Unveiling the Green Equity Premium: A Macro-Financial Outlook*

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October 30, 2024

Abstract

This paper introduces a novel methodology for classifying asset greenness and examines the impact of carbon pricing and climate risk on asset returns and equity premiums of greener versus browner assets in the Euro Area. We construct three distinct portfolios based on exposure to regulation (i.e. subject or not to the EU ETS market). Our results show a positive equity premium for greener assets when carbon prices are low, consistent with the theory that greener assets carry higher risk. However, this premium diminishes with stronger policy commitment and rising carbon prices. Using Bayesian estimation within a macro-finance framework, we confirm the empirical findings and identify climate sentiment shocks as key drivers of asset returns, while carbon pricing shows limited influence on the premium given its low levels over the studied period, it can be a catalyst when price levels are high.

Keywords: Green Portfolio, Green Equity Premium, Climate Transition Risk, ETS Carbon Pricing.

JEL: Q58, G12, E32.

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*This draft has benefited from comments and suggestions from David Aikman.

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1 Introduction

This paper introduces a novel methodology to categorize assets according to their greenness and analyzes the drivers of the difference between browner and greener equity returns, which we refer to as the "green equity premium," within a financial economics framework.

Leveraging on diverse datasets and the exposure of firms to carbon pricing under the European Emission Trading System (EU ETS) as a proxy for their environmental stance, we empirically establish that, during the first part of phase 3 of the EU ETS, portfolios characterized by very low emissions intensity within the Euro Area (EA) economies consistently exhibit higher returns and volatility than their brown counterparts. Moreover, our analysis endeavors to propose a novel methodology for assessing the environmental orientation of portfolios within the EU context. By grounding our empirical strategy in the observed regulatory landscape, our approach ensures the plausibility of the green equity premium (i.e., the difference in returns between browner and greener firms) within investor portfolios. The higher returns on green firms before 2017 can be rationalized by market participants' perception of a low carbon price as a weak commitment to the green transition. However, following the EU's announcement of a stronger commitment to the green transition in 2017, and the subsequent rise in carbon prices, the difference in returns between green and brown firms becomes less significant. This shift highlights the impact of policy commitment and carbon pricing in narrowing the equity performance gap.

At the heart of the green equity premium puzzle lies the issue of stranded assets. This climate risk underscores the evaluation of how a company's financial status might be affected by the potential consequences of climate-induced transformations spanning physical, economic, financial, and regulatory spheres. Firms may encounter assets vulnerable to varying degrees of climate-related physical risk (i.e. extreme weather events), while their profitability could be influenced by the emergence of carbon levies or climate policies promoting decarbonization (climate transition risk). Enterprises classified as environmentally sustainable or climate-friendly, possessing low CO_2 emissions intensity and thus better equipped to prosper in a low-carbon future, are commonly labeled as green firms. In contrast, those with higher emissions intensity and less alignment with climate objectives are designated as brown firms.

The comparative equity performance of browner versus greener firms has ignited extensive debate among scholars in climate finance, industry professionals, and policymakers alike. Numerous mechanisms have been proposed to shed light on how a firm's environmental characteristics may impact its financial performance and cost of capital. Bolton and Kacperczyk [2021] and Bolton and Kacperczyk [2022] adhere to conventional efficient capital markets theory, employing a standard risk-return trade off framework to analyze the interplay between brown and green firms. Brown firms are argued to confront heightened climate-related financial, liability, and regulatory risks owing to their reliance on fossil-fuel energy sources. Notably, high-carbon emitters are susceptible to increased "climate transition risk", wherein prospective rises in carbon pricing or analogous climate policies disproportionately affect these entities, potentially resulting in asset devaluation and business model disruption (referred to as "stranded assets"). Consequently, investors in brown firms demand higher expected returns to offset the incremental climate risk, commonly termed the "carbon risk premium." This premium implies that brown firms face a higher cost of capital and are assigned lower valuations (price multiples) on projected earnings. Similarly, Bansal, Kiku, and Ochoa [2019] posit that climate change risk is factored into stock market valuations, evidenced by the adverse impact of low-frequency global temperature fluctuations on asset prices and the concurrent presence of a positive risk premium. Our results confirm the consistently higher average returns of browner firms compared to greener ones within the context of the Euro Area over the studied period (2013-2022).

Conversely, multiple studies have reported substantial returns for portfolios favoring green equities over brown ones (Garvey, Iyer, and Nash [2018]; In, Ki, and Young Park [2019]; Pástor, Stambaugh, and Taylor [2022], Bauer, Huber, Rudebusch, and Wilms [2022], Huij, Laurs, Stork, and Zwinkels [2023], and Jaccard, Kockerols, and Schüler [2023]). While these studies find that greener portfolios exhibit higher returns than their browner counter part, superior realized returns of green stocks may stem from heightened concerns about climate change, rather than inherently higher expected returns (Pástor et al. [2022] and Ardia, Bluteau, Boudt, and Inghelbrecht [2022]). Thus, the current body of climate finance literature has yet to conclusively establish the recent comparative performance of green and brown equities on both ex ante and ex post bases. The literature on the existence of a green premium in the bond market is similarly divided. For instance, Baker, Bergstresser, Serafeim, and Wurgler [2018] and Karpf and Mandel [2017] look at U.S. municipal bonds, finding that returns on brown bonds are on average higher than those for the green bonds. Zerbib [2019] looks at a broader set of bonds and finds that the yield of green bonds is lower than the conventional bond, concluding that the preference for green bonds drives this differential. On the other hand, Larcker and Watts [2020] and Flammer [2021] find that the green premium is non-existent.

The heterogeneity of results often stems from either: i) the estimation methodology employed, and/or ii) the data and portfolio construction of green indicators. Firstly, empirical climate finance studies commonly rely on regression analysis for estimation, which can be particularly sensitive to specification choices as discussed in Bauer et al. [2022] and Larcker and Watts [2020] and demonstrated in Huij et al. [2023]. Additionally, the classification of a firm's and portfolio's greenness can be highly sensitive to both the data utilized and the methodology employed to gauge environmental friendliness. The quality of the data, whether measured directly or self-reported by firms, can yield markedly disparate outcomes (Aswani, Raghunandan, and Rajgopal [2024]). Moreover, the choice between specific sample selections of firms or the utilization of CO_2 emissions levels to assess greenness versus alternative metrics such as emissions normalized by firm size (emission intensity), emission growth rates, or composite environmental scores like the "E" component of ESG ratings provided by financial data providers, can lead to divergent findings (Cheema-Fox, LaPerla, Serafeim, Turkington, and Wang [2021]; Bolton and Kacperczyk [2021]; Pástor et al. [2022]).

In our study, we propose a new methodology to classify the brownness and greenness of firms in the EA based both on their exposure to climate regulation and emission intensity. Therefore, we categorize firms into three groups: brown, orange, and green. Both brown and orange firms exhibit higher emission intensity compared to their green counterparts. The primary distinction between brown and orange firms lies in their exposure to the EU ETS regulatory framework. Brown firms are currently subject to the EU ETS, whereas orange firms are not yet included but are anticipated to be incorporated in future phases of the EU ETS.[1] As emphasized by Bauer et al. [2022], data selection and categorization choices may significantly influence the results.[2] Therefore, we conduct several robustness checks and explore alternative cutoffs, as detailed in the data section. Our findings remain consistent across a variety of choices and robustness checks.

In the estimation phase of our study, we aim to: (i) evaluate how our greenness measure contrasts with those used in the existing literature, (ii) identify the role of policy in influ-

[1] Further details on the construction of these categories based on emission intensity and exposure to the EU ETS are provided in the data and portfolio construction section.

[2] Our proposed measure aims to address the above mentioned limitations, such as limited emission data, self-reporting biases, and methodological biases in score construction. It does so by accounting for sectoral differences while maintaining comparability across sectors.

encing asset returns, and (iii) estimate the determinants of the equity premium and asset returns. To achieve these objectives, we begin by empirically comparing asset returns across our greenness classifications with those from existing measures. We then demonstrate the importance of policy commitment and rising carbon prices in narrowing the equity premium gap, followed by using a macro-finance approach to assess the drivers of the carbon premium at a monthly frequency. This last approach offers a fresh perspective by focusing on cyclical drivers rather than the contentious long-run outcomes. By employing a macro-financial framework for our Bayesian estimation, we contribute a novel angle to the ongoing debate. Our framework is aligned with the model proposed by Jaccard et al. [2023], where they develop a macro-finance model featuring two sectors (brown and green) to examine the impact of carbon pricing on the equity premium. Utilizing a simulated method of moments, they match their model aggregates to empirical observations with the portfolios they construct, and find that the green returns increase with carbon pricing. In contrast, we employ a framework that incorporates three sectors and investor preferences for assets and rely on Bayesian estimation to dissect the monthly drivers of the equity premium. We find that carbon pricing does not play a significant role in driving the green premium whereas preferences for green assets is key.

The paper is structured as follows: we begin by detailing the data collection process and portfolio construction in section 2. Section 3 contrasts the categorization introduced in this paper with conventional measures of greenness. Section 4 presents the empirical results and offers an in-depth analysis of the results regarding the greenness measure and the impact of policy on asset returns. Section 5 describes the macro-financial model employed to estimate the cyclical drivers of equity returns, and Section 6 summarizes the estimation procedure. Section 7 presents the quantitative analysis, followed by concluding remarks.

2 Climate variables and Portfolios Classification

This section provides an overview of the key variables in our analysis, which is conducted on a monthly basis and spans from January 2013 to December 2022.

We start by introducing two indicators that reflect climate policy commitment and investor preferences at the European level: i) the EU Emissions Trading System (ETS) price and ii) a transition risk indicator (TRI). Next, we explain the process of how we calculate monthly firm-level returns. Then we present a novel approach that assigns each firm a specific tier based on the EU regulatory framework; this forms the basis of our Climate Regulation Tier (CRT). To conclude, leveraging on the CRT, we construct tier-based portfolios and emissions, analyzing their evolution over time.

2.1 EU ETS price and transition risk index

The EU ETS price data is sourced from Refinitiv Eikon and is aggregated on a monthly basis by calculating the average of daily prices for each month.[3] The series has been deflated using the monthly harmonized Consumer Price Index for the EA19, as provided by Eurostat. Permits prices variations are driven by both supply (policy regulation) and demand shocks (e.g. consumption and output shocks) as highlighted in Benmir, Roman, and Taschini [2023]. Figure 1 underscores the importance of policy regulations. In 2017, when the EU Carbon Market Reform Deal was approved, this reform led to an increase in carbon price due to the introduction of an annual linear reduction factor of allowances among other features.

To capture transition risk, we use the index developed by Bua, Kapp, Ramella, and Rognone [2022], which assesses perceived risks from regulatory changes, shifts in preferences, and technological advancements. The index uses a text-analysis approach close to Engle, Giglio, Kelly, Lee, and Stroebel [2020] and focuses on EU feeds taken from Reuters News to develop a vocabulary list for transition and physical concern. Since the measure is available at daily frequency, we aggregate it to a monthly level using the same method described above.

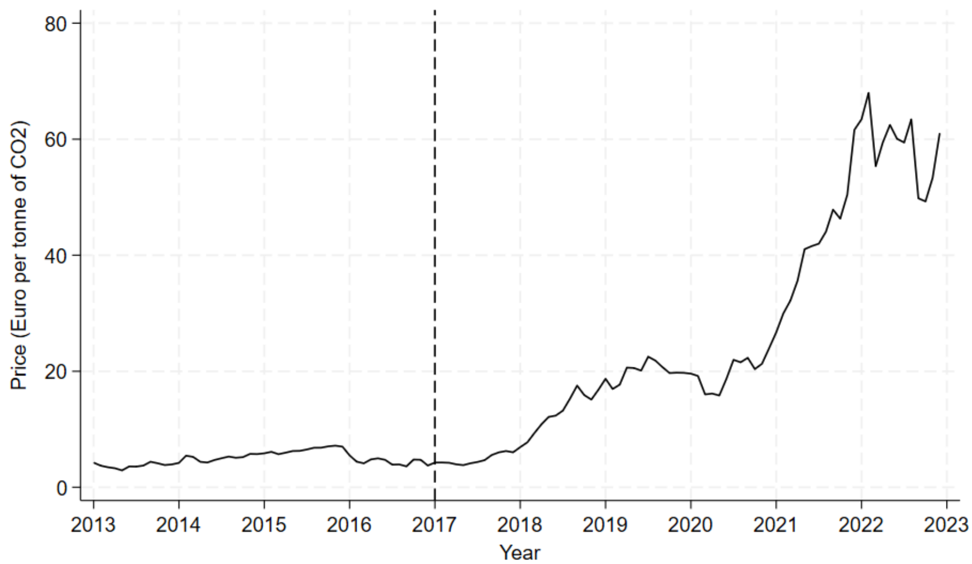
2.2 Returns

We collect daily firm level equity returns from Refinitiv Datastream, covering the period from January 2, 2013, to December 31, 2022. Our dataset includes a representative sample of European stocks, selected after applying commonly used filters.[4] Initially, our raw data set consists of 3,373 EU firms. To avoid unreliable returns data (stemming from extreme values), we apply further filters. Specifically, we observe that some firms experienced extended periods of zero returns, often due to low trading volume. Therefore, we exclude firms that have zero returns on more than 75% of the available trading days. In addition, we remove

[3]Prices before May 2021 refers to phase 3 of the EU ETS while those after relates to phase 4.

[4]We focus on securities traded on the following exchanges: Deutsche Börse AG (DE), Euronext Paris (FR), Borsa Italiana (IT), Mercado Continuo Español (ES), Euronext Amsterdam (NL), Euronext Bruxelles (BE), Euronext Lisbon (PT), and the Vienna Stock Exchange (AT). For a given company, only major securities with primary quotes are considered. The currency is Euro.

Figure 1: Real EU ETS price



Note: Real price at monthly frequency from January 2013 to December 2022. Source: Refinitiv Eikon.

outliers by calculating a z-score at the sector level,[5] excluding observations that deviate from the mean by more than three standard deviations. After these adjustments, our final dataset includes 2,637 firms across 79 NACE level 2 sectors. Finally, we aggregate the returns at monthly frequency by compounding the daily returns over each month.[6]

2.3 Climate Regulation Tier

The CRT classifies firms into three tiers: brown, orange, and green. The classification is determined by the sector to which each firm belongs. The brown tier includes sectors that are currently subject to EU ETS Phase 4 and were also regulated under Phase 3 of the trading scheme. These sectors are the most significant emitters at European level. The orange tier consists of sectors that began to be regulated under the EU ETS during Phase 4 or are expected to be regulated in the near future. Finally, the green tier includes industries with low emissions and emission intensity that are not subject to the scheme and are unlikely to be regulated in the future.

To construct our classification, we use the EU-ETS Information Dataset developed by

[5] We do not remove any outliers flagged in March 2020 to account for COVID-19.
[6] We note that results remain robust to these filters and data cleaning choices.

Abrell [2023]. This dataset provides detailed information on emissions and compliance behavior at the installation level within the EU ETS. We specifically focus on the May 2021 version of the dataset, which includes transaction data up to April 2018 and compliance data through 2020, consequently covering phase 3 of the EU ETS. Among other variables, the dataset includes the NACE level 4 sector classification for each installation–such classification is based on the 2015 carbon leakage assessment of the European Commission–as well as an official list of sectors and sub-sectors considered to be at significant risk of carbon leakage for the period between 2015 and 2019. We exploit this information to identify brown sectors, which we define as those with at least one installation included in the dataset.

There are instances where a single installation engages in multiple activities, however, only one of these activities is used to define the sector of the installation. This can pose a problem when the sector's primary activity is not regulated under phase 3, but the sector is still classified as brown due to its secondary activity. For example, Charles De Gaulle Airport is included in our dataset not because it is categorized as "Aircraft Operations", but due to its fuel combustion activities.[7] As a result, we could mistakenly classify air transport as a brown sector. To address these issues and the fact that our analysis is conducted at the more aggregated NACE level 2 sector,[8] We evaluate the specific characteristics and regulatory status of each brown sector, with particular emphasis on those with a small number of installations. Based on this assessment, we reassign them to the most appropriate category.

Sectors not included in the EU ETS Information Dataset are categorized as either orange or green. To properly allocate these sectors, we consider their own attributes with a particular focus on their compliance with Phase 4 of the EU ETS. For industries where emission intensity data are available, we further validate our classification by examining sectoral emission intensity levels. As depicted in Figure A1, there is a distinct discontinuity in emission intensities levels that aligns with our color-based classification system.

The complete list of NACE level 2 sectors along with their respective color classifications within the CRT is provided in table Table B1. As displayed in Table 1, approximately 55%

[7] Airports often operate their own energy production facilities to meet their infrastructure's energy demands.

[8] We encounter situations where a NACE lev. 2 sector should be labelled as brown based solely on the presence of a small number of installations within a specific NACE lev. 4 subsector. For example, Sibylla, a food retail company in Sweden, is regulated under the EU ETS in accordance with Article 24 of Directive 2003/87 from the European Commission. Sibylla belongs to NACE lev. 4 sector *47.29* (Other retail sale of food in specialised stores). Consequently, this could incorrectly result in the entire NACE lev. 2 sector *47* (Retail trade, except of motor vehicles and motorcycles) being classified as brown.

of the sectors are brown, while the remaining portion is equally divided between orange and green.

Table 1: Color classification of NACE level 2 sectors

	Green	Orange	Brown	Total
Number of sectors	20	17	42	79
	25%	22%	53%	100%

Notes: the table presents the number of NACE lev. 2 sectors within each color, along with their respective shares relative to the total.

2.4 Portfolios

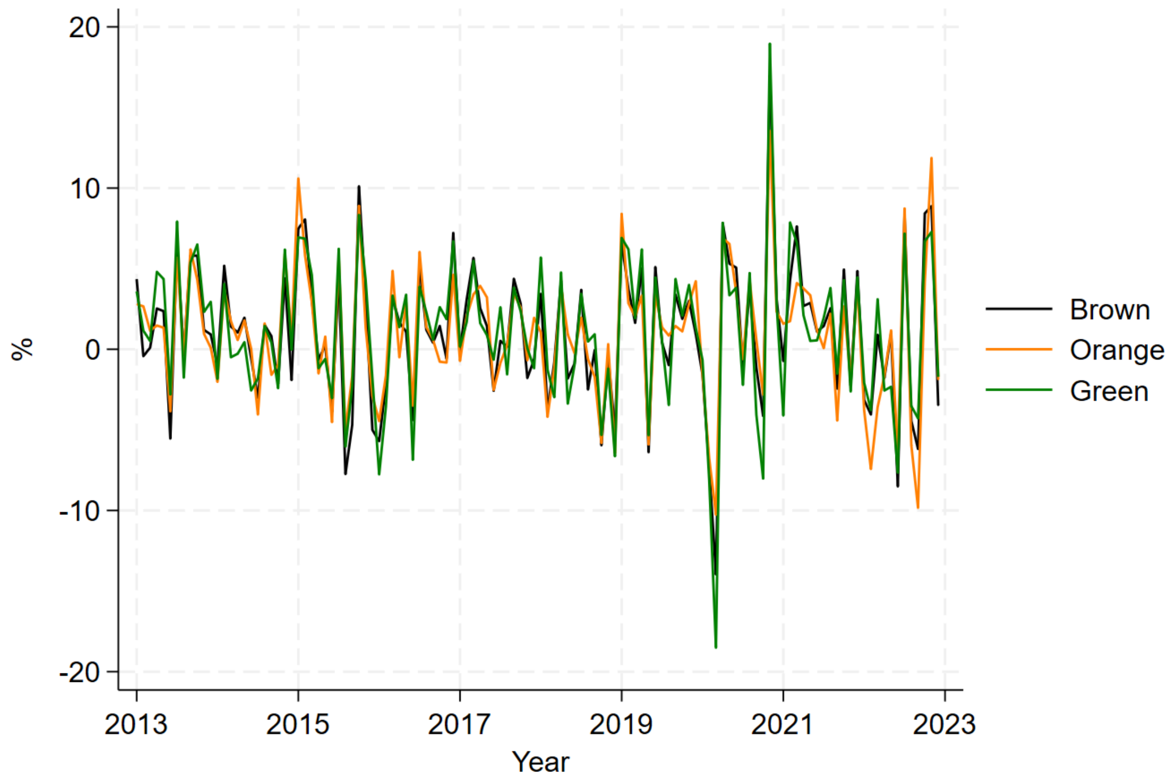
Since each firm's sector is known and has been assigned a specific tier, we can determine the tier designation for each companies in our analysis. Table B2 presents the distribution of firms by tiers. Results closely match those observed at the sector level, with brown firms being the most represented in our sample.

We construct the three tier portfolios by aggregating firm-level daily returns weighted by market capitalization and compounding the daily figures to generate monthly returns. The resulting three series, shown in Figure 2, are highly correlated and exhibit a significant drop in March 2020 due to the onset of COVID-19, followed by a rebound in November of the same year driven by vaccine news. Beyond the pandemic, we observe two other periods of heightened volatility: the first in 2015-2016, driven by political uncertainty and turbulence in the Chinese stock market; the second in 2022, fueled the Russia-Ukraine war and the consequent energy crises.

Table B3 provides a summary of the descriptive statistics of the indices. On average, the green portfolio delivered higher returns compared to the orange and brown portfolios. However, when adjusting for risk (i.e. the Sharpe ratio), the performance of the three indices is identical.

Having identified 2017 as a pivotal year for policy commitment on climate issues, we analyzed the performance of the portfolios before and after this period. This analysis will allow us to dissect the policy role and the commitment perception of the regulator to the green transition by the market participants. As shown in Table 2, green portfolio outperformed its brown and orange counterparts prior to 2017, indicating a higher risk associated with

Figure 2: Colors returns



Note: the returns are at monthly frequency. Source: EU-ETS Information, Refinitiv Datastream and authors' calculations.

the green assets. However, since 2017, policy commitment has closed this gap, with the premium between green and brown portfolios narrowing from 29 basis points before 2017 to -10 basis points afterward. Similarly, the gap between orange and green portfolios has decreased from 19 to 12 basis points. Notably, while volatility has increased over the last six years of our sample in light of the aforementioned developments, this has not led to a corresponding increase in average returns, which have declined across all portfolios.

Table 2: Portfolio returns

	Pre-2017			Post-2017		
	Mean	Std	Sharpe Ratio	Mean	Std	Sharpe Ratio
Green	1.42	3.90	0.36	0.81	5.12	0.21
Orange	1.23	3.54	0.34	0.69	4.44	0.22
Brown	1.13	3.92	0.28	0.91	4.73	0.25

Notes: the table presents the average return, standard deviation, and Sharpe Ratio for the three color-coded portfolios, calculated for two sub-samples: January 2013 to December 2016, and January 2017 to December 2022. All returns are expressed as percentages.

2.5 Emissions

The emissions data is sourced from EDGAR - Global Greenhouse Gas Emissions,[9] which provides records of CO_2 emissions for various sectors on a monthly basis across different countries. We focus on the EA20 countries, aggregating the emissions for each sector across the countries of interest. Subsequently, we deseasonalize the series and calculate the emissions per capita. We assign emissions per capita to a given color by employing the correspondence between the NACE and the IPCC codes as described in the methodological note on FIGARO - CO_2 Estimates (European-Comission [2024]). [10] The list of EDGAR Industries and their respective color is provided in Table B5.

As illustrated in Figure A2, there is a noticeable downward trend in emissions from the brown aggregate sector after 2018, whereas the emissions of the orange aggregate sector have remained relatively stable over the period of interest.

3 CRT in relation to conventional measures of greenness

This section examines the relationship between our newly developed measure–the Climate Regulation Tier–and standard metrics used in the climate literature. We begin by outlining these common metrics and exploit them to validate our measure. Following this, we utilize

[9]See Commission, Centre, Crippa, Guizzardi, Schaaf, Monforti-Ferrario, Quadrelli, Risquez Martin, Rossi, Vignati, Muntean, Brandao De Melo, Oom, Pagani, Banja, Taghavi-Moharamli, Köykkä, Grassi, Branco, and San-Miguel [2023].

[10]An industry is classified as brown if the majority of the NACE sectors within that industry are brown. Otherwise, it is classified as orange.

the CRT and the dataset built in section 2.2 to provide new insights into findings previously reported in the literature.

3.1 Common climate metrics

Broadly speaking, two categories of metrics are commonly used to assess the environmental performance of companies: emission-based and score-based measures.

Emission-based measures offer a straightforward method for evaluating a company's environmental impact by quantifying the amount of direct (Scope 1) and energy-related (Scope 2) emissions it produces (e.g. Bolton and Kacperczyk [2021], Pástor et al. [2022]). In practice, these emissions are often scaled by an indicator of company size, such as revenue or market capitalization, to assess how efficiently the company generates output relative to its emissions and to enable comparisons across different firms. A drawback of this first category is that emissions are reported by only a limited number of companies, reducing the heterogeneity in the sample. Furthermore, emissions data are reported with lags (usually within 1 year) as argued in Hsu, Li, and Tsou [2023].

Score-based measures extend beyond reported data by incorporating additional qualitative metrics to evaluate a company's greenness (e.g. Bauer, Offner, and Rudebusch [2023]). A widely used source for these scores is the Refinitiv ESG database, which provides two relevant metrics in our context: the environmental pillar score and the emissions score. The environmental pillar score combines nearly 70 metrics across three categories: emissions, innovation, and resource use. The emissions category, represented by the emissions score, assesses how effective and committed a company is to reducing its emissions and relies heavily on estimated emissions data but also considers factors such as the quality of the company's environmental management systems. While score-based measures have broader coverage than reported emissions, they evaluate companies in comparison to their peers within the same industry. This approach can result in two companies with vastly different pollution levels receiving similar scores.[11]

[11] For instance, the emission score for RWE AG - one of Europe's most polluting companies - is 76 out of 100 in 2022. Such value must be compared only with other companies in the multi-line utility sector rather than across all industries.

3.2 Validation

The measures outlined in the previous subsection assess a company's climate performance. Our Climate Regulation Tier, on the other hand, evaluates the degree of regulation a company faces under the European framework, based on the sector to which the company belongs. Although emission-based and score-based measures differ from our metric in the aspects they capture, the former can still be used to cross-validate the latter.[12] Intuitively, companies with higher emission intensities are more likely to be found in heavily regulated brown sectors, whereas lower emitters are more prone to belong to less regulated green sectors. At the same time, being the emission score constructed at the sector level, we expect the percentage of firms belonging to a sector classified as green, brown, or orange to remain consistent across different score levels.

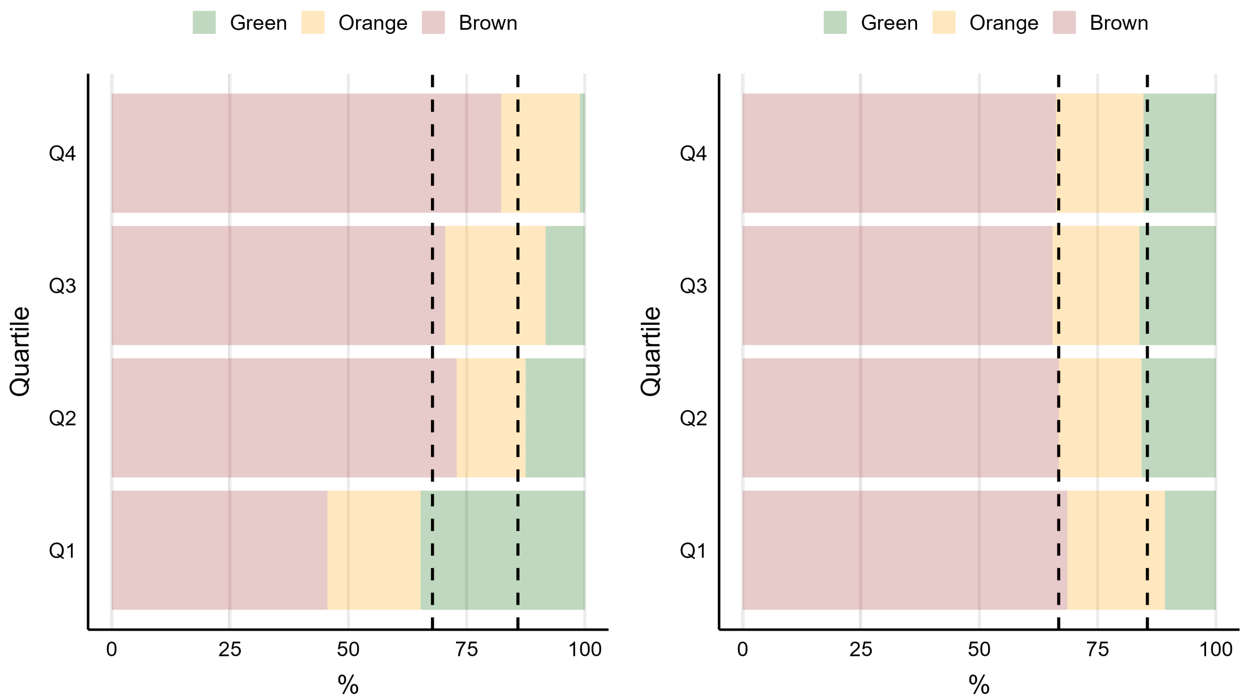
This relationship is illustrated in Figure 3. Data on emissions and emission scores are sourced from Refinitiv Eikon and emission intensity is calculated as the ratio of total emissions (scope 1 and scope 2) to the company's revenues. In the left-hand figure, companies with available emission intensity data are grouped into quartiles based on their emission intensity. In the right-hand figure, companies with available emission score data are similarly categorized into quartiles based on their emission score. As emission intensity increases, the proportion of companies classified within regulated sectors rises significantly, with 99% of companies in the fourth quartile belonging to either a brown or orange sector. The same value decreases to 86% when considering the unconditional distribution and to 62% when assessing the lower quartile. Turning to the emission score, the color distribution remains consistent across quartiles and closely mirrors the unconditional pattern, where approximately 86% of companies belong to either brown or orange sectors.

3.3 New insights from CRT

By design, the Climate Regulation Tier is available for all companies in the sample described in section 2.2, which represents a comprehensive cross-section of EU companies. However, only a small percentage of these companies report emission intensity or have an emission score available. As shown in Table B4, from 2013 to 2022, the proportion of companies with emission scores has never exceeded 40%, while the share disclosing emission intensity has

[12] We use emission intensity and emission score as representative metrics for emission- and score-based measures, respectively. Results remain consistent when using emissions and the environmental pillar score.

Figure 3: Color distribution - by quartiles



Note: the left-hand-side chart includes only the companies with emission intensity data available from the sample specified in section 2.2 and assigns them to quartiles based on their average emission intensity from 2013 to 2022; the right-hand-side chart does the same but using emission scores. Higher values of emission intensity reflect a less environmentally friendly company, whereas higher emission scores reflect a more environmentally friendly company. The bars represent the percentage of companies allocated to a given color for a given quartile. Color allocation is described in section 2.3 The black dotted line show the unconditional distributions. Data sources: EU-ETS Information, Refinitiv Datastream, Refinitiv Eikon, and authors' calculations.

never surpassed 33%. This discrepancy in data availability justifies a comparison between the characteristics of the subset of companies with available climate measures and the broader sample of all companies. We focus on two specific features: the first and obvious one is the tier distribution in the Climate Regulation Tier, while the second is company size. The latter is particularly relevant given recent studies that examine how the effects of climate change can vary depending on a company's size. [13]

Starting with the tier distributions shown in Figure A3, we observe that the two subsamples with available climate data closely resemble the full sample. For instance, the

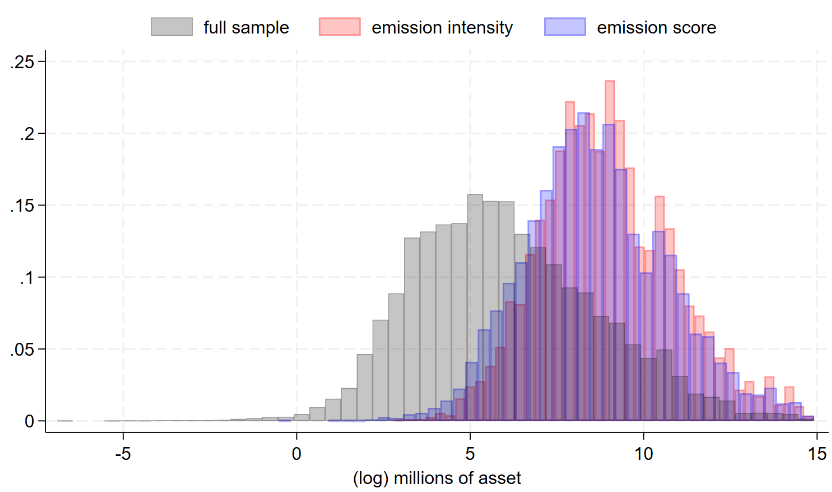
[13] Zhang, Deschenes, Meng, and Zhang [2018], Chen and Yang [2019], Ponticelli, Xu, and Zeume [2023] and Tarsia [2023] among others.

percentage of companies with emission intensity allocated to brown sectors is only 6% higher than in the overall distribution; this difference decreases to 5% when considering firms for which emission scores are available. The results are noteworthy because they indicate that, even though the sub-samples represent less than half of the full company universe, both score-based and emission-based measures effectively reflect the regulatory burden of the entire population.

Turning to company size, Figure 4 shows the asset distributions for two sub-samples along with the one for the full dataset. [14] The distributions for companies with available emission scores and emission intensity data are right-skewed, indicating the presence of larger firms in these sub-samples.

These findings suggest that although current EU-level studies on the impact of a company's environmental performance effectively represent the climate regulatory burden, they may be limited by not accounting for significant differences in company size. Considering these size differences is crucial for a complete understanding of the effects.

Figure 4: Asset distributions



Note: chart shows the distribution of (log) assets for three groups: the full sample, the subsample with available emission intensity data, and the subsample with available emission score data. Asset values are measured in millions of euros. Source: Compustat and authors' calculations.

[14]To capture company size we use quarterly asset data obtained from the Compustat Global database - Fundamentals Quarterly.

4 Empirics

This section evaluates the impact of EU's regulatory framework on reducing climate-related risks in financial markets by analyzing the effect of policy on equity returns between 2013 and 2022. For this purpose, we use the Climate Regulation Tier (CRT) classification introduced above to capture the degree of regulatory oversight that a firm faces. We expect that effective regulatory scrutiny should eliminate any differences in equity returns across the different tiers since it indicates that regulation has been able equalize climate-related risks across the tiers. To investigate this, we begin by analyzing the entire sample period from 2013 and 2022. However, noting a shift in policy commitment in 2017 as discussed before, we split the sample at this point to investigate the impacts of the change in the degree of commitment. Since our classification is more representative of firms' characteristics, we also present results decomposed by size to better understand the dynamics captured by less disaggregated results. Lastly, we conclude the section by conducting a series of checks to ensure the robustness of our findings.

As discussed in the previous section,the Climate Regulation Tiers places firms into three categories: brown, orange, or green based on the degree of regulatory scrutiny they face. For the regression we use the variable $T_i \in 1, 2, 3$ to represent brown, orange and green tiers respectively[15]. To investigate the impact of the regulatory scrutiny as captured by CRT on equity returns we regress equity returns on our classification, the EU ETS carbon price and the standardised transition risk index on monthly returns while controlling for firm-level and macroeconomic variables. In particular, we control for leverage ratio, gross profit margin ratio, tax burden, revenue growth, assets, volatility index (VIX) and short term interest rates (3 months). Firm-level control variables are obtained from COMPUSTAT, the VIX is sourced from Refinitiv and the short-term interest rate from EUROSTAT. Our firm-level controls are inspired by Bauer et al. [2023]. We define the leverage ratio as (Total Assets/Total Equity), the gross profit margin ratio as (Gross Profit/Total Revenue), and the tax burden as (Corporate Tax/Total Revenue)[16].

The summary statistics for the controls are shown in Table 3 below.

[15] See Table B2 for the distribution of firms across the different tiers.

[16] The tax burden measure is missing for a large number of firms, and like Bauer et al. [2023] we replace the missing values with zero though we do not add an indicator variable identifying missing observations.

Table 3: Control Variables: Summary Statistics

	Obs	Mean	SD.	Min	Max
Leverage Ratio	198,216	3.54	4.24	-12.24	33.63
Gross Profit Margin	160,133	0.40	0.30	-2.04	1.08
Tax Burden	213,667	0.01	0.05	-0.51	0.24
Revenue Growth	194,608	0.06	0.37	-0.97	3.49
Log Assets	198,325	6.04	2.66	-6.91	14.92
VIX	213,667	20.67	6.51	12.23	57.77
Short Term Interest Rate	213,667	-0.15	0.43	-0.58	2.06

Notes: This table presents the summary statistics for the control variables used in the analysis, including Leverage Ratio, Gross Profit Margin Ratio, Tax Burden, Revenue Growth, Log Assets, VIX, and Short Term Interest Rate (3 Months). Source: Compustat, Eurostat, Refinitiv datastream and authors' own computations.

We include the carbon price and the transition risk index to examine how policy stringency and shifts to climate policies and public preferences may impact equity returns. The EU ETS carbon price serves as an assessment of policy commitment's impact on firms' returns since the trading scheme operates through allowances whose supply is determined by the EU. In contrast, the transition risk index, captures shocks to regulatory environment and public preferences. This measure seeks to reflect how investors use news to form and update their beliefs. Moreover, the inclusion of these two variables helps mitigate the confounding effects when analyzing the impact of tiers of regulatory scrutiny on firms' returns.

Ultimately, the baseline regression specification is shown below where $R_{i,t}$ are the monthly returns for firms i at time t, CRT_i is the CRT classification, TRI_t is the transition risk index, CP_t is the carbon price, $X_{i,t}$ are the various controls discussed before, and $\epsilon_{i.t}$ the error term. Moreover, for our baseline we look at observations of the controls between 1st and 99th percentile, discarding the outliers except for the logarithm of assets.

$$R_{i,t} = \alpha + \beta_1 CRT_i + \beta_2 TRI_t + \beta_3 ETS_t + \boldsymbol{\beta}' X_{i,t} + \epsilon_{i,t} \tag{1}$$

Column 1 in Table 4 below shows that over the whole sample period, the tier classification does not have discernible or statistically significant impact on monthly returns. This indicates that over the whole sample period, the EU ETS regulation is effective since it eliminates the difference in returns between the tiers of firms. Moreover, a negative and statistically significant coefficient on the transition risk index suggests that shocks to climate regulations or shifts in preferences reduces the demand for "brown" and "orange" stocks relative "green" stocks, causing returns to fall. This effect is driven by "brown" and "orange" firms, which forms 82% of the sample. The coefficient on the carbon price though statistically significant is negligible in magnitude denoting that the carbon price does not impact the returns.

4.1 Climate Policy Commitment

As illustrated in Figure 1, carbon prices remained low until recently, failing to provide a sufficiently strong incentive for firms to be climate-conscious in their production processes. The low carbon price reflects long standing concerns that the EU ETS, a key regulatory tool against climate change, was not sufficiently stringent. This is due to the accumulation of a large surplus of allowances, which eroded the credibility of the carbon price in the eyes of investors[17]. However, 2017 marks the rise in ETS Carbon price following the approval of the overhauling of the EU ETS in February 2017 and given the concerns expressed above, this was an important regulatory change. Moreover, in November 2017, the European Parliament and European Council also reached a provisional agreement on Phase 4 of the carbon market. Though provisional, it was the end of prolonged negotiations among member states and demonstrated that addressing climate change is a common policy goal that the EU is actively committed to. Therefore, we argue that 2017 is a pivotal year of both policy commitment and intent. This may be more significant than when the policy changes are implemented since such changes are already internalised in the stock market.

Following this, we divide the sample period to before and after 2017 to investigate if the change in policy credibility and commitment discussed above notably change the results across the two periods. Table 4 presents two additional columns, showing results for pre- and post-2017 in columns 2 and 3. Prior to 2017 (column 2), the coefficients on carbon price and TRI are not significant, suggesting that market participants did not consider carbon pricing to be exacting enough and did not deem shocks to climate regulation or preferences particularly influential. With policy lacking commitment and credibility, investors had little reason to believe that shifts in preferences or regulatory shocks would impact returns, as there was no credible mechanism for these changes to affect market behaviour and equity returns. More importantly, we observe that the less regulated the firm is the higher the returns their equities yield, likely reflecting a higher risk premium associated with these stocks. This can be seen with the positive coefficient on CRT_i, which indicates that as you

[17] See Neuhoff, Acworth, Betz, Burtraw, Cludius, Fell, Hepburn, Holt, Jotzo, Kollenberg, Landis, Salant, Schopp, Shobe, Taschini, and Trotignon [2015].

move from a regulated tier such as "brown" to an unregulated one such as "green", the monthly returns increase by 0.3%. This is because market participants doubt the rigor or commitment to environmental policies and as such, "green" firms face greater uncertainty and potential risk exposure. Consequently, investors may demand a higher risk premium to compensate for the perceived volatility and unpredictability of favorable regulations for these firms. On the other hand, after the aforementioned changes were announced, the results in column 3 show that the coefficients on both the transition risk index and the carbon price are statistically significant. This demonstrates that market participants are factoring in these variables in response to the greater credibility in climate regulation through changes to the carbon price and the long-term commitment shown by an agreement on Phase 4 of the EU ETS. In particular, a 1€ increase in carbon price results in a 1 basis point rise in monthly returns, which when extrapolated to a larger change in price could have a significant impact on the returns. As the carbon price rises, the cost of production for regulated firms also rises, prompting market participants to demand higher returns to compensate for increased risk associated with higher production costs. As for the transition risk, a one standard-deviation shock causes the market returns to decrease by about 1.5%. A shock to transition risk signals an introduction or tightening of climate regulation or stronger preferences for such transition. Given post-2017 marks a period of committed and credible climate policies, instances of shifts in transition risk reduces the demand for "brown" and "orange" stocks relative to "green" stocks, resulting in the negative coefficient since, as noted before, "brown" and "orange" firms form 82% of the sample as seen in Table B2. Furthermore, after 2017, the effectiveness of the regulation eliminated differences in returns between tiers, as credible and committed policy announcements removed the risk premium discussed above associated with "green" firms relative to "brown" or "orange" firms.

Given that the CRT classification reflects a range of company sizes, we further decompose the effects discussed above to examine the impact of the tiers, the TRI, and the carbon price on the equity returns of firms of different sizes. This also sheds light on the size of firms that drive the results we see across the full sample for before and after 2017. We categorise companies into three different size tiers based on market capitalization by dividing them into thirds within each month and carry out the same analysis as above and this shown in Table C1. One of the key results we derived from Table 4 were that TRI and carbon price did not have an impact before 2017 though after 2017, these variables did have an impact on firms' returns due to more committed and credible policy announcements. The second key results is that post-2017 the difference in returns across the different tiers is eliminated due to effective policy. We find that both these results are driven by small and medium sized firms, which are often unaccounted for by other measures of greenness used in the literature as seen in Figure 4.

We conduct a series of robustness checks, which includes retaining all control variable outliers, removing firms where more than 50% of their monthly returns are zeros, not trimming the returns outliers and lastly, using CRT as dummy variables instead of a categorical variable[18]. We find that the two key results discussed above are robust across these different data cleaning procedures and model specifications. These results can be found in Appendix C.

In the next section, we decompose the cyclical drivers of the equity returns as well as the equity premiums using a structural model Bayesian estimation.

[18] We replace the CRT with "brown" and "orange" dummy variables, thus their coefficients should be interpreted as effects relative to the "green".

Table 4: Baseline Specification

	(1) $R_{i,t}$	(2) $R_{i,t}$ Pre-2017	(3) $R_{i,t}$ Post-2017
CRT	0.0555	0.286***	-0.0847
	(0.80)	(3.54)	(-1.02)
TRI	-1.056***	-0.00629	-1.469***
	(-21.47)	(-0.09)	(-23.21)
CP	-0.00472**	0.0592	0.0103***
	(-2.00)	(1.47)	(3.50)
Leverage Ratio	-0.0345*	-0.0533**	-0.0236
	(-1.66)	(-2.07)	(-0.86)
Gross Profit Margin Ratio	0.524***	0.478**	0.557**
	(2.76)	(1.97)	(2.40)
Tax Burden	5.725***	5.015***	5.929***
	(5.61)	(3.42)	(4.73)
Revenue Growth	0.438***	0.234	0.639***
	(3.23)	(1.28)	(3.22)
Log Assets	0.273***	0.255***	0.285***
	(11.05)	(9.72)	(9.11)
VIX	-0.153***	-0.347***	-0.146***
	(-25.19)	(-26.59)	(-19.93)
Short Term Interest Rates	-0.0356	-2.396***	-0.432***
	(-0.49)	(-9.33)	(-5.26)
Constant	0.723***	5.479***	-0.125
	(2.76)	(13.52)	(-0.39)
Observations	159319	59408	99911

t statistics in parentheses
* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

5 The Model

The modeled economy is characterized by discrete-time and an infinite horizon, consisting of three sectors: brown (B), orange (O), and green (G) firms, an infinitely lived representative household, a government, and an environmental agency.

As explained in the portfolio construction section, the main distinction among the sectors (brown, orange, and green) lies in the fact that brown sector firms represent the economy's firms EU ETS up to phase 3, while orange firms are expected to enter the EU ETS regulation in future phases. Green firms represent all other firms with very low CO_2 emissions intensity (near zero), thus not expected to be subject to EU ETS regulation.

In this setup, production by brown and orange firms induces an environmental externality through CO_2 emissions, while green firms are considered emission-neutral (i.e., they do not emit CO_2). Emissions stemming from the production side of brown and orange firms affect household welfare through utility damages due to rising emissions.

We begin by presenting the aggregate firm's production problem, before discussing the dynamics of the environmental externality and presenting the production problems of sectoral firms. We then focus on the household's problem, followed by the government and environmental agency's policy settings.

5.1 Firms and the environmental externality

In all that follows, we will denote variables that follow a trend with a capital letter X, while variables that are stationary will be denoted with lowercase letters x. In the appendix, we present the detrended version of the model.

5.1.1 The final firms

In the spirit of the multi-sector framework Carvalho and Nechio [2016], the brown, orange, and green production sectors, denoted by $k \in B, O, G$, consist of final firms. These representative final firms produce a final good $Y_{t,k}$ in these three competitive sectors.

$$Y_t = \left(\sum_k \varkappa_k^{\frac{1}{\theta}} Y_{t,k}^{1-\frac{1}{\theta}} \right)^{\frac{1}{1-\frac{1}{\theta}}}, \tag{2}$$

With $\theta \in (1, \infty)$ representing the elasticity of substitution between the two sectors, and $\varkappa_k$ denoting the weight of each sector (with $\sum_k \varkappa_k = 1$).

The aggregate final firm aims to maximize profit D_t given a price p_t, subject to the production of sectoral goods indexed by k at prices $p_{t,k}$:

$$D_t = p_t Y_t - \sum_k p_{t,k} Y_{t,k} \tag{3}$$

Under perfect competition and free entry, the prices of final aggregate good is given by:

$$p_t = \left(\sum_k \varkappa_k p_{t,k}^{1-\theta} \right)^{\frac{1}{1-\theta}}, \tag{4}$$

5.1.2 The environmental externality

Following standard integrated assessment models (IAMs) (see Nordhaus [1991] and Nordhaus and Yang [1996]), we cast environmental externality within a macro-finance framework. A significant portion of the accumulation of carbon dioxide and other Greenhouse Gases (GHGs) in the atmosphere is attributed to the human activity of economic production. We describe the temperature and concentration process of carbon dioxide in the atmosphere as follows. Firstly, the global temperature T_t^o is linearly proportional to the CO_2 emission stock – the cumulative amount of emissions – as posited by Matthews, Gillett, Stott, and Zickfeld [2009]:

$$T_{t+1}^o = \zeta_1^o(\zeta_2^o X_t - T_t^o) + T_t^o, \tag{5}$$

with ζ_1^o and ζ_2^o chosen following Dietz and Venmans [2019].[19]

Second, cumulative CO_2 emissions, denoted as X_t, follow a law of motion:[20]

$$X_{t+1} = \eta X_t + E_t^T + E_t^*, \tag{6}$$

where X_{t+1} is the concentration of gases in the atmosphere, $E_t^T \geq 0$ anthropogenic emissions of CO_2 E_t^T are comprised of both brown and orange sectoral emissions.[21], E_t^* represents the rest of the world emissions,and $0 < \eta < 1$ represents the persistence of CO_2 emissions, which is chosen to be very close to 1, as argued by Dietz and Venmans [2019].

The brown and orange sectoral emissions $E_{t,k}$ arise from production $Y_{t,k}$, and are influenced by an exogenous trend Γ_t^X and an AR(1) shock $\epsilon_{t,k}$. This trend encapsulates the decoupling between CO_2 emissions and production (as shown in Figure A2), while the AR(1) shock captures exogenous changes to emissions' intensity over the studies period. The relationship can be expressed as:

$$E_{t,k} = (1 - \mu_{t,k})\,\varphi_k Y_{t,k} \Gamma_t^X \epsilon_{t,k}, \tag{7}$$

[19] We observe that although variations in climate dynamics and damage modeling over the long horizon (be it à la Golosov, Hassler, Krusell, and Tsyvinski [2014], à la Nordhaus [2017], or à la Matthews et al. [2009], among others) lead to subsequent effects on macroeconomic aggregate equilibria, over the business cycle horizon (and under equivalent calibrations), these modeling specifications do not result in significant changes to macroeconomic aggregate equilibria.

[20] To ensure convergence in the auto-regressive law of motion for the stock of emissions process, and without a loss of generality, we deviate slightly from the transient climate response to cumulative CO_2 emissions theory by setting $\eta \neq 1$. However, we select η to be sufficiently close to one so that $X_t \approx X_0 + \sum_{i=0}^{t}(E_i^T + E_i^*)$.

[21] Where $E_t^T = E_{t,B} + E_{t,O}$.

where $\varphi_k Y_{t,k}$ is the total CO_2 influx resulting from production prior to the implementation of any abatement measures. The variable $\mu_{t,k} \geq 0$ represents the fraction of emissions that are mitigated (abated) by firms, while $\varphi_k \geq 0$ is a carbon-intensity parameter that defines the steady-state relationship between emissions and output.

5.1.3 Sectoral Firms

Our brown, orange, and green representative firms seek profit maximization $D_{t,k}$ by making a trade-off, on one hand between capital $K_{t,k}$ investment $I_{t,k}$ and labor $l_{t,k}$, and on the other hand, the level of investment in abatement technology $Z_{t,i}$ and the cost of the environmental policy (or expected carbon price τ_t in the case of the brown and orange firms only):

$$Y_{t,k} = \varepsilon_t^A K_{t,k}^{\alpha_k} (\Gamma_t^Y l_{t,k})^{1-\alpha_k}, \ \alpha_k \in (0,1), \tag{8}$$

ε_t^A is an exogenous technology shock that follows an AR(1) shock process: $\log(\varepsilon_t^A) = \rho_A \log(\varepsilon_{t-1}^A) + \sigma_A \eta_t^A$, with $\eta_t^A \sim \mathcal{N}(0,1)$.

Furthermore, our sectoral representative brown and orange firms incur a cost $Z_{t,k}$ for every emission unit abated, where $\mu_{t,k}$ is the abatement level.

Following Nordhaus [2017], abatement costs reads as follows:

$$Z_{t,i} = f(\mu_{t,i}) + \xi \left(\frac{\mu_{t,i}}{\mu_{t-1,i}} \right) Y_{t,i}, \tag{9}$$

where

$$f(\mu_{t,i}) = \theta_{1,i} \mu_{t,i}^{\theta_{2,i}}, \ \theta_{1,i} > 0, \ \theta_{2,i} > 1, \tag{10}$$

with i the subset of sector k including brown and orange firms solely. $\theta_{1,i}$ and $\theta_{2,i}$ represents the cost efficiency of abatement parameters for the brown sector.

Moreover, $\xi_{t,i}$ represents the abatement adjustments costs faced by firms in the spirit of investment adjustment costs Smets and Wouters [2007], where

$$\xi_{t,i} = \frac{\theta_{3,i}}{2} \left(\frac{\mu_{t,i}}{\mu_{t-1,i}} - 1 \right)^2 \mu_{t,i}$$

where $\theta_{3,i} > 0$ represents the degree of abatement adjustment costs. The adjustment cost is introduced to reflect the stickiness in abatement investment choices, which exhibits similar patterns to capital adjustment costs.

The revenues are the real value of the sectoral good $Y_{t,k}$, while the costs arise from wages

$w_{t,k}$ (paid to the labor force $l_{t,k}$), investment $I_{t,k}$ in capital $K_{t,k}$, and abatement $\mu_{t,i}$ (in the case of the brown and orange firms), and any environmental costs captured by carbon pricing τ_t (environmental taxes on the brown sector). The profit equation for each sector reads as:

The brown sector

$$D_{t,B} = p_{t,B}Y_{t,B} - w_{t,B}l_{t,B} - I_{t,B} - Z_{t,B} - \tau_t E_{t,B} \tag{11}$$

The orange sector

$$D_{t,O} = p_{t,O}Y_{t,O} - w_{t,O}l_{t,O} - I_{t,O} - Z_{t,O} \tag{12}$$

The green sector

$$D_{t,G} = p_{t,G}Y_{t,G} - w_{t,G}l_{t,G} - I_{t,G} \tag{13}$$

Since each firm partakes in investment, it also faces investment adjustment costs Λ_k and needs to consider investment in $K_{jt+1,k}$ as defined by the following equation:

$$\Lambda_k\left(\frac{I_{t,k}}{I_{t-1,k}}\right) = \left(1 - \frac{\phi_k}{2}\left(\frac{I_{t,k}}{I_{t-1,k}} - \gamma^y\right)^2\right) I_{t,k} \tag{14}$$

$$K_{t+1,k} = \Lambda_k(\cdot) + (1-\delta)K_{t,k} \tag{15}$$

As delineated in the data and portfolio construction, the orange sector comprises firms with a high emissions intensity compared to the green sector, despite not being currently subject to the EU ETS Scheme. These firms anticipate inclusion in the Scheme in future phases due to their high emissions, thereby facing potential future environmental taxes on their emissions.

We envision a specialized sustainability strategy team that we refer to as managers within the orange sector, which recognizes that the orange firm will be subject to future regulation. Consequently, this team selects the level of abatement today such that the marginal cost of today's abatement equals the marginal discounted future savings from such abatement. In this scenario, the abatement costs are reflected in the dividends of orange firms, as depicted above, while the discounted future taxes are not accounted for.

The managers' problem reads as: [22]

$$\min_{\mu_{t,O}} \mathbb{E}_0 \left\{ \sum_{t=0}^{\infty} \beta^t \left[\left(f(\mu_{t,O}) + \xi \left(\frac{\mu_{t,O}}{\mu_{t-1,O}} \right) \right) Y_{t,O} + \tau_{T-t} E_{T-t,O} \right] \right\} \tag{16}$$

For the full model derivations, please refer to the technical appendix.

5.2 Household

The representative household problem is approached using a CRRA utility function. The household chooses between: i) real consumption expenditures C_t subject to habit formation H_t, ii) labor hours $l_{t,k}$, and iii) investment in long-term government bonds b_t at price P_t^B, and/or risky assets (equity shares) $s_{t,k}$ at price $P_{t,k}^S$, which yield dividends $D_{t,k}$ and for which they exhibit preferences $\mathcal{U}_t^{s_k}$.

$$\max_{\{C_t, H_{t+1}, s_{t+1,k} l_{t,k}, B_{t+1}\}} E_0 \sum_{t=0}^{\infty} \beta^t \frac{(C_t - H_t)^{1-\sigma}}{1-\sigma} - \tilde{\lambda}_t \mathcal{U}_t^{s_k} - D^c(T_t^o) - \Gamma_t^{1-\sigma} \sum_k \frac{\chi_k l_{t,k}^{1+\Phi}}{1+\Phi}, \tag{17}$$

with the representative household budget constraint:

$$p_t C_t + T_t + P_t^B b_{t+1} + \sum_k (P_{t,k}^S s_{t+1,k} + \Lambda^{P^k}(.)) = \sum_k \left(w_{t,k} l_{t,k} + s_{t,k}(P_{t,k}^S + D_{t,k}) \right) + b_t, \tag{18}$$

$$H_{t+1} = m H_t + (1-m) C_t. \tag{19}$$

Here, $\beta \in [0,1]$ represents the time discount factor, $\sigma > 0$ is the curvature parameter, $m \in [0,1]$ signifies the habits formation parameter, χ_k denotes labor disutility, and Φ represents the inverse Frisch labor elasticity. Stationary labour hours are adjusted by ${\Gamma_t^Y}^{1-\sigma}$ to allow for a balanced growth path as in Greenwood, Hercowitz, and Krusell [1997]. Additionally, the government imposes a lump-sum tax, denoted by T_t.

In our framework, the lifestyle habits formation as in Jaccard [2014] allows to better match the low volatility of consumption with respect to output and captures a higher degree of volatility in the discount factor. This is paramount to our analysis as we focus on the asset pricing where the stochastic discount factor plays a key role.

[22]Notice that we consider that $T \approx \infty$ given that we estimate our model until time T. The managers discount the lifetime profits using time preferences β instead of the stochastic discount factor associated to the orange firms for computational tractability (otherwise the model will generate over 450 state variables). The results however remain robust to this specification (the impulse response functions to carbon price and climate presence shocks for both cases are sensitively similar).

In addition, $\mathcal{U}_t^{s_k}$ represents the preferences for financial assets in the utility function as described in Sidrauski [1967] and Krishnamurthy and Vissing-Jorgensen [2012]. To ensure a balanced growth path, $\mathcal{U}_t^{s_k}$ is scaled by the trend adjusted marginal utility $\tilde{\lambda}_t$ as in Cozzi, Pataracchia, Pfeiffer, and Ratto [2021].

We apply a similar scaling approach to climate damages $D^c(T_t^o) = \phi_T T_t^{o2} \Gamma_t^T$, where Γ_t^T represents the climate trend within the utlity function which allows us to retreive a balanced growth path[23]. ϕ_T denotes the damage intensity to welfare as in Barrage [2020]. The preferences $\mathcal{U}_t^s$ are given by

$$\mathcal{U}_t^s = \sum_k (\Xi_{t,k}^s + \epsilon_t^{P_k^s}) P_{t,k}^s s_{t+1,k} \tag{20}$$

with $\epsilon_t^{P_k^s}$ a financial market AR(1) shock to asset prices and $\Xi_{t,k}^s$ the portfolio climate preferences variable:

$$\Xi_{t,k}^s = \alpha^{s_k} + \alpha^{GT_k} \epsilon_t^{GT} + \alpha^{GP_k} \epsilon_t^{GP} \tag{21}$$

where we distinguish between two types of shocks: i) ϵ_t^{GT}, an AR(1) shock capturing climate transition risk, and ii) ϵ_t^{GP}, an AR(1) shock capturing climate physical risk. Here, α^{s_k} represents the long-run steady-state difference in returns between the three assets, while α^{GT_k} and α^{GP_k} captures the intensity of climate preferences within each asset class.

Finally, $\Lambda^{P^k}(.)$ represents quadratic portfolio adjustment costs:

$$\Lambda^{P^k}(.) = \frac{\phi_{S^k}}{2} (P_{t,k}^s s_{t+1,k} - \gamma^Y P_{t-1,k}^s s_{t+1,k})^2 \tag{22}$$

with ϕ_{S^k} portfolio adjustment costs intensity. These quadratic portfolio adjustment costs capture the imperfect substitution between green, orange, and brown assets, particularly when the economy is hit by different shocks.[24]

5.3 Public authorities

5.3.1 Government

The issuing of bonds and collection of taxes allows the government to finance its expenditures as follows:

$$G_t = T_t + \tau_t E_{t,B}, \tag{23}$$

[23] Please refer to the Appendix section on the BGP for further details.

[24] We note that γ^Y allows to have a zero steady state value for the adjustment costs.

where G_t refers to the public expenditures, T_t the lump-sum tax, and $\tau_t E_{t,B}$ the revenues raised from the environmental policy. In line with a standard business cycle model, government spending is determined as a percentage of total output Y_t:

$$G_t = gY_t, \tag{24}$$

where, g is calibrated to match the percentage of public spending as a share of total output in the Euro Area.

5.3.2 The environmental agency

The environmental regulator (e.g. the EU Commission) decides to target a specific emission level (i.e. set a quantity objective "CAP") such that of the European Trading Scheme:

Proposition 1 *The regulator decides to set an emissions cap on the brown sectors in order to achieve a specific emission reduction rate:*

$$E_{t,B} = Carbon\ Cap_t \tag{25}$$

which inherently determines a carbon price level τ_t:

$$\tau_t = Carbon\ Price_t. \tag{26}$$

where $Carbon\ Cap_t$ is the path of the cap on emissions consistent with the net-zero objective, and $Carbon\ Price_t$ the inherent carbon price associated with this objective. To reach the net-zero target, the price is expected to steadily increase in order to match the expected decrease in the cap.[25]

5.3.3 Market clearing

The resource constraint of the economy reads as follows:

$$p_t Y_t = p_t C_t + G_t + \sum_k \Lambda \left(\frac{I_{t,k}}{I_{t-1,k}} \right) + \sum_k Z_{t,k}. \tag{27}$$

6 Bringing the Model to Data

Leveraging on the dataset constructed in section 2 and on climate sentiment data, we identify structural shocks and model parameters across the study period (2013-2023). After calibrating a subset of parameters to align with critical economic and climate metrics within the Euro

[25] Carbon $\text{Price}_t = E\{\text{carbon price}\}\varepsilon_t^\tau \Gamma_t^\tau$, where ε_t^τ is a shock on the carbon price level and Γ_t^τ the carbon price trend.

Area, we estimate the standard deviations of shocks and the auto-regressive components, as well as various underlying trends in our model.

Our model is estimated using Bayesian techniques on monthly data from the Euro Area spanning January 2013 to December 2022. To map our model to the data, we augment our equilibrium equations with a set of observation equations as follows:

$$\begin{bmatrix} \text{Green Equity Returns} \\ \text{Orange Equity Returns} \\ \text{Brown Equity Returns} \\ \text{Per Capita Real GDP Growth} \\ \text{Per Capita Brown Emission Growth} \\ \text{Per Capita Orange Emission Growth} \\ \text{Real Carbon Price Growth} \\ \text{Transition Risk Shock} \\ \text{Physical Risk Shock} \end{bmatrix} = \begin{bmatrix} r_t^G \\ r_t^O \\ r_t^B \\ \log \gamma^Y + \Delta \log (y_t) \\ \log \gamma^X + \Delta \log \left(e_t^B\right) \\ \log \gamma^X + \Delta \log \left(e_t^O\right) \\ \log \gamma^\tau + \Delta \log (\tau_t) \\ \varepsilon_t^{GT} \\ \varepsilon_t^{GP} \end{bmatrix}, \tag{28}$$

where γ^X represents the trend in emissions, γ^Y the trend growth rate of the economy and γ^τ trend growth rate of the carbon price.[26] Given the model's assumption of stationarity, it is crucial to render the series stationary before mapping them the model. Following the seminal contribution of Smets and Wouters [2007], we stationarise the data exhibiting a unit root, specifically by taking the logarithmic difference of the series as needed.

6.1 Calibration

This section outlines the model's parametrization process, focusing on aligning our model with key observed economic and environmental indicators specific to the Euro Area. For parameters for which the time interval is relevant, the calibration is monthly. Key aggregates such as sector-specific emissions, sectoral mean average returns, market shares, and the average price of EU ETS allowances are meticulously matched to the data presented in Table C.2. This rigorous calibration guarantees that our model accurately captures the essential trends and dynamics observed in these environmental and economic indicators.

The structural parameters of our model follow conventional business cycle theories. Standard parameters like the discount factor β, the capital depreciation rate δ, and the coefficient

[26]Please refer to appendix for the complete description of the BGP.

of risk aversion σ are set to commonly used values in macroeconomic modeling. For the CES production function, we select an elasticity of substitution $\theta = 0.40$, recognizing the potentially low substitutability between goods from different sectors. Despite the absence of a clear consensus on this parameter within the literature, our robustness checks confirm the stability of our main results under variations in this parameter.

In calibrating the climate block of the model, we follow Dietz and Venmans [2019] and set the parameters for the global temperature function $\zeta_1^o = 0.50$ and $\zeta_2^o = 0.00125$. We rely on Nordhaus [2011] to calibrate the abatement cost function parameters. Emission intensities are chosen to match the steady state emissions per capita in each sector.

Regarding financial parameters, we calibrate the preferences for each type of asset to reflect the mean returns observed for each asset category as detailed in the data section. Moreover, the adjustment of preferences in response to climate sentiment shocks is empirically estimated to effectively capture the financial market's reactions to changes in environmental conditions. The complete set of calibrated parameters can be found in Table C.1.

6.2 Estimation

Our model's shock processes and trends are estimated using a heteroskedastic filter, specifically selected for its effectiveness in accommodating the inclusion of the COVID-19 period in our analysis. This filter is able to handle standard errors of shocks that may vary unexpectedly across different periods. Given the data in our possession, we assume heteroskedasticity on the productivity and carbon price shocks.

To approximate the posterior distribution of parameters, we employ the Metropolis-Hastings algorithm, utilizing four independent chains to construct our results. The outcomes of these estimations are succinctly summarized in Table C.3. where we present both the prior and posterior densities of the estimated parameters.

7 Quantitative Analysis

7.1 Model Dynamics

To illustrate the Bayesian estimation results and contextualize the model dynamics with the empirical findings, we examine how carbon price and climate sentiment shocks impact expected returns. Figure 5 shows the impact of these shocks on equity returns. Consistent with the empirical findings, a positive climate sentiment shock—reflecting increased concerns about transition risk—decreases returns for brown and orange equities while increasing returns for green equities, suggesting that investors uniformly incorporate climate risks into their valuations.

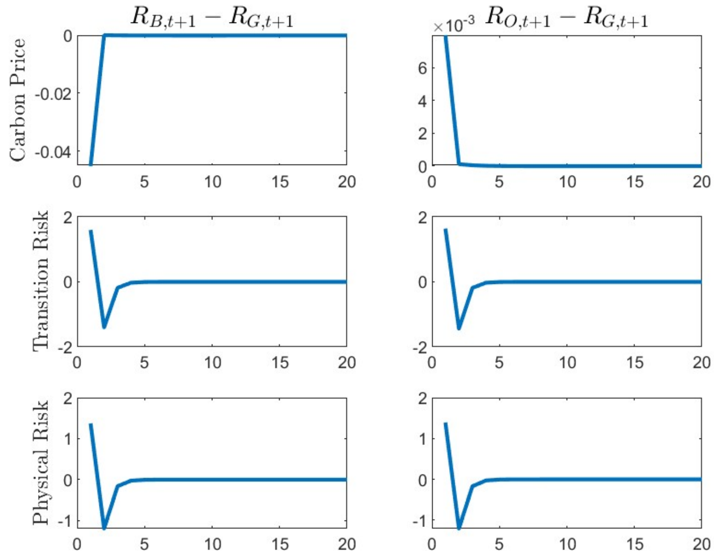


Figure 5: IRF to Equity Returns Premia

Notes: The figure shows the impulse responses of equity returns to shocks on carbon prices and transition climate sentiment, using the estimated parameters and standard deviations.

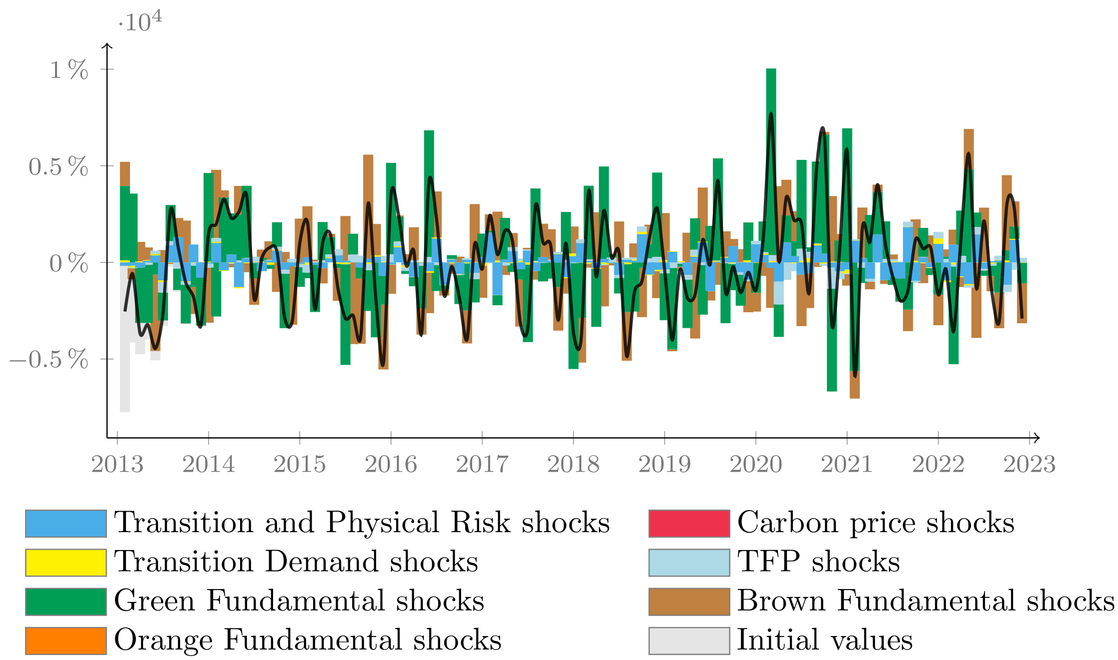
Regarding the impact of carbon price shocks, their influence on equity returns is relatively minimal—approximately fifty times less significant than that of climate sentiment shocks, consistent with the empirical findings. This observation aligns with the fact that total abatement costs as a percentage of output are relatively low, resulting in dividends that are largely unresponsive to unexpected changes in carbon prices. Consequently, carbon price shocks are not anticipated to be major determinants of equity returns in the historical shock decomposition due to their low levels during the estimated period. However, as carbon prices continue to rise, the influence of these shocks could escalate significantly. In our model, this growing concern could be reflected in sentiment about climate transition.

7.2 Equity Premia and Climate-Related Factors

Figure 8 illustrates the fluctuations in the premium between brown and green equity returns (represented by the solid black line) and breaks down these fluctuations into their primary components. Predominantly, risk premium shocks (i.e. the asset fundamentals) explain most of these variations. Nevertheless, climate sentiment—pertaining to both physical and transition risks—also significantly influences this difference in returns. The two types of climate sentiment shocks tend to steer the equity premium in the same direction as an disorderly transition becomes more likely when the physical risk rises. Notably, their impact has increased over time, contributing considerably to the premium changes in recent periods. This finding aligns with a growing awareness among investors regarding climate risks and a shift in their preferences (Pástor et al. [2022]). It is particularly interesting to note that this effect predominantly stems from how climate sentiment shocks affect the returns of brown firms. As detailed in the appendix, returns on green firms are considerably less affected by these shocks, suggesting that investors respond more intensely to climate change risks associated with brown assets.

In line with the impulse response functions (IRFs) discussed in the previous subsection, the influence of carbon price and emissions shocks on the premium is minimal and hardly noticeable amidst the broader variations observed.

Figure 6: Brown vs green equity premium historical decomposition

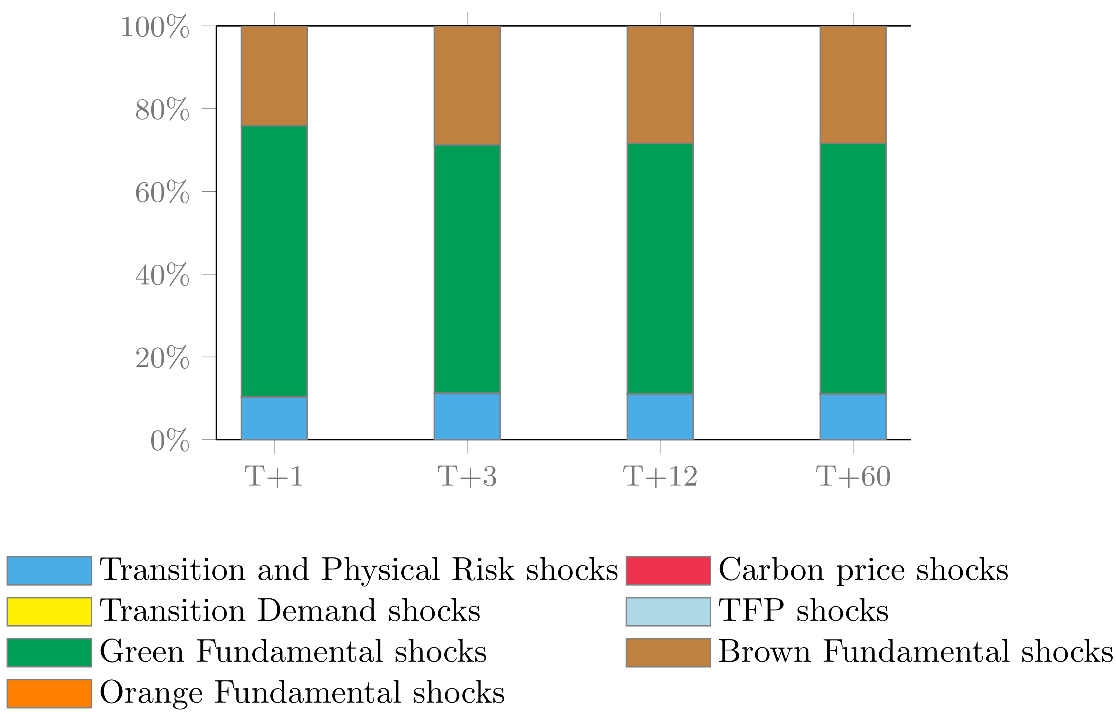


Notes: the figure decomposes the path of the premium between green and brown equity returns into to its main drivers over the estimated period (2013–2023).

[Figure 7](#) showcases the contribution of each factor to the variance of the equity premium over different horizons, emphasizing those shocks that have a sustained impact on the disparity between brown and green returns.

In this theoretical analysis, the primary influences on the equity premium align with the key drivers identified in the historical shock decomposition. Over the long term, the importance of climate sentiment shocks increases, underscoring the recognition that climate risk is a long-term concern for investors.

Figure 7: Brown vs Green Equity Premium Variance Decomposition



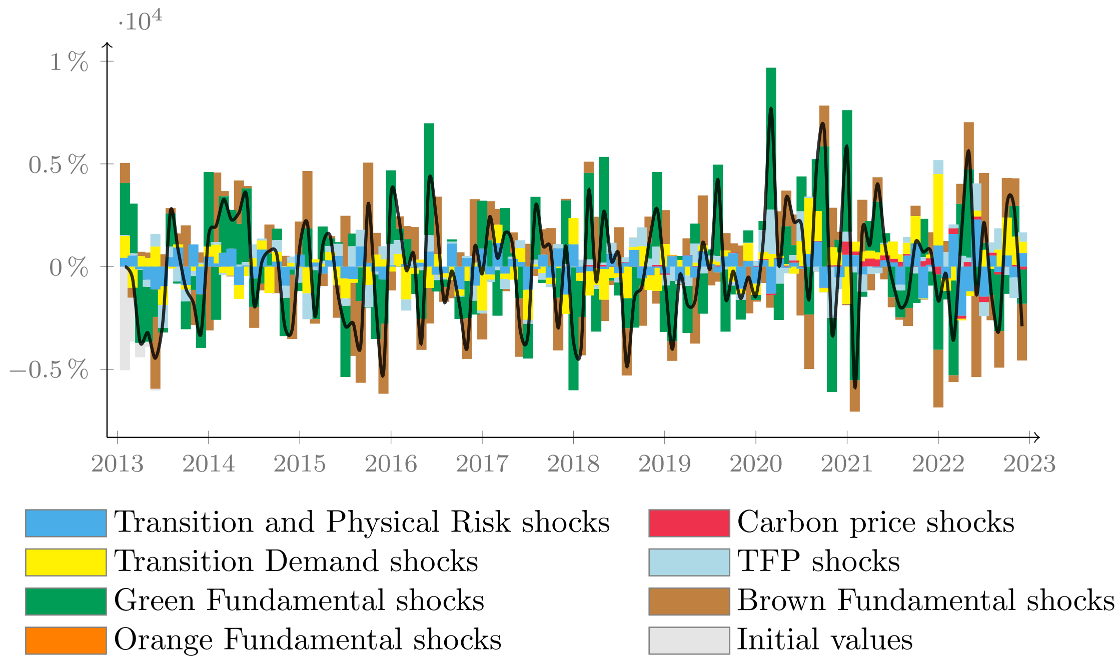
Notes: the figure displays the variance decomposition of premium between green and brown equity returns based on different horizons: one month, three months, one year, and five years. This represents the theoretical variance decomposition of the premium, taking into account the estimated variances of shocks.

7.3 Counterfactual: an EU economy with high carbon price

The IAM literature has long argued that high carbon pricing is key to mitigate the transition risk with respect to stranded assets (Van Der Ploeg [2020]).

Figure 7 shows that implementing high carbon pricing levels (e.g. 250 Euro/tCO_2) would have an important impact on asset returns and equity premium.

Figure 8: Brown vs green equity premium historical decomposition



Notes: the figure decomposes the path of the premium between green and brown equity returns into to its main drivers over the estimated period (2013–2023) under the counterfactual scenario of a 250 Euro/tCO_2 price.

By implementing higher levels of caps, thus implicitly higher carbon pricing, the regulator would close the equity premium as high the carbon price would signal a strong will and pushes investors to re-balance their portfolios. In addition, these higher carbon prices induce higher abatement and energy decoupling as shown by the transition demand shocks which capture the energy efficient improvements in the economy.

8 Conclusion

The existence and drivers of the green equity premium are currently prominent topics in climate finance, especially due to their direct link to stranded assets, which may pose considerable risks to financial stability.

While some literature indicates a negative premium (lower browner returns compared to greener returns), predominantly in the context of the US, our study propose: i) a novel methodology to classify firms' greeness and ii) identifies the role of policy commitment in closing the equity premium, which is key in mitigating climate risk associated with stranded assets.

Our empirical analysis, which is robust across various data cutoffs and specifications, shows that carbon policy and EU commitment are two key drivers. We show that premiums before 2017 (i.e. when the policy is not perceived yet as stringent by investors and market participant) are significant while the climate risk and carbon price are not. After 2017, date at which we argue the EU commitment and policy framework matured, the significance of our colour measure disappears as both carbon prices and transition risk index become key in steering asset returns.

To dissect the drivers of the green equity premium, we propose a macro-finance framework that includes: (i) three sectors (brown, orange, and green); (ii) investor preferences across these different asset classes; (iii) risks associated with climate transition and physical impacts; and (iv) carbon pricing mechanisms similar to the EU ETS. While our stationary model does not directly investigate the average difference in returns, we provide a decomposition of the factors driving the green equity premium at monthly frequency, offering insights into investor behavior. Notably, we find that climate sentiment shocks are a significant driver of variations in the spread between brown and green equity returns. Both brown and orange returns react more intensely to these shocks, underscoring their greater susceptibility to climate-related risks. This suggests that investors might be inclined to accept lower risk-adjusted returns on green equities as a hedge against potential future climate-related volatility.

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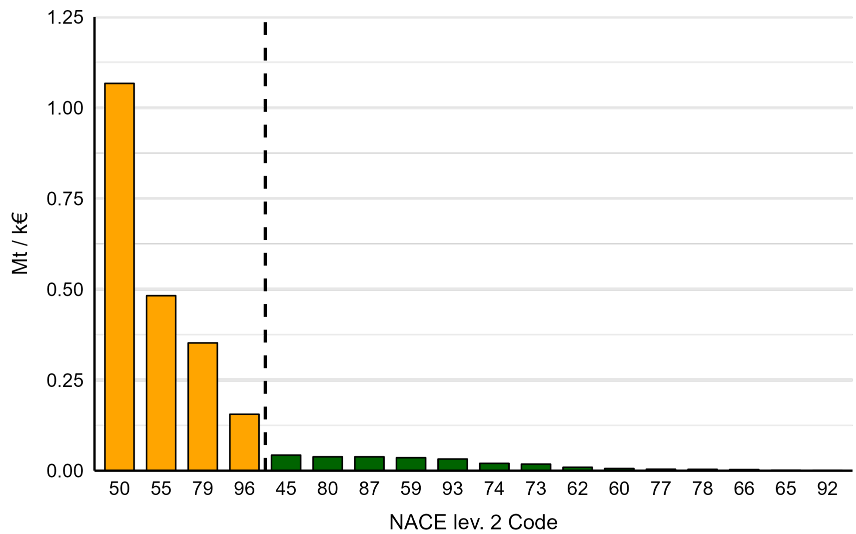
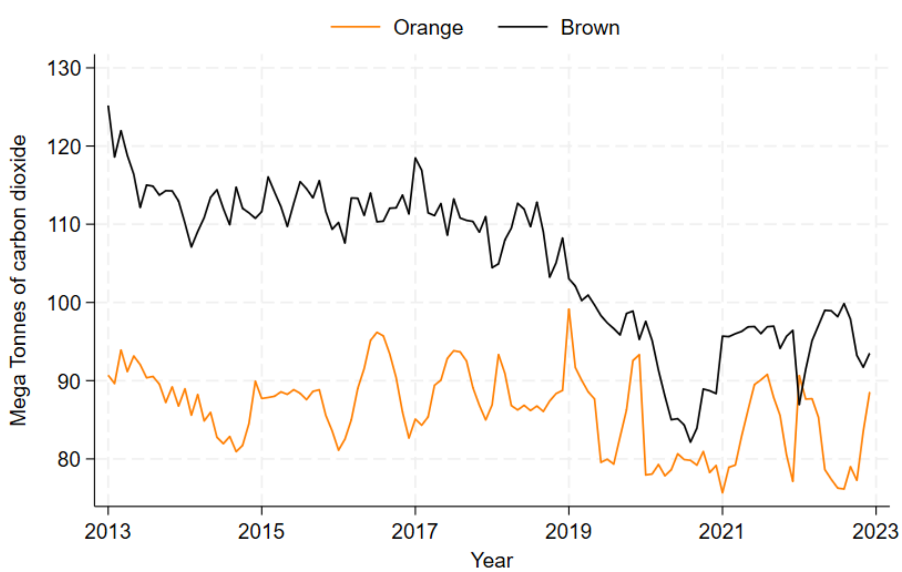
A Additional figures

Figure A1: Emission intensity for non-brown sectors



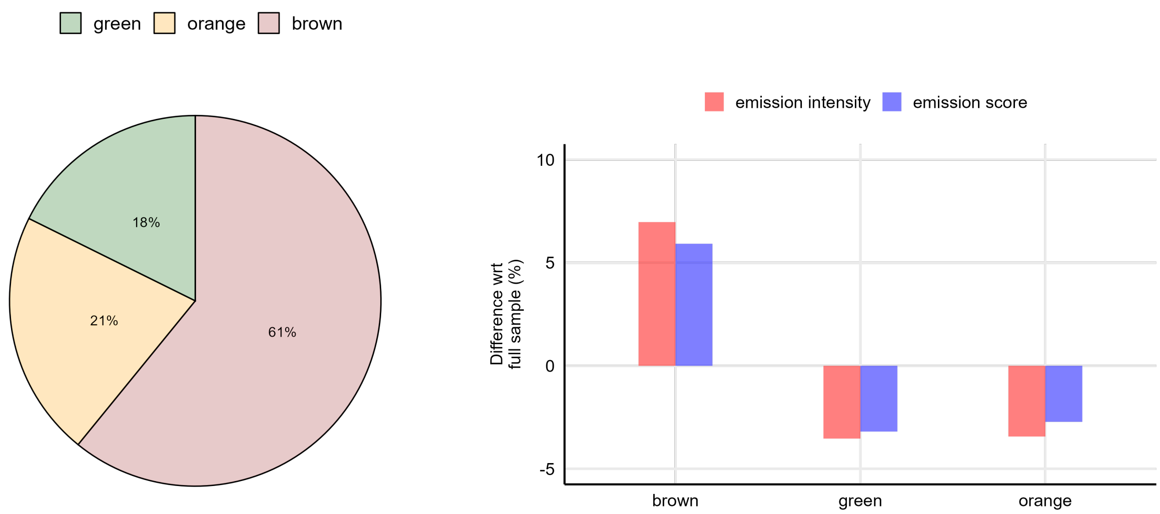
Note: emission intensities at the NACE level 2 sector are calculated by taking a weighted average of the emission intensities of firms within each sector, using firm revenues as weights. This calculation is done annually from 2013 to 2022, and the results are averaged over these years. The chart includes only non-brown sectors that have at least one company with emission intensity data available from our initial sample, as described in Section 2.2. Source: Refinitiv Datastream and authors' calculations.

Figure A2: Emissions



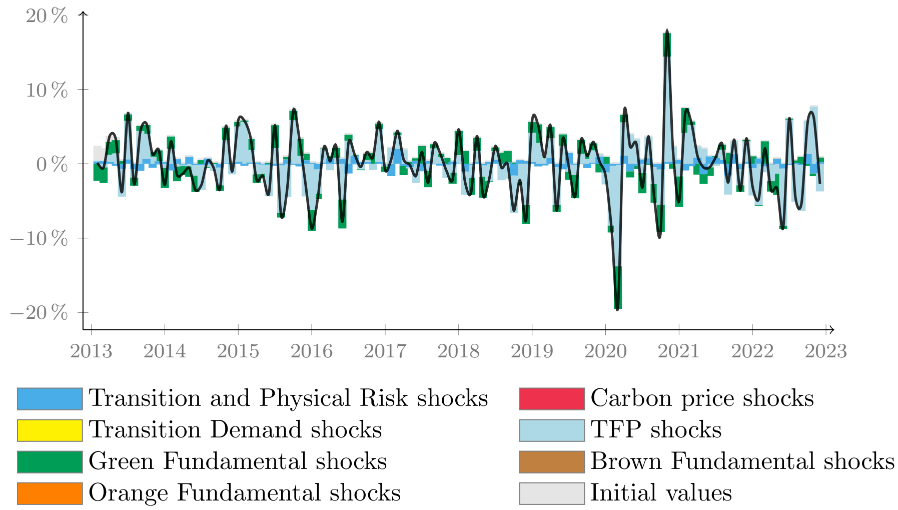
Note: emissions are at monthly frequency from January 2013 to December 2022 and are adjusted for seasonality. Source: EDGAR and European Comission's FIGARO Project

Figure A3: Color distribution - sample comparison



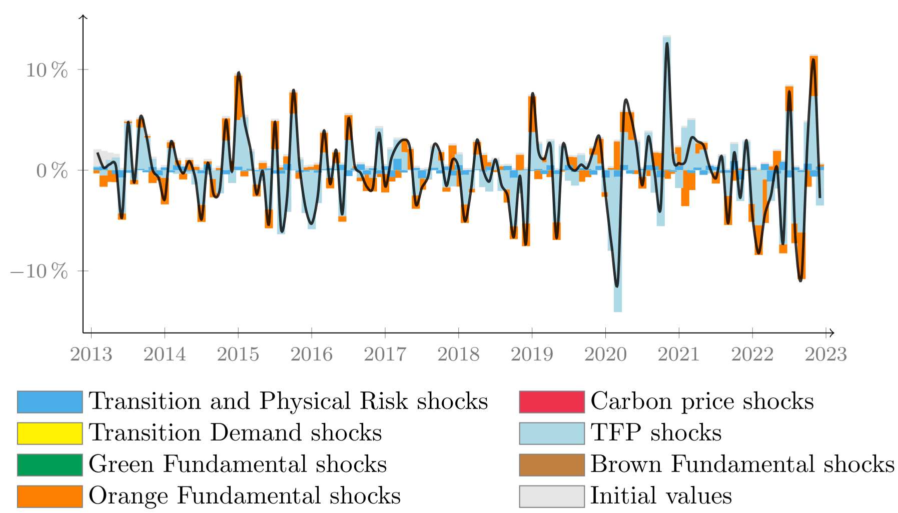
Note: the left hand side chart displays the percentage of companies from the sample described in section 2.2 categorized as green, orange and brown; the right hand side chart calculates the difference in the percentage of companies categorized within a given color in the subsample with available emission intensity data and the full sample (red bars) and in the subsample with available emission score data and the full sample (blue bars).

Figure A4: Green equity return historical decomposition



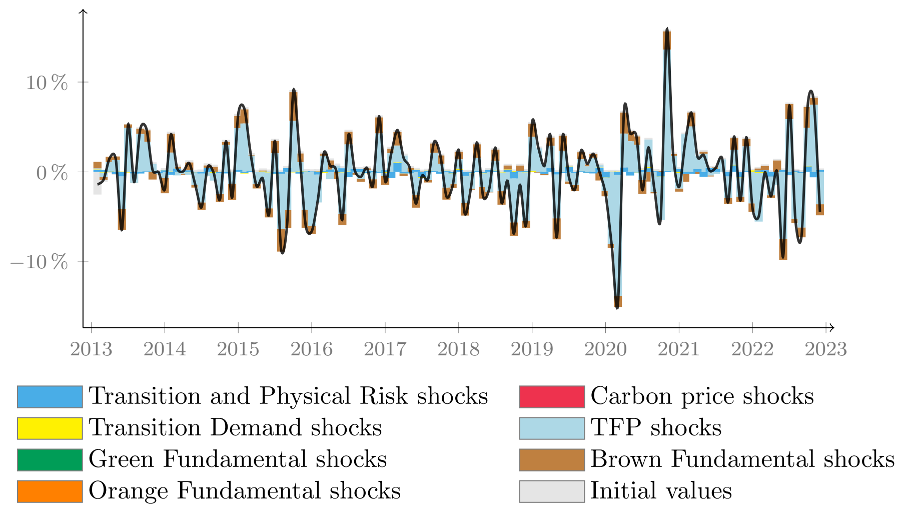
Note: the figure decomposes the path of the green equity return into to its main drivers over the estimated period (2013–2023).

Figure A5: Orange equity return historical Decomposition



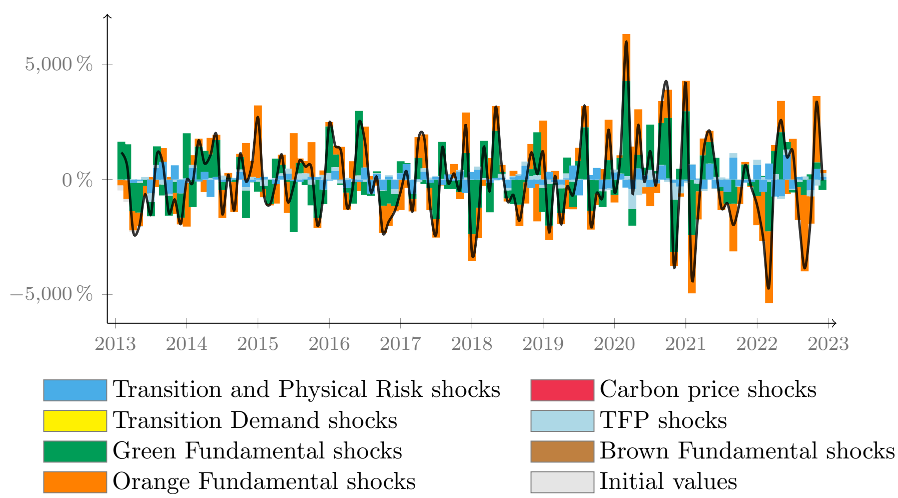
Note: the figure decomposes the path of the orange equity return into to its main drivers over the estimated period (2013–2023).

Figure A6: Brown equity return historical decomposition



Note: the figure decomposes the path of the brown equity return into to its main drivers over the estimated period (2013–2023).

Figure A7: Orange vs green equity premium historical decomposition



Note: the figure decomposes the path of the premium between orange and green equity returns into to its main drivers over the estimated period (2013–2023).

B Additional tables

Table B1: Color classification of NACE level 2 sectors

Brown			
Code	Sector Name	Abrell [2023]	Emiss. Intensity
1	Crop and animal production, hunting and related	1	1
6	Extraction of crude petroleum and natural gas	1	1
7	Mining of metal ores	1	1
8	Other mining and quarrying	1	1
9	Mining support service activities	1	1
10	Manufacture of food products	1	1
11	Manufacture of beverages	1	1
13	Manufacture of textiles	1	1
14	Manufacture of wearing apparel	1	1
15	Manufacture of leather and related products	1	1
16	Manufacture of wood and of products of wood and cork	1	1
17	Manufacture of paper and paper products	1	1
18	Printing and reproduction of recorded media	1	0
19	Manufacture of coke and refined petroleum products	1	1
20	Manufacture of chemicals and chemical products	1	1
21	Manufacture of basic pharmaceutical products	1	1
22	Manufacture of rubber and plastic products	1	1
23	Manufacture of other non-metallic mineral products	1	1
24	Manufacture of basic metals	1	1
25	Manufacture of fabricated metal products	1	1
26	Manufacture of computer, electronic and optical	1	1
27	Manufacture of electrical equipment	1	1
28	Manufacture of machinery and equipment n.e.c.	1	1
29	Manufacture of motor vehicles	1	1
30	Manufacture of other transport equipment	1	1
31	Manufacture of furniture	1	1
32	Other manufacturing	1	1
33	Repair and installation of machinery and equipment	1	0
35	Electricity, gas, steam and air conditioning supply	1	1
37	Sewerage	1	1
38	Waste collection, treatment and disposal activities	1	1
41	Construction of buildings	1	1
42	Civil engineering	1	1
43	Specialised construction activities	1	1
49	Land transport and transport via pipelines	1	1
52	Warehousing and support activities for transportation	1	1
58	Publishing activities	1	1
61	Telecommunications	1	1
64	Financial service activities, except insurance	1	1
84	Public administration and defence	1	0
85	Education	1	0
86	Human health activities	1	1

Orange			
Code	Sector Name	Abrell [2023]	Emiss. Intensity
2	Forestry and logging	0	0
3	Fishing and aquaculture	0	0
36	Water collection, treatment and supply	1	0
46	Wholesale trade, except motor vehicles	1	1
47	Retail trade, except motor vehicles and motorcycles	1	1
50	Water transport	0	1
51	Air transport	1	1
53	Postal and courier activities	1	1
55	Accommodation	0	1
56	Food and beverage service activities	1	1
63	Information service activities	1	1
68	Real estate activities	1	1
70	Activities of head offices; management consultancy	1	1
72	Scientific research and development	1	1
79	Travel agency, tour operator	0	1
82	Office support and other business support activities	1	1
96	Other personal service activities	0	1
Green			
Code	Sector Name	Abrell [2023]	Emiss. Intensity
45	Wholesale and retail trade of motor vehicles	0	1
59	Motion picture, video and television	0	1
60	Programming and broadcasting activities	0	1
62	Computer programming, consultancy	0	1
65	Insurance, reinsurance and pension funding	0	1
66	Activities auxiliary to financial services	0	1
69	Legal and accounting activities	0	0
71	Architectural and engineering activities	1	1
73	Advertising and market research	0	1
74	Other professional, scientific and technical activities	0	1
77	Rental and leasing activities	0	1
78	Employment activities	0	1
80	Security and investigation activities	0	1
87	Residential care activities	0	1
88	Social work activities without accommodation	0	0
90	Creative, arts and entertainment activities	0	0
91	Libraries, archives, museums and cultural activities	0	0
92	Gambling and betting activities	0	1
93	Sports activities and amusement and recreation	0	1
95	Repair of computers and personal and household goods	0	0

The table displays color classifications for the 79 NACE Level 2 sectors included in our return dataset. The column "Abrell [2023]" indicates whether the sector has at least one installation listed in the May 2021 version of the EU-ETS Information Dataset. The column "Emiss. Intensity" shows whether emission intensity data is available for at least one company within the sector.

Table B2: Color classification of firms

	Green	Orange	Brown	Total
Number of firms	466	566	1,605	2,637
	18%	21%	61%	100%

Notes: the table presents the number of firms in our dataset within each color, along with their respective shares relative to the total.

Table B3: Portfolio returns - full sample

	Mean	St. Dev.	Min	Max	Sharpe Ratio
Green	1.06	4.66	-18.51	18.96	0.26
Orange	0.91	4.10	-10.26	13.54	0.26
Brown	1.00	4.41	-13.96	16.95	0.26

Notes: the table reports summary statistics for the monthly returns in the 3 aggregate sectors for the period between January 2013 and December 2022. Returns are expressed in percent.

Table B4: Coverage of emission-based and score-based metrics

	Emission Intensity sub sample	Emission Score sub sample
2013	13.39	17.75
2014	13.96	18.01
2015	14.37	18.07
2016	15.72	18.64
2017	18.07	21.22
2018	24.85	31.91
2019	27.46	33.45
2020	31.23	39.45
2021	32.80	38.97
2022	31.98	37.11
Average 2013 - 2022	22.54	27.64

Notes: the table shows the percentage of companies from the sample described in section 2.2 for which data on emission intensity and emission scores are available during the years from 2013 to 2022.

Table B5: Color classification for the industries in EDGAR database

Brown		
IPCC code	IPCC name	NACE code
1.A.1.a	Main Activity Electricity and Heat Production	D
1.A.1.bc	Petroleum Refining - Manufacture of Solid Fuels	C19, C24, D
1.A.2	Manufacturing Industries and Construction	B to C18, C20 to C33, E36 to F
1.A.3.c	Railways	H49
1.A.3.e	Other Transportation	H49
1.B.1	Solid Fuels	C19, C24
1.B.2	Oil and Natural Gas	B, C19 to C21, D
2.A.1	Cement production	C23
2.A.2	Lime production	C23
2.A.3	Glass Production	C23
2.A.4	Other Process Uses of Carbonates	C20, C23
2.B	Chemical Industry	C20
2.C	Metal Industry	C24
2.D	Non-Energy Products from Fuels and Solvent Use	C16 to G45
3.C.2	Liming	A01
3.C.3	Urea application	A01
4.C	Incineration and Open Burning of Waste	A01, B to C33, E37-E39, M74-M75, Q86, Q87-Q88, S96
Orange		
IPCC code	IPCC name	NACE code
1.A.3.a	Civil Aviation	See chapter 3.3.2.3[1]
1.A.3.b_noRES	Road Transportation no resuspension	All NACE except U [2]
1.A.3.d	Water-borne Navigation	See chapter 3.3.2.2[3]
1.A.4	Residential and other sectors	A1 to A3, G45 to G47, H52 to T
1.A.5	Non-Specified	D, G45 to T

Notes: The table lists the 22 industries from the EDGAR database, each identified by their IPCC code (2006). The corresponding NACE codes (either at level 1 and/or level 2) are also provided. An industry is classified as brown if the majority of the NACE sectors within that industry are brown. Otherwise, it is classified as orange.

[1] we refer to NACE code H51 (Airlines)
[2] The most represented color is brown. However, since all the NACE code lev. 1 but U are considered we set the color as orange.
[3] we refer to NACE code H50 (Marine transport).

C Empirics Appendix

Table C1: Decomposition by Company Size by Market Capitalization

	Pre-2017			Post-2017		
	Small Firms	Medium Firms	Large Firms	Small Firms	Medium Firms	Large Firms
CRT	0.655***	0.183	-0.0712	0.0715	-0.0235	-0.226***
	(4.31)	(1.60)	(-0.80)	(0.42)	(-0.26)	(-2.97)
TRI	-0.121	-0.0544	0.178*	-1.359***	-1.450***	-1.572***
	(-0.72)	(-0.47)	(1.84)	(-9.35)	(-15.28)	(-20.30)
CP	-0.0465	0.0973	0.130**	0.00440	0.0128***	0.0153***
	(-0.53)	(1.47)	(2.54)	(0.66)	(2.91)	(4.38)
Leverage Ratio	-0.0319	-0.0347	-0.0180	-0.0112	0.0358	-0.0221
	(-0.85)	(-0.77)	(-0.61)	(-0.25)	(1.14)	(-1.00)
Gross Profit Margin	1.290***	-0.665**	-0.171	0.569	0.163	-0.0305
	(3.08)	(-2.31)	(-0.57)	(1.38)	(0.63)	(-0.13)
Tax Burden	4.047	8.457***	-2.679	5.646***	4.081***	4.297***
	(1.56)	(4.58)	(-1.43)	(2.64)	(2.83)	(2.62)
Log Assets	-0.0108	-0.0121	-0.126***	0.327**	-0.210***	-0.158***
	(-0.10)	(-0.15)	(-3.58)	(2.44)	(-3.32)	(-4.88)
Revenue Growth	0.264	-0.109	0.668**	0.231	0.884***	0.724***
	(0.78)	(-0.45)	(2.54)	(0.52)	(3.52)	(4.11)
VIX	-0.327***	-0.385***	-0.330***	-0.122***	-0.163***	-0.151***
	(-11.22)	(-18.33)	(-18.36)	(-7.38)	(-14.11)	(-17.16)
Interest Rates	-1.845***	-3.105***	-2.600***	-1.129***	-0.329***	0.124
	(-3.27)	(-7.40)	(-8.22)	(-5.92)	(-2.77)	(1.25)
Constant	4.701***	8.639***	8.957***	-1.706***	3.493***	4.281***
	(5.66)	(12.11)	(15.37)	(-2.62)	(7.53)	(11.99)
Observations	18606	20881	19921	32883	34149	32879

t statistics in parentheses
* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

Table C2: Baseline Specification - No Control Outliers Removed

	(1) $R_{i,t}$	(2) $R_{i,t}$ Pre-2017	(3) $R_{i,t}$ Post-2017
CRT	0.0248	0.284***	-0.130
	(0.35)	(3.31)	(-1.51)
TRI	-1.073***	-0.0202	-1.473***
	(-21.62)	(-0.27)	(-23.40)
CP	-0.00514**	0.0254	0.00975***
	(-2.16)	(0.64)	(3.36)
Leverage Ratio	-0.00000838	0.0000246	-0.0000130
	(-0.66)	(0.67)	(-0.82)
Gross Profit Margin Ratio	0.000346	0.00211	-0.00169**
	(0.38)	(1.40)	(-1.97)
Tax Burden	0.00368*	0.00246**	0.0117***
	(1.69)	(1.98)	(5.95)
Revenue Growth	-0.0000725*	-0.0000691	-0.0000892***
	(-1.80)	(-1.20)	(-4.29)
Log Assets	0.302***	0.282***	0.313***
	(11.95)	(9.55)	(9.89)
VIX	-0.156***	-0.339***	-0.150***
	(-26.18)	(-25.97)	(-21.08)
Short Term Interest Rates	-0.0861	-2.247***	-0.475***
	(-1.20)	(-8.35)	(-6.01)
Constant	0.796***	5.348***	0.0716
	(3.14)	(13.06)	(0.23)
Observations	165942	60865	105077

t statistics in parentheses

* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

Table C3: Baseline Specification - companies with 50% or more observations that have zero monthly returns dropped

	(1) $R_{i,t}$	(2) $R_{i,t}$ Pre-2017	(3) $R_{i,t}$ Post-2017
CRT	0.200***	0.346***	0.109
	(2.80)	(4.11)	(1.29)
TRI	-1.055***	-0.00696	-1.455***
	(-22.66)	(-0.10)	(-24.05)
CP	-0.00529**	0.0616	0.0136***
	(-2.33)	(1.49)	(4.61)
Leverage Ratio	-0.0411**	-0.0788***	-0.0208
	(-2.09)	(-3.01)	(-0.83)
Gross Profit Margin Ratio	0.657***	0.473*	0.768***
	(3.29)	(1.87)	(3.12)
Tax Burden	5.741***	4.799***	5.993***
	(5.51)	(3.19)	(4.74)
Revenue Growth	0.513***	0.200	0.748***
	(4.05)	(1.17)	(4.52)
Log Assets	0.382***	0.334***	0.411***
	(14.81)	(12.36)	(12.69)
VIX	-0.158***	-0.349***	-0.157***
	(-25.39)	(-27.57)	(-20.74)
Short Term Interest Rates	0.139**	-2.555***	-0.309***
	(1.99)	(-10.33)	(-3.98)
Constant	-0.343	4.851***	-1.461***
	(-1.21)	(11.83)	(-4.33)
Observations	147057	54404	92653

t statistics in parentheses
* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

Table C4: Baseline Specification: No Returns Outliers Dropped

	(1) $R_{i,t}$	(2) $R_{i,t}$ Pre-2017	(3) $R_{i,t}$ Post-2017
CRT	0.225	0.305***	0.176
	(1.44)	(2.62)	(0.72)
TRI	-1.171***	-0.103	-1.468***
	(-10.70)	(-0.80)	(-17.57)
CP	-0.00560*	0.0668	-0.00347
	(-1.66)	(1.36)	(-0.51)
Leverage Ratio	-0.00358	-0.101***	0.0489
	(-0.09)	(-2.61)	(0.86)
Gross Profit Margin Ratio	0.666	0.0744	0.981
	(1.20)	(0.11)	(1.22)
Tax Burden	2.722*	1.309	3.500***
	(1.72)	(0.30)	(3.04)
Revenue Growth	0.713***	0.872*	0.758***
	(3.18)	(1.83)	(3.27)
Log Assets	-0.104	0.00777	-0.164
	(-1.40)	(0.17)	(-1.42)
VIX	-0.144***	-0.408***	-0.120***
	(-15.21)	(-13.08)	(-13.33)
Short Term Interest Rates	-0.484***	-4.137***	-0.548***
	(-4.11)	(-3.07)	(-4.82)
Constant	3.197***	9.163***	2.636***
	(11.50)	(7.57)	(6.85)
Observations	159322	59405	99917

t statistics in parentheses

* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

Table C5: CRT Dummy Variable Model Specification

	(1) $R_{i,t}$	(2) $R_{i,t}$ Pre-2017	(3) $R_{i,t}$ Post-2017
Brown	-0.256*	-0.686***	0.0104
	(-1.85)	(-4.12)	(0.06)
Orange	-0.649***	-0.780***	-0.544**
	(-3.13)	(-3.50)	(-2.09)
TRI	-1.056***	-0.00634	-1.469***
	(-21.47)	(-0.09)	(-23.21)
CP	-0.00452*	0.0596	0.0104***
	(-1.93)	(1.48)	(3.54)
Leverage Ratio	-0.0345*	-0.0535**	-0.0235
	(-1.67)	(-2.07)	(-0.86)
Gross Profit Margin Ratio	0.519***	0.478**	0.548**
	(2.75)	(1.98)	(2.37)
Tax Burden	5.530***	4.858***	5.719***
	(5.38)	(3.31)	(4.52)
Revenue Growth	0.443***	0.236	0.646***
	(3.27)	(1.29)	(3.26)
Log Assets	0.274***	0.256***	0.286***
	(11.07)	(9.74)	(9.12)
VIX	-0.153***	-0.347***	-0.146***
	(-25.20)	(-26.60)	(-19.93)
Short Term Interest Rate	-0.0369	-2.405***	-0.430***
	(-0.51)	(-9.36)	(-5.24)
Constant	1.078***	6.487***	-0.173
	(4.48)	(17.06)	(-0.60)
Observations	159319	59408	99911

t statistics in parentheses

* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

D Model calibration and estimation

Table D1: Parameters Value

Parameter	Value	Definition
σ	2.00	Risk Aversion
β	0.9986	Discount Factor
α	0.33	Elasticity to Capital Input in Production
θ	0.40	Substitution Parameter in the CES
δ	0.0083	Depreciation of Capital
m	0.80	Habit Level
χ_G	0.18	Share of Green Sector
χ_O	0.40	Share of Orange Sector
χ_B	0.42	Share of Brown Sector
ϕ_G	1.00	Green Capital Adjustment Cost Function
ϕ_O	1.00	Orange Capital Adjustment Cost Function
ϕ_B	1.00	Brown Capital Adjustment Cost Function
$\bar{L}_G$	0.33	Hours Worked Green Sector
$\bar{L}_O$	0.33	Hours Worked Orange Sector
$\bar{L}_B$	0.33	Hours Worked Brown Sector
Φ	1.00	Inverse Frisch Elasticity
α_G^S	0.0053	Level of Green Equity Preference
α_O^S	0.0076	Level of Orange Equity Preference
α_B^S	0.0075	Level of Brown Equity Preference
φ_O	0.3581	Emission Intensity in Orange Production
φ_B	0.7421	Emission Intensity in Brown Production
ϕ_T	0.10	Dis-utility Sensitivity to Temperature
η	0.0081	Decay Rate of Emissions in the Atmosphere
ζ_1^o	0.50	Climate Transient Parameter
ζ_2^o	0.00125	Climate Transient Parameter
$\theta_{1,O}$	0.0326	Level of Orange Abatement Cost Function
$\theta_{1,B}$	0.0354	Level of Brown Abatement Cost Function
$\theta_{2,O}$	2.70	Curvature of Orange Abatement Cost Function
$\theta_{2,B}$	2.70	Curvature of Brown Abatement Cost Function
$\theta_{3,O}$	5.00	Orange Abatement Adjustment Cost Function
$\theta_{3,B}$	5.00	Brown Abatement Adjustment Cost Function
$\frac{\bar{g}}{\bar{y}}$	0.20	Government Spending to Output Ratio

Table D2: Moments matching

Variable	Symbol	Target	Source
Real Monthly GDP per Capita (EA, k€)	y	2.49	Eurostat
Green Sector Share (EA, %)	$(p_G * y_G)/(p * y)$	18	Authors' calculation
Orange Sector Share (EA, %)	$(p_O * y_O)/(p * y)$	40	Authors' calculation
Brown Sector Share (EA, %)	$(p_B * y_B)/(p * y)$	42	Authors' calculation
Mean Monthly Return on Green Equity (EA, %)	r_G	0.79	Authors' calculation
Mean Monthly Return on Orange Equity (EA, %)	r_O	1.03	Authors' calculation
Mean Monthly Return on Brown Equity (EA, %)	r_B	1.01	Authors' calculation
ETS Mean Carbon Price (EA, €)	τ	17.7	ICE
Cumulative Emission (World, GtC)	x	850	Copernicus (EC)
Monthly Emission Flow p. Capita (Brown EA, tCO2)	e_B	0.31	Authors' calculation
Monthly Emission Flow p. Capita (Orange EA, tCO2)	e_O	0.25	Authors' calculation
Temperature (World, °C)	t^o	1.06	NOAA

Notes: All the values reported in this table are perfectly matched by the model at the steady state.

Table D3: Estimated Parameters

		Prior Distributions			Posterior Distributions	
		Distribution	Mean	Std. Dev.	Mean	[0.05 ; 0.95]
Shock processes:						
Std. Dev. Productivity	σ_A	$\mathcal{IG}_2$	0.10	0.05	0.04	[0.03 ; 0.04]
Std. Dev. Carbon Price	σ_τ	$\mathcal{IG}_2$	0.5	0.1	0.29	[0.28 ; 0.31]
Std. Dev. Preference for Green Equity	$\sigma_{P^S_G}$	$\mathcal{IG}_2$	0.10	0.05	0.02	[0.02 ; 0.03]
Std. Dev. Preference for Orange Equity	$\sigma_{P^S_O}$	$\mathcal{IG}_2$	0.10	0.05	0.03	[0.02 ; 0.04]
Std. Dev. Preference for Brown Equity	$\sigma_{P^S_B}$	$\mathcal{IG}_2$	0.10	0.05	0.04	[0.02 ; 0.06]
Std. Dev. Climate Transition Sentiment	σ_{GT}	$\mathcal{IG}_2$	0.10	0.05	0.01	[0.01 ; 0.02]
Std. Dev. Climate Physical Sentiment	σ_{GS}	$\mathcal{IG}_2$	0.10	0.05	0.01	[0.01 ; 0.02]
Std. Dev. Emissions Orange	σ_{E_O}	$\mathcal{IG}_2$	0.10	0.05	0.04	[0.03 ; 0.04]
Std. Dev. Emissions Brown	σ_{E_B}	$\mathcal{IG}_2$	0.10	0.05	0.03	[0.03 ; 0.04]
AR(1) Productivity	ρ_A	$\mathcal{B}$	0.50	0.20	0.89	[0.86 ; 0.94]
AR(1) Carbon Price	ρ_τ	$\mathcal{B}$	0.50	0.20	0.82	[0.76 ; 0.90]
AR(1) Preference for Green Equity	$\rho_{P^S_G}$	$\mathcal{B}$	0.50	0.20	0.74	[0.69 ; 0.79]
AR(1) Preference for Orange Equity	$\rho_{P^S_O}$	$\mathcal{B}$	0.50	0.20	0.64	[0.50 ; 0.72]
AR(1) Preference for Brown Equity	$\rho_{P^S_B}$	$\mathcal{B}$	0.50	0.20	0.55	[0.43 ; 0.66]
AR(1) Climate Transition Sentiment	ρ_{GT}	$\mathcal{B}$	0.50	0.20	0.10	[0.03 ; 0.18]
AR(1) Climate Physical Sentiment	ρ_{GS}	$\mathcal{B}$	0.50	0.20	0.13	[0.04 ; 0.21]
AR(1) Emissions Orange	ρ_{E_O}	$\mathcal{B}$	0.50	0.20	0.68	[0.58 ; 0.77]
AR(1) Emissions Brown	ρ_{E_B}	$\mathcal{B}$	0.50	0.20	0.93	[0.90 ; 0.98]
Structural Parameters:						
Green Equity Preference Reaction to Transition Risk	α^{GT_G}	$\mathcal{N}$	5.00	2.00	4.73	[1.47 ; 7.99]
Orange Equity Preference Reaction to Transition Risk	α^{GT_O}	$\mathcal{N}$	-5.00	2.00	-3.47	[-6.63 ; 0.04]
Brown Equity Preference Reaction to Transition Risk	α^{GT_B}	$\mathcal{N}$	-5.00	2.00	-3.81	[-7.15 ; -0.67]
Green Equity Preference Reaction to Physical Risk	α^{GP_G}	$\mathcal{N}$	5.00	2.00	4.10	[0.81 ; 7.43]
Orange Equity Preference Reaction to Physical Risk	α^{GP_O}	$\mathcal{N}$	-5.00	2.00	-4.78	[-7.36 ; -1.65]
Brown Equity Preference Reaction to Physical Risk	α^{GP_B}	$\mathcal{N}$	-5.00	2.00	-4.44	[-7.97 ; -1.70]
TFP Trend	$(\gamma^Y - 1) \times 100$	$\mathcal{N}$	0.1	0.02	0.12	[0.09 ; 0.14]
Emissions Trend	$(\gamma^X - 1) \times 100$	$\mathcal{N}$	-0.20	0.05	-0.21	[-0.25 ; -0.16]
Carbon Price Trend	$(\gamma^\tau - 1) \times 100$	$\mathcal{N}$	2.00	0.50	2.22	[1.72 ; 2.57]

Notes: $\mathcal{IG}_2$ denotes the Inv. Gamma distribution (type 2), $\mathcal{B}$ the Beta and $\mathcal{N}$ the Gaussian distribution.

E The balanced growth path equilibrium

In this section we present the de-trended model and show the condition under which the existence of the balanced growth path is satisfied.

E.0.1 The Firms

The growth rate of Γ_t^Y determines the growth rate of the economy along the balanced growth path[27]. This growth rate is denoted by γ^Y, where:

$$\Gamma_t^Y = \gamma^Y \Gamma_{t-1}^Y \tag{29}$$

The production function of sectoral emissions is also subject to technological progress. We denote the emission trend by Γ_t^E. The growth rate of Green technological progress is then γ^E:

$$\Gamma_t^E = \gamma^E \Gamma_{t-1}^E \tag{30}$$

Similarly, the carbon price exhibits a trend Γ_t^τ, which reads as:

$$\Gamma_t^\tau = \gamma^\tau \Gamma_{t-1}^\tau \tag{31}$$

As mentioned in the model section, stationary variables are denoted by lower case letters, whereas variables that are growing are denoted by capital letters. For example, in the growing economy output in each sector is denoted by $Y_{t,k}$. De-trended output is thus obtained by dividing output in the growing economy by the level of growth progress:

$$y_{t,k} = \frac{Y_{t,k}}{\Gamma_t^Y} \tag{32}$$

The detrended aggregate output reads as:

$$y_t = \frac{Y_t}{\Gamma_t^Y} \tag{33}$$

Sectoral emissions, which we denote by $E_{t,k}$, in the growing economy are given as follows:

$$E_{t,k} = (1 - \mu_{t,k})\varphi_k Y_{t,k} \Gamma_t^E \epsilon_{t,k} \tag{34}$$

[27]In our setup all sectors grow at the same rate Γ_t^Y.

Thus, in the de-trended economy, brown sector emissions law of motion reads as following:

$$e_{t,k} = (1 - \mu_{t,k})\varphi_1 y_{t,k}\epsilon_{t,k} \tag{35}$$

where, the flow of detrended emissions reads as:

$$e_{t,k} = \frac{E_{t,k}}{\Gamma_t^X} \tag{36}$$

where $\Gamma_t^X = \Gamma_t^Y \Gamma_t^E$.

The abatement cost in the growing economy is:

$$Z_{t,i} = (f(\mu_{t,i}) + \xi(\mu_{t,i}/\mu_{t-1,i}))Y_{t,i} \tag{37}$$

Thus, in the de-trended economy, abatement costs of the brown and orange sector reads as following[28]:

$$z_{t,i} = (f(\mu_{t,i}) + \xi(\mu_{t,i}/\mu_{t-1,i}))y_{t,i} \tag{38}$$

where $z_{t,i} = \frac{Z_{t,i}}{\Gamma_t^Y}$ and $i \in (B, O)$.

The cumulative emissions are denoted by X_t, while the temperature is refereed to as T_t^o in the growing economy:

$$X_{t+1} = \eta X_t + E_t + E_t^* \tag{39}$$

$$T_{t+1}^o = \upsilon_1^o(\upsilon_2^o X_t - T_t^o) + T_t^o, \tag{40}$$

The de-trended X_t and T_t^o read as following:

$$\gamma^{X^{-1}} x_{t+1} = \eta x_t + e_t + e_t^* \tag{41}$$

$$\gamma^X t_{t+1}^o = \upsilon_1^o(\upsilon_2^o x_t - t_t^o) + t_t^o \tag{42}$$

[28]Please note that μ_t is stationnary.

where:

$$e_t^* = \frac{E_t^*}{\Gamma_t^X} \tag{43}$$

$$x_t = \frac{X_t}{\Gamma_t^X} \tag{44}$$

$$t_t^o = \frac{T_t^o}{\Gamma_t^X} \tag{45}$$

$$\gamma^X = \gamma^E \gamma^Y \tag{46}$$

In the growing economy, with the above growth progress, the sectoral production functions are as follows:

$$Y_{t,k} = \varepsilon_t^A K_{t,k}^{\alpha_k} (\Gamma_t^Y l_{t,k})^{1-\alpha_k} \tag{47}$$

where per sector labour $l_{t,k}$ and the technology shock $\varepsilon_t^{A_k}$ are stationary variables. De-trending the production functions, yields the following:

$$y_{t,k} = \varepsilon_t^A k_{t,k}^{\alpha_k} (l_{t,k})^{1-\alpha_k} \tag{48}$$

with the de-trended sectoral output and capital reads as:

$$y_{t,k} = \frac{Y_t}{\Gamma_t^Y} \tag{49}$$

$$k_{t,k} = \frac{K_t}{\Gamma_t^Y} \tag{50}$$

The capital-accumulation equation for both the green and brown sectors in the growing economy reads as:

$$K_{t+1,k} = (1-\delta)K_{t,k} + I_{t,k}\left(1 - \frac{\phi_I}{2}\left(\frac{I_{t,k}}{I_{t-1,k}} - \gamma^Y\right)^2\right) \tag{51}$$

In the de-trended economy, we thus have:

$$\gamma^Y k_{t+1,k} = (1-\delta)k_{t,k} + i_{t,k}\left(1 - \frac{\phi_I}{2}\left(\gamma^Y \frac{i_{t,k}}{i_{t-1,k}} - \gamma^Y\right)^2\right) \tag{52}$$

with the de-trended investment reading as: $i_{t,k} = \frac{I_{t,k}}{\Gamma_t^Y}$.[29]

[29] We also note that wage $w_{t,k}$ are stationary and don't need de-trending.

E.0.2 The Economy Resource Constraint

The economy budget constraint reads as:

$$Y_t = C_t + \Lambda(I_{t,k}/I_{t-1,k}) + G_t + Z_{t,k} \tag{53}$$

Thus,

$$y_t = c_t + \Lambda(\gamma^Y i_{t,k}/i_{t-1,k}) + g_t + z_{t,k} \tag{54}$$

where: $c_t = \frac{C_t}{\Gamma_t^Y}$ and $g_t = \frac{G_t}{\Gamma_t^Y}$.

E.0.3 Households

Under the presence of a labour augmenting technology economy growth rate Γ_t^Y the utility function reads as: $U(C_t, H_t, \mathcal{U}_t^{s_k}, T_t^o, l_{t,k}) = \frac{(C_t - H_t)^{1-\sigma}}{1-\sigma} - \tilde{\lambda}_t \mathcal{U}_t^{s_k} - D^c(T_t^o) - \Gamma_t^{1-\sigma} \sum_k \frac{\chi_k l_{t,k}^{1+\Phi}}{1+\Phi}$.

As in Greenwood et al. [1997], we introduce exogenous trends to labour disutility, climate diutility and asset preferences to allow for the existence of a balanced growth path. The de-trended welfare/utility reads as:

$$\sum_{t=0}^{\infty} \beta^t U(c_t, h_t, \mathcal{U}_t^{s_k}, t_t^o, l_{t,k}) = \sum_{t=0}^{\infty} \tilde{\beta}^t \Big(\frac{(c_t - h_t)^{1-\sigma}}{1-\sigma} - \lambda_t \mathcal{U}_t^{s_k} - D^c(t_t^o) - \sum_k \frac{\chi_k l_{t,k}^{1+\Phi}}{1+\Phi} \Big) \tag{55}$$

where $\tilde{\beta} = \beta \gamma^{Y^{1-\sigma}}$.

The climate damages defined as $D^c(T_t^o) = \Gamma_t^T \phi_T T_t^{o2}$ are detrended as follows:

$$D^c(t_t^o) = \phi_T t_t^{o2} \tag{56}$$

where $\Gamma_t^T = \frac{\Gamma_t^{1-\sigma}}{(\Gamma_t^X)^2}$.

The asset preferences $\mathcal{U}_t^{s_k}$ exhibt a trend within the price $P_{t,k}^s$. The term $\tilde{\lambda_t} = \frac{\lambda_t}{(\Gamma_t^Y)^\sigma}$ allows for a consistent BGP while normalizing the stochastic discount factor associated to each asset with respect to the long-run preferences. Thus the detrended asset prices reads as:

$$p_{t,k}^s = \frac{P_{t,k}^s}{\Gamma_t^Y}. \tag{57}$$

The de-trended budget constraint reads as:

$$\sum_k \big(w_{t,k} l_{t,k} + s_{t,k}(p_{t,k}^S + d_{t,k}) \big) + b_t = p_t c_t + t_t + p_t^B b_{t+1} + \sum_k (p_{t,k}^S s_{t+1,k} + \lambda^{p^k}(.)) \tag{58}$$

where bond price $p_t^B = \frac{P_t^B}{\Gamma_t^Y}$, dividends $d_{t,k} = \frac{D_{t,k}}{\Gamma_{t,k}}$, and portfolio adjustment costs $\lambda^{p^k}(.) = \frac{\phi_{Sk}}{2}(p_{t,k}^S s_{t+1,k} - p_{t-1,k}^S s_{t+1,k})^2$.

The de-trended habits formation reads as:

$$\gamma^Y h_{t+1} = mh_t + (1-m)c_t \tag{59}$$

where $h_t = \frac{H_t}{\Gamma_t^Y}$.

E.0.4 The government

Finally the carbon price grows at:

$$G_t + T_t = \tau_t E_{t,B} \tag{60}$$

$$g_t + t_t = \tau_t \frac{E_{t,B}}{\Gamma_t^Y} \tag{61}$$

$$g_t + t_t = \tau_t \frac{\Gamma_t^X}{\Gamma_t^Y} e_{t,B} \tag{62}$$

$$g_t + t_t = \tau_t \Gamma_t^E e_{t,B} \tag{63}$$

$$g_t + t_t = \tilde{\tau}_t e_{t,B} \tag{64}$$

Using the implied ETS carbon price $\tau_t = \text{Carbon Price}_t \Gamma_t^\tau$, we then extract the growth rate of the carbon price:

where $\tilde{\tau}_t = \tau_t \Gamma_t^E = \text{Carbon Price}_t \Gamma_t^\tau \Gamma_t^E$

F The competitive equilibrium

F.1 The household problem

The household problem (maximizing its utility) under the balanced growth path is characterized as follows:

$$\mathcal{L} = E_0 \Bigg\{ \sum_{t=0}^{\infty} \widetilde{\beta}^t \Big(\frac{(c_t - h_t)^{1-\sigma}}{1-\sigma} - \lambda_t \mathcal{U}_t^{s_k} - D^c(t_t^o) - \sum_k \frac{\chi_k l_{t,k}^{1+\Phi}}{1+\Phi} \Big)$$
$$+ \sum_{t=0}^{\infty} \widetilde{\beta}^t \lambda_t \left[\sum_k \big(w_{t,k} l_{t,k} + s_{t,k}(p_{t,k}^S + d_{t,k}) \big) + b_t - p_t c_t - t_t - p_t^B b_{t+1} - \sum_k (p_{t,k}^S s_{t+1,k} + \lambda^{p^k}(.)) \right]$$
$$+ \sum_{t=0}^{\infty} \widetilde{\beta}^t \lambda_t^H \left[\gamma^Y h_{t+1} - m h_t - (1-m) c_t \right] \Bigg\}$$

The marginal utility of consumption c_t is:

$$\lambda_t + \lambda_t^H (1-m) = (c_t - h_t)^{-\sigma} \tag{65}$$

The optimal habits formation h_t is given by:

$$\lambda_t^H \gamma^Y = m \tilde{\beta} E_t \left\{ \lambda_{t+1}^H + \tilde{\beta} E_t \left(c_{t+1} - h_{t+1}\right)^{-\sigma} \right\} \tag{66}$$

The first order condition with respect to government bonds holding reads as follows:

$$E_t \left\{ \frac{p_t^B}{(p_{t+1}^B + 1)} \right\} = \widetilde{\beta} E_t \left\{ \frac{\lambda_{t+1}}{\lambda_t} \right\} \tag{67}$$

where we define the returns r_t^B as:

$$(1 + r_{t+1}^B) = \frac{(p_{t+1}^B + 1)}{p_t^B} \tag{68}$$

Finally, the first order conditions with respect to asset (k) holding reads as follows:

$$E_t \left\{ \frac{p_{t,k}^s}{(p_{t+1,k}^s + d_{t+1,k})} \right\} = \widetilde{\beta} E_t \left\{ \frac{\lambda_{t+1}}{\lambda_t^k} \right\} \tag{69}$$

where $\lambda_t^k = \lambda_t \left(1 + \alpha^{s_k} + \alpha^{G_k} \epsilon_t^G + \epsilon_t^{P_k^s} + \frac{\lambda^{p^k \prime}(.)}{p_{t,k}^s} \right)$ We define then the asset returns as:

$$(1 + r_{t+1,k}^s) = \frac{(p_{t+1,k}^s + d_{t+1,k})}{p_{t,k}^s} \tag{70}$$

F.2 Brown Firms problem

First the brown firms decide on their demand for inputs (capital, abatement, and carbon price) and output they produce by maximizing their profits:

$$\max_{y_{t,B},i_{t,B},k_{t+1,B},l_{t,B},\mu_{t,B},e_{t,B}} E_0 \sum_{t=0}^{\infty} \widetilde{\beta}^t \frac{\lambda_t}{\lambda_0^B} \{(p_{t,B}y_{t,B} - (i_{t,B} + w_{t,B}l_{t,B} + (f(\mu_{t,B}) + \xi(\mu_{t,B}/\mu_{t,B}))y_{t,b} + \tau_t e_{t,B})\} \tag{71}$$

s.t.

$$\epsilon_t^{A^B} k_{t,B}^{\alpha_B} (l_{t,B})^{1-\alpha_B} \geq y_{t,B} \tag{72}$$

$$e_{jt} = (1 - \mu_{t,B})\, \varphi_B y_{t,B} \tag{73}$$

$$\gamma^Y k_{t+1,B} = (1-\delta)k_{t,B} + \Lambda(.) \tag{74}$$

The maximization problem reads:

$$\mathcal{L} = E_0 \left\{ \sum_{t=0}^{\infty} \widetilde{\beta}^t \frac{\lambda_t}{\lambda_0^B} (p_{t,B}y_{t,B} - (i_{t,B} + w_{t,B}l_{t,B} + (f(\mu_{t,B}) + \xi(\mu_{t,B}/\mu_{t,B}))y_{t,B} + \tau_t (1-\mu_{t,B})\, \varphi_B y_{t,B}))) \right.$$
$$+ \sum_{t=0}^{\infty} \widetilde{\beta}^t \frac{\lambda_t}{\lambda_0^B} \varrho_{t,B} \left[\epsilon_t^{A^B} k_{t,B}^{\alpha_B} (l_{t,B})^{1-\alpha_B} - y_{t,B} \right]$$
$$\left. + \sum_{t=0}^{\infty} \widetilde{\beta}^t \frac{\lambda_t}{\lambda_0^B} q_{t,B}^E \left[(1-\delta)k_{t,B} + \Lambda(.) - \gamma^Y k_{t+1,B} \right] \right\}$$

The first-order condition with respect to the firm's optimal choice of labour, investment, capital, abatement, and output are as follows:

$$w_{t,B} = (1-\alpha)\varrho_{t,B} \frac{y_{t,B}}{l_{t,B}}, \tag{75}$$

$$1 = q_{t,B}\Lambda(.)' + \tilde{\beta} \frac{\lambda_{t+1}}{\lambda_t} q_{t+1,B}\Lambda(.)' \tag{76}$$

$$\gamma^Y q_{t,B} = \tilde{\beta} \frac{\lambda_{t+1}}{\lambda_t} (q_{t+1,B}(1-\delta) + \psi_{t+1,B}\alpha_B y_{t+1,B}/k_{t+1,B}) \tag{77}$$

$$\tau_t = \frac{f^{'}(.) + \xi^{'}(.)}{\varphi_B \varepsilon_t^E \Psi_t}, \tag{78}$$

$$p_{t,B} = \varrho_{t,B} + f(\mu_{t,B}) + \xi(\mu_{t,B}/\mu_{t-1,B}) + \tau_t(1-\mu_{t,B})\varphi_{1,B} \tag{79}$$

$$\tag{80}$$

where $\varrho_{t,B}$ represents the input marginal cost of brown firms and $q_{t,B}$ the Tobin Q.

F.3 Green Firms problem

Turning now to the green firms, the problem is simpler as green firms are not subject to carbon pricing or abatement efforts. The problem thus reads:

$$\max_{y_{t,G},i_{t,G},k_{t+1,G},l_{t,G}} E_0 \sum_{t=0}^{\infty} \widetilde{\beta}^t \frac{\lambda_t}{\lambda_0^G} \{(p_{t,G}y_{t,G} - (i_{t,G} + w_{t,G}l_{t,G})\} \tag{81}$$

s.t.

$$\epsilon_t^{A^G} k_{t,G}^{\alpha_G} (l_{t,G})^{1-\alpha_G} \geq y_{t,G} \tag{82}$$

$$\gamma^Y k_{t+1,G} = (1-\delta)k_{t,G} + \Lambda(.) \tag{83}$$

The maximization problem reads:

$$\begin{aligned}\mathcal{L} = E_0 \Bigg\{ &\sum_{t=0}^{\infty} \widetilde{\beta}^t \frac{\lambda_t}{\lambda_0^G} (p_{t,G}y_{t,G} - (i_{t,G} + w_{t,G}l_{t,G})) \\ &+ \sum_{t=0}^{\infty} \widetilde{\beta}^t \frac{\lambda_t}{\lambda_0^G} \varrho_{t,G} \left[\epsilon_t^{A^G} k_{t,G}^{\alpha_G} (l_{t,G})^{1-\alpha_G} - y_{t,G}\right] \\ &+ \sum_{t=0}^{\infty} \widetilde{\beta}^t \frac{\lambda_t}{\lambda_0^G} q_{t,G}^E \left[(1-\delta)k_{t,G} + \Lambda(.) - \gamma^Y k_{t+1,G}\right] \Bigg\}\end{aligned}$$

The first order conditions with respect to labour, investment, capital, and output in this case reads:

$$w_{t,G} = (1-\alpha_G)\psi_{t,G}\frac{y_{t,G}}{l_{t,G}} \tag{84}$$

$$1 = q_{t,G}\Lambda(.)' + \tilde{\beta}\frac{\lambda_{t+1}}{\lambda_t} q_{t+1,G}\Lambda(.)' \tag{85}$$

$$\gamma^Y q_{t,G} = \tilde{\beta}\frac{\lambda_{t+1}}{\lambda_t}(q_{t+1,G}(1-\delta) + \psi_{t+1,G}\alpha_G y_{t+1,G}/k_{t+1,G}) \tag{86}$$

$$p_{t,G} = \varrho_{t,G} \tag{87}$$

F.4 Orange Firms problem

The orange firms problem is similar to the green firm with one major difference that is the orange firms engage in abatement and thus pay abatement costs although they are not subject to the environmental policy. The orange firm's problem then reads as:

$$\max_{y_{t,O},i_{t,O},k_{t+1,O},l_{t,O}} E_0 \sum_{t=0}^{\infty} \widetilde{\beta}^t \frac{\lambda_t}{\lambda_0^O} \{p_{t,O}y_{t,O} - (i_{t,O} + w_{t,O}l_{t,O} + z_{t,O})\} \tag{88}$$

s.t.

$$\epsilon_t^{A^O} k_{t,O}^{\alpha_O}(l_{t,O})^{1-\alpha_O} \geq y_{t,O} \tag{89}$$

The maximization problem reads:

$$\begin{aligned}\mathcal{L} = E_0 \Bigg\{ & \sum_{t=0}^{\infty} \widetilde{\beta}^t \frac{\lambda_t}{\lambda_0^O} (p_{t,O}y_{t,O} - (i_{t,O} + w_{t,O}l_{t,O} + z_{t,O})) \\ & + \sum_{t=0}^{\infty} \widetilde{\beta}^t \frac{\lambda_t}{\lambda_0^O} \varrho_{t,O} \left[\epsilon_t^{A^O} k_{t,O}^{\alpha_O}(l_{t,O})^{1-\alpha_O} - y_{t,O}\right] \\ & + \sum_{t=0}^{\infty} \widetilde{\beta}^t \frac{\lambda_t}{\lambda_0^O} q_{t,O}^E \left[(1-\delta)k_{t,O} + \Lambda(.) - \gamma^Y k_{t+1,O}\right] \Bigg\}\end{aligned}$$

The first order conditions with respect to labour, investment, capital, and output in this case reads:

$$w_{t,O} = (1-\alpha_O)\varrho_{t,O}\frac{y_{t,O}}{l_{t,O}} \tag{90}$$

$$1 = q_{t,O}\Lambda(.)' + \tilde{\beta}\frac{\lambda_{t+1}}{\lambda_t} q_{t+1,O}\Lambda(.)' \tag{91}$$

$$\gamma^Y q_{t,O} = \tilde{\beta}\frac{\lambda_{t+1}}{\lambda_t}(q_{t+1,O}(1-\delta) + \psi_{t+1,O}\alpha_O y_{t+1,O}/k_{t+1,O}) \tag{92}$$

$$p_{t,O} = \varrho_{t,O} + \varrho_{t,O} + f(\mu_{t,O}) + \xi(\mu_{t,O}/\mu_{t-1,O}) \tag{93}$$

F.5 Orange Firms Specialized Managers problem

The specialized sustainability team within the orange firms chooses the amount of abatement the orange sector will need to abate in expectation of the carbon price enforcement within the new ETS phases. They essentially solve the following problem:

$$\min_{\mu_{t,O}} E_0 \sum_{t=0}^{\infty} \widetilde{\beta}^t \frac{\lambda_t}{\lambda_0^O} \{z_{t,O} + \tau_{T-t}(1-\mu_{T-t,O})\varphi_O y_{T-t,O}\epsilon_{T-t,O}\} \tag{94}$$

s.t.

$$z_{t,O} = (f(\mu_{t,O}) + \xi(\mu_{t,O}/\mu_{t,O}))y_{t,b} \tag{95}$$

The first order conditions with to abatement reads:

$$f_\mu(\mu_{t,O}) + \xi_\mu(\mu_{t,O}/\mu_{t-1,O}) + \beta\frac{\lambda_{t+1}}{\lambda_t}\xi_\mu(\mu_{t+1,O}/\mu_{t,O}) = \beta^T\frac{\lambda_{T+t}}{\lambda_t}\tau_t\varphi_o \tag{96}$$

These expectation about future taxes, induces a substantial increase in the number of state variables (more than 450). As such we consider that the orange firm's managers use a time preference discount rate instead of the full orange sector stochastic discount factor. This assumption does not have a major impact on the response of the economy to shock as we show in the model dynamics figure, however it eases the estimation procedure.

F.6 Aggregate Firm problem

The aggregate final firm aims to maximize profit d_t given a price p_t, subject to the production of sectoral goods indexed by k at prices $p_{t,k}$:

$$\max_{y_{t,B},y_{t,O},y_{t,G}} E_0\sum_{t=0}^{\infty}\tilde{\beta}^t\frac{\lambda_t}{\lambda_0}d_t \tag{97}$$

s.t.

$$d_t = p_t y_t - \sum_k p_{t,k}y_{t,k} \tag{98}$$

$$y_t = \left(\sum_k \varkappa_k^{\frac{1}{\theta}} y_{t,k}^{1-\frac{1}{\theta}}\right)^{\frac{1}{1-\frac{1}{\theta}}}, \tag{99}$$

The first order condition for the final firm profit maximization problem yields:

$$y_{t,k} = \varkappa_k\left(\frac{p_{t,k}}{p_t}\right)^{-\theta}y_t. \tag{100}$$