How do Climate Policy Events Shape the Pricing of Carbon in ETS Compliance and Voluntary Carbon Credit Markets?

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Abstract

Carbon pricing is the most important economic tool in the fight against climate change. We study the impact of three important climate policy events, COP 21 in Paris in 2015, the Paris Agreement 2016, and COP 26 in Glasgow 2021 on the pricing of carbon in the EU ETS compliance and the voluntary carbon credit market. Using standard event study methodology and cointegration analysis, we show that these climate policy events have a significant impact on the pricing of carbon. Overall, compliance markets react stronger to climate policy events. On the other hand, voluntary carbon markets price-in expectations of stimulating policy interventions early but then negatively react to disappointing results post-event. We conclude that in order to achieve net zero goals, stronger and more targeted policy interventions for voluntary carbon markets are needed.

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Keywords: Climate Change, Climate Finance, Carbon Emissions, Emissions Trading Systems, Event Study, Voluntary Carbon Offsets

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1. Introduction

Climate change and the ensuing global warming are two of the most defining and pressing problems of this century. Every year, representatives of governments, market participants and other interested parties gather over a two-week period to discuss advances, failures, and new measures to stop or at least slow down the pace of climate change and global warming. These events, referred to as climate conferences (or Conferences of the Parties, COP), take place in changing locations around the globe. The main goal of these conferences is to develop new and improved regulatory frameworks, methods, and measures in the fight against climate change.

Over the last 15-20 years, carbon pricing has emerged as the most important and most powerful economic tool for addressing climate change and global warming. Efficient carbon-price trajectories begin with a strong price signal in the present and a credible commitment to maintain prices high enough in the future to deliver the required changes. Relatively high prices today may be more effective in driving the needed changes and may not require large future increases, but they may also impose higher, short-term adjustment costs (Stern and Stiglitz, 2017). Carbon prices have to generally be higher in order to fund the decarbonization of the global economy and to develop climate change mitigation and adaptation measures. Ours is the first-of-its-kind study that analyses the impact of important climate policy events on carbon pricing.

Carbon offset markets can broadly be divided into compliance carbon markets and voluntary carbon offset markets. Carbon offsets which are eligible for compliance reasons are traded on organized exchanges and are the central part of emissions trading systems (ETS) such as the European Union ETS (EU ETS) or the California Cap-and-trade system. On the contrary, voluntary carbon offsets such as carbon credits resulting from forestry projects are in most jurisdictions not eligible for compliance reasons.[1] In voluntary

[1] There are several exceptions such as the California Cap-and-trade system. However, the California Cap-and-trade only allows the inclusion of carbon offsets from forestry projects up to a certain percentage and only if they are generated from projects in the U.S. As of today, forestry projects that comprise the tropical rainforest is, to the best of our knowledge, not eligible in any compliance market in the world, albeit being the most important source of greenhouse gas emissions resulting from deforestation or forest degradation.

markets, most transactions are still over-the-counter transactions as organized exchanges for voluntary carbon offsets are still in their infant stages.

Carbon pricing mechanisms vary widely across jurisdictions.[2] However, there seems to be broad consensus that economic agents still maintain net emissions exposures beyond compliance market coverage which may be offset with voluntary carbon certificates as the world pushes towards net zero. Voluntary carbon markets are uniquely positioned to facilitate capacity building for climate change mitigation and adaptation especially in developing countries. Although smaller in comparison to compliance carbon markets (Bayer and Aklin, 2020), voluntary carbon projects are important in the fight against climate change and lead to the development of climate-friendly technologies.

In this paper, we study the impact of important climate policy events on the pricing of carbon offsets in compliance and voluntary markets. Specifically, we study the impact of three recent climate policy events on the pricing of carbon. First, we investigate how the Paris Conference in 2015 (COP 21) shaped prices on carbon markets. Next, we analyze the impact of the Paris Agreement in 2016 and, lastly the impact of the Glasgow Conference in 2021 (COP 26) on carbon prices. In the fight against climate change, these events are groundbreaking in many aspects and hence our focus on them in this paper.

We use two empirical approaches to capture the effect of these events on the pricing of carbon. We fist employ standard event study methodology (Campbell et al., 1997; MacKinley, 1997) to estimate the abnormal carbon price reactions prior and after the occurrence of the climate policy events. The event studies we perform will inform us about how expectations formed before the actual occurrence of the climate policy event and how expectations changed – whether they were met or not – after the events. Secondly, we make use of cointegration analyses (Engle and Granger, 1987) to analyze how the price differential between carbon offsets traded on the compliance market and carbon offsets negotiated on voluntary markets behave before and after the respective policy event. The cointegration analysis informs

[2] Compliance carbon markets (277 billion US-Dollars in 2020; Reuters, 2021) are significantly larger than voluntary carbon markets ($473 million US-Dollars in 2020; Ecosystem Marketplace, 2021) in trading volume.

us about whether there was a structural shift in the price behavior of carbon offsets in both markets as a response to the outcomes of the climate policy events.

We obtain several interesting and important results that may help to better understand the pricing of carbon offsets in both markets and to better understand market participants' reactions to the outcomes of important climate policy events. The principal finding is that climate policy events matter significantly for carbon offset pricing. However, they seem to matter differently for compliance and voluntary carbon offset markets and is shaped by different pre-event expectations of market participants. Market reactions are generally positive when pre-event expectations are met or surpassed and negative otherwise. While this result is expected and therefore not surprising in itself, it is surprising that in most cases, the compliance market participants seem to be satisfied with the outcomes of the climate policy events while voluntary market participants generally are not. Otherwise stated, the climate policy events we study in this paper seem to have catered more to compliance carbon offset markets than to voluntary carbon offset markets.

On the cointegration tests, we also make the interesting observations of (i) a relative price inversion between voluntary and compliance carbon market price proxies (voluntary proxies increase more rapidly than compliance proxies) two or close to two months before the events and (ii) cointegration relationships between compliance and voluntary carbon market proxies before the Paris Conference vanish post event. We interpret these results to be synonymous of a structural break or decoupling of voluntary and compliance carbon market prices post Paris Conference.

This paper contributes to several strands of literature. First, it contributes to the literature on climate change in general. Secondly, it contributes to the literature on climate finance. Thirdly, it most specifically contributes to the new strand of literature on carbon asset pricing.

The remainder of the paper is organized as follows. In Section 2, we give an overview of the key institutional facts about carbon markets. In Section 3, we present our empirical approaches to investigate if and how climate policy events shape carbon offset markets. The event study and cointegration analyses results are presented in Section 4. Section concludes and provides some policy implications of our findings.

2. Institutional background and data

2.1. Key institutional facts about carbon markets

From a market framework and policy perspective, the Kyoto Protocol was the United Nations Framework Convention's (UNFCCC) first detailed and broadly accepted framework for addressing climate change. It provided Annex I (developed) countries the opportunity to fulfill their Kyoto emissions reduction obligations by developing carbon projects in Annex II (developing) countries. Annex II countries, with the financial support received from Annex I countries for developing carbon-based projects could pursue their own sustainable goals. The Kyoto Protocol introduced three market-based mechanisms: the international emissions trading system (ETS), the Joint Implementation (JI) and the Clean Development Mechanism (CDM). Instead of Kyoto's top-bottom approach, other climate conferences, such the Paris Climate Conference have sought to implement a bottom-up approach (Popovski, 2018).

The Paris Climate Conference was significant in the context that it represented the first time 196 countries signed a binding climate agreement defining the key goal of limiting global warming to well below 2ºC, preferably to 1.5ºC compared to 1850.[3] A key provision in the Paris Agreement is the country obligation to submit five-year ambition plans on nationally determined contributions (NDCs). Under the NDCs, countries would report on concrete actions taken to reduce greenhouse gases in their bid to meet the Paris Agreement goals. In Article 6.2, countries may bilaterally or pluri-laterally trade emissions reductions or removals. The seller country may sell any additional emissions reductions or removals, after or on track towards meeting its own Paris climate pledge. The buyer country would be any nation that has or will fall short against its own goals (Hamrick et al., 2021). A particular sticking point in the Paris Agreement were the negotiations around Article 6.4 of the Parisian rulebook. Article 6.4, while left unfinalized, intended a framework for voluntary cooperation between countries by introducing new mechanisms to meet climate mitigation requirements called the Sustainable Development Mechanism (SDM). A body of Climate Finance literature depicts SDM as the successor to the CDM (Schneider and La Hoz Theuer, 2019).

[3] Peters et al, 2013, UNFCC, 2011 highlight the 'significant gap' between the current trajectory of global greenhouse gas emissions and the likelihood of limiting global temperature levels to below 2ºC above pre-industrial levels

Subsequent attempts to finalize Article 6.4 in particular, proved unsuccessful at the Madrid Conference of Parties (COP) in 2019. In spite of the significance of the Paris Climate Accord, the expectation through the NDCs was to see countries return to subsequent COPs with more ambitious targets.

The Glasgow Climate Conference (COP 26) represents the current state of global policy in the fight against climate change and global warming. Market developments are a result of the prevailing regulatory and policy environment (Levich and Walter, 1989). On this backdrop, COP 26 refocused the conversation on climate change among others on mitigation, adaptation finance and the use of the best available science in making climate change assessments. Decarbonizing the global economy requires broad collaboration across all sectors (Kronshell et al., 2019). In this regard, a number of important commitments were made at COP 26. The Glasgow Financial Alliance for Net Zero pledged more than 130 trillion US-Dollars over the next three decades to combat climate change. Other major commitments from Glasgow included the "phase down" of coal, the removal of fossil fuel subsidies and the elimination of illegal deforestation by 2030. Regarding Article 6 of the Paris Climate Accord, Glasgow COP 26 delegates only agreed to avoid "going backwards" in their governments' levels of ambition.

The rapid and sustainable large reduction in human-driven carbon emissions is critical to achieving the net zero targets specified in the Paris Climate Agreement. While carbon pricing does not address all the critical challenges of transitioning to an energy system void of fossil fuels (Patt and Liliestam, 2018), carbon pricing is broadly accepted as one of the most important tools in the fight against climate change (Rogelj et al., 2018). Carbon markets may be classified broadly into two groups: compliance markets, also known as cap-and-trade schemes, and voluntary carbon markets. Compliance-based certificates offer the holder a real long option to pollute, backed by a regulator. A holder exercises this real option by emitting the CO_2 equivalent of the certificate held. Compliance schemes offer regulators the flexibility to reduce the cap of emissions thresholds over the compliance period and hence drive technological innovation and efficiency.

The EU Emissions Trading System (EU ETS) was the world's first compliance market, introduced in 2005. The EU ETS comprises primary and the secondary markets. The primary market is an auction platform where agents directly purchase certificates. The secondary market facilitates agent interactions on exchange and OTC platforms and provides liquidity and price support. The major participants in the EU ETS include utility firms and banks. Utilities sell a significant share of their power one to three years ahead of delivery often for project financing reasons and manage price risk until delivery. Corporate risk management requires that contracts for fuel and carbon input are signed in parallel. This creates hedging needs for carbon emissions (Schopp et al., 2015). Risk management requirements typically mean that utilities have limited capacity to bank beyond their hedging needs. Surplus certificates thus require market participants that acquire allowances as speculative investments. Surplus certificates provide a market for speculators who pursue shorter-term small-scale investments in emissions certificates to arbitrage price changes, thus providing liquidity and reducing short-term fluctuations in the market. Arbitrage is mostly pursued by banks. Emissions certificates since phase II are bankable at zero cost. Banks can thus procure significant amounts and sell them on the forward markets (Betz et al., 2016).

In the EU ETS, when agent interactions do not yield sufficient support for price, the regulator still has supply side tools to sustain prices. In 2014, the European Commission designed a Market Stability Reserve (MSR) in a bid to provide price stability in the EU ETS. These unilateral market interventions are a means of managing an over or under-supplied carbon market by removing or releasing certificates from reserve (EU COM, 2014).

Participation in voluntary carbon markets is on a non-compulsory basis. Voluntary carbon market participation has gained in popularity over the last decade, fueled by Environmental, Sustainability and Governance (ESG) investors and net-zero commitments of corporations. Corporate carbon-neutral pledges drove a record 104 $MtCO_2e$ of transaction volume in 2019 (<60 $MtCO_2e$ in 2010) (Ecosystem Marketplace, 2020). Compliance schemes currently do not cover the entire economy. Voluntary markets remain the only existing viable market mechanism for offsetting unregulated agent carbon exposure.

Even though there is broad consensus about the need for (efficient) carbon pricing, economists, politicians, scientists and climate activists differ in what the fair price of carbon should be. The battle of competing incentives and interests makes carbon pricing an extremely complex topic (Fairbrother et al., 2019).[4]

Compliance and voluntary markets place very different prices on carbon emissions. The price differential between compliance and voluntary carbon certificates is important. Low voluntary carbon prices disincentivize voluntary carbon project providers from issuing certificates and sets voluntary participants at comparative price disadvantage to compliance certificate holders. The role of appropriate prices on emissions is a central part of public policies to encourage the development of technologies that will combat global warming (Nordhaus, 2011). Low prices are not likely to provide sufficient incentives for low carbon technological advancements either. A direct consequence may be deforestation instead of afforestation.

The carbon pricing gap – which compares actual carbon prices and real climate costs, estimated at €30 per ton of CO_2 – was 76.5% in 2018. This compares favorably with the 83% carbon gap reported in 2012 and the 79.5% gap in 2015, but is still insufficient (OECD, 2018). At the current pace of decline, carbon prices will only meet real costs in 2095 (OECD, 2018). Lower prices for voluntary carbon certificates imply less funding for accomplishing the economic scale sustainability and climate change mitigation actions need to achieve. As such, it is important to understand drivers of the huge disparity in the price characterization of compliance and voluntary market certificates while finding economically viable and sustainable policies for bridging the pricing gap.

2.2. The EU ETS phases

Since its introduction in 2005, the EU ETS has developed in phases. Phase I was a pilot study to understand how the market would and needed to function. 15 European countries participated in this phase, lasting from 2005 to the end of 2007. Country certificate allocations were mostly grandfathered in this phase. Concerns over overallocation and measurement of actual and verified emissions led to a price collapse in

[4] Economists speak in this context of a carbon tax. Gillingham and Stock provide a comprehensive discussion and an overview on this topic (2018).

2007 (Hintermann, 2010). In addition, Phase I certificates could not be banked for use in Phase II. Phase I certificates expired on 31 December 2007.

Phase II spanned 2008 to 2012 with a 6.5% emissions cap reduction and ran concurrently with the introduction of the CDM and JI. Futures trading in Phase II EU ETS certificates existed already in 2007. This resulted in the redirection of demand to Phase II credits and accelerated the demise of Phase I. Similar to Phase II, market concerns over oversupply, quality and additionality of credits issued under CDM were partially responsible for the collapse of the EU ETS to under 5 €/t by the end of 2012 (Aatola et al., 2013; Alberola et al.; 2008; Koch et al., 2014).

Phase III of the EU ETS ran from 2013 to 2020 with 31 countries. Significantly, the EU introduced a single EU-wide emissions cap to replace national caps. Phase II credits were bankable and provided the added benefits of price stability for EU ETS certificates until 2018 where we observe an upward structural break in price [see figure 1].

Phase IV runs from 2021 to 2030 with a yearly cap reduction set at 2.2%, replacing the previously set 1.74% cap. The EU ETS Carbon price has risen sharply since the beginning of 2021 with the cap reduction increasing the upward price squeeze. Demand sources for the EU ETS are regulatorily fixed. Utilities in particular, have to pay more for balancing their carbon footprints as the substitution effect partly due to soaring natural gas and coal prices in 2021.

2.3. Data

In the event study and cointegration analyses, we use publicly available time series datasets as proxies for prices on compliance and voluntary carbon markets. For compliance market prices, we use the prices of the EU ETS (European Allowances, EUA). The datasets used as proxies for prices on voluntary carbon markets in this paper are as follows.

Certified Emissions Reductions (CER)

CDM and JI introduced certified project-based carbon reduction solutions and their related credit issuances. Carbon credits issued out of CDM-certified projects are referred to as Certified Emissions

Reductions (CER) while those under JI were referred to as Emission Reductions Units (ERU). Under CDM, a single CER credit is a ton of greenhouse gas emission reduction and qualifies for meeting emission reduction obligations under Kyoto. Credits are connected to a carbon project in a developing country which are issued following verification of the project methodology under CDM standards approved by the CDM Executive Board.

It is important to distinguish between CERs and verified emission reduction certificates (VERs). VERs aim to neutralize carbon footprints and are motivated mainly by Corporate Social Responsibility, reputation and environmental and social benefits. The main difference to CER therefore is that VERs do not qualify for emissions reductions under Kyoto. When subjected to CDM-certification standards, however, VERs may be converted to CERs (Yuvaraj and Babu, 2011). Anticipated climate change regulation and increasingly rigorous CDM approvals (in the Kyoto commitment period I) boosted the amount of CDM 'pre-compliance' credits reaching the voluntary market, because a large number of CDM offset projects were being held up or rejected (Lovel, 2010) on concerns about additionality of CDM-certified projects. It is estimated that at least 83% of CDM credits used by German companies in 2008 and 2009 were of questionable environmental integrity (credits from HFC-23 and adipic acid projects) (Hermann et al., 2010). Ultimately, the European Commission decided to exclude the use of specific CERs (nuclear, energy, HFC-23 and N2O and afforestation activities) while introducing quantitative restrictions on the eligible international credits in the EU ETS from May 2013 onwards.

On the basis of the above, we consider CER to be more representative of the voluntary carbon market than the compliance market in the events we analyze. In particular, we use the CER time series prices as a proxy for voluntary carbon markets for the analyses of the Paris Climate Conference and Agreement events.

Figure 2 shows the development of compliance market (EUA) and voluntary market (CER) prices over parts of the Kyoto compliance periods I (Jan 2008 – Dec 2012) and II (Jan 2013 – Dec 2015). Price time series for EUA and CER were obtained from Datastream. The figure shows that compliance market prices in the entire time period depicted in the figure were above voluntary market prices as proxied by

CER. The figure also shows that the price movement and differential were stable until approximately July 2012. From then onwards, we observe a decoupling of prices between the two markets. While prices in the voluntary markets fell sharply to very low values until January 2013, compliance market prices did not. CER prices remained at very low levels until October 2016, the end of the time period depicted in the figure. On the other hand, EUA prices trended upwards until the Paris Conference 2015 and afterwards it hovered around 5 €/t until October 2016.

Global Emissions Offset Futures (GEO) and Nature-based GEO (N-GEO)

The GEO Global Emissions Offset futures index was launched by the Chicago Mercantile Exchange (CME) Group in March 2021. It provides delivery of physical carbon offset credits from three different registries: VCS (Verified Carbon standard), ACR (American Carbon Registry) and CAR (Climate Action Reserve) as the underlying. GEO-based offsets meet the eligibility criteria for the Carbon Offsetting and Reduction Scheme for International Aviation (CORSIA) program.

Similar to GEO, N-GEO offers the possibility for corporations to offset net carbon emissions using nature-based agriculture, forestry and other land use (AFOLU) projects. Launched in August 2021 by the CME Group, N-GEO projects are registered under the Verified Carbon Standard (VCS) and Climate Community and Biodiversity Standards (CCB) labels. Price time series for and GEO and N-GEO were obtained from Bloomberg.

GEO and N-GEO bring transparency to the price discovery process in the voluntary market and offer risk and portfolio managers new tools for managing net emission exposures and risks. Due to their relative short pricing history, we can only consider GEO and N-GEO as proxies for the voluntary carbon market for the event study surrounding the Glasgow Conference. Figure 3 shows the prices of GEO, N-GEO and EUA since 2021.[5] The figure shows that the prices for voluntary carbon credit offsets were relatively stable until August 2021, but after that a clear upward price trend could be observed. Both GEO

[5] GEO and N-GEO are scaled by factor 10 for ease of graphical representation. Hence, the absolute levels cannot be interpreted easily, but only the relative increases vis-à-vis each other and the compliance market.

and N-GEO increase till the end of November with the N-GEO showing a stronger increase particularly in the days before the Glasgow conference. The EUA prices, shown in absolute levels in the figure, also show an overall upward trend. Starting from a price level of 40 €/t in February 2021, they increased to around 75 €/t by the end of November 2021, almost twice as high as the starting level. We conclude that prices on both compliance and voluntary carbon markets increased significantly in 2021 with a relatively bigger price increase on voluntary carbon markets therewith diminishing the pricing gap between compliance and voluntary carbon offsets.

3. Empirical Approach

We study the impact of three climate policy events and their impact in shaping prices and price differentials on compliance and voluntary carbon markets, the Paris Climate Conference, the Paris Climate Agreement and the Glasgow Climate Conference. We use two different methodologies to investigate our research question. First, we apply standard event study methodology (Campbell et al., 1997; MacKinley, 1997) to analyse the price effects of climate policy events on compliance and voluntary carbon offset markets. For the event study, we make use of the constant mean return and for robustness, the market model, as is standard in the finance and economics literature.

The Constant Mean Return Model and the Market Model

The first model we apply to compute abnormal (AR) and cumulative abnormal returns (CAR) is the constant mean model. First, we compute daily returns of the ETS prices and respective indices described above. Let daily observed returns be denoted by r_t obtained by first differencing the price time series:

$$r_t = \text{In}\left({}^{P_{t+1}}/_{P_t}\right) \qquad (1)$$

To estimate the constant mean model, we further need to make use of a training or estimation window in which the normal return is computed. In our case, the training window comprises 265 days before each event. We estimate the mean return of the training window as follows:

$$r_{avg} = \frac{1}{T}\sum_{t}^{T} r_t \qquad (2)$$

where T is the number of trading days in the training window. In a second step, we compute the abnormal returns (AR). Define an event window [-t, t] each for the Paris Climate Conference, the Paris Climate Agreement and the Glasgow Climate Conference. Then the abnormal return for the t*th* day may be characterised as:

$$AR_t = \mathrm{r_t} - r_{avg} \qquad (3)$$

And the cumulative abnormal return (CAR) as:

$$CAR = \sum_{\forall\, t} AR_t \qquad (4)$$

The final step is to test the null hypotheses that the CAR before and after the event is zero.

Second, we apply the market model to test for significant CARs. We make use of the classical event study methodology that relies on the market efficiency hypothesis (Fama et al., 1969), initially applied mainly to corporate finance research, but also, for instance, within the field of regulatory economics (Jong et al., 2014). The market model implicitly assumes that markets are efficient: if all available information impacting voluntary and compliance carbon prices are already incorporated in the observed price, then the importance of an event for price discovery should be negligible. The market model serves as a robustness test for the results we obtain in the constant mean model. We use the KraneShares Global Carbon ETF and the Barclays Ipath Global Carbon ETN as proxies for global carbon prices. Both datasets are obtained from Datastream.

The KraneShares Global Carbon ETF seeks to outperform the IHS Markit Global Carbon Index and thus provides exposure to the EU ETS, the California cap-and-trade scheme and the Regional Greenhouse Gas Initiative (RGGI) in effectively 0.70:0.22:0.08 weights respectively as of November 2021. We choose KraneShares due to the public availability of the data and the empirical benefit of a global carbon exposure, albeit mainly to compliance markets. KraneShares has a short history, beginning in July 2020 and is, hence, only used in the market model for the Glasgow Conference event study.

For the Paris event studies market models, we use the Barclays Ipath Global Carbon ETN. The Barclays Ipath Global Carbon ETN offers exposure to the EU ETS and CER in the ratio 99.97% ICE ECX EUA FUTURES to 0.03% ICE ECX CER FUTURES. It tracks the Barclays Global Carbon II TR USD Index ("Original Index"). In 2017, the Barclays Ipath Global Carbon ETN was replaced with Barclays Global Carbon II TR USD Index ("Successor Index").

There are a reasonable number of days within our Paris training window where CER prices were zero and had no traded volumes. We expected this to impact our results and lead to less informative training windows. To account for any bias resulting from this, we also implement a trade-by-trade approach as done in Dimson (1979) and Marsh (1979) and show results alongside the unfiltered trading window.

To estimate "abnormal" returns in the market model, a business-as-usual estimate is required. We derive abnormal returns caused by events from an OLS regression for each of the price time series. The OLS regressions are defined as follows:

$$r_{i,t} = \propto_i + \beta_i r_{m,t} + \varepsilon_{i,t} \qquad (5)$$

These OLS regressions are run in a sufficiently large time period of 265 days before each event, in the training window. Plugging in the training window intercepts $\widehat{\propto_i}$, $\widehat{\beta_i}$ and event window's realized return $\overline{r_t}$ for price time series i and market return (r_{mt}) into Eq. (5):

$$r_{i,t} = \widehat{\propto_i} + \hat{\beta}_i r_{m,t} + \varepsilon_{it} \qquad (6)$$

The error term ε_{it} is the abnormal return (AR_{it}). We aggregate AR over the event window as in (4) to obtain CAR. As with the constant mean model, we test the null hypothesis that AR and CAR are 0 at 90%, 95% and 99% confidence levels. The underlying logic is that if these returns are significantly different from 0 during the event window, they will not revolve around zero but maintain a new level in what will be a structural break caused by the event.

3.2. Cointegration Model

In a second set of tests, we make use of cointegration analysis. This is a formal test for structural breaks or decoupling of compliance from voluntary carbon prices. Cointegration (Engle and Granger, 1987) has been traditionally used to address spurious correlation due to non-stationarity of time series data and to establish long and short run relationships between variables. In this study we test for whether voluntary and compliance carbon market prices are co-integrated before and after events. We use a 6-month window length for the cointegration analysis, hence, covering 12 months in total.

Before carrying out cointegration tests, we determine the optimal lag lengths for price time series variables using the Akaike Information Criterion (AIC). In the training window pre-event, we define a generalized VAR specification using Johansen (1987) as follows:

$$X_t = \mu + \Pi_1 X_{t-1} + \cdots + \Pi_k X_{t-k} + \varepsilon_t \qquad (7)$$

We re-write the model in first differences using the lag operator Δ:

$$\Delta X_t = \vartheta + \Gamma_1 \Delta X_{t-1} + \cdots + \Gamma_{k-1} \Delta X_{t-k+1} + \Pi X_{t-1} + \varepsilon_t \qquad (8)$$

where $\Gamma_i = -(\Pi_{i+1} + \cdots + \Pi_k)$, i=1, …, k-1

and $\Gamma_i = -(I - \Pi_1 - \cdots - \Pi_k)$

In our case:

X are 2x1 vectors in each case, i.e., EUA and CER, EUA and GEO, and EUA and N-GEO.

We interpret model results as follows:

If:

I. rank (Π)=p, then X_t is stationary and the rank is full

II. rank (Π)=0, then Π is a zero matrix and there is no relationship between the variables

III. 0 < rank (Π) $= r$<p, then Π is of reduced rank and there exists two p x r matrices $\alpha \; and \; \beta$ such that $\Pi = \alpha\beta'$. In III, the cointegrating vector or matrix β has a stationary process creating property if

multiplied with the vector X_t which coincidentally means the two variables are cointegrated. Equation 7 resolves to the error correction model.

Next, we test the rank of Π using Johansen and Juselius (1990). We test the null hypothesis

H_0: $\exists\ r$ cointegration relationships

H_1: $\exists\ r+1$ cointegration relationships

This is the maximum eigen value test which is χ^2-distributed with the test characterized as follows: $-T.In(1-\ \lambda_{r+1})$, where λ are the eigenvalues.

We also conduct a trace test as suggested by Johansen and Juselius (1990) characterized as follows:

$$-T.\sum_{i=r+1}^{p} In(1-\ \lambda_i)$$

After this, the last step is to estimate the cointegrating vector β. What we define is the cointegrating space using an arbitrary normalization vector, i.e., setting the coefficient for one variable equal to one. We use Phillips (1991) triangular representation to conveniently simulate a cointegrating vector $\beta = (1, -\hat{\beta})$ for the bivariate co-integrated system $X = (X_1\ , X_2)$. The estimator β becomes a consistent estimator. We use the Augmented Dickey-Fuller test to show stationarity of the cointegration vector derived by multiplying β with X_t. In the post-event window, the same vector β is used to build the cointegration vector and to test if stationarity is preserved. Otherwise, this would be proof of a structural shift in the price relationship in X.

4. Results

4.1. Event study results for the Paris Conference (COP 21)

We start by presenting the descriptive statistics for all indices used in the empirical analyses. We present mean, standard deviation, median and 5- and 95-percentiles in the respective training windows. Table 2 contains the values. For both, the Paris Conference in 2015 and the Paris Agreement in 2016, we can make use of a 265-day training window. For the Paris Conference, the Barclays Index has the highest mean return, albeit with relatively small differences between it, EUA and CER. Interestingly, the standard deviation of

CER is quite high, suggesting that there was a significant price volatility in voluntary carbon offset markets one year before the Paris Conference, regardless of price levels. For the Paris Agreement, the mean returns in the year leading up to the event are all negative, but again relatively similar in magnitude. For the Glasgow Conference comparable means for GEO and N-GEO that are much higher than the means for EUA and the KranShares index. This confirms the finding from Figure 2 which showed a much steeper increase in voluntary carbon offset prices. Interestingly, the median return for GEO is zero, while it is positive for the other three with the highest median for N-GEO with 0.80%.

For the empirical analyses, we employ three models for our tests, the constant mean model, the market model and a cointegration approach. While the first two serve to investigate the impact of the climate policies on the price levels of compliance and voluntary carbon offsets, the cointegration approach seeks to identify any structural shifts in prices between compliance and voluntary carbon price proxies. Hence, the results of the cointegration test speak to the development of the price differential between both markets prior and after the policy events. As described above, the EUA is used as a proxy for the compliance market while CER, GEO and N-GEO are used as proxies for the voluntary carbon market. Figure 4 shows daily ARs and CARs for EUA using the constant mean return model for the Paris Conference.

In the pre-conference window, the ARs for EUA are mostly negative with the exception of two days, November 30 and December 3, 2015. Consequently the CARs in the pre-conference period trend downwards. This suggests negative expectations of the conference outcomes of participants in compliance carbon offset markets. On the other hand, in the post-conference period, there were almost as many positive as negative ARs. As a result, the CARs does show a light upward trend.

The results depicted in Figure 5 suggest a different reaction of prices in voluntary carbon offset markets. Most of the ARs pre and post conference are negative. As a result, we can see a strong negative CAR trend pre-conference that continues also post-conference. It seems that there were negative expecations before the start of the conference and that the conference outcomes did not reverse these expectations.

Table 3, Panel A shows the results for the event study using the constant mean return model. The null hypothesis is that CARs pre and post event are statistically different from zero. Pre-conference CARs for EUA (-1.87%) in column (1) and CER (-7.54%) in column (2) are significantly negative at the 5%-(EUA) and the 1%-level (CER), statistically confirming the graphical results from Figures 4 and 5.

The Paris Conference as an event was significant for adaptation finance by widening the normative framing around adaptation and calling for stronger adaptation commitments from states (Lesnikowski et al., 2017). It proposed a legally binding framework 196 countries would eventually agree to and defined the key goal of limiting global temperature increase to below 2ºC, preferably to 1.5ºC compared to 1850 and introduced 5-year renewable NDCs. Compliance carbon offset markets clearly reacted positively as shown in column (1) by a CAR of 1.74% which is significant at the 5%-level. On the other hand, the CAR for voluntary carbon offsets is still negative and significant at the 5%-level with a size of -5.42%. However, while the CAR is by itself negative, it is smaller than the pre-conference CAR with a difference of 2.12%. This is suggestive of participants in voluntary carbon markets reacting somehow positively to the outcomes of the Paris Conference as well. When we use the trade-by-trade approach (depicted by CER*) the results in column (3) are qualitatively similar, but smaller in size and not significant for voluntary carbon offset markets.

The results for the market model are shown in Panel B of Table 3. The pre-event CAR for EUA is now positive and significant at the 5%-level (with a magnitude of 1.78%). This stands in contrast to the results we obtained when using the constant mean return model. The post-event CAR continues to be positive and highly significant, confirming the previous result. For the CER, the CARs in the pre- and post-event window confirm the results from the constant mean return model. Both are negative, highly significant and of similar size as before. In addition, the difference between the pre- and post-event CAR is similar to before. For the CER using the trade-by-trade method, we find a similar result to before pre-event, but a positive and significant CAR in the post-event window. This stands in contrast to the previously found post-event CAR, which was negative, small and not significant. While most results are very comparable between the constant mean and market models, it seems that the model choice impacts to some extent the CARs surrounding the Paris Conference.[6]

4.2. Event study results for the Paris Agreement

The negotiations of the Paris Conference outcomes culminated in the Paris Climate Agreement released on November 4, 2016. We make use of the Paris Agreement as the second policy event to study. For this event, we use a smaller event window as the event took place on one particular day and did not stretch over a time period of several weeks as the climate conferences. For this reason, our event window spans only 6 days before and after the agreement rather than the 11 days pre and post that we applied to the climate conference event studies. As before, we begin by presenting some graphical evidence.

Figure 6 shows the ARs and the CARs before and after the event date. In the pre-event period, we see only positive abnormal returns, while on the event date itself and in the 6 days after the event only negative abnormal returns. This is quite striking as it clearly suggests very optimistic expectations of participants in the compliance carbon offset markets. However, when the agreement was finally adopted, the market was apparently disappointed. Figure 7 shows the ARs and CARs for the voluntary carbon offset market (CER). Before the event, there were almost exclusively positive abnormal returns (apart from one very small negative abnormal return). In particular, there was one day with a very high abnormal return. Overall, this resulted in increasing CARs. As in the case of the compliance market, voluntary market participants were apparently very optimistic about the final outcomes of the Paris Conference. However, shortly after the final agreement was approved, market participants reacted strongly negatively. This was followed by a series of positive reactions of smaller magnitudes.

Table 4 shows the significance tests of the CARs for both EUA and CER. The constant mean return model results are depicted in Panel A. In the pre-period, both CARs were positive (6.52% for EUA and 2.94% for CER) and highly significant. The CAR for the compliance market carbon offset was more than

[6] Graphical evidence for the constant mean return model for the CER using the trade-by-trade approach and for the market model is provided in Appendix Figures A1 and A2, respectively. Another reason may be that the market index used – the Barclays Index – is predominantly compliance driven, with only 0.3% weight to CER.

twice as large as for the voluntary market. For the post-period, we find a negative, but only weakly significant CAR for the compliance market (-5.82%) and a negative and highly significant CAR for the voluntary market (-2.23%). The most striking finding is that both, positive and negative reactions are very similar in size, therewith nearly cancelling each other out. The results for the voluntary market using the trade-by-trade approach confirm the findings for the voluntary market. The results when using the market model are very similar with regard to magnitude and significance.[7] This suggests that the positive build-up of expectations in both markets was disappointed by the final agreement and that overall, markets were not affected (at least not in the short run). The Paris Agreement did neither have a significant impact on carbon offsets in the compliance nor in the voluntary market.

Some studies portray the Paris Agreement as not ambitious enough. In fact, from our results we cannot conclude that the legally binding character of the Paris Agreement matters in a significant way for carbon markets (Bodansky, 2016). There were no defined repercussions for countries which did not honour their NDCs. In effect, both the compliance and the voluntary market judged the agreement to not be far-reaching enough. This suggests that the Paris Agreement needed (more) effective mechanisms in order to provide satisfactory results (Cherry et al., 2021).

4.3. Event study results for the Glasgow Conference (COP 26)

The third policy event that we study is the Glasgow Conference (COP 26) that took place in November 2021. Figure 8 shows the daily ARs and CARs for EUA using the constant mean return model for the Glasgow Conference. In the pre-conference window, EUA reports an equal number of days with positive and negative AR. As the positive ARs are bigger in magnitude, the CAR is upward trending. This trend continues in the post-evend window. In fact, it becomes even stronger after the end of COP 26. Although there are some days with negative ARs, the number of days with positive ARs is higher and the magnitudes are bigger. Figure 9 shows the daily GEO ARs and CARs for the Glasgow Conference. We find a similar pattern in the voluntary market as in the compliance market with the difference that the magnitudes are

[7] Graphical evidence for the constant mean return model for the CER using the trade-by-trade approach and for the market model is provided in Appendix Figures A3 and A4, respectively.

even bigger. On the other hand, after the end of the conference, we find overall more negative than positive ARs resulting in a downward trend for the CAR. Finally, in Figure 10[8], we depict the ARs and CARs for N-GEO. The pre-conference ARs and CARs are very similar to the GEO case. Contrary to GEO, however, we do not find a downward trend for N-GEO, but first a constant CAR and then an upward spike at the end of the event-window.

These results suggest very optimistic expectations of COP 26 by market participants in both compliance and voluntary carbon offset markets. While it seems, at least in the short run, that these expectations were fulfilled for carbon offset prices in compliance markets, market participants in voluntary markets appear to have overall been disappointed by the outcomes of COP 26. However, it is also important to note that voluntary carbon offset prices for nature-based solutions reacted differently, at least the expectations of those market participants seem to have been partially fulfilled.

Table 5 provides the event study results for the Glasgow Conference. Panel A presents the results using the constant mean return model. For the EUA we see a positive, but not significant CAR, while for GEO and N-GEO a large and highly significant positive pre-event CAR. The GEO CAR is 5.22% and the N-GEO CAR 12.65%, more than twice as large than the GEO CAR and about 10 times as large as the EUA CAR. On the other hand, we see a very large and highly significant CAR for EUA in the post-event window, a negative and significant CAR for GEO and a positive and highly significant CAR in the post-event window for N-GEO. These results confirm the findings from the graphical analysis. All results are confirmed when the market model is used (Panel B), with the major difference being the size of the post-event CAR for EUA, which is only about half the size of the constant mean return model post-event CAR.

The Glasgow Conference produced a number of key outcomes and commitments critical to the decarbonisation of the global economy. The Parties agreed to remove fossil fuel subsidies and to phase out the usage of coal by 2030. Further to that, the Parties agreed to eradicate illegal deforestation by 2030 and to incentivize global finance to be sustainability conscious. While it remains to be seen how COP 26 outcomes will actually be implemented, compliance markets appear to have embraced them more. One

[8] The results shown in Figures 8-10 are all based on the constant mean return model.

reason for this reaction could be the structural features of compliance markets. Compliance carbon markets are shaped by market frameworks and regulation. For example, implementation of the coal phase down implies that utilities will have to choose between cleaner technologies for energy production or contribute to upward demand pressures on compliance carbon certificates.

Interestingly, GEO prices – proxying voluntary carbon markets minus nature-based certificates – decreased in the post-event window. Although a major outcome for voluntary carbon markets at COP 26 was adaptation finance, which was promised at COP 15 in 2009, the 100 billion US-Dollar target is now only scheduled to be achieved by 2023. Adaptation finance was and will remain important to low income and developing countries that are likely to be impacted most by the effects of climate change (Puig et al., 2016). On the other hand, N-GEO overall increased. One of the reasons for this could be that the Parties agreed to end illegal deforestation by 2030. This should entail an increase in demand, for instance in projects of avoided deforestation, which drives up prices for carbon credit offsets resulting from such projects.

4.4. Cointegration results for the Paris Conference and the Glasgow Conference[9]

Our second set of results consists of cointegration tests of the different price series. The cointegration results provide additional insight into how the policy events shape voluntary and compliance carbon markets. In particular they inform us about the development of the price differential between compliance and voluntary carbon offset prices and whether a decoupling or structural shift of the two markets occur as a result of climate policy events.

We first investigate the stationarity of the price differential between compliance and voluntary carbon prices by testing for stationarity of the cointegration process derived in Section 3. Figure 11 shows the co-integrating process and the price differential between EUA and CER using a time window of 6 months before the Paris Conference. We observe visually that the co-integrating process appears stationary

[9] We do not show cointegration results for EUA-CER for the Paris Agreement pre and post. The occurrence of too many zero prices for CER (especially post event) make the length of the co-integrating vector relatively small and hence turn it not useful for interpretation.

before the Paris Conference. It is worth noting there is a relative price inversion[10] on October 4, 2015, two months before the conference. CER prices, the proxy for voluntary carbon offset prices indicate higher price returns than for compliance carbon prices (EUA). We interpret this observation as an increased expectation price-in for voluntary carbon markets ahead of the Paris Conference.

Figure 12 replicates Figure 11 with the only difference being that we observe the co-integrating process and price differential between EUA and CER post Paris. We visually observe non-stationarity of the cointegrating process. For the Glasgow conference, we show the cointegrating process and price differential between EUA and GEO 6 months ahead of the conference in Figure 13 and visually observe stationarity between the two. It is also worth noting there is a price inversion between GEO and EUA close to two months before the Glasgow Conference. Again, we interpret this observation as a pricing-in of voluntary carbon market expectations shortly before the start of the Glasgow Conference.[11]

In Table 6, we present the cointegration test results pre and post Paris Conference and pre-Glasgow conference using Johansen Eigenvalue and Johansen Trace test. We include Augmented Dicker-Fuller test results for stationarity of the cointegrating process for each of the Johansen tests[12]. We test the null hypothesis that the rank (r) of the cointegrating vector is equal to zero. Rejecting the null means there is at least one cointegration relationship between the prices. Rejecting $r \leq 1$ implies there exist two cointegrating relationships between the prices in our case[13]. We argue that the absence of a cointegrating relationship reflects a structural shift or break in the pricing relationship between compliance and voluntary carbon markets. We observe a weak (p-value of 0.10) co-integrating relationship between EUA and CER pre-Paris in ADF tests which does not exist post Paris (p-value 0.87). For the Glasgow Conference, we observe a stronger cointegration relationship pre-conference between EUA and GEO (p-value of 0.01), but not

[10] CER is scaled by factor or 15. While we test cointegration on prices, the relative price inversion discussed is synonymous with higher price returns for CER compared with EUA in the lead-up to the Paris Conference
[11] We do not show cointegration visualization results post Glasgow for EUA, GEO and N-GEO as there are not sufficient data available.
[12] The beta generating of the cointegrating process derived from the generalized VAR specification is not necessarily unique and hence dependent on the cointegration test
[13] We exactly have a 2x1 cointegrating vector in each case. Max number of cointegrating relationships is 2.

between EUA and N-GEO. However, it is important to note that the price series for N-GEO begins only in August 2021, hence, we are not able to cover the full six months.[14]

The results of the cointegration tests show that voluntary carbon markets priced-in expectations ahead of the Paris and Glasgow conferences more highly than compliance markets. With regards to the Paris Conference, the cointegration relationship vanishes post event. We interpret this as a decoupling of the voluntary and compliance markets due to structural shifts in their prices post Paris.

Taken together, the results of the cointegration tests and the constant mean return model, we can claim to observe a structural break (absence of cointegration) between voluntary and compliance carbon price proxies especially in case of the Paris Conference. In fact, based on our observations for the Paris Conference (constant mean return, market model and cointegration results) and the Glasgow Conference (constant mean return, market model and pre-event cointegration results), we believe that there will be a further decoupling of voluntary carbon prices from compliance prices, ceteris paribus.

5. Conclusion

This paper analyses the impact of three recent important climate policy events on the pricing of carbon offsets in compliance and voluntary markets, COP 21 in Paris in 2015, the Paris Agreement in 2016, and COP 26 in Glasgow in 2021. We collect publicly available data for compliance market carbon prices and publicly available proxies for voluntary carbon prices. We then apply standard event-study methodology to estimate the market reaction to all three policy events and perform cointegration tests for the Paris Conference as well as the Glasgow Conference. In the pre-event period before the Paris Conference, both compliance and voluntary carbon markets react negatively, while in the post-event period, compliance markets react positively and voluntary markets negatively. This suggests that there was a reversal of expectations in compliance markets because of the outcomes of the Paris Conference, but a manifestation of the negative expectations for participants in voluntary carbon markets.

[14] We cannot test for cointegration post Glasgow as the necessary data are not available.

On the other hand, the reactions of market participants in both markets to the Paris Agreement are similar. Optimistic expectations are followed by disappointment, with both effects being stronger in compliance carbon offset markets. Finally, before the Glasgow Conference, expectations in voluntary markets were extremely positive, but market participants were once again disappointed with the outcomes of the conference, while market participants in compliance markets react extremely positively to the outcomes of COP 26.

The cointegration results show that the conferences significantly impact the price differential of carbon offsets in both markets. We find a structural shift in the price differential after the Paris Conference and a similar price differential pattern before both conferences. Taken together, our results show that important climate policy events indeed shape carbon pricing on both compliance and voluntary markets, but that the outcomes of the conferences seem to be more favorable overall for market participants in compliance markets.

These results give rise to a number of policy implications. First, to achieve net zero goals, stronger and more targeted policy interventions are needed for voluntary carbon markets. Climate change effects are and will remain non-homogenous. Full decarbonization of the global economy is impossible at present using only compliance certificates. Furthermore, poor and underdeveloped countries need stronger adaptation measures to mitigate the effects of climate change. Voluntary carbon markets may provide very useful to facilitate this form of capacity-building. Third, as we observe that voluntary carbon markets price-in expectations of stimulating policy interventions and negatively recalibrate expectations post events if the expectations are not fulfilled, strong and sustained signals from governments, backed with tangible and achieved adaptation finance targets, may trigger a voluntary carbon market response that is price-incentivizing and may ultimately narrow the carbon funding gap.

Whether such policy changes are beneficial for markets in general depends. We show that compliance carbon markets react more to climate policy events. New, ambitious and targeted commitments in climate regulation and compliance may spur innovation in compliance jurisdictions and force an upward squeeze on compliance prices. Finally, as we observe that carbon markets react strongly to a lack of ambition and enforcement of climate policies, commitments made at future policy events should be kept in order not to disrupt compliance and voluntary carbon markets.

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Figures

Figure 1: Continuous ETS prices in each phase

This figure shows the continuous ETS prices from 2005 to 2021. It includes all phases of the EU ETS system so far. The vertical dashed lines represent the Kyoto Protocol, the Paris Agreement and COP26. The yellow shade is the period of the Paris conference. The data were retrieved from EEA and Datastream.

Figure 2: EUA and CER prices, first and second commitment

This figure shows the EUA and CER prices from 2009 to 2016. EUA represent the one-year future of EU ETS prices that is rolled over every year in December and CER the Certified Emissions Reduction index. The vertical dashed line represents the Paris Agreement. The yellow shade is the period of the Paris conference. The data were retrieved from Datastream.

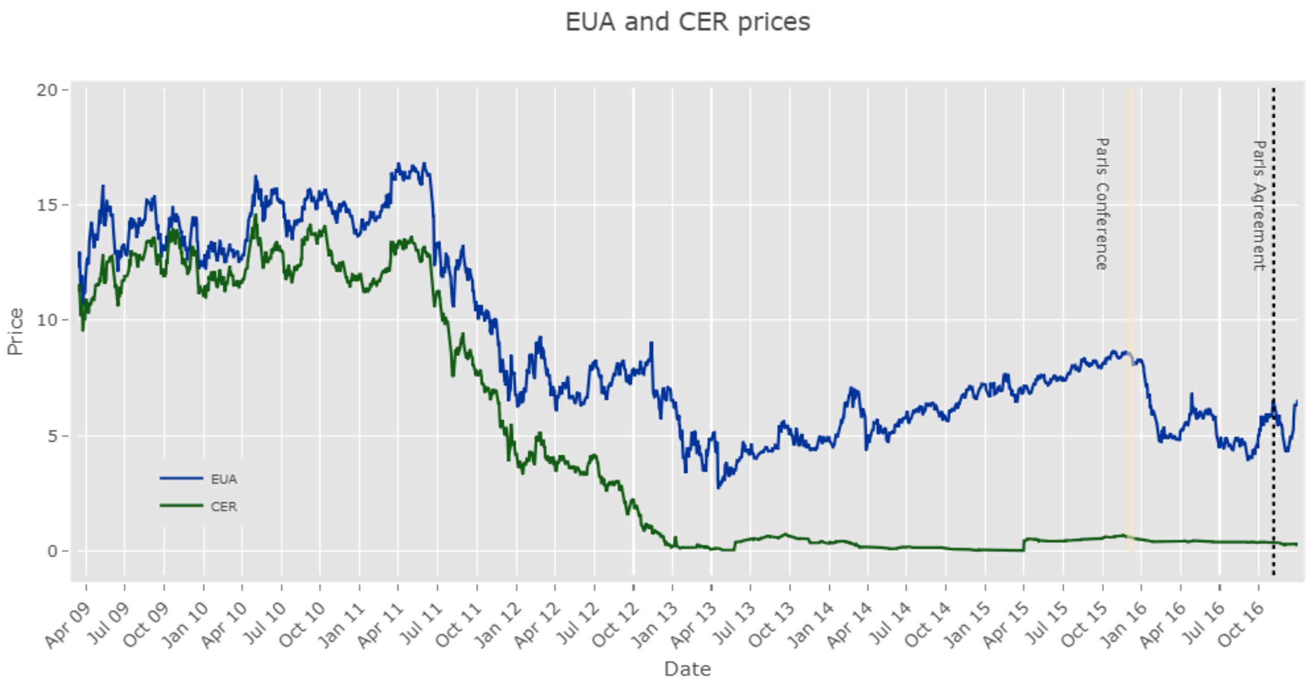


Figure 3: Development of EUA, GEO, and N-GEO in 2021

This figure shows the EUA, GEO and N-GEO prices in 2021. EUA is explained in Figure 2, GEO represents the Global Emissions Offset Futures index, N-GEO is the Nature-based GEO. The data were retrieved from Datastream and Bloomberg. The prices of GEO and NGEO were scaled by 10.

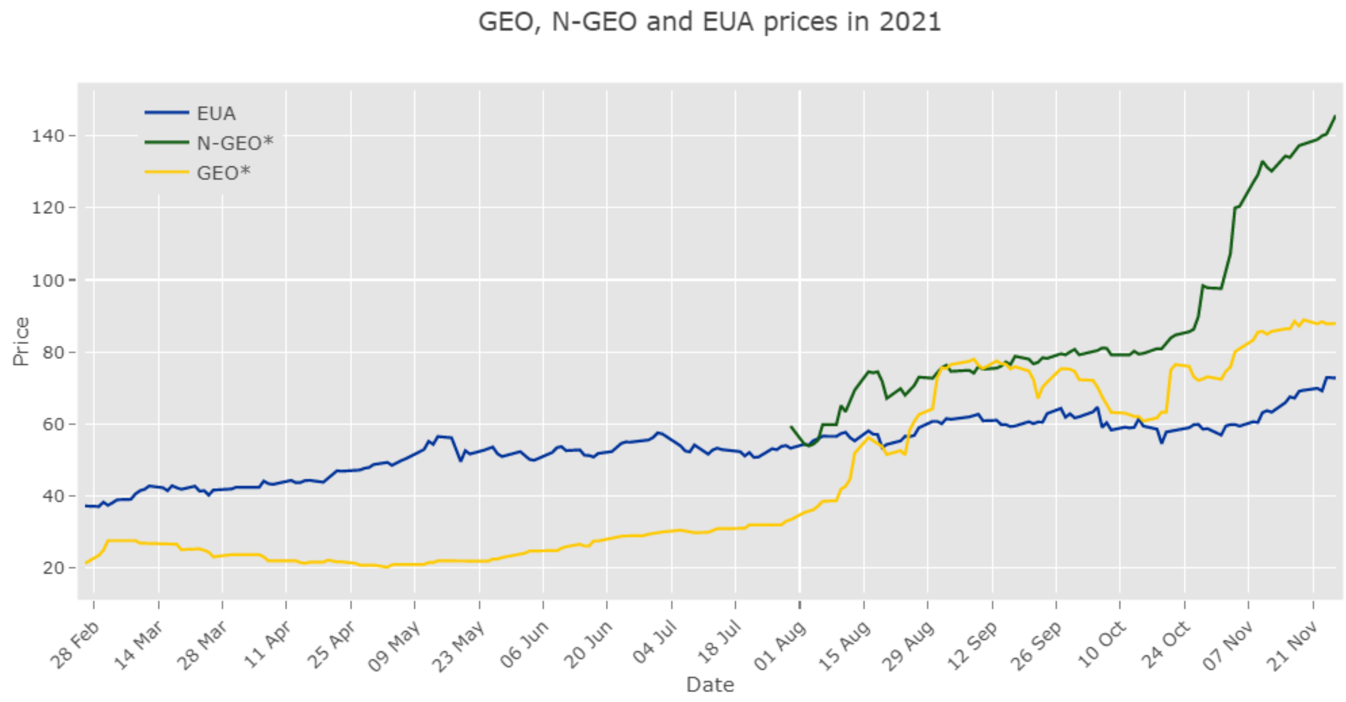


Figure 4: Paris Conference Constant mean return model: EUA abnormal returns and CAR

This figure shows the abnormal and cumulative abnormal returns of EUA during and after the Paris conference. EUA is explained in Figure 2. The vertical dashed line represents the last day of the conference. The green shade is the period of the Paris conference.

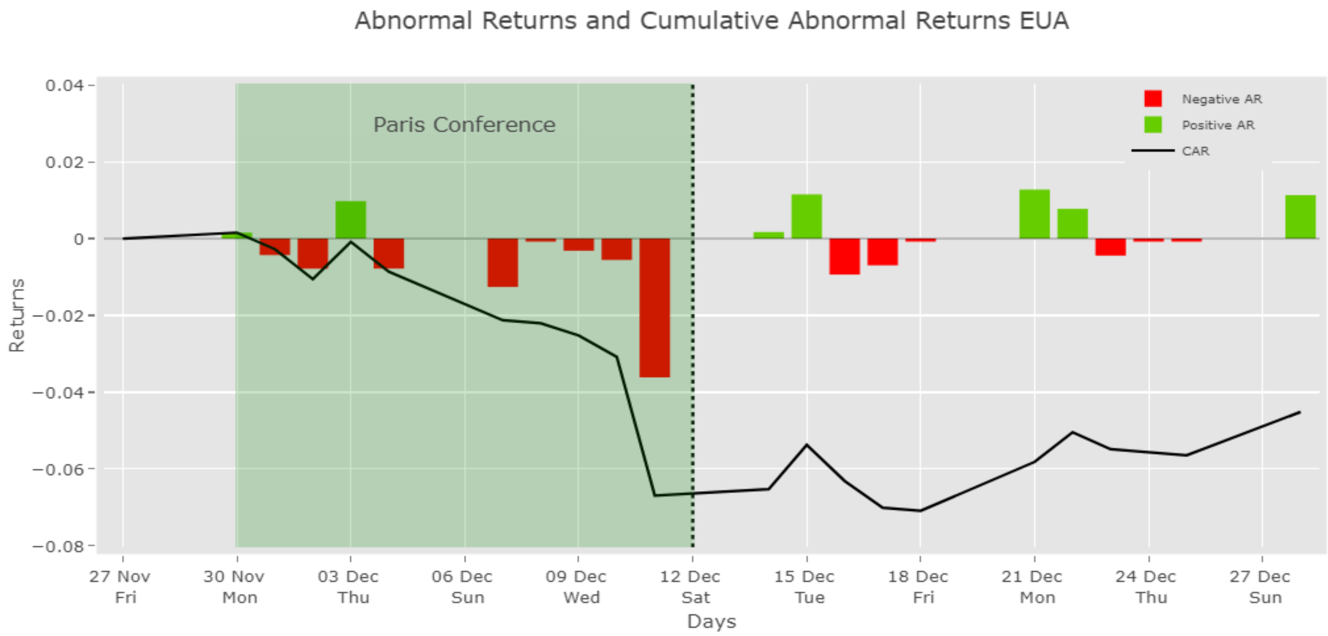


Figure 5: Paris Conference Constant mean return model: CER abnormal returns and CAR

This figure shows the abnormal and cumulative abnormal returns of CER during and after the Paris conference. CER is explained in Figure 2. The vertical dashed line represents the last day of the conference. The green shade is the period of Paris conference.

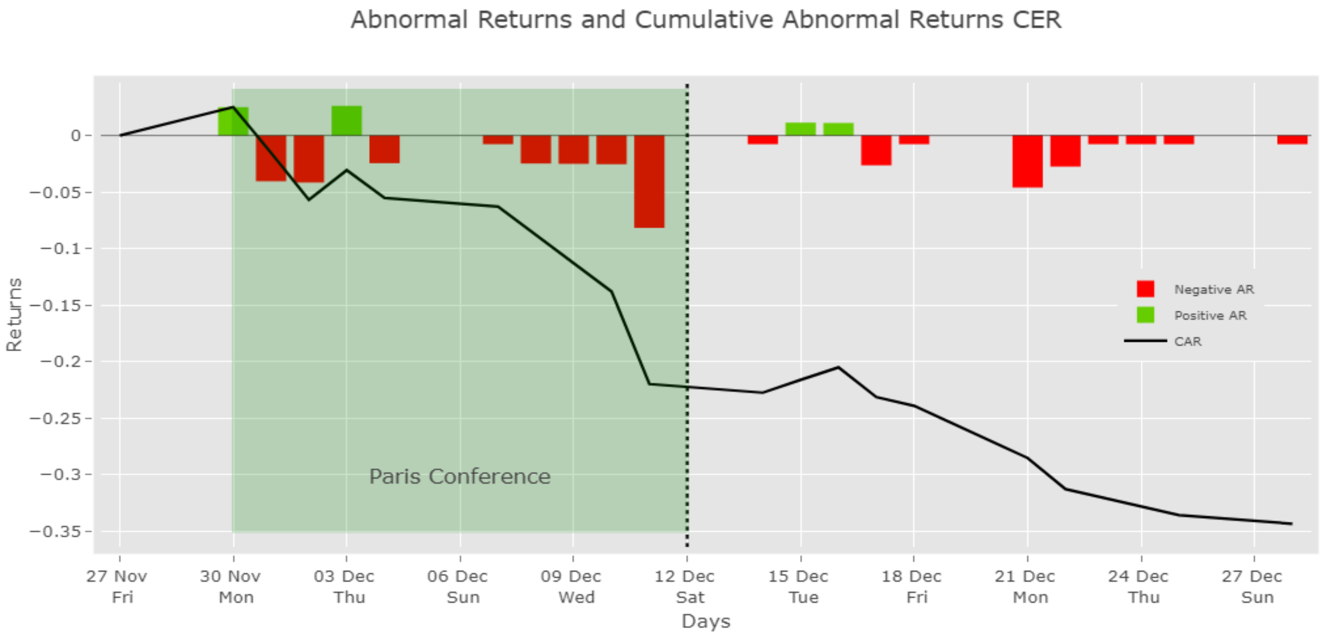


Figure 6: Paris Agreement Constant mean return model: EUA abnormal returns and CAR
This figure shows the abnormal and cumulative abnormal returns of EUA before and after the Paris agreement. EUA is explained in Figure 2. The vertical dashed line represents the day of the agreement.

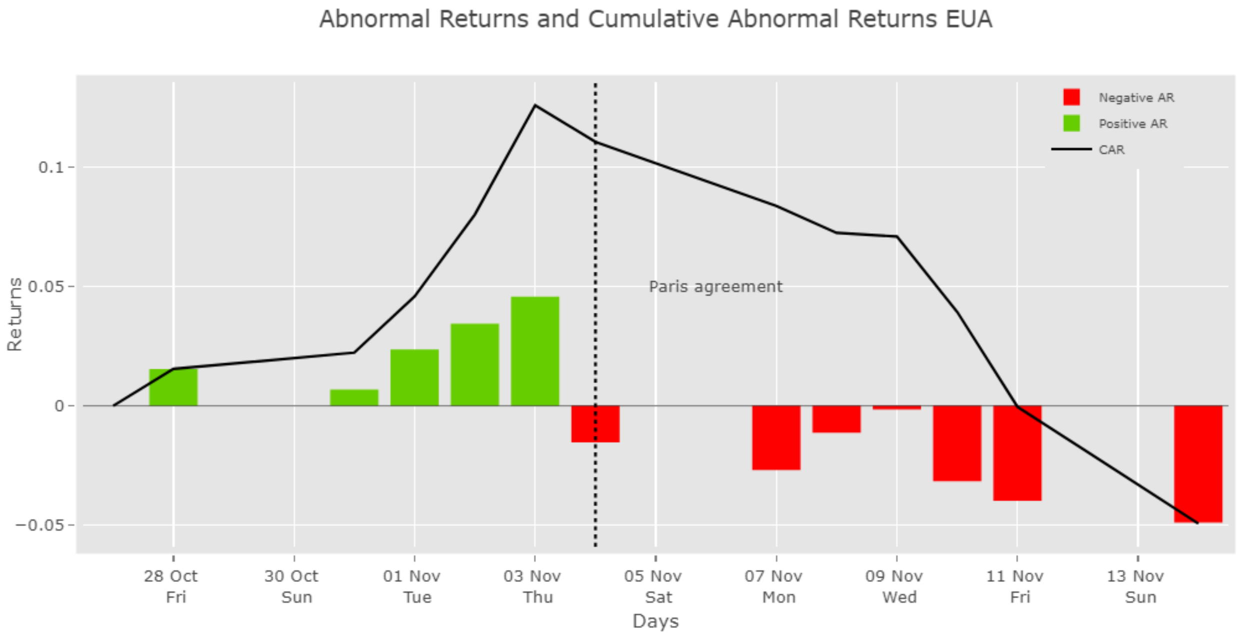


Figure 7: Paris Agreement Constant mean return model: CER abnormal returns and CAR

This figure shows the abnormal and cumulative abnormal returns of CER before and after the Paris agreement. CER is explained in Figure 2. The vertical dashed line represents the day of the agreement.

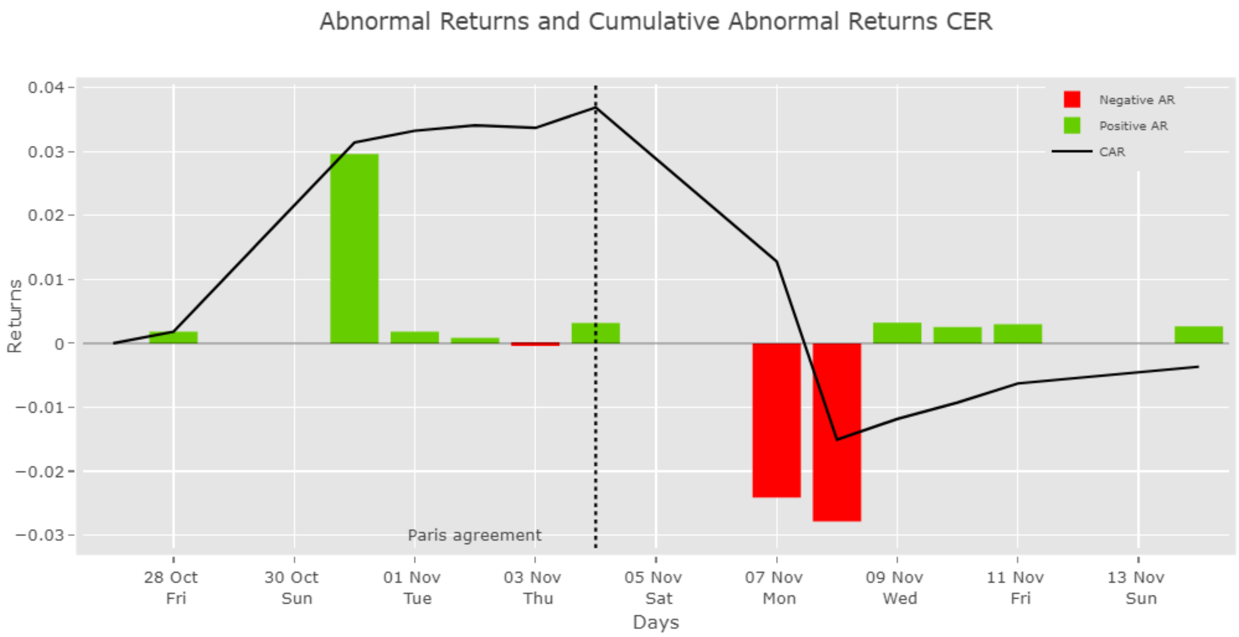


Figure 8: Glasgow Conference Constant mean return model: EUA abnormal returns and CAR
This figure shows the abnormal and cumulative abnormal returns of EUA during and after the Glasgow conference. EUA is explained in Figure 2. The vertical dashed line represents the last day of the conference. The green shade is the period of the Glasgow conference.

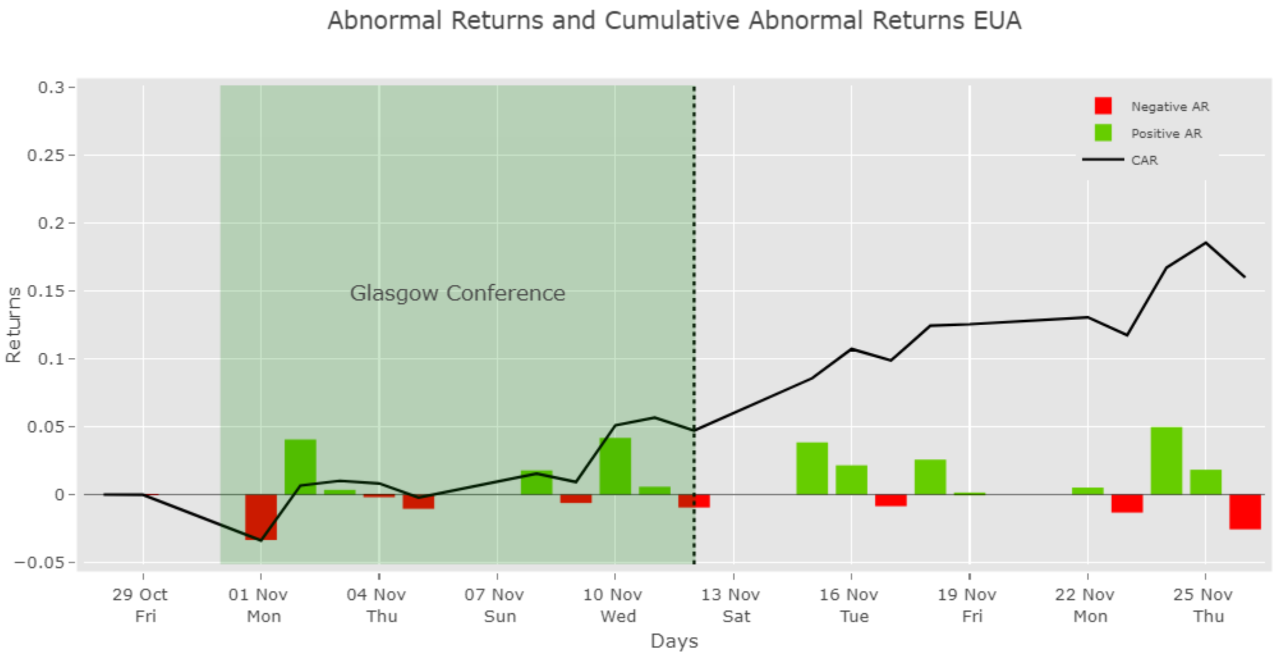


Figure 9: Glasgow Conference Constant mean return model: GEO abnormal returns and CAR
This figure shows the abnormal and cumulative abnormal returns of GEO during and after the Glasgow conference. GEO is explained in Figure 3. The vertical dashed line represents the last day of the conference. The green shade is the period of the Glasgow conference.

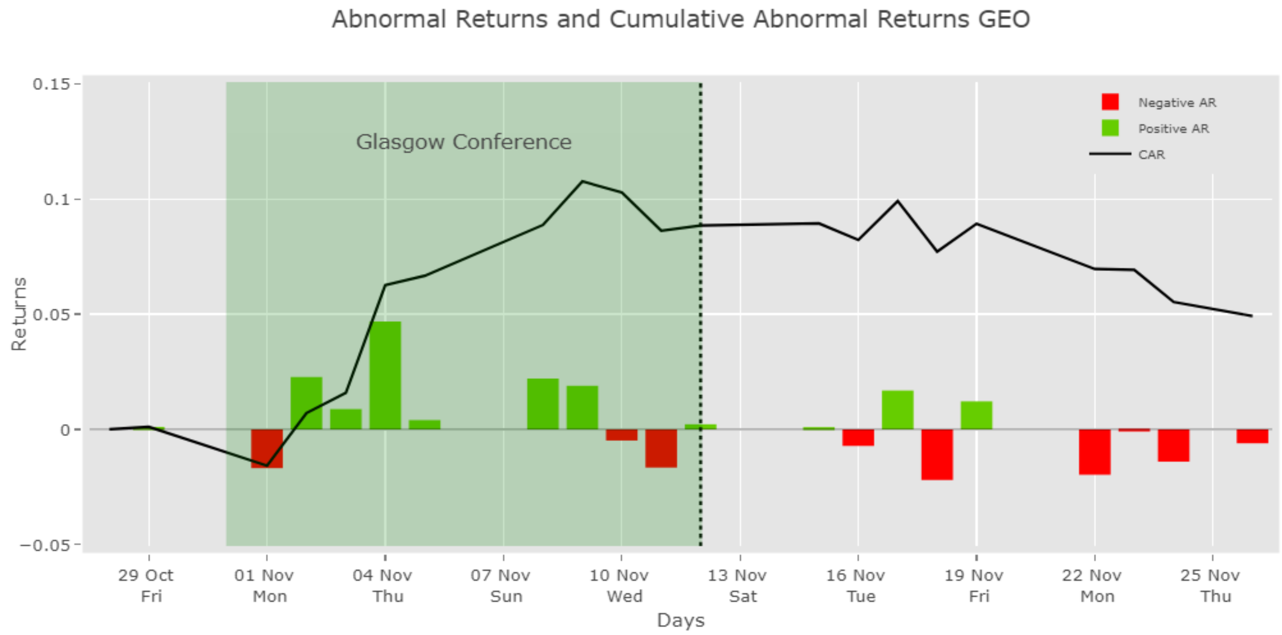


Figure 10: Glasgow Conference Constant mean return model: N-GEO abnormal returns and CAR

This figure shows the abnormal and cumulative abnormal returns of N-GEO during and after the Glasgow conference. N-GEO is explained in Figure 3. The vertical dashed line represents the last day of the conference. The green shade is the period of Glasgow conference.

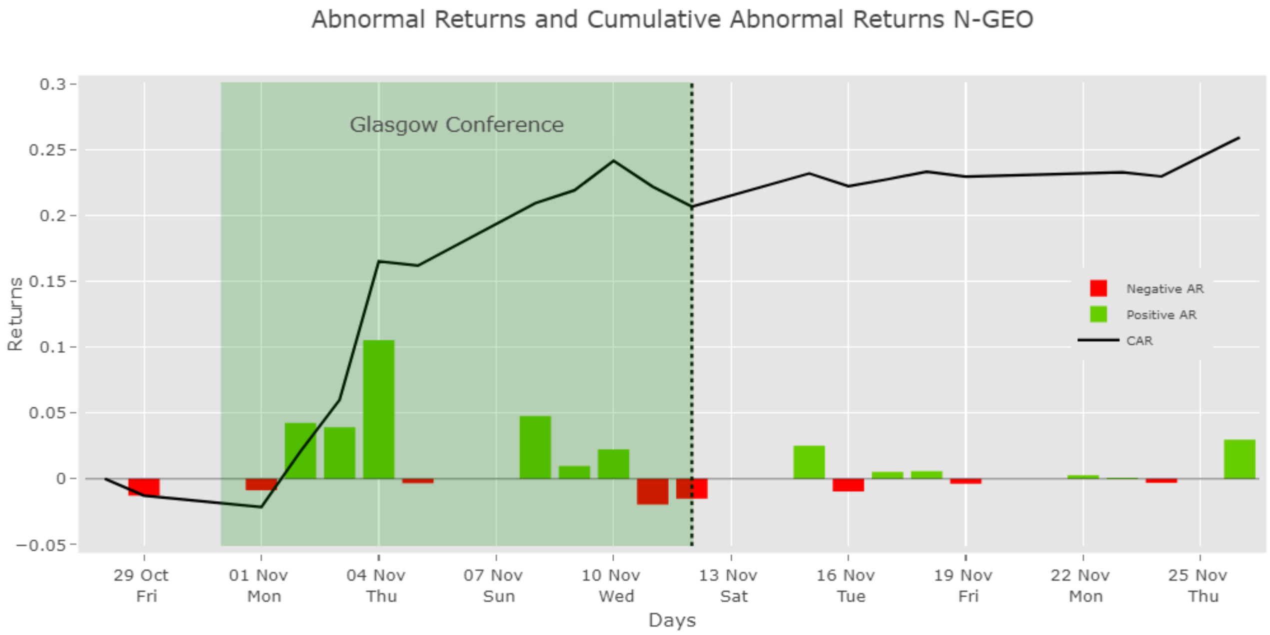


Figure 11: Cointegration between EUA and CER prices before the Paris Conference

This figure shows the cointegration vector and the EUA and CER prices six months before the Paris conference. EUA and CER are explained in Figure 2. The horizontal dashed line represents the average of the process. The vertical dashed line represents the day two month before the conference, we can see and inversion in the prices. The green shade is the difference between the prices. The price of CER was scaled by 15.

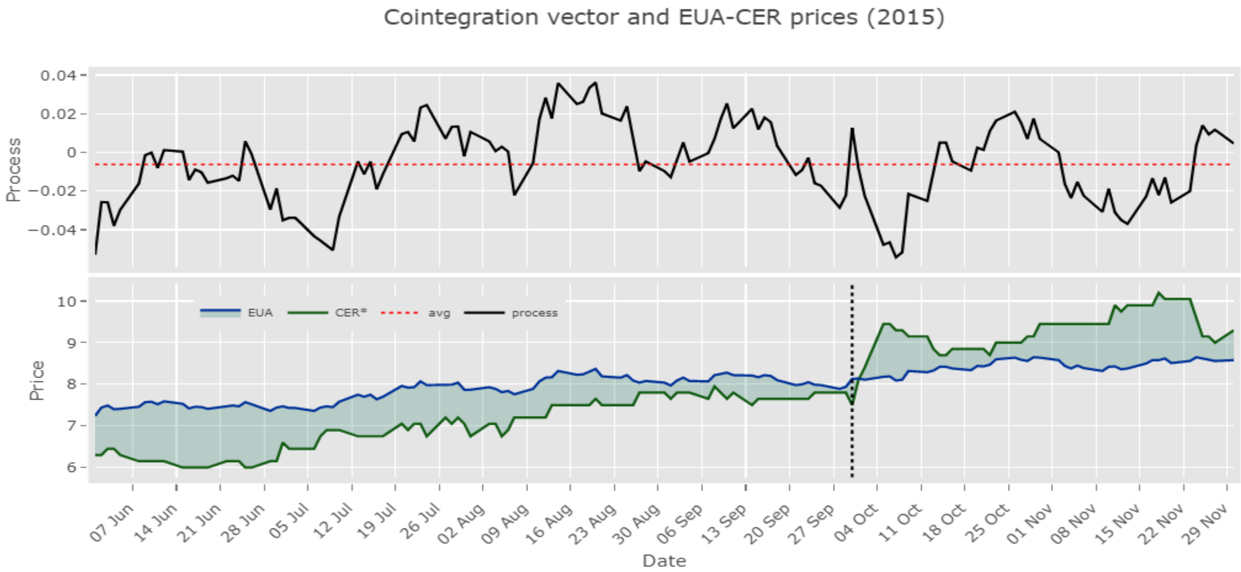


Figure 12: Cointegration between EUA and CER prices after the Paris Conference

This figure shows the cointegration vector and the EUA and CER prices six months after the Paris conference. EUA and CER are explained in Figure 2. The horizontal dashed line represents the average of the process. The vertical dashed line represents the day two month before the conference. The green shade is the difference between the prices. The price of CER was scaled by 15.

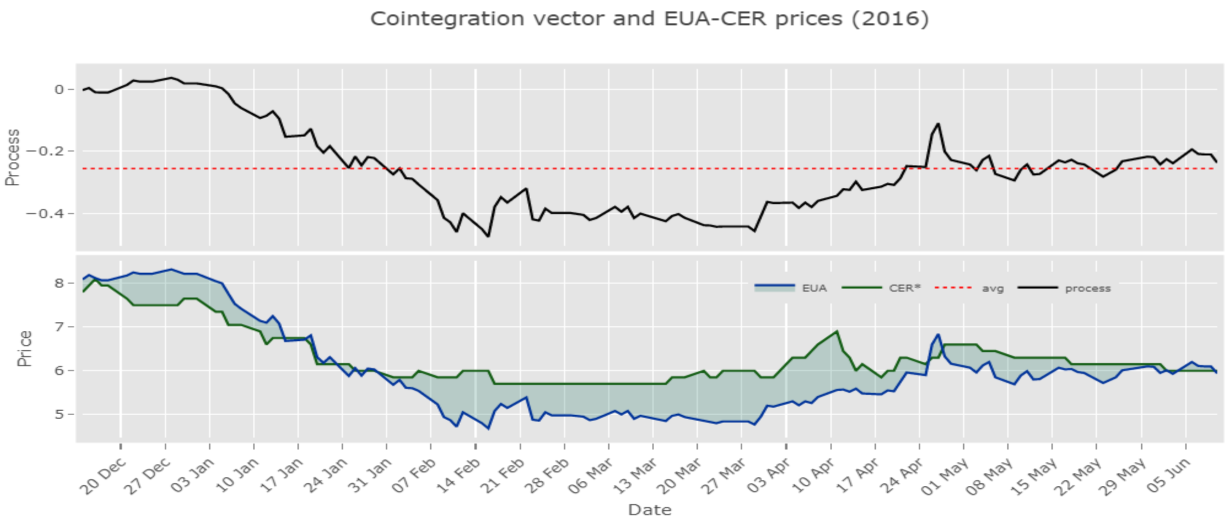
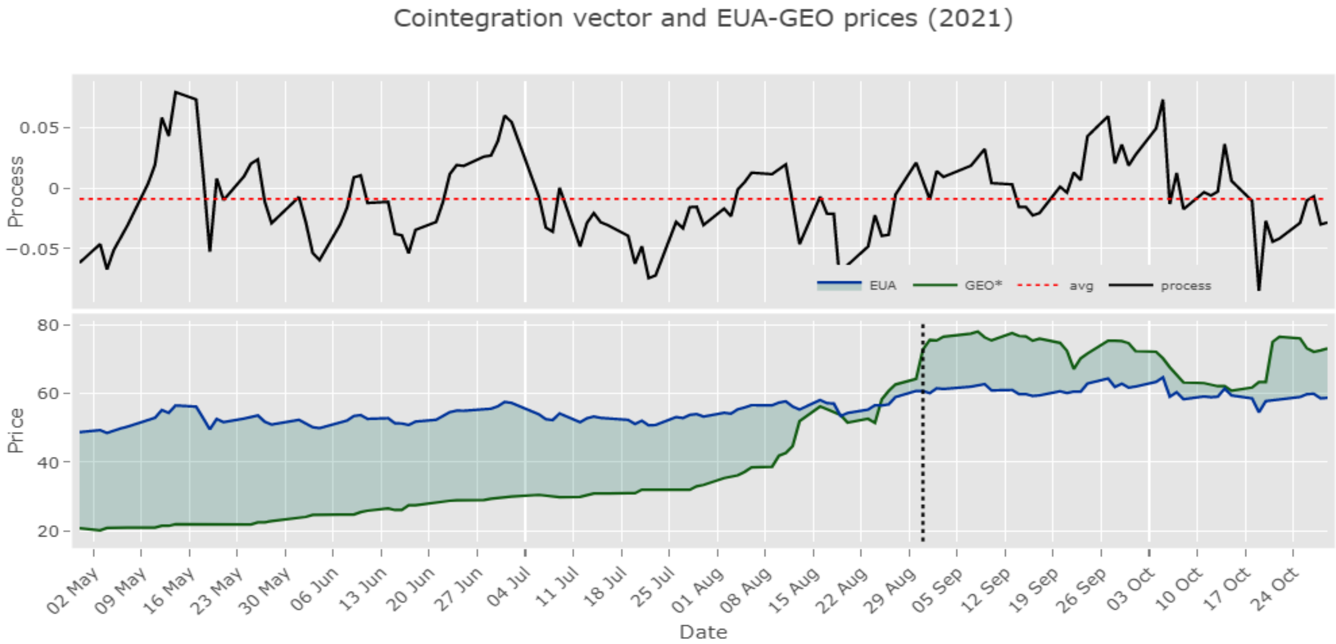


Figure 13: Cointegration between EUA and GEO prices before the Glasgow Conference

This figure shows the cointegration vector and the EUA and GEO prices six months before the Glasgow conference. EUA is explained in Figure 2 and GEO is explained in Figure 3. The horizontal dashed line represents the average of the process. The vertical dashed line represents the day two month before the conference. The green shade is the difference between the prices. The price of GEO was scaled by 10.



Tables

Table 1: Event study and cointegration windows

This table shows the training windows, the pre-event windows, and the post-event windows for the Paris Conference 2015, the Paris Agreement in 2016 and the Glasgow Conference in 2021. GEO and N-GEO are explained in Figure 3.

	Event Study			**Cointegration Test**	
Period	**Paris Conference**	**Paris Agreement**	**Glasgow Conference**	**Paris Conference**	**Glasgow Conference**
Training window	2014-11-20 to 2015-11-26	2015-10-21 to 2016-10-26	2021-02-26 to 2021-10-27		
Pre-event window	2015-11-27 to 2015-12-11	2016-10-27 to 2016-11-04	2021-10-28 to 2021-11-11	2015-05-30 to 2015-11-30	GEO: 2021-04-30 to 2021-10-31 N-GEO: 2021-07-30 to 2021-10-31
Post-event window	2015-12-12 to 2015-12-28	2016-11-05 to 2016-11-14	2021-11-12 to 2021-11-26	2015-12-12 to 2016-06-12	

Table 2: Descriptive statistics for training windows for all three policy events

This table shows the descriptive statistics for all datasets used in the empirical analyses. EUA and CER are explained in Figure 2, GEO and N-GEO are explained in Figure 3. Kraneshares is the Kraneshares Global Carbon ETF. SD are the standard deviation, 5% and 95% are the 5- and 95-percentiles, respectively.

	Descriptive statistics					
	Observations	Mean	SD	5%	Median	95%
Panel A: Paris Conference						
EUA	265	0.79%	1.57%	-2.32%	0.00%	2.54%
CER	265	0.77%	26.01%	-17.67%	0.00%	6.97%
Barclays Index	265	0.86%	3.23%	-5.39%	0.00%	5.24%
Panel B: Paris Agreement						
EUA	265	-0.13%	3.02%	-5.07%	-0.21%	4.64%
CER	265	-0.19%	2.02%	-3.37%	0.00%	2.72%
Barclays Index	265	-0.15%	5.15%	-8.27%	0.00%	6.51%
Panel C: Glasgow Conference						
EUA	173	0.27%	2.37%	-3.43%	0.46%	3.81%
GEO	170	0.71%	3.26%	-3.23%	0.00%	5.80%
N-GEO	62	0.67%	2.95%	-2.64%	0.80%	4.84%
KraneShares	173	0.24%	1.88%	-3.25%	0.31%	3.22%

Table 3: Averages of abnormal and cumulative abnormal returns before and after Paris Conference

The windows are 11 days before the conference and 11 days after the conference. Panel EUA and CER are explained in Figure 2. CER* is based on the trade-by-trade method. *, **, and *** indicate significance at the 10, 5, and 1 percent levels, respectively.

	Cumulative Abnormal Returns Tests (-11; +11)		
Panel A: Constant mean return model			
	(1) EUA	(2) CER	(3) CER*
Pre	-1.87%**	-7.54%***	-2.36%
Post	0.74%**	-5.42%**	-0.24%

Panel B: Market model			
	(1) EUA	(2) CER	(3) CER*
Pre	1.78%**	-7.02%***	-0.89%
Post	0.94%***	-4.35%**	2.11%***

Table 4: Averages of abnormal and cumulative abnormal returns before and after the Paris Agreement

The windows for the Paris Agreement are 6 days before the agreement and 6 days after the agreement. EUA and CER are explained in Figure 2. CER* is based on the trade-by-trade method. *, **, and *** indicate significance at the 10, 5, and 1 percent levels, respectively.

	Cumulative Abnormal Returns Tests (-6; +6)		
Panel A: Constant mean return model			
	(1) EUA	(2) CER	(3) CER*
Pre	6.53%**	2.94%***	3.57%***
Post	-5.82%*	-2.23%***	-1.72%***
Panel B: Market model			
	(1) EUA	(2) CER	(3) CER*
Pre	5.52%**	2.83%***	3.53%***
Post	-5.55%**	-2.22%***	-1.71%***

Table 5: Averages of abnormal and cumulative abnormal returns before and after the Glasgow Conference

The windows are 11 days before the conference and 11 days after the conference. EUA is explained in Figure 2, GEO and N-GEO are explained in Figure 3. *, **, and *** indicate significance at the 10, 5, and 1 percent levels, respectively.

	Cumulative Abnormal Returns Tests (-11; +11)		
Panel A: Constant mean return model			
	(1) EUA	(2) GEO	(3) N-GEO
Pre	1.21%	5.22%***	12.65%***
Post	8.29%***	-1.28%**	2.63%***

Panel B: Market Model			
	(1) EUA	(2) GEO	(3) N-GEO
Pre	-0.23%	5.08%***	11.52%***
Post	4.41%***	-1.69%**	1.13%***

Table 6: Cointegration results before and after the Paris Conference and the Glasgow Conference

The table shows the Johansen test on the price time series and the Augmented Dickey-Fuller test on the cointegrated vector for each period. EUA and CER are explained in Figure 2, GEO and N-GEO are explained in Figure 3. *, **, and *** indicate significance at the 10, 5, and 1 percent levels, respectively.

	Cointegration tests					
	Johansen Eigenvalues Test		Augmented Dickey Fuller Test on the cointegration vector	Johansen Trace Test		Augmented Dickey Fuller Test on the cointegration vector
Pairs Paris Conference						
	H_0	Test	p-value		Test	p-value
EUA – CER pre	r ≤ 1	3.29	0.10*	r ≤ 1	3.29	0.10*
	r = 0	13.32		r = 0	16.61	
EUA – CER post			0.87			0.87
Pairs Glasgow Window						
EUA – GEO pre	r ≤ 1	6.51	0.01***	r ≤ 1	6.51	0.01***
	r = 0	18.58**		r = 0	25.09***	
EUA – N-GEO pre	r ≤ 1	8.30*	0.41	r ≤ 1	8.30*	0.41
	r = 0	20.36***		r = 0	28.66***	

Appendix

Figure A1: Paris Conference Constant mean return model trade-to-trade: CER abnormal returns and CAR

This figure shows the abnormal and cumulative abnormal returns of CER during and after the Paris conference. CER is explained in Figure 2. The vertical dashed line represents the last day of the conference. The green shade is the period of Paris conference.

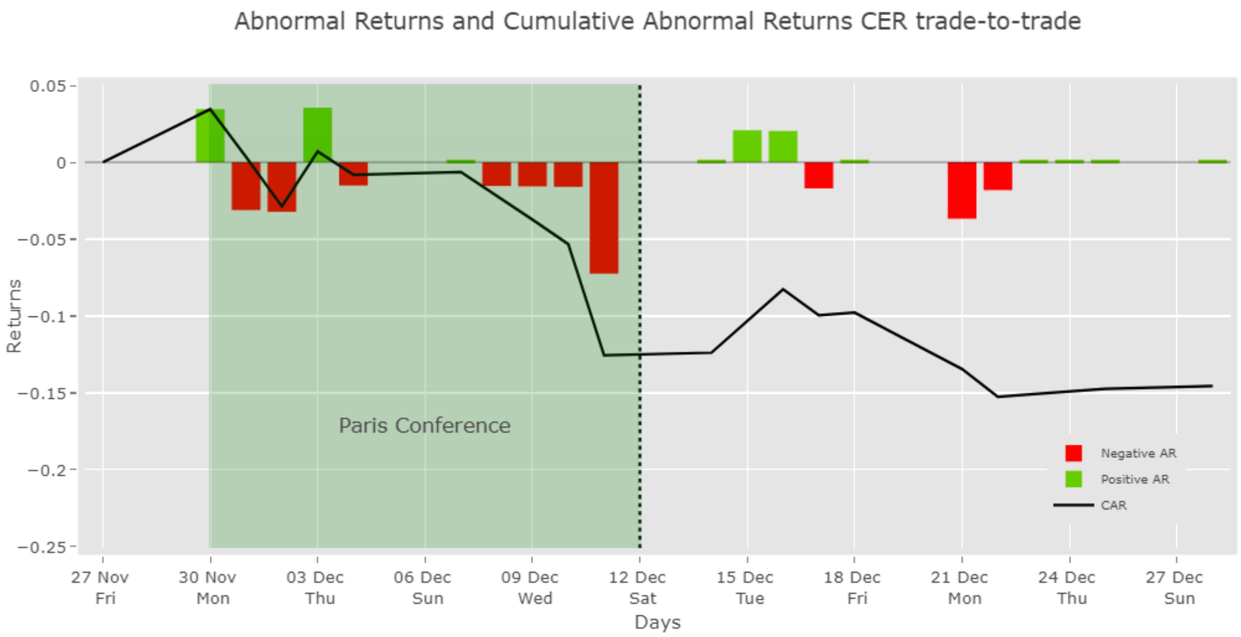


Figure A2: Paris Conference Market model: CER abnormal returns and CAR

This figure shows the abnormal and cumulative abnormal returns of CER during and after the Paris conference. CER is explained in Figure 2. The vertical dashed line represents the last day of the conference. The green shade is the period of Paris conference.

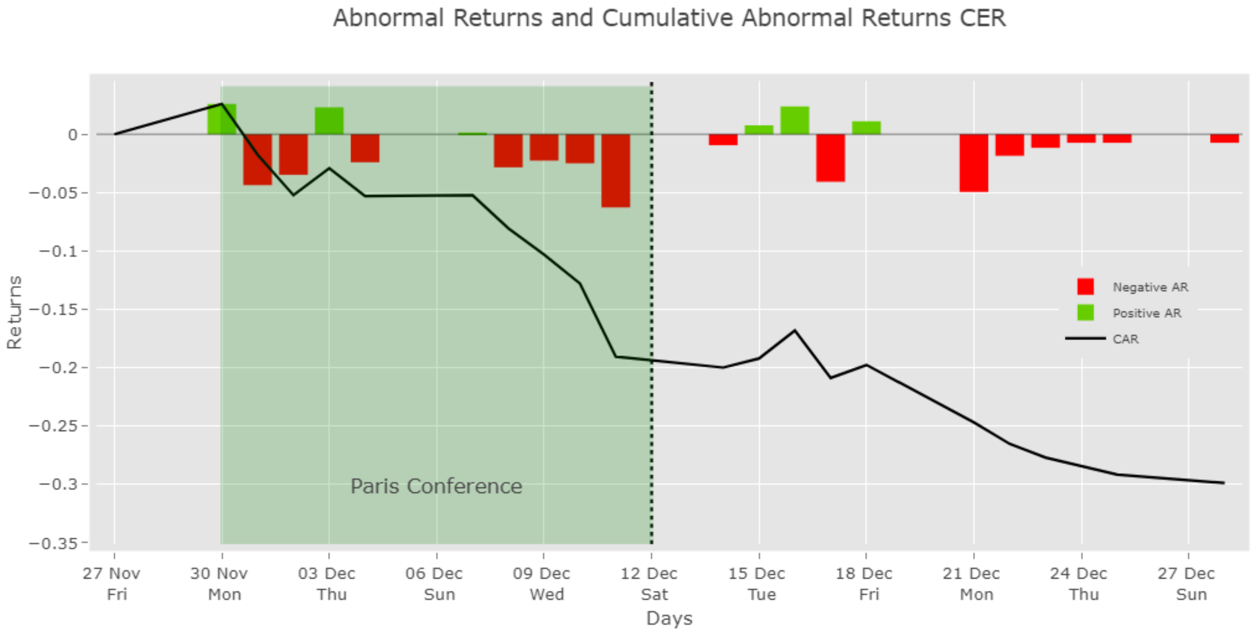


Figure A3: Paris Agreement Constant mean return model trade-by-trade: CER abnormal returns and CAR

This figure shows the abnormal and cumulative abnormal returns of CER before and after the Paris agreement. The vertical dashed line represents the day of the agreement.

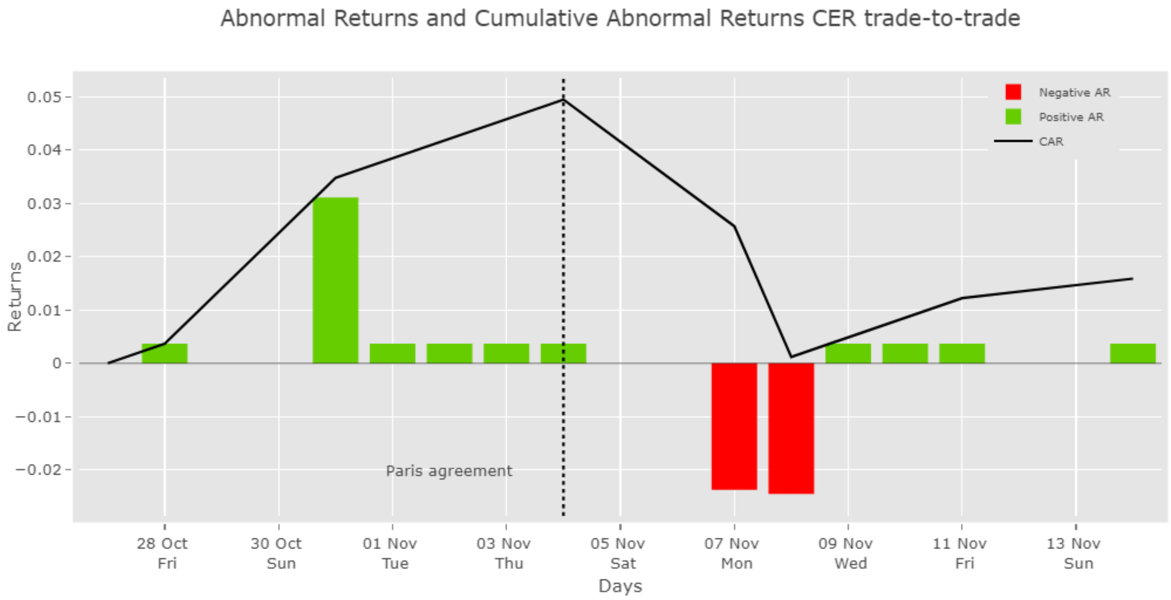


Figure A4: Paris Agreement Market model: EUA abnormal returns and CAR

This figure shows the abnormal and cumulative abnormal returns of EUA before and after the Paris agreement. EUA is explained in Figure 2. The vertical dashed line represents the day of the agreement.