for political and economic events, many have considered structural breaks to be an important area of research (Alberola et al., 2008; Batten et al., 2021). Overall, the empirical findings on the carbon price dynamics have been somewhat scattered throughout the different phases.

In Phase I, a common finding has been that fuel switching had a limited influence on EUA prices. It has been argued that this was mainly due to institutional factors (Alberola and Chevallier, 2009). In 2006, the legislative bodies announced that there had been an over-allocation of allowances due to the National Allocation Plans. This heavily influenced the market price (Mansanet-Bataller et al., 2007; Alberola et al., 2008; Hintermann, 2010). In the first year of its operation, Mansanet-Bataller et al. (2007) found that oil and gas prices were significant determinants of the EUA price, while the switching price between coal and gas was not significant. Neither was the coal price itself. Alberola et al. (2008) investigated subperiods of Phase I. The authors found that policy proxies were the main driver of the carbon price for the first half of Phase I, while the fundamentals of the energy sectors (fuel switching, oil- and electricity prices) governed carbon price movements in the second half of Phase I when the price had stabilized. Further analysis by Hintermann (2010) suggests that although marginal abatement costs did not initially drive prices, this inefficiency was corrected after the accounting for structural breaks caused by the institutional factors.

Bredin and Muckley (2011), Creti et al. (2012), and Aatola et al. (2013) later conducted thorough analysis in efforts to compare results between Phase I and Phase II. Through cointegration tests, the authors found that although oil and economic activity (production indices) were significant determinants of the EUA price in both phases, the importance of fuel-switching was only evident in Phase II. It is noteworthy that Koch et al. (2014) and Fell and Vollebergh (2015) also tested the relevance of switching and other energy-related fundamentals during Phase II, but with OLS-regression models. Compared with the studies that used cointegration tests, the latter authors did not find any statistical significance from their variables.

In the related literature, there have been discussions on which financial contracts are the most appropriate for estimating carbon price dynamics, namely, spot or futures contracts. While Alberola et al. (2008) conduct their analysis using spots to capture daily needs, Koch et al. (2014) suggest using futures contracts as the vast majority of EUA transactions are in futures. Creti et al. (2012) further emphasise future contracts showing more stable price paths and address that spots are more sensitive to structural breaks. Mansanet-Bataller and Pardo (2008) confirm that when comparing spots and futures contract during the earlier stages of the EU ETS, spots were heavily exposed to structural breaks following the institutional events of Phase I. Studies from Benz and Trück (2009) and Paolella and Taschini (2006) finds evidence for nonlinear dynamics in spot price allowances.

There are not many studies that have covered the entirety of the third phase since it recently ended. As stated in the EU ETS handbook, the third phase was expected to propel the system from a learning state to an efficient market and policy instrument (European Comission, 2015). Moving into Phase III, there were uncertainties on whether the impact of market fundamentals on EUA prices would be diminished as the economic crisis in 2008 left the market with an excessive amount of allowances (Creti et al., 2012; Koch et al., 2014). This issue was acknowledged by implementing policies such as back-loading and the MSR (European Comission, 2015). Now in hindsight of the third phase, it is time to address whether the market functioning has improved compared to the earlier phases and if the explanatory power of fuel switching has increased.

4 Empirical analysis

To test our hypothesis, if changes in the EUA price can be explained by the price changes in the implicit fuel switching price (derived in Section 3.1.2), an econometric study is conducted. More specifically, a multivariate linear regression model consisting of the EUA price, the fuel switching price, and other energy-related commodity prices and variables accounting for economic activity. Furthermore, Chow tests are performed to find potential structural breaks following economic and regulatory events. We ran five regressions in total. The period ranges from January 2013 to December 2020, covering the entire Phase III.

4.1 Methodology

To estimate the relative importance of fuel switching on the EUA price, we follow the methodology of Hintermann (2010), and regress the EUA price changes[5] on a set of exogenous explanatory variables. More precisely, we set up the following regression model:

$$\begin{aligned} EUA_t = &\beta_0 + \beta_1 Switch_t + \beta_2 Gas_t + \beta_3 Coal_t + \beta_4 Oil_t + \beta_5 Electricity_t + \\ &\beta_6 IPI_t + \beta_7 ESI_t + \beta_8 STOXX600_t + \beta_9 CPIEU27_t + \epsilon_t \end{aligned} \tag{5}$$

where t is the time period, β_0 is a constant, $Switch_t$ is the price change series of the fuel switching price, Gas_t, $Coal_t$ and Oil_t are each respective commodity's price change series, $Electricity_t$ is the electricity price change series, IPI_t is the Industrial Production Index change series, ESI_t is the Economic Sentiment Indicator index change series, $STOXX600_t$ is the European STOXX600 index change series, and *CPIEU27* is the European Union Consumer Price Index change series.

From Equation (4) in Section 3.1.2, the implicit fuel switching price, $Switch_t$, is calculated by using coal and gas futures contracts. In addition, we also include the coal and gas prices by themselves in the same model to address their individual magnitude on carbon price movements. Electricity prices are included in the model to capture the changes in EUA demand that arise from changes in electricity consumption (Declercq et al., 2011). Following previous research, oil prices are included as well (Alberola et al., 2008; Creti et al., 2012). The inclusion of oil prices in previous studies has been variously motivated. Koch et al. (2014) motivated it as a proxy for the economic activity while we have chosen the motivation of Mansanet-Bataller et al. (2007) and Creti et al. (2012), who uses it to account for energy-related abatement.

To capture changes in production and thus changes in emission levels (Creti et al., 2012), four proxies for economic activity are included. Through production-, economic sentiment-, and equity indices, we measure for both forward- and backward-looking economic activity (Koch et al., 2014). Also, to account for inflation rates in the EU, a consumer price index is

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[5] $\Delta P_t = \frac{P_t - P_{t-1}}{P_{t-1}}$

incorporated.

As there have been several big institutional and economic events during Phase III, we perform Chow tests to identify potential structural breaks in our time series. The events included are the Brent crude oil price plunge in June 2014 (Khan et al., 2017), the release of the revised EU ETS Directive 2018/410 in April 2018 (European Parliament), and the announcement declaring COVID-19 a pandemic in March 2020 (World Health Organization). The chosen events are based on findings from Batten et al. (2021), Friedrich et al. (2019), Elkerbout and Zetterberg (2020) and Gerlagh R (2020). Although these events have shown a significant impact on the European Union, we acknowledge the possibility of there being other global events in Phase III that could affect the EU ETS. Lastly, several other studies include (extreme) weather variables in their models to capture sudden shocks in energy demand. However, we omit these variables as it has been shown that their impact on the carbon price is indirect and can instead be captured by the changes in electricity prices (Creti et al., 2012; Koch et al., 2014).

The quality of the regressions is verified by testing for potential heteroscedasticity or autocorrelation. Breusch-Pagan and White's test are used to test for heteroscedasticity. Durbin Watson and Breusch-Godfrey tests are performed to test for autocorrelation. The test results are presented for each regression in the regression summary (see Figure 9). In addition to heteroscedasticity and autocorrelation, multicollinearity is accounted for by examining the pairwise correlation and conducting a Variance Inflation Factor (VIF) test. Any variable with a VIF > 5 was run in a separate regression where the correlated variable was omitted.

4.2 Data and descriptive statistics

The data used in the model are extracted from Refinitiv Database (2021) and Eurostat (2021). Regarding the carbon price series, we rely on the settlement price of the month ahead EUA December futures contract from the Intercontinental Exchange (ICE) platform. ICE is the leading EU ETS trading venue with the most liquid market for futures contracts[6] (European Comission, 2015). Following previous studies, we use futures contracts rather

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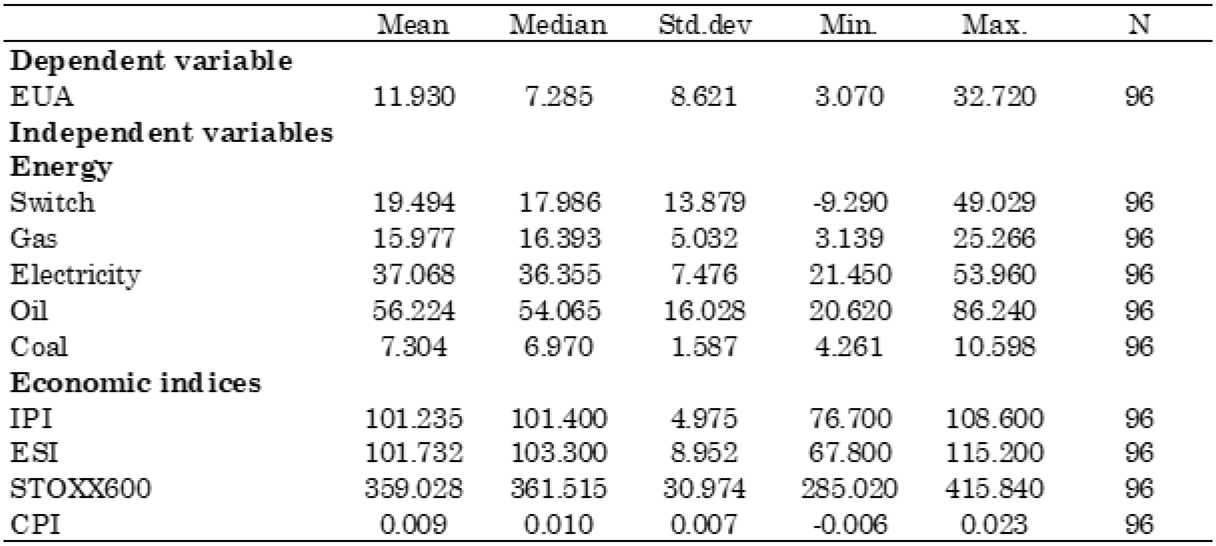
[6] accounting for approximately 80% of the exchange-traded volume in the European market

than spot ones, as the latter are more volatile and might not reflect market mechanisms (Creti et al., 2012; Alberola et al., 2008; Chevallier, 2009; Brohé et al., 2012). The unit of the price of the contract is denoted in €/tCO_2.

Equivalent to the EUA prices, the energy and electricity prices are based on futures contracts. In terms of the energy commodity prices, the month ahead futures contracts for oil, natural gas, and coal have been chosen from the most liquid trading points in Europe to reflect benchmark prices (Hintermann, 2010; Creti et al., 2012; Alberola et al., 2008). The contracts are ICE National Balancing Point Monthly Natural Gas Future, ICE Rotterdam Coal Monthly Future, and ICE Brent Crude Oil Monthly Future. The electricity price series is the German EEX Phelix Baseload Energy Monthly Future. An important notice is that no electricity price will represent the electricity price of the entire European continent. Still, according to the European Commission, the German market serves as a point of reference due to its liquidity (European Commission, 2016a).

To measure forward-looking economic activity, stock price movements are used (Creti et al., 2012; Koch et al., 2014). The stock price variable is the STOXX EUROPE 600 index, a broad benchmark tracking 18 European countries' performance (Refinitiv Datastream, 2021). The other forward-looking variable is the Economic Sentiment Indicator (ESI) which is published by Eurostat. The confidence indicator combines expectations and perceptions about economic activity in Europe based on business surveys (European Comission, 2016). In addition to forward-looking indicators, it is also relevant to consider a backward-looking indicator (Alberola et al., 2008; Koch et al., 2014). Thus, the Industrial Production Index (IPI) is included. The index is published by Eurostat and tracks the past output and activity of European industries (Eurostat, 2021). Lastly, the European Union Consumer Price Index 27 (EU27 CPI) is the chosen proxy to control for inflation during Phase III, extracted from the OECD (2021) database.

Figure 3 presents an overview of all included variables, describing the mean, median, standard deviation, min, max, and the number of observations for the price level of each asset class.



	Mean	Median	Std.dev	Min.	Max.	N
Dependent variable						
EUA	11.930	7.285	8.621	3.070	32.720	96
Independent variables						
Energy						
Switch	19.494	17.986	13.879	-9.290	49.029	96
Gas	15.977	16.393	5.032	3.139	25.266	96
Electricity	37.068	36.355	7.476	21.450	53.960	96
Oil	56.224	54.065	16.028	20.620	86.240	96
Coal	7.304	6.970	1.587	4.261	10.598	96
Economic indices						
IPI	101.235	101.400	4.975	76.700	108.600	96
ESI	101.732	103.300	8.952	67.800	115.200	96
STOXX600	359.028	361.515	30.974	285.020	415.840	96
CPI	0.009	0.010	0.007	-0.006	0.023	96

Figure 3: Descriptive statistics on the price levels of each asset class

Figure 4 presents a line chart of the price levels for emission allowances and the energy-related commodities mentioned above. However, gas and coal are converted to a comparable metric of €/MWh. Gas is converted from €/therm (1 therm = 0.0293071 MWh). Coal is converted from €/tonne (1 tonne = 0.1228350326 MWh) (Refinitiv Datastream, 2021).

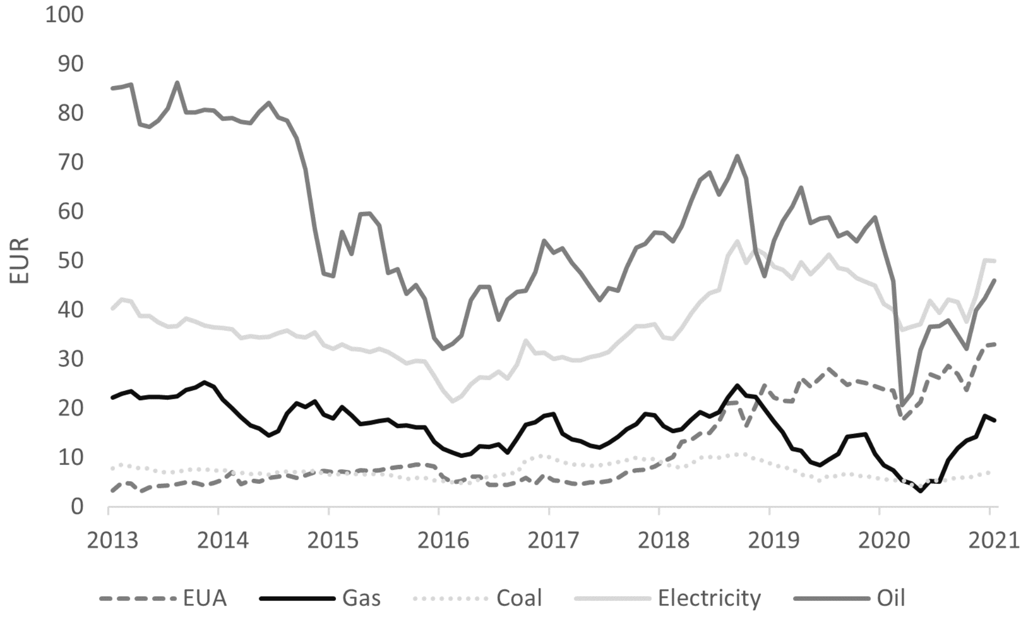


Figure 4: Price chart over Phase III for energy related commodities and EUA

Figure 5-8 presents all the economic activity variables index series.

Figure 5: Changes in CPI

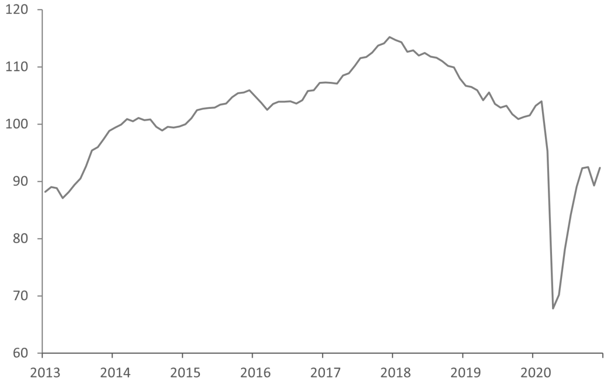


Figure 6: ESI price levels

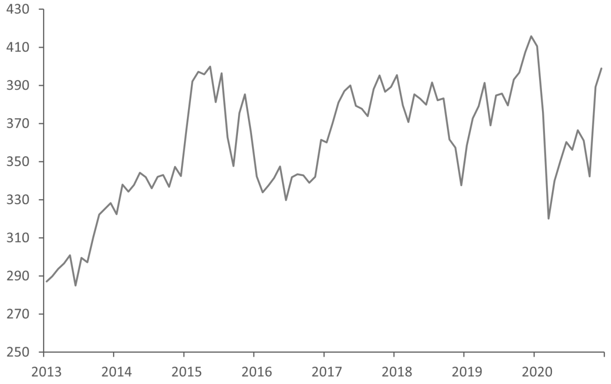


Figure 7: STOXX600 price levels

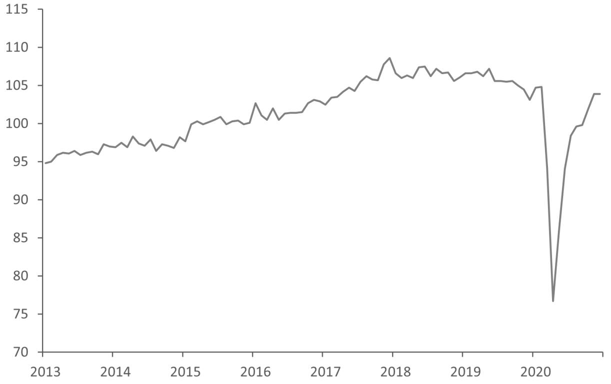
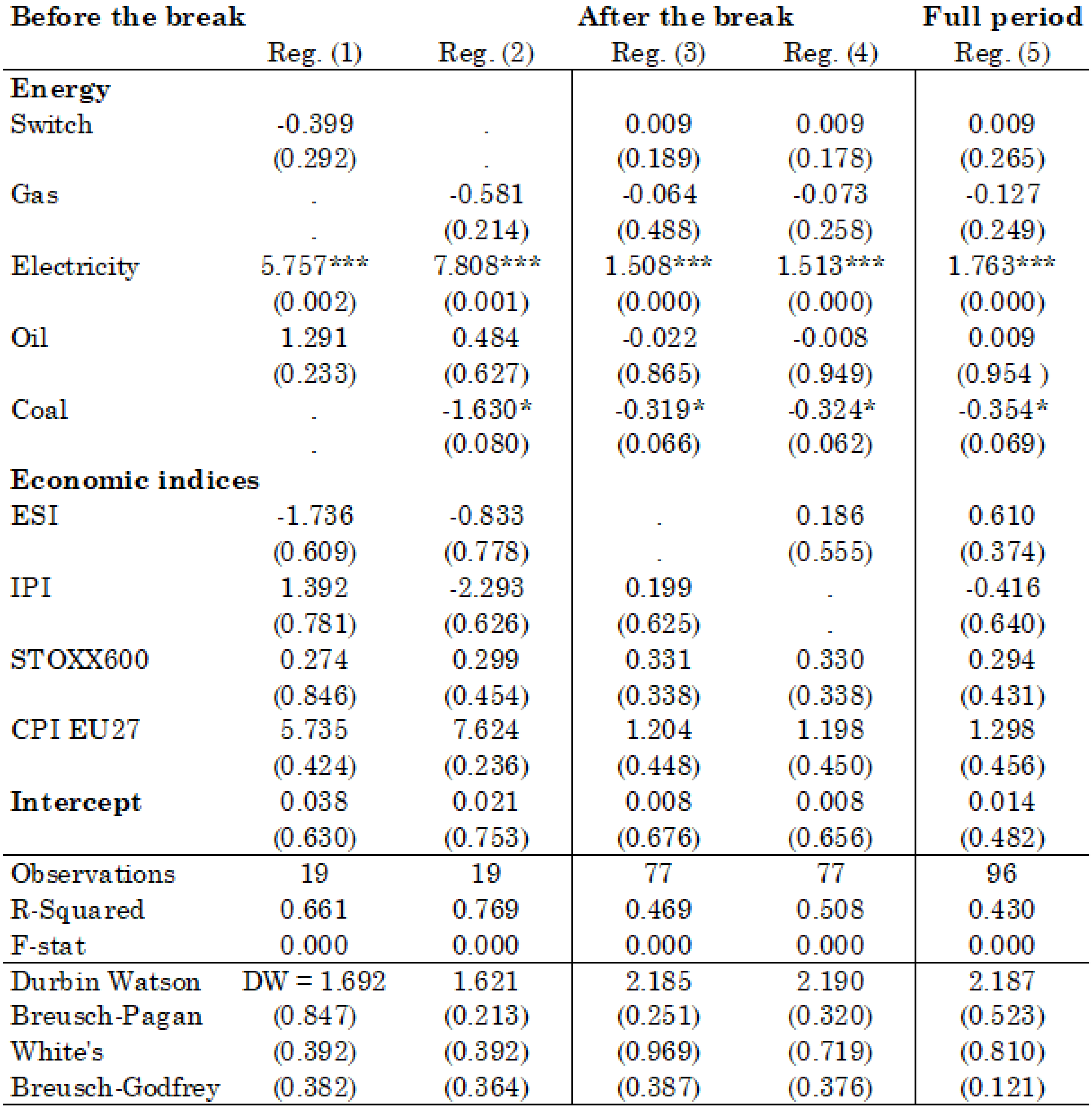


Figure 8: IPI price levels

4.3 Results and interpretation

First, Chow tests were conducted in case of any structural breaks following the three major events. A break was found in June 2014, possibly caused by the Brent crude oil price plunge. No structural breaks were found on the other tested dates (see Figure 12 in the Appendix). However, it is noted that the implicit effect of daily announcements could be diminished by using monthly data. Due to the identified structural break, the initial regression was separated into three regressions: before the break, after the break, and the full period. Second, no heteroscedasticity nor autocorrelation was found in any of the regressions (see Figure 9). However, there was evidence of multicollinearity in both subperiods (before and after the break). This resulted in two additional regressions being run, concluding with five regressions in total. The first regression omitted gas and coal as they showed a very high correlation with the switch variable. Analogously, the second regression was run without fuel switching. The third regression excluded ESI as it showed mild correlation with IPI, and the fourth regression thus excluded IPI. The fifth and final regression was run on the full period. A summary of the regressions is presented below in Figure 9.



Before the break			**After the break**		**Full period**
	Reg. (1)	Reg. (2)	Reg. (3)	Reg. (4)	Reg. (5)
Energy					
Switch	-0.399	.	0.009	0.009	0.009
	(0.292)	.	(0.189)	(0.178)	(0.265)
Gas	.	-0.581	-0.064	-0.073	-0.127
	.	(0.214)	(0.488)	(0.258)	(0.249)
Electricity	5.757***	7.808***	1.508***	1.513***	1.763***
	(0.002)	(0.001)	(0.000)	(0.000)	(0.000)
Oil	1.291	0.484	-0.022	-0.008	0.009
	(0.233)	(0.627)	(0.865)	(0.949)	(0.954)
Coal	.	-1.630*	-0.319*	-0.324*	-0.354*
	.	(0.080)	(0.066)	(0.062)	(0.069)
Economic indices					
ESI	-1.736	-0.833	.	0.186	0.610
	(0.609)	(0.778)	.	(0.555)	(0.374)
IPI	1.392	-2.293	0.199	.	-0.416
	(0.781)	(0.626)	(0.625)	.	(0.640)
STOXX600	0.274	0.299	0.331	0.330	0.294
	(0.846)	(0.454)	(0.338)	(0.338)	(0.431)
CPI EU27	5.735	7.624	1.204	1.198	1.298
	(0.424)	(0.236)	(0.448)	(0.450)	(0.456)
Intercept	0.038	0.021	0.008	0.008	0.014
	(0.630)	(0.753)	(0.676)	(0.656)	(0.482)
Observations	19	19	77	77	96
R-Squared	0.661	0.769	0.469	0.508	0.430
F-stat	0.000	0.000	0.000	0.000	0.000
Durbin Watson	DW = 1.692	1.621	2.185	2.190	2.187
Breusch-Pagan	(0.847)	(0.213)	(0.251)	(0.320)	(0.523)
White's	(0.392)	(0.392)	(0.969)	(0.719)	(0.810)
Breusch-Godfrey	(0.382)	(0.364)	(0.387)	(0.376)	(0.121)

Figure 9: P-value is presented in the parenthesis
***/**/* significance at 1%/5%/10%

As shown in Figure 9, the switch variable lacks statistical significance at the 10% confidence level in all regressions and has little explanatory power of EUA price changes. The insignificance of the switching variable could indicate the there have been low incentives to switch between coal and gas during Phase III. Although the model cannot provide such definitive answers, the coefficients of coal and gas by themselves give additional insight. In Reg.(2)-(5), coal was statistically significant at the 10% confidence level, unlike gas. Thus, a little of the switch variable's insignificance might be partially explained by the insignificant EUA price sensitivity to gas. The switch variable, a combination of coal and gas, could have its explanatory power dampened by the insignificant gas variable. In contrast, the coal variable seems to convey more information. As seen in Figure 10 the switching price is above the actual EUA price for most of Phase III. As stated in Section 3.1.2, fuel switching between coal and gas will occur only if $EUA_t > Switch_t$. Since this has not been the case for most of the time, coal has likely been first in merit order. Accordingly, decreasing coal prices would result in a higher share of coal-fired production, which affects the demand for allowances (and increases the EUA price). Hence, the negative coefficient of coal was anticipated. The results of a statistically significant coal price effect and an insignificant gas price effect have contradicted several previous findings (Koch et al., 2014; Hintermann, 2010; Mansanet-Bataller et al., 2007).

Considering Figure 10, the plot implies that fuel switching has occurred to a low degree in Phase III. Also, there is a notable spread between the EUA price and the switch price for most of the time series. Reciting Section 3.1.1, if the EU ETS is to achieve emission reduction at least cost, the equality $EUA_t = MC_t$ must hold. The appearance of Figure 10 suggests that the equality does not hold and that emission reduction has perhaps not been achieved at least cost in the EU ETS.

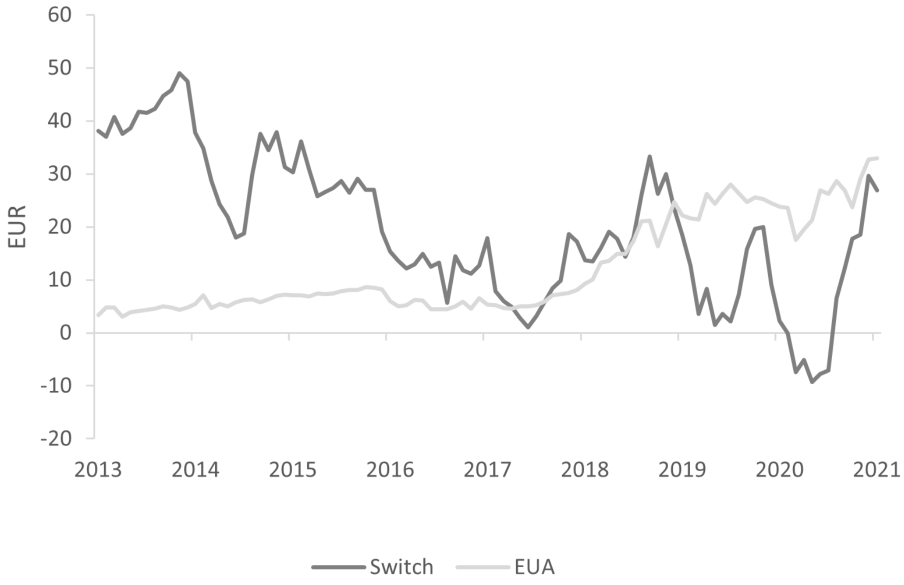


Figure 10: The switching price and the actual EUA price series

Out of all variables in the model, only the electricity price was significant at the 1% and 5% confidence levels. This finding is on par with Alberola et al. (2008) and Aatola et al. (2013). There are a few noteworthy discoveries regarding the electricity price variable. First, when comparing the regressions, the coefficient magnitudes vastly differ in the period before the structural break and after. Before the break, the coefficient suggests that a 1% increase in the electricity price should impose a 5.76-7.81% increase in EUA price. After the break, however, the electricity price effect on the EUA price is reduced to 1.51-1.76%. Also, the positive coefficient is unexpected. Declercq et al. (2011) argue that the consumer demand for electricity decreases with increasing electricity prices. A reduction in demand for electrical energy results in lower production from the electrical power plants. The following lower emission levels lessen the demand for emission allowances and so the EUA price decreases. Therefore, the expected relationship between electricity prices and EUA prices is negative. Suggestions for a potential cause of the positive coefficient are provided by Fezzi and Bunn (2009), Fell (2010), and Hintermann (2016). The authors show that carbon costs are largely passed through electricity prices to the end consumer, meaning that if EUA prices increase, so will the electricity price. Further analysis was conducted on the electricity price to realise its explanatory power. Separate regressions (not presented) were run on the periods before and after the break, using only the electricity price. The difference in R^2 was relatively small (approximately 10%) when compared with the whole set of explanatory variables. This further implies that most of the variation in the EUA price is explained by the variation in the electricity price. However, given the evidence on cost pass-through, it is possible that the electricity price is a biased estimate of the EUA price and potentially an endogenous variable (Koch et al., 2014). The result should thus be read with caution.

The remainder of the variables, that is, the oil price and the economic indices showed no significant results. While Koch et al. (2014) was able to show that market agents exhibit a forward-looking behaviour in Phase II, our insignificance in both forward- and backward-looking economic indicators imply that no conclusions can be drawn on whether EUA prices are determined by current economic activity or future expectations in Phase III.

4.4 Discussion

The results from our model show little information on what drives the carbon price. Marginal abatement costs—fuel switching—have seemingly had a minimal impact on carbon price movements during Phase III.

Fuel switching in the context of this analysis was based on the premise of equality between carbon price and marginal abatement costs (see Equation 1). Now, suppose it is assumed that the market model we used was correct and did not exclude any important price drivers linked to aggregate short-term abatement methods. In that case, our results indicate that marginal abatement costs were most likely not equal to the carbon price (see Equation 4). The equality between carbon price and marginal emission abatement costs is essential for the EU ETS to reach emissions reduction at least cost. Given these assumptions, the EU ETS may have experienced market inefficiencies during Phase III. For the EU to achieve socially optimal welfare in the EU ETS, it is necessary to evaluate why the carbon price was not determined by marginal abatement costs and potential causes of market inefficiency.

One of the main reasons why the Phase III market might have experienced inefficiency could have been the oversupply of allowances that carried over from phase II in the aftermath of the 2008 economic crisis (Joltreau and Sommerfeld, 2019). At the start of Phase III, the surplus of allowances amounted to approximately 2 billion allowances. This number further increased to more than 2.1 billion by the end of 2013. By 2015, emissions declined at a slower rate than the allowance supply, which helped reduce the allowance surplus. Yet, phase III had to deal with a surplus of over 1.7 billion allowances (European Comission, 2015). This amount equals about one year of EU ETS total emissions (Joltreau and Sommerfeld, 2019). The effect of an oversupply in the market was a low price that greatly reduced the incentive to abate emissions, i.e., switching fuels. Reviewing the inequality given in Section 3.1.2, fuel switching will occur if $EUA_t(e_c - e_g) > \eta_g GAS_t - \eta_c COAL_t$. In other words, as long as the EUA price was lower than the additional cost of fuel that comes with gas-fired production, the oversupply and resulting low EUA price most likely discouraged any switches as coal-fired production was more profitable. This is further supported by the coefficients and p-values of coal and gas prices in our results. The regression results showed that gas had essentially no explanatory power, while coal had a negative coefficient with significance at the 10% level. Thereby, it is likely that the demand for EUAs was driven mainly by coal plant power production, as coal was first in merit order due to its lower marginal cost.

In addition to an oversupplied market, the later stages of the third phase's price formation have been subject to regulatory uncertainty. Friedrich et al. (2019) results from an estimated Markov regime-switching model suggest that the discretionary intervention from the legislative bodies in phase III, e.g., the "back-loading" and MSR reforms, has caused regulatory uncertainty to increase. The reason is that discretionary changes in policy generate changes in the economic system, which in turn lead to market participants adjusting their expectations. This implied adjustment and uncertainty distorts the price upward and downward depending on the participants' anticipations regarding regulatory intervention in the future. In other words, firms act on inefficient decision making which results in a volatile market (Rickels et al., 2010). The implied volatile setting in the latter stages of phase III affected the explanatory impact of market fundamentals. (Friedrich et al., 2019).

A third and last proposition for market inefficiency given by Hintermann (2017), Dechezleprêtre et al. (2018), and Joltreau and Sommerfeld (2019) is that the EU ETS is not determined by the interaction of price takers in an efficient market setting but rather set by dominant firms who seek to maximize their profits. Particularly, dominating firms have the ability to influence the carbon price over time and decouple it from the fundamentals. It has been seen in previous phases that large electricity power producers—who exhibit the greatest potential for market power—obtained large profits due to a combination of free allocation of allowances and the cost pass-through in the electricity price (Dechezleprêtre et al., 2018). In Phase III, the main allocation form was changed to auctioning to correct this shortcoming. However, Hintermann (2017) finds that even though the dismissal of free allocations to the electricity sector, there are still motives for exercising market power. The effect of full cost pass-through is that the electricity price will increase the CO_2 cost of the marginal electricity generator, but the price increase applies to the whole output. Thus, the firms with a lower emission intensity than the average marginal generator profit from participating in an emission trading market. Even if they have to purchase all of their emission allowances, the revenue increase from the electricity price will be bigger than the compensating amount from abating emissions (Dechezleprêtre et al., 2018). Although the results from our model cannot provide any definite conclusions on cost pass-through in phase III, the positive electricity price coefficient and the statistically significant p-values does support this hypothesis.

Concluding the results and discussion, our regression models cannot capture any relationship between EUA price and marginal abatement costs. Potentially this is due to inefficiencies in the market that disconnects the carbon price from its fundamentals. Several authors have reached similar conclusions. However, previous research has argued that there are potential weaknesses in estimating relationships in the EU ETS by just using a linear regression model. This is because any long-term relationship between the variables is lost due to differencing (Creti et al., 2012; Koch et al., 2014). Therefore, several studies have included cointegration tests as a robustness check. Perhaps this method would have provided additional information on the relationship between the variables used in our study.

5 Conclusion

This paper aimed at investigating the carbon price dynamics during Phase III. More specifically, we examined to what extent the EUA price can be explained by abatement-related fundamentals—fuel switching—based on the theory on emission markets. Our results show that marginal abatement costs do not explain the fluctuations of the EUA price. Moreover, most of the other included variables that have shown explanatory power in previous research do not provide any statistical significance. Exceptions are coal and electricity prices. However, the latter result should be treated carefully as the variable possibly reflects a case of endogeneity due to a high degree of cost pass-through in the electricity sector.

Given that fuel switching has little to no explanatory power in Phase III, further research should consider alternative approaches to identifying what indeed drives the carbon price. The actual answer to this question goes beyond the scope of this paper. However, the empirical discussion suggests that the market has suffered from inefficiency due to an oversupply of allowances, volatility, and market power exercising. Understanding the price signal of the market is crucial for the effectiveness of future policies in Phase IV and to achieve future environmental reduction targets. The main objective of the EU ETS is to achieve these emission reduction targets at least cost. To achieve this objective, there must be a continued effort towards stabilizing the market so that its participants find credibility in the system and are strongly encouraged to abate their emissions.

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A Appendix

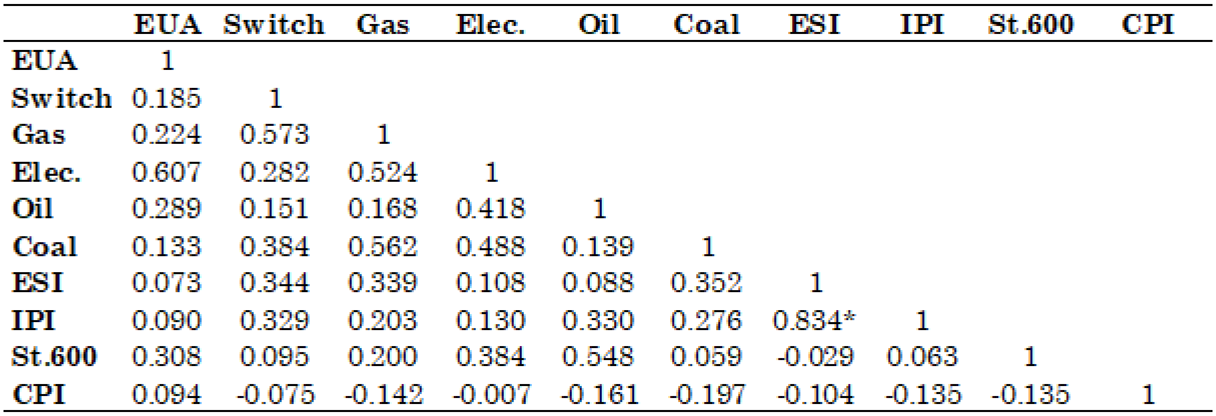
Based on Bertrand (2012), emission and heating rate calculations are as follows:

$$h_c = \frac{MWh_{electric}}{coal(tonne)} = 0.144 * \frac{1}{\eta_c} \tag{6}$$

$$h_g = \frac{MWh_{electric}}{MWh_{thermal}} = \frac{1}{\eta_g} \tag{7}$$

h_c is expressed in tonnes, and h_g in thermal MWh. To attain comparable metrics, coal is transformed. One thermal MWh of coal = 0.144 tonne coal (Bertrand, 2012). η = thermal efficiencies. Effiency rates are extracted from Refinitiv Datastream (2021). The rates are based on industry averages where $\eta_c = 36\%$ and $\eta_g = 50\%$.

In Figure 11 it can be seen that there is the high correlation between ESI and IPI. At a correlation of 0.834 the regression is running a risk of experiencing multicollinearity [7]. As mentioned in the Section 4.1 we account for this by testing VIF.



	EUA	**Switch**	**Gas**	**Elec.**	**Oil**	**Coal**	**ESI**	**IPI**	**St.600**	**CPI**
EUA	1									
Switch	0.185	1								
Gas	0.224	0.573	1							
Elec.	0.607	0.282	0.524	1						
Oil	0.289	0.151	0.168	0.418	1					
Coal	0.133	0.384	0.562	0.488	0.139	1				
ESI	0.073	0.344	0.339	0.108	0.088	0.352	1			
IPI	0.090	0.329	0.203	0.130	0.330	0.276	0.834*	1		
St.600	0.308	0.095	0.200	0.384	0.548	0.059	-0.029	0.063	1	
CPI	0.094	-0.075	-0.142	-0.007	-0.161	-0.197	-0.104	-0.135	-0.135	1

Figure 11: Correlation matrix of asset class returns
* emphasizes high correlation

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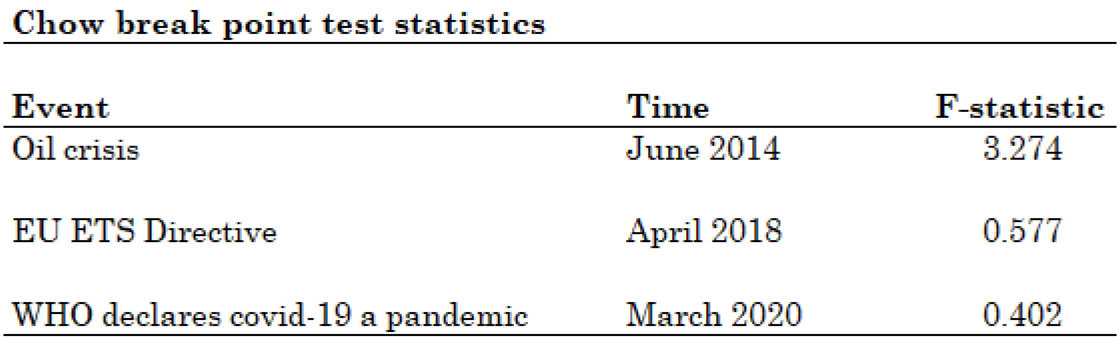
[7] Rule of thumb: $|\rho| > 0.8$ runs a severe risk of experiencing multicollinearity, where ρ represents correlation Grewal et al. (2004)



Chow break point test statistics

Event	Time	F-statistic
Oil crisis	June 2014	3.274
EU ETS Directive	April 2018	0.577
WHO declares covid-19 a pandemic	March 2020	0.402

Figure 12: We reject the null of no break for F-statistic > 1.6