The Impact of Climate Change and Carbon Policy on Company Earnings

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Abstract

Climate change and climate policy have started to reconfigure global financial systems. However, financial institutions need guidance on how to incorporate the future impacts of climate change and climate policy into the investment decision making process. Here, using European companies and installations as a case study, we develop a framework to evaluate the impact of climate change and climate policy on company earnings. We combine novel econometric and carbon pricing models to build a framework for an asset-level, climate adjusted valuation of company earnings. In the European context, we see disparate impacts between and within sectors with carbon pricing impacts largest in the heavy emitting sectors, equivalent to -2% of earnings at the mean, whereas the physical impacts of climate change are more geographically segregated, with a median impact of -14% discounted 20 years into the future. We intend for the structure of this study to inform more impactful integration of climate risks into financial risk management processes.

1 Introduction

Climate change poses systemic threats to our global financial systems. Recent studies have found that warming at 3C will result in 10-12% of global GDP declines by 2100 and less than 2% in a well-under 2C world.[1] To catalyze climate action in the financial sector, The Task Force on Climate-Related Financial Disclosures (TCFD) clarified that investors, central banks, and other financial institutions are likely unprepared for climate-related surprises that will impact economic outcomes.[2–4] As financial managers begin to better understand climate risks, fiduciary duty calls for the inclusion of climate change information into broader risk assessments of investment activity. As such, central banks have begun mandating this assessment.[5,6] TCFD as well as the Network for Greening the Financial System (NGFS) break climate risk into two main components: physical risk and transition risk.[2,3,7] Physical risk describes the impact of changes of the physical climate on economic outcomes. This includes, for example, the impact of storm surge on a facility's production, or the insurance losses from changes in expected wildfire.[8,9] Transition risk describes the impact of transitioning to a decarbonized world on any one economic agent.[8] This may include carbon taxes that render fossil fuel production at specific sites too expensive to continue operating. These risks are often not contemporaneous, with transition costs often regarded as upfront and physical costs delayed, and these axes of risk often move in opposite directions.[8] If high transition risk is realized, then in theory, physical risk should be mitigated.[10–12]

Some work has been done in translating these macro and micro economic risks into asset-specific financial risk. Venturini (2022) provides a succinct summary into how one should distill physical and transition risk into its various components.[9] For physical risk this includes climate data, disaster data, and asset level locations. For transition risk, the components include emissions data, innovation data, and policy information. These data sources have informed numerous relationships between climate change, climate policy and investment risk. Studies have shown that temperature anomalies do impact stock returns.[9,13–16] Similarly, high emissions have been found in cases to affect price-to-earnings ratios for listed institutions and led to higher costs of capital across both the U.S. and Europe.[17]Frameworks comparing physical and transition risk across regions and temperature pathways are being developed with the aim of identifying the most tangible macro risk by region.[18]

While there is continued investigation into the inclusion of climate risk for investment decision-making, there is little standardization for fundamental assessments to determine how climate change and climate policy will impact company performance. Whereas most climate risk in finance is assumed to be transferred from the broader macroeconomic impacts of climate change and policy,[7] this study offers a method for standardizing the impact of both climate change and climate policy for investors through the lens of company earnings and company facility mapping. We offer a unified, facility-based approach for modelling both physical and transition risk, that accounts for past company performance.

1.1 Physical Risk

Temperature,[19–22] precipitation,[23] storm severity,[24] flooding,[24] among other climatic variables, have been shown to have bottom-up and top-down impacts on socioeconomic outcomes. Bottom-up climate risk assessment often incorporates the impact of rising temperatures, for example, on energy demand,[25] labor productivity,[26] human health,[24,27] and crop yields.[28,29] Conversely, with a macroeconomic approach, climate risk assessment includes the impact of temperature on GDP growth rates,[19–21] migration,[30] and employment.[7,31] Including these aforementioned impacts has been critical in disclosing the risks of climate change to date, yet the challenge still remains in finding methods that aggregate across all categorizations of physical risk into metrics directly digestible by asset management.

Despite the continued work of academics and policy makers to better the disclosure of physical climate risks, every day practitioners struggle with deciding on the form and function of calculating physical risk. This study borrows from the growing field of climate econometrics to simplify the connection of bottom-up and top-down impacts of climate change on company earnings. As laid out in Hsiang (2016), the weather for spatial unit i can be described as vector at time t:

$$V_{it} = [\text{Temperature}_{it}, \text{Precipitation}_{it}, \text{Humidity}_{it}, ...] \tag{1}$$

Climate can be described then as the joint probability of weather realizations over a prolonged period τ:

$$V_{i\tau} = \psi(C) \tag{2}$$

In a linear econometrics framework, the impact of climate on socioeconomic variable Y is then described as:

$$\mathrm{Y}_{i\tau} = \alpha_i + \mathrm{C}_{i\tau}\beta_{\mathrm{TS}} + \mathrm{X}_{i\tau}\gamma + \phi_i(\tau) + \epsilon_i \tag{3}$$

where τ is a sufficiently long period of study; α is a constant; β is the impact of observed climate variables, γ describes effects of observables; ϕ describes fixed effects (both entity and time); ϵ is an error term. For full details on this econometric framework, please see Hsiang (2016).

Numerous studies have successfully employed this longitudinal framework for climate impact purposes at the country[19] and regional[20, 21, 23] resolution, but few have applied it to company fundamentals. This study aims to ameliorate this gap in the literature.

1.2 Transition Risk

Company risk is not limited to the physical manifestations of climate change, but to the continual legislative efforts to slow emissions and reduce the overall cumulative impact of climate change.[18, 32, 33] Governing bodies have to this end enacted pricing and control mechanisms to encourage emission abatement, with these legislative efforts showing promise across a range of economies at varying stages of development.[34]

The EU emissions trading system (EU ETS) serves as an example for this GHG abatement regulation. It is a cap and trade ETS which covers a range of sectors within the EU ranging from the production of metal and concrete to utility companies with a mandate to expand to sectors such as maritime in the coming years.[35] The EU ETS itself has undergone many transformations since its introduction in 2005 to account for exogenous supply shocks and other pricing dynamics that challenged the initial format of the program.[36] It remains under continual political supervision, leading to the potential for mechanism and scope change.[37, 38]

The development of similar legislation globally - RGGI, WCI, K-ETS, China ETS etc.[39–42]- and the possibility of reputational risk[43] arising from the continuation of heightened emissions has led to investors not only expecting a premium for carbon emission exposure but manifests in a higher cost of capital for higher emitters.[17,44,45] Furthermore, it has also been found that select stock returns exhibit a negative relationship to carbon policy shocks, exhibited even in firms not directly participating in the EU ETS.[46,47]

This would imply that a combined measure of decarbonisation pathway and policy adherence readiness for any given corporate would provide a better understanding for future cash flows than either in isolation. This study considers aspects of company behavior such as hedging and banking of allowances to take into account policy preparedness alongside an emissions forecast to give a more complete picture of future earnings.

2 Methods

2.1 Impact of Climate Change on EBITDA Growth Rate

To evaluate the physical impact of climate change on company fundamentals we use three sets of data: company facility location data, yearly EBITDA data, and high-resolution climate data. Using this data, we develop an annual longitudinal study spanning 2012-2022 covering 1183 companies with 888,440 facilities.

2.1.1 Company Fundamentals - EBITDA

We obtain our company fundamentals data from WorldScope. Company EBITDA is computed as the sum of trailing four quarters Earnings Before Interests and Taxes (EBIT) and Depreciations and Amortizations (DA) in their reported currency. We align the fundamentals at the fiscal year end date, and compute the annual growth rates of EBITDA. The growth rates are calculated robustly by replacing the denominator with the average of absolute values of EBITDA of the current year and previous year to account for potential small denominations, as in[48]Davis, Haltiwanger and Schuh (1996).

Our motivation of using EBITDA for our analysis is that EBITDA is one of the most closely tracked company fundamentals. Compared to the top line items such as revenue, EBITDA reflects fluctuations from both the demand side and the supply side. Previous studies have established climate change impacts on labor productivity[24] energy demand[25] and economic productivity[19,21,49] that will likely affect both the demand of companies' products (revenue) and the cost of company's operations (costs).

2.1.2 Location Data

The source for the location data is Dunn and Bradstreet, who uses data and filings to gather information on the precise location of each facility. In addition to location data, Dun and Bradstreet provide an associated modelled number of employees at each facility.

2.1.3 Climate Data

ERA-5 land reanalysis data was used for the historical climate data.[50] Hourly maximum temperature and minimum temperature were aggregated for two climate variables: average annual temperature and day-to-day temperature variability. Here, day-to-day temperature variability is calculated as the annual average of the monthly standard deviation of daily temperatures.[21] These variables were chosen because studies have detailed relationships between these variables and economic productivity.[19, 21] The climate data was aggregated for each company using a weighted average with the number of employees as the weight.

2.1.4 Climate Econometrics

This study employs a longitudinal panel model assessing the impact of climate change on EBITDA growth rates using the quadratic framework set out in Hsiang (2016). To do so, this study constructs a panel model using the following formula:

$$\Delta \mathrm{EBITDA}_{ct} = \alpha_c + \beta_1 CV_t + \beta_2 CV_t 2 + \gamma \Delta \mathrm{EBITDA}_{t-1} + \phi_{cis} \tag{5}$$

We explore EBITDA growth rate for company c as a function of exogenous climate variable, CV, at time i, EBITDA growth rate from the time t-1, accounting for sector (s), time (i), and company (c) fixed effects. Additionally, multivariate models are built with combinations of the aforementioned climate variables.

2.1.5 Climate Projections

We use bias corrected and downscaled CMIP6[51] data using ERA5 land reanalysis data,[50] quantile delta mapping,[52] and four climate models within SSP245 experiments. The climate models we employed are GFDL-ESM4, GISS-E2-1-G, FIO-ESM-2-0, and FGOALS-F3-L. We chose these climate models based on skill weights and independence weights as laid out in Brunner et al. (2020). For each projection, we subtract the historical average of the period of 1990-2020 from all projection years as in Hsiang (2016). We then take a 10 year rolling, centered average to smooth the results through time. Our goal is not to evaluate the uncertainty from the climate models, but rather showcase how climate modeling can be used for company-specific risk assessment. Therefore, we take a weighted mean[53] across included climate models and use only the mean coefficients from our longitudinal study. Future impacts are discounted at a 8.64% rate using the weighted average cost of capital for European firms.[10]

2.2 Transition Risk

The impact of carbon policy risk on company cash flow is measured with a separate, granular model. This model is a ground up, asset level mapping of the EU ETS database for facilities which is paired with realized company behavior to arrive at a predicted change in earnings for selected companies.

2.2.1 EU ETS: EUTL

The EU Transaction Log (EUTL) is downloaded and a proprietary mapping is applied to the database to match each of the covered facilities to parent companies.[54] This mapping provides historic emissions and transactions related to EUAs (with transactions lagged by 3 years) for each facility covered by the EU ETS. Historic and preliminary future allowances for each installation are also listed on the EUTL out to 2025 as they are dependent on established emission reduction curves and rely on installation classifications.

Forecasted emissions and for Scope 1 are provided by ClearBlue Markets as are allocations post 2025. Grid intensities are also required for forecasting for both scope 2 emissions and renewable energy deployment with values interpolated from the European Commission.[55]

2.2.2 Company Behavior

Companies exposure to carbon pricing is a function of their allowance shortfall relative to their emissions in the previous year. Companies can combat this with multiple forward thinking strategies. The strategies to reduce carbon compliance costs for any given year that are accounted for in this paper are by no means exhaustive but are as follows:

Hedging Through either options or futures, companies can purchase EU ETS allowances (EUAs) in advance and achieve a lower price compared to spot at delivery of an EUA. As an estimation of the price paid for an EUA derivative, we assign the yearly average price to the notional delivered, with both year of purchase and size of position retrieved from company statements.

Banked Allowances Allowances have no expiry date and as such companies with an over-allocation in previous years may use or continue to bank EUAs.

Passthrough A company with strong carbon efficiency will be able to pass on the same fractional carbon costs as their competitors and as such benefit from lower emissions.

2.2.3 Cost Impact

Combining forecasted emissions and company behavior then allows the forecasting of carbon compliance related costs for any given company and year. This cost is then normalised by EBITDA to allow comparison across our universe.

For any given year t, a company gains a positive cashflow equal to any EUA sold S_t minus any banked B_t, multiplied by the average price of each permit for that financial year P_t. They must then surrender allowances equal to their combined Scope 1 E_t^1, E_t^2 minus any free allocation, A_t they have been provided or have banked from previous financial years, again multiplied by the price of each permit. Companies can pass ρ_t a fraction of this cost downstream and thus any shortfall is adjusted by $(1 - \rho)$.

Companies may also have entered into derivatives contracts in any previous financial year to ensure delivery of any number of EUAs $\boldsymbol{H}_{\tau t}$, paying for delivery at the price agreed upon in the financial year of entering into the instrument $\boldsymbol{P}_\tau$, they may also pass on the current costs of these EUAs akin to any other surrendered allowances at the current passthrough rate.

Finally, companies producing renewable, nuclear or any fossil-free power will then generate a certain positive cashflow for this F_t.

$$\begin{aligned}\text{Earnings}_t = (S_t - B_t)P_t - (1-\rho_t)(E_t^1 + E_t^2 - A_t)P_t \\ + \boldsymbol{H}_{\tau t}\big(\rho_t P_t \mathbf{1}_\tau^T - \boldsymbol{P}_\tau^T\big) + F_t \end{aligned} \tag{6}$$

2.3 Scope of Evaluation - Indices

The analysis of this paper focuses on the impact of climate change and carbon pricing on five indices. These companies exist at varying stages of maturity in their relationship to carbon markets, emission profiles and decarbonisation potential. Index constituents were locked on Feb 2nd, 2023 from Bloomberg. Some defining characteristics of the indices are summarised in 1 where we can identify both the cumulative allocation vs emission relationship 1a and the evolution of this relationship over time 1b. This allows us the characterisation of sectoral behaviour as detailed below:

- **SX6P:** ***Utilities*** Low numbers of free allocations and high emissions lead to advanced hedging strategies and ambitious decarbonisation plans. Select names in this index can thus be viewed as mature participants in the market.

- **SXPP:** ***Basic Materials*** Initial generous free allocation led to limited decarbonisation plans, hence only large names have developed hedging strategies.

- **SXNP:** ***Ind Goods & Services*** A varied mix of companies with a range of exposure and allocations. Serve as an interesting example of "unexposed" carbon intensive index.

- **SXEP:** ***Oil & Gas*** A declining free allocation but with no exposure to CBAM mean limited decarbonisation plans. In house trading desks mean mature hedging strategies.

- **SX5E:** ***Euro STOXX 50*** Due to majority of emissions being Scope 2, the index serves as a benchmark for less carbon intensive industries.

3 Results

3.1 Physical Risk

3.1.1 Panel Model Results

We construct a longitudinal study to investigate how climate change may impact company EBITDA using climate reanalysis data and company facility locations. The study shows a robust relationship between climate and EBITDA growth rates for both annual average temperature and day-to-day temperature variability. The coefficients, as shown in Table 1, detail that both average temperature and temperature variability have a significant relationships with EBITDA growth rates with the absolute value of the t-statistics above 2. The base model, given the results, is model 1 in Table 1. We chose this model because, as discussed in the introduction, quadratic functional forms are common in the climate econometric literature. We find an optimal annual average temperature point is 6.8C (Figure 2).

3.1.2 Climate Model Projections

We evaluate the impact of climate change on company EBITDA at the index level until 2053. Each index corresponds with specific economic sectors and/or companies with the largest market share. More details on the indices can be found in the methods section. The physical, climate-only (SSP245) impact on EBITDA (net present value of the cumulative impacts until 2053 at 8.64% discount rate) for the selected indices is shown in Figure 4a. The median impact across all indices is negative at -14% of EBITDA. At the median, SX6P (Utilities) is the most impacted index, where SXPP (Materials) is the least impacted.

The geographic distribution of impact is more variable than that of the index-based impact. When aggregating the across countries using all facilities within the study, we find that northern Europe is the least exposed or positively exposed to climate change impacts on EBITDA as seen in Figure 3. Iceland, Norway, and Finland are the only countries with net positive exposure. Southern Europe, particularly the Iberian Peninsula and Greece, are most exposed.

3.2 Transition Risk

3.2.1 Carbon Price Impacts

To evaluate the impact of carbon pricing on company EBITDA, we project EUA prices until 2030 across a range of potential values focusing on €134 as a central analyst forecast and aggregate pricing impacts to the index level (Fgiure 4). Accounting for the the price trajectory until 2030 and current company behavior, the carbon market impact ranges quite widely across indices. We find the relative impact is low with a small distributions in SXNP (Industrial Goods and Services) and SX5E (50 Largest Companies) indices. The impact is largest within the SXPP (Materials) sector, but the greatest positive tail is found in SX6P (Utilities) (Figure 5a). The mean risk across all companies is -2% of EBITDA.

3.3 Overall Risk

The distribution of physical and tranistion risk significantly vary (Figure 5). For a comprehensive view of how these indices look in comparison to one another, the indices are plotted along both axes of physical and transition risk in Figure 6. We construct quantile radii that demarcate where each index, on average sits in climate risk space. We find that all indices fall close to the median risk quantile on average. SXPP has the greatest amount of transition risk, but the least physical risk. SXEP is the only index that, on average, has material transition and physical risk. SX6P has the greatest physical risk and the largest earnings gain from transition risk. SXNP and SX5E have limited transition risk but have significant physical risk.

When plotting each individual company member on both axes of risk, we see that most companies fall in the bottom left quadrant with some levels of both physical and transition risk (Figure 6). There are more companies at the tail of transition risk, whereas the distribution of physical risk is more even across all companies. There are fewer companies in the upper left and bottom right quadrants, with opposing directions of risk across the physical and transition risk dimensions. Whereas the majority of companies that we evaluated have negative physical risk, a more significant fraction of companies have positive transition risk. However, there are no companies in the upper right quadrant, which would contain companies with both positive physical and transition risk.

4 Discussion

Climate change, both its physical manifestation and mitigation mechanisms, have disparate impacts on company fundamentals. We offer a novel, facility mapping approach to evaluate the impact of climate change and climate policy on company fundamentals. We find that in Europe, under two distinct carbon price and physical climate scenarios, there are significant index and geographic differences in climate impacts on company earnings.

We posit that climate has a statistically significant impact on EBITDA growth rates as expressed through annual average temperature and temperature variability. This finding is inline with the current understanding of the impact of climate change on economic productivity.[19, 20] We find that the relationship that other studies have exhibited, showing that average temperature and temperature variability impact regional economic productivity, is also expressed at the granularity of the company. This result is important because when navigating climate stress tests and risk assessments at the company level, often times practitioners will translate regional impacts into company impacts, which relies on various assumptions about company exposure to specific geographies. We find that this translation from country to company, following the well-studied quadratic relationship between temperature and economic productivity, in theory, is not misguided with respect to the quadratic relationship that we found between temperature and company earnings. Incorporating company locations with explicit EBITDA impacts instead of economic productivity impacts, however, is a critical step towards better resolving the physical risk of climate change at a company-level. Our method no longer requires the assumptions of translating economic productivity, such as GDP growth rates, to EBITDA or similar metrics of company performance.

Our projections of physical risk are more concentrated by geography rather than index, meaning that the indices have enough geographic dispersion to maintain similar distributions of physical risk. The geographic concentration of risk is in southern Europe. This finding does not deviate from similar studies on regional and national economic productivity, which found persistently higher damages in southern Europe and potential boons for northern Europe.[19, 21, 22] We have excluded temperature variability from our projections as temperature variability has differing impacts on EBITDA dependent on the panel model specifications. When projecting the impact of climate change using projections of day-to-day temperature variability, we must be careful to ensure that temperature distributions are maintained between the historical data and the downscaled projections. Further work will better explore the relationship between company fundamentals and day-to-day temperature variability, and expand the analysis to extreme climate events such as flood and heatwaves.

Our results within transition risk offer a similar step forward in better resolving company earnings risk of climate change. When considering a base case in line with literature and analyst predictions, where EUA prices rise to €134 by 2030, companies are exposed to a near doubling of costs. That in itself poses a large risk to companies who are exposed to carbon, and a potential revenue source for those who are not in shortfall. By also accounting for company behavior, we show that select European companies are not simply exposed to carbon price as a product of their level of carbon emission intensity. The results, in this sense, are intuitive and the potential for positive returns is in line with previous literature.[33] Utilities (SX6P) that have internal policies that hedge carbon price risk and that can decarbonize readily, are positively exposed along the transition risk axis. Conversely, companies within the materials and industrials index (SXPP) are most exposed to carbon price hikes as a function of both the price itself and lack of hedging behavior. Somewhat surprisingly, companies within the oil and gas index, SXEP, who are regulated within some of the most stringent climate mitigation mechanisms, are less exposed within the transition risk axis than those in SXPP due to a pivot to renewables dampening negative impacts. Further to this, we see a wide range of intra-index transition risk exposure outlining that although trends by sector do exist individual company behavior does have a material impact.[32]

We do not explicitly aggregate across our physical risk and transition risk models as they are two distinct models with two distinct set of assumptions. We do, however, analyse the axes of risk in the context of one another. Our study deploys a Cartesian comparison of transition and physical risk. Under this comparison, we find that all indices, on average fall within median quantile of total risk. While sector based climate risk assessment is common,[5–7] our finding of risk clustering around the median warrants a more granular approach to climate risk assessment. When we view these axes at the company-level, this median quantile artefact is less relevant. Most companies fall within the quadrant of negative exposure to both physical and transition risk, whereas no companies fall within positive exposure within both indices. We acknowledge that there are only 212 unique companies within these indices, but given that their membership is a product of their market capitalization, the lack of companies in this quadrant speaks to the magnitude of climate risk across the European economy. Another finding worth noting is the distribution of risk. Transition risk is concentrated around zero, but has a significant number of companies toward 100% and -100%. Physical risk, conversely has a more even distribution across all companies.

Our study has multiple pathways for integration into current climate risk practices for the financial sector. Currently, there are two common modes of calculating company-level physical climate risk: economic productivity impacts (macroeconomic models) and the application of regional econometric models to company locations.[2,3,7] While both have been fruitful in building the language of climate risk for the financial sector, neither method is calibrated for company-specific impacts. We hope our study can be used to thread these two specific methods by applying company-level models to company locations. Further to this, our method builds upon the most recent literature that also quantifies transition risk at a company level by introducing company behavior, leading to the potential for further intrasector variation.[56] The combination of physical and transition risk in these contexts allow a more ready comparison between these two factors with the aim that this will help optimize the methods for comparative risk assessment and stress testing.

Our findings show that there are intuitive methods for determining the impact of climate change and carbon policy on company fundamentals. To ensure that they are resilient to climate change, investors need to account for the proper amount of climate risk within their portfolios. This study details that risk within a digestible risk management metric, EBITDA. With this metric, the magnitude of climate risk can be more easily integrated with other drivers of risk at the company and portfolio levels. To better aid in that integration, we suggest that future studies should couple carbon price and climate scenarios in one model to allow for simple aggregation across climate risk axes.

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5 Supplementary Material

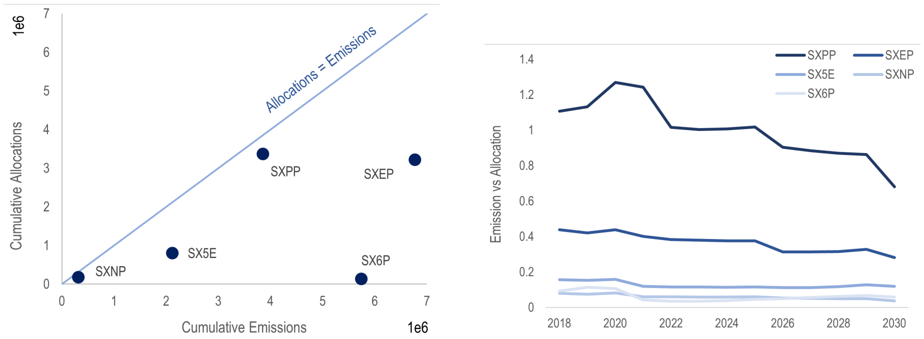
5.1 High Transition Risk

To investigate a higher risk scenario and further understand the implications of carbon pricing on institutions we forecast a high transition risk pricing scenario for EUAs out to our 2030 time horizon based on five distinct underlying variables: Crude Oil, Coal, Gas and German Electricity prices alongside auction volumes for EUAs themselves.

A Granger Causality test reveals the price of EUAs is Granger-caused by the four price variables and we thus run a linear univariate model for the price of EUAs (ARIMA model) with weekly pricing data sourced from Bloomberg and auction volumes from Primary Auction Data.[57] The data covers the time period of May 2018 to January 2023.

Although non-linear models in our research appeared to better predict the pricing evolution of EUAs, implying that the correlations among variables and to EUA prices evolves over time as expected, the short window of pricing history following the introduction of the Market Stability Reserve (MSR) compared to our forecast horizon of 2030 restricts the training set usable for VAR-DNN models for example.[58] However, literature does suggest that the utilisation of traditional linear models over long term horizons can produce higher accuracy for predictions than VAR-DNN models.[59]

Utilising this higher price forecast we can investigate the response of companies in a high transition risk environment. We see continuation of a complicated response function for individual indices and the average for all companies as seen in supplementary figure S7, ranging from -30-30% across index averages. The high positive returns of SX6P continue, as we believe to be driven by renewable investment and hedging strategies discussed in the paper, and indeed pushes the average return above zero. However we also note that the dispersion between returns for indices widens, giving rise to a further disparate impact when high transition risk is realised, increasing the negative impact on exposed companies.



(a) (b)

Figure 1: This pair of figures investigates the relationship of Free Allocations of EUAs to Emissions for indices as a whole. 1a plots cumulative values from 2018 to 2030 and helps explain different hedging and company behaviours when interacting with the EU ETS, whereas 1b displays the requirement for all companies to decarbonise over time to limit their transition risk.

Variable	**Model 1*** **	**Model 2*** **	**Model 3*** **
T	0.0273*** (0.0043)	0.03*** (0.0038)	0.0308* (0.018)
T2	-0.002*** (0.0004)		-0.0022** (0.001)
Td			-0.0027 (0.0734)
Td2			-0.0009 (0.018)
Key Metrics			
Citing Literature	Burke et al. (2015)	Kotz et al. (2021)	Burke et al. (2015), Kotz et al. (2021)
R-squared	0.09	0.08	0.08

Table 1: This table shows the the three main model configurations explored in our paper. T represents annual average temperature. T2 represents the square of annual average temperature. Td represents day-to-day temperature variability. Td2 is the square of day-to-day temperature variability. Significance is implied at the 0.01, 0.05, 0.1 levels with ***,**, and * respectively. All models account for time, entity, and sector fixed effects, as well as the earnings growth from the previous year. Additional configurations can be found in supplementary Table S1

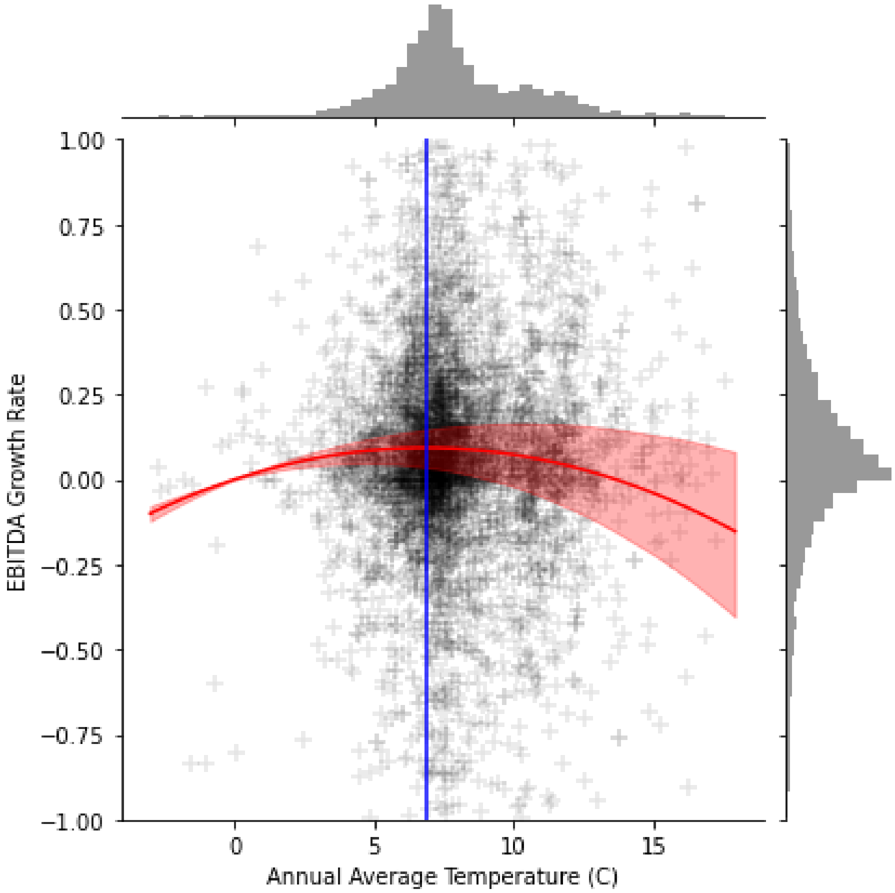


Figure 2: This joint plot details the base model finding from the panel model in orange within a joint distribution plot of the annual average temperatures (C) and EBITDA growth rates used in the study. The shaded area around the orange line is the 95% confidence interval. The blue line crosses the the optimal temperature threshold at 6.8 C.

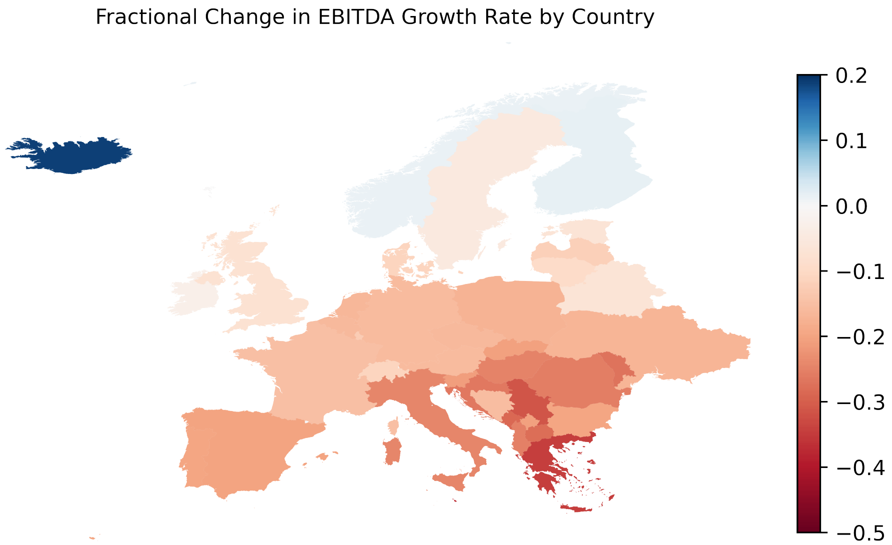


Figure 3: This map details the climate model projections of our base econometric model finding at the country level. Data is aggregated at a facility-resolution using the number of employees as the weight.

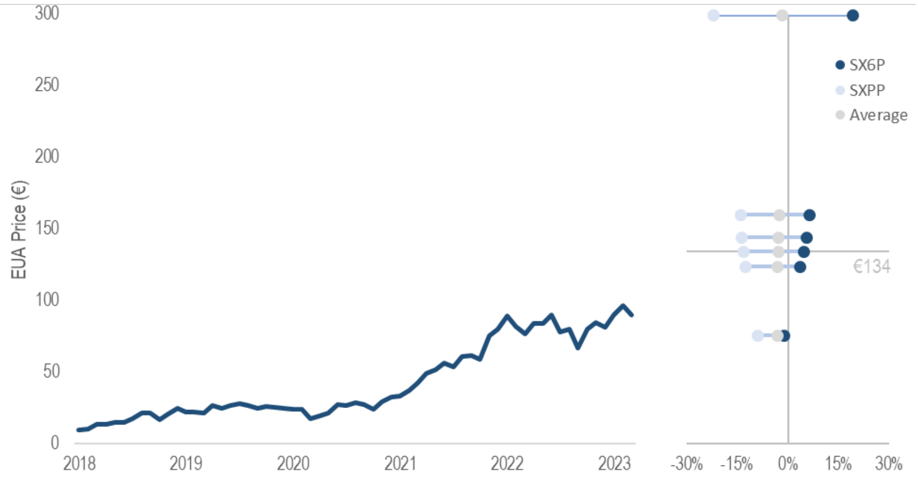
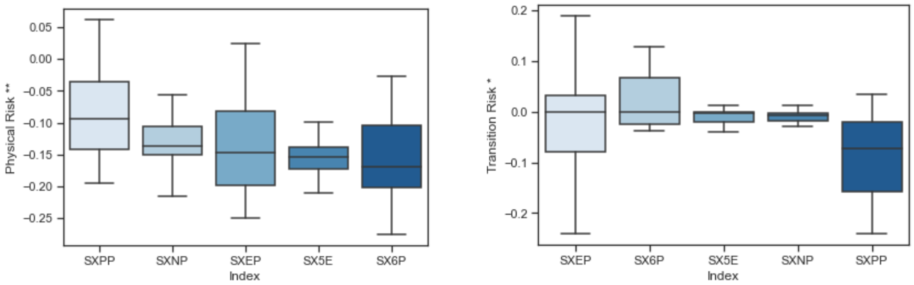
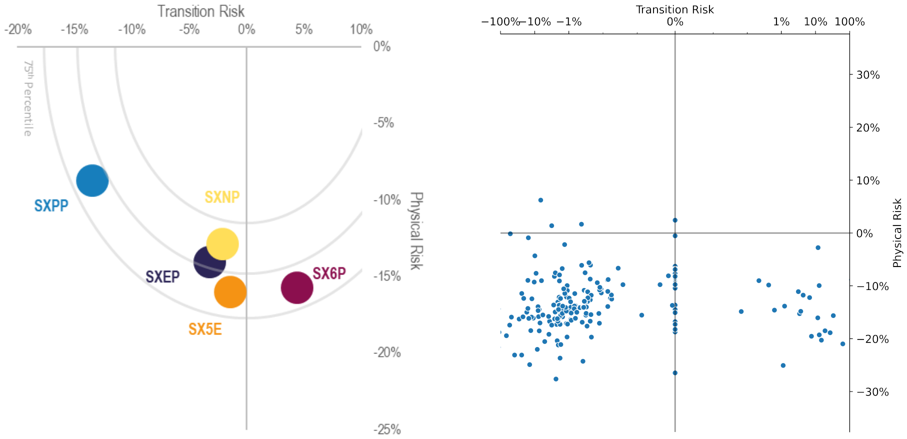


Figure 4: This figure displays both price evolution of EUAs over time since the establishment of the MSR and potential forecasted 2030 values by analysts and the accompanying transition risk for the SX6P, SXPP and the average across all indices. €134 is highlighted as the base case analyst price and subsequent forecasted transition risk used in our discussions.



(a) (b)

Figure 5: 5a details the distribution of physical risk by index in terms of fractional EBITDA impact to 2053. 5b details the distribution of transition risk by index in terms of fractional EBITDA impact to 2030.



(a) (b)

Figure 6: 6a compares the mean value of physical and transition risk by index in terms of percent of EBITDA. Quantile radii are drawn from the data at the company-level. 6b compares the distribution of physical and transition risk by company in terms of percent EBITDA.

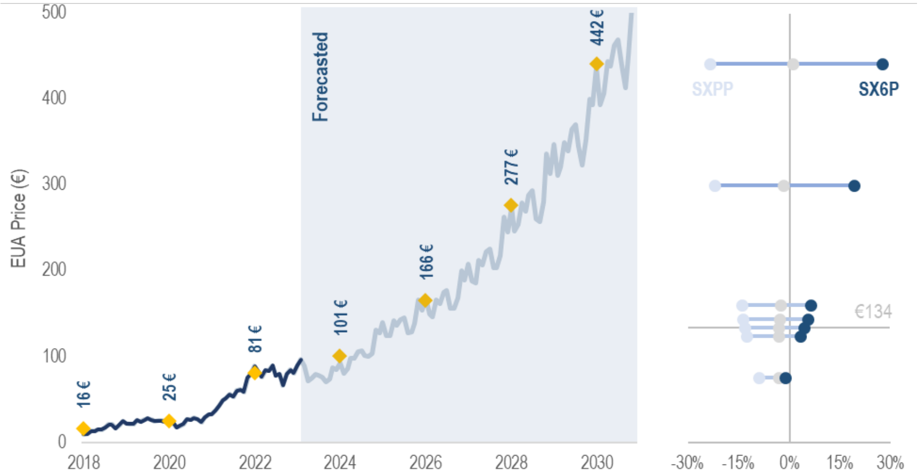


Figure S1: This figure displays both price evolution of EUAs over time since the establishment of the MSR and the linear model forecasts 2030 values by analysts and the accompanying transition risk for the SX6P, SXPP and the average across all indices. €442 is highlighted as the high risk case price.