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Transition Versus Physical Climate Risk Pricing in European Financial Markets: A Text-Based Approach⋆

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Abstract

Under its climate regulation, the EU is expected to become the first continent with a net-zero emissions balance. We study the pricing of climate risks, physical and transition, within European markets. Using text-analysis, we construct two novel (daily) physical and transition risk indicators for the period 2005-2021 and two global climate risk vocabularies. Applying our climate risk indices to an asset pricing test framework, we document the emergence of economically significant transition and physical risk premia post-2015. From a firm-level analysis, using firms' GHG emissions, GHG emissions intensity, environmental, and ESG scores, we find that rises in transition (physical) risk are typically associated with an increase (decrease) in the return of green (brown) stocks. Firm-level information is used by investors to proxy firms' climate-risks exposure, especially for transition risk since 2015, whereas the sectoral classification appears to proxy firms' exposures to physical risk. From a country-level analysis emerges an intensified connection between European stock markets and climate risks post-2015, yet with some heterogeneity. Our results have important economic implications and show that investors demand compensation for their exposure to both climate risk types. Our novel climate risk vocabularies and indicators find several applications in identifying, measuring, and studying climate risks.

Keywords: Climate risks premia, Transition risk, Physical risk, ESG, Text-analysis

JEL Codes: C58, G12, G14, G28, Q51, Q54

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The climate risk indicators and vocabularies constructed in this paper can be downloaded from the Lavinia Rognone's library or from the Economic Policy Uncertainty website.

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1. Introduction

As climate change progresses, investors are expected to reflect climate-related risks in firms' valuations. While this may seem obvious in light of the overarching evidence that climate change represents a source of financial risk, documenting climate risk premia is not as trivial, as demonstrated by conflicting results throughout the green finance literature (In et al. 2019; Hsu et al. 2023; Alessi et al. 2021; Bolton and Kacperczyk 2023; Pástor et al. 2022). Several factors might impede climate risk-informed investment decisions such as the lack of agreed metrics for firms' exposure to climate risks, alongside the difficulty of identifying and measuring climate risk events over time (Engle et al. 2020). It follows that investors might not be able to easily screen firms exposed to climate risks, failing to detect climate-risky investments (Bolton and Kacperczyk 2021). In contrast, market participants might be insensitive to climate change shocks, suggesting they do not perceive these as financial risks.[1] Both scenarios could lead to a mispricing of climate risks with consequences for the functioning of the financial sector as such and as a vehicle to transmit climate policies.

Besides the key role played by the EU in international environmental agreements such as the UN Climate Convention, the Kyoto Protocol, and the Paris Agreement, there is evidence of a "self-policy" that makes the EU progressing as an entity different from other countries when talking about climate regulation. In fact, the European Council has set the goal to reduce the EU greenhouse gas emissions by 55% by 2030, compared to 1990, and reach climate neutrality by 2050. In June 2021, the Council also adopted the "European climate law", part of the European Green Deal, under which EU countries are legally obliged to reach the 2030 and 2050 climate goals. To facilitate these objectives, the EU has released the "Fit for 55" package of proposals to revise and update the EU legislation, aims to spend 30% of the EU 2021-2027 budget to tackle

[1] Unawareness and market inattention to the financial implications of climate risk can impact the pricing of such risks in assets. Engle et al. (2020) suggest that climate risk pricing may depend on investors' attention. Murfin and Spiegel (2020) and Hong et al. (2019) identify inefficiencies in climate risk pricing, partly attributing this to scepticism or market inattention to climate risks.

climate change, and has introduced a "Just Transition Mechanism" valued more than €100 billion and devoted to the green transition. Under these premises, the EU is expected to be the first continent to reach a net-zero emissions balance.

The EU adoption of a self-climate regulation and the ambitious roadmap to become the first net-zero emissions continent create room for research on understanding, exploring, and deepening the relationship between Europe, specifically, and climate change risks. With this paper, we therefore want to study whether climate risks, physical and transition, are priced in European markets documenting to which extent these are perceived as financial risks and whether investors consider some firms or activities as more exposed to climate risks than others. Nevertheless, to run a rigorous analysis of the different roles of physical and transition risk, it is pivotal to have as comprehensive, informative, and reliable measures of these as possible. Previous studies mainly capture sub-dimensions of physical and transition risk, e.g. natural disasters or climate policies, ignoring relevant aspects of these complex risks leading to restricted results. A deeper understanding of the impact of physical and transition risk as a whole remains largely unexplored and becomes essential to, e.g., make climate-informed investment decisions or make an effective climate risks management. Using text-analysis, we create two novel climate risks vocabularies which enjoy several advantages, improving on the existent literature and delivering sophisticated climate risk indicators allowing us to unveil new financial implications of climate change.

In particular, we distinguish between physical and transition risk using a text-based approach similar to Engle et al. (2020) acknowledging that the two can impact financial markets differently. Physical risk represents loss of value or costs due to chronic, e.g. sea level rise and drought, and/or acute, e.g. floods and heat waves, hazards. Transition risk arises from the costly adjustment towards a climate-neutral economy, typically prompted by climate policies, technological advances, and shifts in public preferences. To dissect climate change risks, we first examine scientific texts on climate change to build two novel *global* and comprehensive climate vocabularies on physical and transition risk. We then construct a Physical Risk Index (PRI) and Transition Risk Index (TRI) by comparing the vocabularies with a corpus of news sourced from Reuters News. This approach posits that investors use news to update beliefs about climate change risks and that climate change news coverage intensifies with climate risks (Engle et al. 2020). The resulting PRI and TRI spike during days when the discussion on either risk type increases substantially. PRI captures multiple aspects of physical risk, e.g. detecting news concerning rising sea levels, permafrost thawing, floods, and adaptation measures, whereas TRI detects regulatory climate news as well as news discussing the importance of technological advances to achieve a greener economy, among others.

Drawing upon standard asset pricing theories, which suggest that assets hedging against future market conditions changes tend to have higher prices, implying lower expected returns (e.g. Breeden (1979)), and considering that climate change risks affect future investment and consumption opportunities (e.g. Huynh and Xia (2021)), it is expected that investors would prefer to hold assets that perform well in the face of increasing climate change risks, even if this entails accepting lower returns for such climate-hedging assets (e.g. Engle et al. (2020); Huynh and Xia (2021)).[2] We therefore employ the two novel physical and transition risk indices to gauge the presence of physical and transition climate risk premia in European equity markets. In particular, we adopt a standard portfolio sorting approach over the period from January 2005 to October 2021 and, in line with recent studies that document a higher importance of climate risks since the time of the Paris Agreement (e.g. Bolton and Kacperczyk 2023; Goldsmith-Pinkham et al. 2023), we further consider two sub-periods as before and after 2015 to investigate any time-varying relationship between equity markets and climate risks.

We perform time series regressions of equity returns on climate risks, controlling for the Fama and French (2015) five factors known to drive returns, and estimate equity market sensitivities to climate risks. The resulting loading on the climate risk factors, i.e. transition and physical risk betas, determine our estimates of firm-level climate risk exposure. Stocks with positive/high climate

[2] Pástor et al. (2021) also predict that the lower expected return of green assets compared to brown assets reflects a risk premium, as greener assets offer better climate risk hedging. Additionally, under the carbon risk premium hypothesis of Bolton and Kacperczyk (2021), there exists a positive link between a firm's carbon emissions and its stock returns, indicating that investors demand compensation for holding stocks of high carbon emitters due to increased carbon risk. Pástor et al. (2021) suggest that price differentials between green and brown assets could also stem from green taste preferences.

risk beta perform well when climate risk increases offering potential hedge against climate change risks to investors who in turn should be willing to accept lower expected returns from such stocks. On the opposite, negative/low climate beta stocks perform badly when climate risks increase suggesting they are climate-risky stocks for which investors should require higher expected returns to compensate for the extra risk they'd bear if holding them within their portfolios. It follows that a low-minus-high (LMH) transition (physical) climate beta portfolio should therefore earn positive excess returns in case a climate risk premium exists. Results show the presence of economically significant transition and physical risk premia as sizable as 7.05% and 6.14% on average per year after 2015, respectively, providing a first-time empirical evidence of both climate-related risks pricing in European equity markets.[3] Results document that investors are demanding compensation for their exposure to physical and transition risk, and that such compensation increases in their exposure, as demonstrated by stronger results when grouping portfolios from quintiles to 25 percentiles.

Due to the lack of agreed metrics of firms' exposure to climate-related risks, we also run a firm-level and sectoral-level analysis to investigate which type of information is more likely used by investors to detect physical and transition risky stocks, further contributing to Bolton and Kacperczyk (2021) who question whether investors consider the industry where firms operate in, rather than firm-level information, as material information on firms' exposure to climate risks. Compared to Bolton and Kacperczyk (2021), we consider a wider range of firm-level information, not only GHG emissions, alongside our comprehensive climate risk measures. We include PRI and TRI into a Fama and French (2015) five factors asset pricing model to test equity sensitivity to climate risks where: i) firms are sorted on GHG emissions levels, GHG emissions intensity, Environmental (E) scores, and Environmental, Social, and Governance (ESG) scores, with returns being aggregated into green and brown portfolios – firm-level analysis; and ii) firms are grouped

[3] Using our comprehensive climate risk measures, we document the emergence of a transition risk premium in Europe, challenging prior findings that, relying solely on GHG emissions, identify Asia as entirely responsible for global transition risk premium around the Paris Agreement (Bolton and Kacperczyk 2023). Thus, we underscore the importance of precise climate risk measurement for uncovering additional economic implications.

by sector (NACE Rev. 2 classification) with returns aggregated accordingly – sectoral-analysis. Overall, firm-level information appears to be used as a gauge for firms' exposure to climate risks, especially for transition risk and since 2015. Rises in transition (physical) risk typically increase (decrease) the excess return of green (brown) stocks under the firm-level analysis. In contrast, the sectoral classification appears sufficient to identify firms' exposure to physical risk. Additionally and motivated by the climate economics literature that underscores the importance of considering geographical locations of climate policies and physical risk (Nordhaus and Yang 1996; Bolton and Kacperczyk 2023; Cruz and Rossi-Hansberg 2023), we provide some insights on European individual countries' sensitivity to climate-related risks over time as an additional test. Our findings suggest that a country-level relation between the stock market and climate risks exists and has increased post-2015, with countries overall experiencing more severe association with climate risks. Yet, the results show some heterogeneity country-by-country further underscoring the importance of the consideration of sub-national conditions in both investment decision-making and when designing climate policies.

This paper contributes and relates to a growing strand of literature which focuses on understanding the impact of climate risks on asset prices.[4] Climate-related risks pose relevant economic challenges (see e.g. Stern 2007; Pankratz et al. 2023), can cause stress in the financial system (Flori et al. 2021), drive the cross-section of both stock (e.g. Hsu et al. 2023; Bolton and Kacperczyk 2023) and bond returns (e.g. Krueger et al. 2020; Painter 2020; Huynh and Xia 2021),[5] and influence relative dynamics between green and brown equities (Bouri et al. 2022) or between ESG and conventional assets (Cepni et al. 2023). Climate-related risks also impact other asset classes,

[4]For a more complete review see Hong et al. (2020) and Giglio et al. (2021).

[5]Differently from Krueger et al. (2020) who consider survey-based data at the sectoral level to examine the implications of climate risks for equity valuations, we employ innovative climate risk metrics derived from objective sources like climate news shocks, as opposed to surveys, and conducts analyses at multiple levels, including sectoral, firm-level, and selected portfolio assessments. Furthermore, whereas Painter (2020) explores climate risk pricing in municipal bonds, motivated by examining whether investors price climate risks when these cannot be easily hedged or eradicated, we focus on the stock market and consider, for instance, sectors with varying degrees of expected climate-risk exposure (e.g. from mining and quarrying to arts), contributing to the initial question of Painter (2020). Finally, Painter (2020) focuses on a single physical risk, whereas we use comprehensive climate risks measures and separate physical and transition risks.

such as foreign exchange markets (Bonato et al. 2022), gold (Cepni et al. 2022; Salisu et al. 2023), real estate (e.g. Bernstein et al. 2019; Baldauf et al. 2020; Murfin and Spiegel 2020), and financial institutions more broadly (e.g. Battiston et al. 2021; Giglio et al. 2021; Do et al. 2022). In addition to the aforementioned literature, theoretical underpinnings from other scientific research, including publications by the IPCC, underscore the pressing risks associated with climate change and emphasize the pivotal role that the financial sector and the broader economy can play in mitigating these risks (IPCC 2023). On one hand, the alarming consequences of climate change and their connections to financial markets motivate our research question to identify an actual climate risk premium within the stock market. On the other hand, there are profound implications of mispricing climate change risks that necessitate assessment. Climate risk mispricing can, in fact, have detrimental effects on the economy through various channels, including financial stability concerns, the emergence of stranded assets, a more abrupt response to future green transitions, the financial sector's inability to facilitate mitigation policies, and more (Drudi et al. 2021; ECB 2023).

The equilibrium model of Pástor et al. (2021) predicts that green assets have lower expected returns compared to brown assets, but they have higher realized returns when agents are surprised by climate change concerns. While this conjecture appears convincing, empirical evidence on the presence of carbon risk premia is not yet conclusive. Some studies find that investors require additional compensation for holding brown assets, especially after the Paris Agreement, whereas others provide no evidence of price differentials (see In et al. 2019; Hsu et al. 2023; Alessi et al. 2021; Bolton and Kacperczyk 2023; Pástor et al. 2022). Additionally, transition risk does not solely represent a carbon/GHG risk, but it also stems from public shifts in preferences toward greener products, technological advances, and changes in environmental regulation – all aspects that jointly determine the financial risks posed by transition risk. For instance, Adomako et al. (2023) show that stakeholder green pressures, e.g. demand for green products, determine an increase of eco-product innovation and Dechezleprêtre et al. (2021) find higher valuations to firms that engage in clean research and development activities. Sena et al. (2022) find that the reshoring of subsidiaries, associated with relocation costs, is more likely in countries with environmental disclosure regulations. Therefore, the green finance literature highlights the need for studying transition risk using enhanced and more comprehensive risk metrics. Similarly, the literature on the financial consequences of physical risk mainly considers specific risk events, such as sea level rise (Painter 2020; Goldsmith-Pinkham et al. 2023), high temperatures (Addoum et al. 2020), droughts (Hong et al. 2019), hurricanes (Kruttli et al. 2021), or other generic extreme events (Baltas et al. 2022), leaving ample room for analyses on the financial implications of physical risk using more complete risk measures.[6] Goldsmith-Pinkham et al. (2023) ignore.

As contributions to these studies, we: i) consider both aspects of climate risks and build comprehensive measures of physical and transition risks which allow us to both document climate risk premia exhaustively and attribute which of the two risk types drives any increase/decrease in green/brown stocks returns, refining or overturning previous findings; ii) focus on Europe, offering an informative study for, but not limited to, European institutions and investors; iii) run a daily analysis, particularly relevant for short-horizon investors and regulators seeking timely decisions, and unlike studies that use lower frequency data or focus on long-run climate implications (e.g. Bansal et al. 2016; Engle et al. 2020); iv) consider both the full sample and sub-periods to expand further the existing literature on the time-varying effects of climate risk; and v) consider various indicators of climate risk exposure, documenting which ones may be used by investors.

This paper also relates to the strand of the climate finance literature which uses text analysis to measure climate risks (Batten et al. 2016; Ardia et al. 2023; Engle et al. 2020; Meinerding et al. 2023; Faccini et al. 2023). While previous studies improve upon climate risk identification, they either consider climate change as a unique risk factor (Engle et al. 2020), focus only on transition risk (Batten et al. 2016; Meinerding et al. 2023), or focus on specific sub-categories of physical and transition risks (Ardia et al. 2023; Faccini et al. 2023).[7] Our paper improves the existent literature

[6]Compared to Goldsmith-Pinkham et al. (2023), for instance, our analysis is not limited to the specific climate-related risks of sea level rise and floods. Instead, our study encompasses different types of physical risks, which we integrate into a comprehensive index. This allows us to thoroughly explore whether there are economic and financial impacts arising from the various sources of physical climate risks. In addition, we further investigate the other pivotal component associated with climate change finance, namely the transition risk component, which

[7]Using a textual analysis approach, Ardia et al. (2023) identify eight climate change sub-categories. Faccini et al. (2023) filter news by "climate change" and "global warming" and employ a Latent Dirichlet Allocation approach to

as our physical and transition risk vocabularies are global vocabularies, i.e. can be applied to any text source, that originate comprehensive climate risk indicators able to capture the entire multifaceted characteristics of the two climate risks without discarding relevant categories.

The remainder of this paper is organised as follows: Section 2 describes the text analysis methodology and provides a discussion of the physical and transition risk indices. Section 3 describes transition and physical risk pricing methodology. Section 4 provides an overview of the data used in this study. Section 5 lays out the main results. Section 6 concludes.

2. Measuring Climate Risk through Text-Analysis

To test financial markets sensitivity to physical and transition risks we need proxies to measure these risks. We exploit newspaper content to identify physical and transition risk shocks expanding upon the text-based approach of Engle et al. (2020) – who proxy innovations to climate change news, but without distinguishing between physical and transition risk. In particular, we compare authoritative texts on climate change with a corpus of European news sourced from Reuters News[8] based on the assumption that events covered in newspapers can carry relevant information on climate change. We then create two separate vocabularies and use these to construct distinct physical and transition risk shock indices. Recent studies have started relying on our measure of physical and transition risks for various analyses (see, for instance, Blasberg et al. (2022); Cepni et al. (2022); Pietsch and Salakhova (2022); Ali et al. (2023); Bouri et al. (2023a,b); Cepni et al. (2023); Goodell et al. (2023); Gupta and Pierdzioch (2023); Karmakar et al. (2023); Arfaoui et al. (2024); Fava et al. (2024)).

cluster news topics into "Natural Disasters", "Global Warming", "International Summit", and "U.S. Climate Policy" factors.

[8]Reuters provides news to professionals via desktop terminals, world's media organizations, industry events, and consumers. Reuters News also includes the Breakingviews.com content (Source reuters.com and reutersagency.com, accessed on 16/06/2021).

2.1. *Physical and Transition Risk Vocabularies*

To construct the climate risk vocabularies, we follow three main steps. First, we select a large number of scientific and authoritative texts on the topic of climate change published by governmental authorities and other institutions, starting with the collection already adopted by Engle et al. (2020). We screen texts' content and retain those whose content can be associated with either physical risk or transition risk topics. We further add financial texts describing both risk types as a genuine attempt to construct risk measures which incorporate multiple perspectives. The complete list of texts is summarised in Table A1 in the Appendix. We then aggregate the 13 (10) texts covering physical (transition) risk to create a single document on physical (transition) risk. The idea is that if one reads the whole physical risk document and transition risk document, he or she would acquire a comprehensive knowledge of physical and transition risk. The two climate documents in fact, aggregating authoritative and scientific publications about climate change, represent our full information about climate risks which we in turn want to find within the news coverage to construct our climate risk indicators, and therefore represent the information we use to feed our text-based algorithms.

As a second step, we create two lists of unique stemmed unigrams and bigrams, jointly referred to as terms, with the associated term frequency scores (*tf*) from the physical and transition risk documents. Then, we create an analogous list of terms and frequencies from Reuters News, where real-time news are aggregated into daily documents. To do so, we retrieve a total of over 2.5 million real-time news in English language from the Factiva database over the period Jan 2005-Oct 2021.[9] Thereafter, we apply a one-day novelty filter to the sample to eliminate redundancy among the data. Specifically, only the first news of the day is kept from a series of similar news published on the same day (see Dang et al. (2015), Rognone et al. (2020), and Faccini et al. (2023)) and only news published during days in which European equity markets are open for trading are retained.[10]

[9]The Factiva database allows users to select a regional focus of the news. We therefore consider Reuters News with a European regional focus (news related to Europe or its constituent countries and regions). It is important to note that, although these news have to be related to Europe, they may also discuss other countries or international issues.

[10]News which corpus length exceeds 5,000 words are not included in our analysis for both computational reasons

The final sample counts 1,096,392 news.

Third, we convert the physical (transition) risk document and each daily news document into term frequency-inverse document frequency (*tf-idf*). Terms earn high *tf-idf* if they are representative of the individual text. This means that they are frequent within the document (high *tf*) and infrequent among other documents (high *idf*). On the opposite, low *tf-idf* score terms are common to many documents (low *idf*) and/or very infrequent within the document (low *tf*) and therefore have poor ability in representing the content of the individual text (Engle et al. 2020; Gentzkow et al. 2019). By multiplying the *tf* scores of the physical risk and transition risk documents by their relative *idf* scores from the collection of news,[11] we are able to obtain vocabularies ranked by term relevance (*tf-idf*).

Thanks to our methodology, which combines the *tf-idf* with the screening of texts on the topic of physical and transition risks, the resulting climate risk vocabularies benefit from several advantages, improving on the existent literature and delivering sophisticated climate risk indicators: i) the phraseology associated with the two types of risks is extracted from the authoritative texts rather than being defined ex-ante by the authors, *no selection bias*;[12] ii) each vocabulary is found to capture the multifaceted characteristics of each climate risk type, rather than single aspects, *complete climate risks information*;[13] iii) to the best of our knowledge, this is the first study distinguishing between physical and transition risk while acknowledging that these share common concepts, *risk interconnections are context-scaled*; iv) the ability to rank terms by relevance allows for a deeper understanding of each risk type and enables to examine which risk aspects are more or less important in the overall risk description, *relevance-ranked vocabularies*;[14] v) the resulting climate risk vocabularies represent global physical risk and transition risk vocabularies, because built

and because they can be considered as outliers due to their great length and very marginal occurrence.

[11]The final collection of documents is then composed by T documents, as a total of T-1 daily news documents and 1 physical (transition) risk document, which enables us to calculate the *idf* scores. At this stage, to lighten the computational load and avoid the so-called machine learning overfitting issue, we consider a subsample of the Reuters News (2015-2019).

[12]Some studies initially use keywords defined by authors to construct climate indicators (e.g. Faccini et al. 2023) or news provider *tags* (e.g. Ardia et al. 2023).

[13]Previous research mainly identifies only sub-categories of climate risks.

[14]Other studies rely mainly rely on a term-frequency ranking.

on scientific information, and can be applied to any type of text to assess the its level of physical risk or transition risk discussion, *global climate risks vocabularies*.

Figure 1 shows the most relevant terms of the physical risk vocabulary (a) and the transition risk vocabulary (b) as word clouds, where each term size is proportional to its *tf-idf* score. The physical risk vocabulary includes multiple dimensions of physical risk such as both extreme and chronic hazards directly caused by climate change, excluding natural disasters attributable to other sources. Accordingly, the transition risk vocabulary includes various aspects of this climate risk such as technological advances and environmental policies. Terms such as "*ecosystems*", "*sea level*", and "*precipitation*" are representative of the physical risk topic, while terms such as "*hydrofluorocarbon*" (HFC), "*bioenergy*", and "*greenhouse gas*" (GHG) are representative of the transition risk topic. Additionally, the figure shows evidence that the constructed vocabularies are likely to capture interconnections between the two complex risks, and to contextualise common terms. For instance, the term "*GHG*" appears in both vocabularies, but to a different extent. It plays a primary role in explaining transition risk and a minor one for physical risk. The term "*adaptation*", on the other hand, is a common concept for physical and transition risk and therefore appears in both vocabularies. However, its semantics differ depending on whether it is being considered within the context of physical or transition risk and thus depends on the other terms in the vocabulary.

Nevertheless, for the exercises to be carried out in this paper, it has to be assured that vocabularies are sufficiently different in terms of the content they describe. To confirm that this is the case, we apply a test proposed by Dang et al. (2015).[15] Results show that the transition risk vocabulary is able to explain less than 5% of the physical risk vocabulary, which in turn carries about 95% of individual information, and vice-versa.

– Insert Figure 1 about here –

[15] We evaluate the actual degree of commonality between the two vocabularies as the R squared from regressing the physical risk vocabulary on the transition risk one, and vice-versa. Despite there not being a clear threshold level (Rognone et al. 2020), the resulting R square of less than 5 percent is considered sufficiently small to support a reliable separation of the two risks.

2.2. *Physical and Transition Risk Indices*

In order to calculate our two risk indices we first compute two "concern" series. These news media concern series for physical/transition risk, on any given day t, are defined as the cosine-similarity between the *tf-idf* vector of the news document and the physical/transition risk document. The cosine-similarity is used in text-analysis to evaluate the similarity between pairs of texts. It expresses the angular distance between two vectors representative of pairs of text, such that the closer they point, the smaller their angular distance, the higher the cosine, and the higher the text similarity. In other words, we consider our physical (transition) risk dictionary as a vector, the direction of which depends on the intensity of each element given by the *tf-idf* of vocabulary terms. This means that daily news that point in the same direction as the physical (transition) risk vector are assessed to discuss the physical (transition) risk topic and the concern score, or cosine-similarity score, roughly represents the portion of daily news corpus dedicated to the topic of physical (transition) risk.

In order to gauge the unexpected change in physical/transition risk, we then construct the Physical Risk Index (PRI) and the Transition Risk Index (TRI) as residuals from autoregressive processes of order 1 (AR1) similarly to Engle et al. (2020), as follows

$$\text{Concern}_{t,PR} = c_{PR} + \phi_{PR}\text{Concern}_{t-1,PR} + \text{PRI}_{t,PR} \tag{1a}$$

$$\text{Concern}_{t,TR} = c_{TR} + \phi_{TR}\text{Concern}_{t-1,TR} + \text{TRI}_{t,TR} \tag{1b}$$

Table 1 reports a summary of the ten highest physical and transition risk shock days, showing the dates, PRI and TRI values, and news topics and titles of the most relevant articles. High shock days can cover a multiplicity of physical and transition risk topics. On one hand, the PRI is found to capture not only acute physical risks such as floods, or extreme weather events, but also a plurality of chronic risks such as permafrost thawing, droughts, and sea level rise, as well as governments and other institutions calls for climate adaptation actions and other adverse impacts of physical risk on, e.g., the ecosystem such as biodiversity loss. This sets our PRI apart from many other physical risk databases, which mainly identify extreme weather events only. On the other hand, news on regulations and measures to curb GHG emissions generate large spikes in the TRI, e.g. news regarding the EU carbon reform deal or the Montreal Protocol, as well as news concerning the costs associated with the transition or the advances of technological innovation and renewable energies to reach, e.g., net-zero emissions targets.

The PRI peak is registered on 19/09/2018, mainly due to an unexpected discussion about an unprecedented loss of arctic sea ice underling a critical level of permafrost thawing risk, but also due to discussions about sea level rise and chronic changes in the salinity of oceans. The largest shock for TRI concurs instead with news published on 24/08/2011, which mainly covered the worryingly high levels of EU GHG emissions which would need to be reduced.

– Insert Table 1 about here –

Figure 2 shows the scatter plots of daily physical and transition media concerns along with major PRI and TRI topics (panels a and b), and their monthly average (panels c and d). Table 2 summarises the AR1 estimates from Equations (1a) and (1b). Both physical risk and transition risk concern time series depict positive drifts ($c_{TR} = 8.462\%$ and $c_{PR} = 7.862\%$), showing that the news coverage toward these climate risks tends to increase over time. The media concern for transition risk seems to be more persistent than that for physical risk with $\phi_{PR} = 0.326$ and $\phi_{TR} = 0.413$. On the other hand, while the risk indices PRI and TRI are positively correlated with a coefficient of 0.37, according to the Dang et al. (2015) commonality test the 86.22% of the PRI and TRI information represents individual information, ensuring an adequate separation of physical and transition risk. In fact, only the 13.78% of PRI can actually be explained by the TRI series, and vice-versa. Because the two risks are naturally interconnected, as for instance one cannot explain the full transition risk without at least mentioning the physical risk, a certain degree of overlap is expected. Additionally, the same news story can sometimes discuss more broadly climate change covering both climate risk types.

– Insert Figure 2 and Table 2 about here –

Positive, zero, or negative values of our climate risk indicators signify an above-expected,

expected, or below-expected level of discussion around climate risk issues (either physical or transition), thus representing a positive, null, or negative innovation, respectively. Essentially, because the TRI and PRI represent innovations/shocks from the AR1 process of the so-called concern series, they can be interpreted in this manner. Theoretical underpinnings, including insights from IPCC reports and existing climate finance literature, strongly support the notion that climate risks represent a source of financial risks. Thus, asset prices should reflect climate risk information, although potential mispricings may arise due to, e.g., the effectiveness of measuring climate risk and exposure, or varying degrees of scepticism regarding climate change issues. Given the ability of our novel PRI and TRI to capture various climate risk aspects, we consider these as new pricing factors to conduct our empirical analysis.

3. Transition and Physical Risk Pricing in European Equity Markets

In the following section, we present the methodological approach to examine the existence of physical and transition climate risk premia in equity markets exploiting the physical and transition risk indicators. Afterwards, we discuss how we investigate which information type may be used by investors to proxy firms' exposure to either physical or transition risk.

3.1. *Transition and Physical Climate Risk Premia*

To assess the presence of climate risk premia for physical and transition risk in the cross-section of European stock returns we adopt a standard portfolio sorting approach. We perform time-series regressions of equity returns on our climate risk indices, controlling for standard risk factors known to drive returns. The resulting loading on the climate risk factors, i.e. the transition and physical risk betas, are our firm-level indicators of climate risk exposure. We use these to sort companies from low to high climate exposure and create portfolios. The negative/low TRI (PRI) beta portfolio includes firms that perform badly when there are increases in transition (physical) risk. Conversely, the positive/high beta portfolio includes firms that perform well when transition (physical) risk rises. Since investors can be expected to want to hedge against climate risks, they should be willing to accept lower expected returns for equities that offer good performance in case of bad transition (physical) risk economy states, i.e. for high beta stocks. In turn, low beta stocks should instead trade at a discount and offer higher expected returns to compensate for the higher risk investors bear to hold such climate riskier stocks in their portfolios. A low-minus-high transition (physical) climate beta portfolio should therefore earn positive abnormal excess returns in the case a climate risk premium exists.

Specifically, at the end of every month, we recursively estimate the sensitivity of each stock i to both transition and physical climate risks (climate betas) adopting a rolling window of daily observation over the past three months and controlling for the standard Fama and French (2015) five factors (FF5) as follows

$$r_{i,t}^{exc} = c_i + \beta_i^{TRI}\text{TRI}_t + \gamma_i^{\prime TRI} X_t + \epsilon_t \tag{2a}$$

for transition risk, and

$$r_{i,t}^{exc} = c_i + \beta_i^{PRI}\text{PRI}_t + \gamma_i^{\prime PRI} X_t + \epsilon_t \tag{2b}$$

for physical risk, where r_i^{exc} denotes the daily excess return on security i, c_i is the constant term, PRI_t and TRI_t are our climate risks measures, and the vector X_t controls for the FF5 factors known to drive the cross-section of stock returns, namely the market, the size, the book-to-market, the profitability, and the investment factors.[16] It could be anticipated that companies whose business is, e.g., adverse to new climate regulations or reliant on climate stability may be characterised by a negative transition or physical climate beta, respectively.

We sort stocks according to their estimated betas at the end of each month and group them into 5, 10, and 25 portfolios for which we compute the post-ranking equal-weighted monthly returns.

[16]The market factor represents market returns above the risk-free rate, the size factor measures additional returns from small-cap stocks, the book-to-market or value factor tracks excess returns for lower-valuation companies, the profitability factor identifies extra returns from highly profitable companies, and the investment factor reflects surplus returns from conservative investment strategies versus more aggressive ones. The Fama and French (2015) five factors are constructed considering the EuroStoxx 600 Index constituents over the period Jan 2005-Oct 2021 for which we calculate the 6 value-weight portfolios formed on size (market capitalization) and book-to-market, the 6 value-weight portfolios formed on size and operating profitability, and the 6 value-weight portfolios formed on size and investment (change in total assets). Data are collected from Eikon. More details on the methodology can be found in the Kenneth R. French' data library.

To examine the TRI-return relation (PRI-return relation), we also form a low-minus-high (LMH) portfolio that takes a long position in the negative-beta TRI (PRI) portfolio and a short position in the positive-beta TRI (PRI) portfolio, and we calculate the returns on this portfolio. We evaluate the transition (physical) risk premium, estimating each LMH climate portfolio alpha while considering the Fama and French (2015) five factors asset pricing model specification as follows

$$r^{exc}_{\beta TRI,t} = \alpha_{TRI} + \gamma'^{TRI}_{i} X_t + \epsilon_t \tag{3a}$$

for transition risk, and

$$r^{exc}_{\beta PRI,t} = \alpha_{PRI} + \gamma'^{PRI}_{i} X_t + \epsilon_t \tag{3b}$$

for physical risk.

Aligned with recent studies which find larger importance of climate risks for financial markets over the past few years (Goldsmith-Pinkham et al. 2023; Krueger et al. 2020; Painter 2020; Bolton and Kacperczyk 2023, 2021), especially from the time of the Paris Agreement, we allow our study to capture potential changes in the relation between European equity markets and climate risks by looking both at the full sample period and at the period before and after 2015.

3.2. *The Use of Climate Exposure Metrics by Investors*

In this paper we refer to "metric" as any type of information investors may use to assess firms' exposure to climate risks. Given the lack of a unique metric, investors can be expected to make use of different types of information to identify climate-risky stocks.[17] We reckon that while most of the common metrics are used to capture exposure to transition, rather than physical risk, the distinction is not always clear and their potential to capture physical exposure has been largely unexplored. For this reason, we decided to test a wide range of exposure metrics in light of their potential use by investors.

We add the Physical Risk Index (PRI) and the Transition Risk Index (TRI) to a Fama and French (2015) five factors (FF5) asset pricing model. We consider the E score, ESG score, GHG emissions level, and GHG emissions intensity as *firm-level* exposure metrics to sort firms and

[17] A discussion of the most common metrics is featured in Appendix A2.

create green and brown portfolios, as follows:

- *E score* and *ESG score* metrics. Firms whose E score is above (below) the 75th (25th) percentile are defined as green (brown). The green (brown) portfolio is then created as an equally weighted portfolio composed of green (brown) firms. The same approach is applied to the ESG score metric. Portfolios are rebalanced annually;
- *GHG emissions level* and *GHG emissions intensity* metrics. The GHG emissions level (GHG_E) is calculated as the sum of Scope 1 and 2, while the GHG emissions intensity (GHG_{EI}) is calculated as the GHG emissions level scaled by firms' net revenue. As before, firms whose emissions level is below (above) the 25th (75th) percentile are defined as green (brown) firms. Portfolios are again rebalanced annually.

At the same time, we conduct a *sectoral-analysis* by aggregating the excess returns of firms belonging to the same sector (NACE Rev. 2) to test the aggregate response of different sectors to shocks to physical and transition risks.

We therefore include our TRI and PRI into a model to gauge equity excess returns

$$r_{p_i,t}^{exc} = c_{p_i} + \beta_{p_i}^{TRI}\text{TRI}_t + \gamma_{p_i}^{\prime TRI} X_t + \epsilon_t \tag{4a}$$

to price transition risk, and

$$r_{p_i,t}^{exc} = c_{p_i} + \beta_{p_i}^{PRI}\text{PRI}_t + \gamma_{p_i}^{\prime PRI} X_t + \epsilon_t \tag{4b}$$

to price physical risk. For the firm-level analysis, $r_{p_i}^{exc}$ denotes the excess return at time *t* for green or brown portfolios where p ={green portfolio, brown portfolio} and i ={GHG_E, GHG_{EI}, E, ESG}. For the sectoral analysis, $r_{p_i}^{exc}$ instead denotes the excess return at time *t* for the portfolio p that aggregates firms of sector i. c_{p_i} is the constant term and the vector X_t controls for the FF5 factors. The coefficients β^{PRI} and β^{TRI} measure the relationship between an unexpected change in physical and transition risk, and the excess returns of portfolios constructed according to different exposure metrics. The results from this exercise could inform us about the metric used by investors to proxy firms' exposure to physical or transition risk.

4. Data

The augmented FF5 model uses the 1-month Overnight Index Swap (OIS) rate as the risk-free rate, and returns of the EuroStoxx 600 Index as a proxy for the market return. All data is used at a daily frequency. We collect closing price time series for the historical constituents of the Eurostoxx 600 Index from Datastream over the period Jan 2005-Oct 2021, resulting in a total of 1,198 companies.

Data on firms' GHG emissions level, GHG emissions intensity, E score, and ESG score are sourced from Refinitiv. The level of GHG emissions indicates the metric tonnes (in thousands) of carbon dioxide equivalent a company produces.[18] We compute the GHG emissions intensity as GHG emissions scaled by the firm's net revenue. The E score rather reflects the environmental performance of a company in terms of its commitment and effectiveness to tackle issues related to the use of resources, emissions, and innovation, while the ESG score is also informative about a firm's performance concerning social and governance issues. E and ESG scores are industry-based relative performances and scores range between 0 and 100, with higher values indicating better firm' performances, relative to sector peers. We define sectors using the Statistical Classification of Economic Activities in the European Community (NACE Rev. 2).[19] Table 3 shows the number of firms in our sample with available GHG emissions, GHG emissions intensity, E scores, and ESG scores data, highlighting a general increase in data coverage over time. The table also reports the threshold values (25^{th} and 75^{th} percentiles) used to construct brown and green portfolios for each metric.

– Insert Table 3 about here –

[18] The GHG Protocol Accounting and Reporting Standard classifies a company's GHG emissions into three scopes (Schmitz et al. 2004). We measure GHG emissions as the sum of scope 1 (direct emissions from company-owned and controlled resources) and 2 (indirect emissions from purchased electricity by the owned or controlled equipment or operations of the firm) because including scope 3 (other supply chain emissions) reduces the data coverage. We consider only data reported by the company.

[19] Eurostat (2008). Dafermos et al. (2020) for example identifies high-carbon intensive activities taking NACE 1-digit sectors that mostly contribute to EU emissions.

4.1. *Descriptive Statistics*

In order to give a better overview of the composition and characteristics of the EuroStoxx 600 Index at the sectoral level, table 4 reports the number of firms in our sample (No.), the average of the exposure metrics (E, ESG, log-GHG$_{EI}$, log-GHG$_E$) and the yearly average contribution of each sector to the GHG emissions of the EuroStoxx 600 Index (GHG$_E$ contribution Index) and EU (GHG$_E$ contribution EU).[20] The table is sorted by GHG emissions in descending order, with lighter (darker) colours being associated with greener (browner) sectors.

As expected, D-Electricity, gas, steam and air conditioning supply, C-Manufacturing, and H-Transportation and storage are among the most GHG emitting sectors, contributing around 70% of total EU emissions and 55% of total EuroStoxx 600 Index emissions, respectively. In comparison, the A-Agriculture, forestry and fishing is a high emissions contributor at the European level (16%), but not in our sample (0%), possibly due to a low representation of companies from this sector in the EuroStoxx 600 Index. B-Mining and quarrying and M-Professional, scientific and technical activities[21] are instead minor GHG contributors at the European level but major in our sample. Additionally, sectors with good average E (and ESG) ratings also have, on average, high GHG emissions levels (and intensity) suggesting that companies with high GHG emissions can receive positive environmental and ESG scores, and vice versa (Boffo et al. 2020). Positive E, or ESG, ratings are therefore not necessarily associated with low carbon emissions, aligned with the assumption that E and ESG can capture aspects of climate risk further to GHG production (Faccini et al. 2023).

– Insert Table 4 about here –

Figure 3 presents the distribution of the four metrics used. E and ESG scores appear quite homogeneous across sectors, while GHG emissions largely differ within and across sectors. This is in line with the fact that Refinitiv ESG scoring methodology is aimed at reducing portfolio

[20]EU27, Data source: Eurostat.

[21]The broad characterization of this sector makes its interpretation challenging. In our sample 70 percent are activities carried on by head offices.

concentration by sectors and thus recalibrates upwards the rating of polluting companies if they are in high polluting sectors, i.e. a company is largely evaluated relative to its sector peers. The distribution of GHG emissions by sectors also shows that the NACE classification may not take into account emissions-related intra-sectoral differences.

Finally, Table 5 shows the sectoral composition of brown and green portfolios according to the different exposure metrics used. We can observe that the composition of the brown (green) E portfolio is very similar to that of the brown (green) ESG portfolio, while the composition of the brown (green) GHG emissions portfolio shares similarities with the brown (green) GHG emissions intensity portfolio. However, the portfolios constructed according to E or ESG criteria differ significantly from the ones based on GHG emissions. This is in line with the observation that high GHG emitting companies can receive high ESG and E scores.

– Insert Figure 3 and Table 5 about here –

5. Results

Results provide evidence of economically significant transition risk and physical risk premia, as sizable as 7.05% and 6.14% from 2015 onwards respectively.[22] Our findings also suggest that, when stocks are sorted according to common metrics to evaluate the "greenness" and "brownness" of firms (such as GHG emissions, ESG score), rises in transition risk typically increase the excess returns of green stocks, while rises in physical risk typically decrease the excess returns of brown stocks. The sectoral analysis reveals that sectoral information may not or no longer be granular enough to capture transition risk exposure. Rather, sectoral characteristics may be used by investors to identify exposures to physical risk.

[22]While increasing over time, the statistical significance of such risk premia remain below the usual acceptance levels for the time period studied.

5.1. *Transition and Physical Climate Risk Premia*

Results indicate the emergence of both a physical and a transition climate risk premium since 2015, providing supporting empirical evidence that investors are already demanding extra compensation for exposure to climate-related risks and that such compensation increases in the level of exposure. Table 6 presents the annualized average excess stock returns in percentage (E[R]-Rf, in excess of the risk free-rate), standard deviations, and Sharpe ratios of the quintiles, deciles and 25 percentiles L, H, and LMH portfolios for transition (Panel a) and physical (Panel b) risk, over the three periods studied (full sample, before and after 2015). The table shows that the 25 percentiles LMH transition (physical) generates an average annualized return of about -3.08% (-3.75%) in the period before 2015 and 9.61% (6.71%) after 2015. The finding that the returns on the LMH portfolios are economically large and increasing over time suggests that firm-level sensitivity to both TRI and PRI may have predictive ability for stock returns. In the case where we consider decile and quintile portfolios, the evidence for increased performance also holds, but to a lower extent. Figure 4 shows the cumulative performances of the LMH transition and physical quintiles (light-grey), deciles (dark-grey), and 25 percentiles (black) portfolios highlighting a very rapid increase in returns after 2015 for the 25 percentiles LMH portfolio. As in table 6, the figure shows stronger effects for more extreme portfolio specifications, i.e. from 5 to 25 percentiles.

– Insert Table 6 and Figure 4 about here –

Table 7 presents the estimated physical and transition climate risk premia, i.e. alphas, from the FF5 factors model for the quintile, decile, and 25 percentile L, H, and LMH portfolios sorted on PRI (Panel a) and TRI (Panel b) over the full sample period, before and after 2015. These estimates document the emergence of physical and transition risk premia since 2015, with the economic significance being stronger for more extreme portfolios. This result implies that the compensation investors require for holding physical and transition risky stocks depends on the degree of climate risks they expose themselves to, demanding higher compensation for higher exposure, e.g. the 25 percentiles LMH portfolio generates a higher alpha than that from the quintiles LMH portfolio.

The 25 percentiles long-short PRI and TRI portfolios are found to generate an average abnormal return of about -4.09% and -3.01% per year before 2015, and of about 6.14% and 7.05% after 2015, respectively. The finding of an elevated transition risk premium is consistent with Bolton and Kacperczyk (2021) who, however, focus on GHG emissions in their analysis. Therefore, our findings expand on Bolton and Kacperczyk (2021) since our measure of transition risk goes beyond carbon emissions and encompasses various sources of transition risk. Consequently, we contribute by demonstrating that the comprehensive transition risk premium is increasing over time[23] Additionally, we contribute to the literature as we observe a similar trend in the physical climate risk premium. This result contradicts findings from, for instance, Faccini et al. (2023) who did not find any pricing associated with the direct manifestations of physical climate change. Faccini et al. (2023) find that investors only hedge against imminent transition risks resulting from government actions to combat climate change. In contrast, our results reveal that, at least in Europe, investors are seeking compensation for both exposure to transition risks and physical risks, in line with the theoretical expectations that climate risks should be incorporated into asset prices.

While our findings do share common ground with Bolton and Kacperczyk (2021) regarding the presence of an elevated transition risk premium, it's important to note a distinction. Bolton and Kacperczyk (2021) identify Asia as "entirely responsible for the rise in the global carbon premium around the Paris agreement" while measuring transition risk as one single factor, i.e. GHG firms emissions. However, our results, which instead consider a more complete measure of transition climate risk, show that a transition risk premium has sharply risen in Europe too, implying that any post-Paris Agreement global transition premium can probably not solely be attributable to Asia. This further demonstrates that empirical results might be sensitive to the use of climate measures, stressing that climate risk measurement needs precision to unveil economically meaningful implications of climate risks.

[23]Compared to Hsu et al. (2023) who find that long-short portfolio constructed from firms with high versus low toxic emission intensity generates an average excess return of around 4.42% per year over the period 1992-2018, our findings depict a higher transition risk premium. It is worth noting that the transition measures, sample periods, and regional focus are different.

– Insert Table 7 about here –

5.2. *Portfolios Sensitivity to Climate Risks*

5.2.1. Firm-level analysis

Table 8 reports the results for the estimated factor sensitivities of green and brown portfolios constructed according to E scores, ESG scores, GHG$_{EI}$, and GHG$_{E}$ from the daily augmented FF5 model as presented in Equations (4a) and (4b) over three periods (full sample, before 2015, and after 2015) reported together with t-statistics and considering Newey and West (1987) robust standard errors.[24]

The table provides insights that both E/ESG and GHG emissions intensity data appear to be useful gauges for investors to identify firms positively exposed to transition risk. We find evidence that the excess return of the green ESG portfolio significantly increases as transition risk rises both before and after 2015, of about 0.308 and 0.345% respectively, and that such increase is robust also when considering the full sample period. This suggests that unexpected changes to transition risk have been incorporated into asset prices as far as 2005, such that firms with good ESG scores have performed well during days where TRI increased, and that ESG-oriented investors have earned positive realized returns during high transition risk days. Additionally, green E and GHG$_{EI}$ portfolios significantly increase in returns of about 0.330 and 0.521%, respectively, when the market is surprised by transition risk news post-2015. Finally, we do not find evidence for an effect of physical risk on green portfolios.

Concerning brown portfolios sensitivity to climate risks, there is no evidence of a significant decrease in returns of brown portfolios in relation to rises to transition risk. However, there is evidence of a statistically significant negative relationship between the excess returns of brown GHG$_{EI}$ and GHG$_{E}$ portfolios and rises in physical risk since 2015, so that firms with a high GHG emission net-revenue ratio drop in returns of about 0.921% a day due to increases in PRI, and firms with high GHG emissions levels decline in returns of about 0.765%.

[24]We use Newey-West standard errors throughout.

By separating physical and transition risk, we are able to refine previous findings from the green finance literature, specifically those of Ardia et al. (2023) and Pástor et al. (2022), by identifying transition risk, rather than physical risk, as the main source of climate risk for green stocks. Additionally, while Ardia et al. (2023) document that unexpected increases in climate change concerns decrease the returns of brown firms, we provide empirical evidence that it is the physical climate risk component, rather than the transition risk one, which drives such a result. Without a distinction between climate change risks, in fact, the previous literature could only determine the relationship between aggregate climate change risk and green/brown stocks returns ignoring if results are driven by the physical or the transition risk component, information that would be instead useful for, e.g., tailored hedging strategies.

5.2.2. Sectoral analysis

Turning to the sectoral classification as a gauge for firms' climate risk exposures, tables 9 and 10 show regression results for the three sample periods (full sample, before 2015, and after 2015), using the NACE sectoral classification to group excess returns of European companies examining transition and physical risk respectively. This exercise and the relative findings further contribute to the work by Bolton and Kacperczyk (2021), who question whether investors consider the industry where firms operate in, rather than firm-level information, as material information on firms' exposure to climate risks.

Table 9 shows that coefficients for TRI are largely insignificant post-2015. This suggests that sectoral information may not or no longer be granular enough to capture transition risk exposure, possibly due to the increased uncertainty about the future course of climate-related policies (Batten et al. 2016) and their impact on sectors and industries. Rather, investors may rely on firm-level information such as ESG or E ratings, as we find in the firm-level analysis, to proxy firms' sensitivity to transition risk. Table 10 shows that, after 2015, PRI coefficients for sectors which are expected to be exposed to physical risk are found to be negative and significant. In particular, we document that the excess returns of the B-Mining and quarrying sector, the H-Transportation and storage sector, and the J-Information and communication sector significantly decrease by about

-2.42, -1.06, and -0.70%, respectively, in relation to rises in physical risk after 2015. These sectors are exposed to physical risk through their infrastructure assets or natural systems such that these activities suffer losses from, e.g. interruptions of operational activities due to physical hazards. Interestingly, the K-Financial and insurance activities sector is found to perform well during days in which news unexpectedly discuss issues related to physical climate risk over the full sample period (0.326%), and before 2015 (0.475%), but no significant effect is documented from 2015 onwards. We also find a negative but not statistically significant relationship between physical risk and the excess returns of L-Real estate activities after 2015. This result appears aligned with the Murfin and Spiegel (2020) belief of optimism about the physical chronic hazard of rises in sea levels or the possibilities of mitigation and bailouts, and contrasts with Bernstein et al. (2019) and Baldauf et al. (2020). Overall, findings suggest that sectoral characteristics may be used by investors in evaluating firms and activities' exposure to physical risk.

5.3. Physical and transition climate risks: A country-level outlook

Climate-related risks are expected to affect different countries in a heterogeneous manner depending on a multiplicity of factors, such as the level of a country's investment in climate resilient infrastructure for, e.g., floods or other climate events and/or the state of national and sub-national climate and environmental policies, making a comprehensive assessment of individual countries' exposure to physical and transition risk difficult to estimate (Bolton and Kacperczyk 2023). The economics literature on climate change finance further underscores the importance of the geographical distribution of climate policies (Nordhaus and Yang 1996) and physical risks (Cruz and Rossi-Hansberg 2023).

In this section, we aim to provide insights on European individual countries' sensitivity to climate-related risks over time by employing our new climate risk factors as an explanatory variable for countries' stock market indices as follows

$$\text{Stock Market Index Country}_{i,t} = \alpha + \beta_i CCR_{j,t} + \varepsilon_t \quad (5)$$

where Stock Market Index $\text{Country}_{i,t}$ is the log-return of the stock market index for the European country i at time t, $CCRI_{j,t}$ is our climate change risk index with j ={physical risk, transition risk} at time *t*. Thus, $CCRI_{\text{physical risk},t} = PRI$ and $CCRI_{\text{transition risk},t} = TRI$. α and β are model parameters and ε is the error term.

Figure 5 displays bar plots representing the Ordinary Least Square (OLS) estimates of β for transition (a) and physical (b) risk factors before 2015 (light grey) and after 2015 (dark grey) for each country within the sample. The significance levels are indicated with one, two, or three asterisks, corresponding to p-values below 0.01, 0.05, and 0.1, respectively. The key takeaways from figure 5 are threefold. First, the sensitivity to climate risks varies country by country both in terms of magnitude and statistical significance. Second, physical and transition risks are confirmed to exert different effects on stock markets. Third, there is heterogeneity in results depending on whether we consider the period before or after 2015. Overall, our results suggest that a country-level connection between the stock market and climate risks exists, while this result is heterogeneous by country further underscoring the importance of the consideration of sub-national conditions in both investment decision-making and when designing climate policies.

Figure 6 illustrates the results in an alternative form, i.e. as coloured heated geographical maps with colder/bluer colours indicating positive country sensitivity to climate risk and warmer/redder colours indicating negative sensitivity. The figure helps to gain an understanding of the evolving exposure of countries to transition and physical risks. Panels a and c show Europe's sensitivity to transition and physical risk on a per-country basis before 2015, while panels b and d provide the findings for the period after 2015. Notably, there is a discernible shift in the overall sensitivity to climate risks between the pre-2015 and post-2015 periods, with the latter being characterized by a more negative overall association with climate risks. In fact, despite some heterogeneity, panels b and d are predominantly shaded in reddish tones compared to panels a and c, indicating that countries are experiencing more pronounced impacts from both transition and physical risks, possibly due to the implementation of stricter climate regulations and the heightened severity and frequency of physical climate events. As an example, Greece emerges as the country most negatively associated with transition climate risks after 2015, indicated by a statistically significant beta of approximately -4. This finding underscores how Greece's stock market is particularly susceptible to risks linked to the shift toward a more environmentally sustainable economy. Meanwhile, Norway stands out as Europe's most vulnerable nation to physical climate risks post-2015, characterized by a highly statistically significant beta of about -3. This observation highlights how the country suffers from tangible manifestations of climate-related hazards, which also have adverse repercussions on its entire stock market.

These findings highlight the importance of incorporating country-specific attributes into the design and development of climate and environmental policies. As climate risks affect countries in distinct ways, neglecting these disparities could have implications for financial stability. Furthermore, we observe that the impact of physical risks on countries' stock markets can yield diverse outcomes. On one side, countries are inherently exposed to distinct physical risks; for instance, one nation might be more susceptible to flood hazards than another to wildfires (Bolton and Kacperczyk 2023; Cruz and Rossi-Hansberg 2023). These inherent distinctions may lead to varied responses to physical risks. On the other side, several other factors can also shape a country's sensitivity to physical risks, such as its capacity to manage and adapt to climate-related events. Thus, our findings suggest, for instance, that improved government-led adaptation measures might take into account country-level characteristics. Finally, from an investor's perspective, our results imply that incorporating country-specific information into investment decision-making can be advantageous to manage both transition and physical risks.

– Insert Figures 5 and 6 about here –

5.4. Policy implications

In addition to advancing our understanding of climate risks in financial markets, our findings also carry important implications for policymakers.

First, the identification of transition and physical risk premia in European equity markets highlights the need for integrating climate risks into the core of financial risk management and regulatory supervision in so far as possible. It becomes crucial for financial institutions to factor in climate risk premia when making portfolio allocation decisions to account for potential shifts in asset valuations due to climate-related events or transition-related policy changes. Regulatory bodies, including the European Central Bank, play a guiding role and, when necessary, mandate the consideration of these climate risks in stress-testing exercises, thereby safeguarding the stability of the financial system.

Second, our findings underscore the importance of firm-level data in gauging a company's exposure to climate risks, particularly those linked to the transition to a greener economy. This suggests that there is value in advocating for enhanced transparency and consistency in firms' disclosure of environmental metrics, such as GHG emissions and ESG performances. Improved disclosures enable investors to make more informed decisions, and regulatory bodies have a pivotal role to play in standardizing and ensuring the accuracy of these disclosures, thereby promoting a more efficient allocation of capital in the markets and reducing the risk of climate-related financial bubbles or shocks.

Third, our results indicate that certain sectors are particularly sensitive to (physical) climate risks from an investor perspective. Recognizing and supporting sectors vulnerable to (physical) risks through infrastructure resilience programs or R&D in sustainable alternatives can contribute to fostering more sustainable economic growth. Conversely, sectors exhibiting resilience or positive performance despite increasing physical risks could be further studied and integrated into broader strategies to combat the economic implications of climate change.

6. Conclusions and Directions for Future Research

The role of climate-related risks in financial markets has attracted large attention from financial market participants, governments, and academics. Investors want to know the asset prices sensitivity to climate change risks and regulators are concerned about the consequences of an incorrect pricing of climate-related risks. Against this backdrop, this paper contributes to our understanding of the financial implications of climate-related risks, exploring whether, and to which extent, physical and transition risks are incorporated into asset prices.

Using text-analysis, we first build two distinct vocabularies for physical and transition risk which derive from authoritative and scientific sources. The constructed vocabularies benefit from several advantages, improving on the existent literature. Then, using the cosine-similarity approach, we compare them to a corpus of news to obtain a novel comprehensive Physical Risk Index (PRI) and Transition Risk Index (TRI). PRI and TRI are found to spike during days of high discussion about either the topic of physical or transition risk, capturing multiple aspects of these risks. PRI and TRI are then employed to examine the existence of physical and transition climate risk premia in European equity markets.

Our results have important economic implications and show the emergence of both economically significant transition and physical risk premia in European markets as sizable as 7.05% and 6.14% on average per year after 2015, respectively. Using our comprehensive climate risk measures, we show that a transition risk premium has arisen in Europe, challenging Bolton and Kacperczyk (2023) who, using only GHG emissions to measure transition risk, find that Asia is entirely responsible for a global transition premium around the Paris Agreement. We provide empirical evidence supporting that (European) investors are demanding extra compensation for their exposure to both transition and physical risks, and that such compensation increases in the level of exposure. We then test the sensitivity of portfolios constructed according to common firm-specific climate risk exposure metrics (e.g. ESG scores and GHG emissions) to our climate risks indicators. Then, comparing the results to those from a sectoral analysis, we are able to investigate whether investors may simply pigeonhole firms into the industry they operate in, rather than use firm-level information, to detect climate-risky stocks. On one hand, findings show that firm-level information appears to be used by investors as a gauge for firms' exposure to climate risks, in particular for transition risk and since 2015. Additionally, by distinguishing physical from transition risk we can better describe the relationship between green/brown stock returns and climate risks, with respect to the existent literature. In this regard, we refine the Ardia et al. (2023) and Pástor et al. (2022) findings showing that rises in transition (physical) risk typically increase (decrease) the return of green (brown) stocks. On the other hand, our results suggest that the sectoral classification may be employed to broadly proxy firms' exposures to physical risk. Finally, from a per-country basis analysis, we observe that European stock markets and climate risk connection have intensified post-2015, yet with some heterogeneity emphasizing the need for national/sub-national considerations in investment and climate policies.

The findings presented in this paper, with the most important contribution being the Transition Risk Index (TRI) and Physical Risk Index (PRI), inform investors, policymakers, and financial institutions about the extent to which financial markets price climate risks and contribute to the on-going debate on how to incorporate climate risks into risk management considerations. Additionally, our climate risk indices can be used to study the role of climate risks for other asset classes, and more broadly find applications to risk and portfolio management issues.

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Table 1: Physical and transition risk top news articles

Date	PRI	Physical risk news topics	Physical risk relevant news titles
19/09/2018	12.3%	Artic Sea Minimum; Melting glaciers; Permafrost thawing Ocean acidification; Sea level rise	Greenland and the hunt for better climate science; In Greenland a glacier's collapse shows climate impact; Coceral cuts sharply EU cereal rapeseed crop estimates
01/02/2007	9.8%	IPCC draft report by the U.N. climate panel in Paris; Climate change affects fishery; Sea level rise	Global warming impacts of temperature rises; Draft findings by U.N. climate panel; Seas rising faster than U.N. predicts study; U.N. panel to link warming to humans project more; Cool water surges could affect fish stocks report; U.N. panel says "very likely" humans cause warming
06/12/2019	9.6%	Biodiversity Loss; Europe must protect rivers and lakes; Fishing, reef, tourism at risk; Increased costs due to climate stress	Europe must do more to protect its rivers and lakes: scientists; Runaway warming could sink fishing and reef tourism researchers warn; Forward prices slip on wetter weather view lower German rates
27/03/2012	9.1%	Global warming irreversible; Spain droughts, water stress; Frost impact on agriculture	Global warming close to becoming irreversible scientists; Spain drought hits hydro, irrigation stocks again; EU wheat too expensive for export - Toepfer
30/01/2007	8.9%	Hunger due to water scarcity; Adaptation measure for companies; Animal migration	Clouds a puzzle for U.N. global warming panel; Millions to go hungry, waterless; Bird ranges move, but is it climate change?; Europe's wheat crop on track, frost fears ease; Compulsory water metering takes step closer
27/02/2020	8.7%	Governments face pressure to protect biodiversity	Governments face pressure to protect nature in biodiversity
18/09/2006	8.7%	Raising temperatures causes floods, droughts, erosion; Hungary risk sand dunes, floods; Rising water costs; Water scarcity	Eco-paradises in crossfire of water scarcity fight; Hungary region battles advancing sand dunes, floods; Water everywhere but not clean enough to drink; Investors bet on rising costs for scarce water; Spanish wetland struggles as water levels drop
05/04/2012	8.6%	People cause climate change, need to understand impact on humans	Climate contrarian case wilts: Gerard Wynn
14/12/2009	8.5%	Forests to climate fight; Coral climate crisis costs; Biodiversity loss; Politic engagement in climate fight	Climate change makes finding Nemo even harder report; Coral climate crisis puts 250 million at risk: U.N.; Forest communities said key to climate fight; Natural disasters at decade low in 2009-UN report; Antarctic researcher commutes across continents for work
08/08/2019	8.4%	Food security	Farming and eating need to change to curb global warming: UN report

Date	TRI	Transition risk news topics	Transition risk relevant news titles
24/08/2011	19.1%	EU GHG emissions higher than reported	EU HFC emissions higher than reported; New research links cosmic rays to cloud formation
13/08/2007	17.5%	Kyoto Protocol; Certified Emission Reduction (CER)	Kyoto projects harm ozone layer: U.N. official; Daily secondary CER market report
01/09/2010	16.3%	Kyoto CO2 scheme probed; CER	HFC cutting plants under Kyoto CO2 scheme probed; EU carbon permit volumes fall in Aug, CERs rise
15/09/2010	15.0%	Review of carbon offsets; Low-carbon heating sources raises industry costs	UN to review CO2 offset request from 9th plant; UK business group warns on new low-carbon support
15/10/2015	13.8%	Emissions regulation; Increase in energy costs	U.S. announces new moves to limit super greenhouse gases; German 2016 green power surcharge at 6.354 cents/kWh - grid firms
09/08/2011	13.8%	Costly transition	Money spinning China carbon scheme may end with loss; Sberbank CO2 role questioned after huge issuance
30/06/2010	12.5%	CER issuances at lowest; Costly transition; International carbon market	Kyoto CO2 offset issuances grind to crawl in June; UK needs step change to meet climate target report; India, China seen partly out of carbon mkt post 2012; EU climate policy said costly with tiny benefits; EU carbon hits fresh 3-wk low on weak German power
24/08/2012	11.8%	CERs request	Developers seek 4.7 mln CERs, incl. 1.5 mln HFC units
28/02/2017	11.4%	Carbon Reform Deal; Renewable energies; Emissions targets	Nineteen EU nations back common position on carbon market reform; France's EDF hydropower availability down 1.3 GW due to strike; Marshall Islands first to ratify global HFC greenhouse gas pact; Austria's EVN puts Bulgarian hydropower project on hold
16/09/2010	11.4%	Green incentive for coal; Clean energy projects; Carbon Capture and Storage technologies	UN panel to rule on green incentives for coal; Ozone recovering but will take longer over poles; UN gives CO2 auditors time to study liability plan; Carbon capturing technology doomed in Europe - study; Mexico says world should trust U.S. on emissions

Note: This table reports the dates, the Physical Risk Index (PRI) and Transition Risk Index (TRI), the main news topics, and lists of relevant article's titles for the ten days with the highest physical and transition risk over the period Jan 2005-Oct 2021. News sourced from Reuters News with a European regional focus.

Table 2: AR1 estimates of physical risk and transition risk concern

	$\text{Concern}_{t,PR}$ x 100	$\text{Concern}_{t,TR}$ x 100
Drift c	7.863	8.462
	(0.047)	(0.061)
ϕ	0.326	0.413
	(0.014)	(0.014)

Note: Estimates of autoregressive process of order 1 (AR1) concern time series on physical risk, as in Equation (1a), and transition risk as in Equation (1b) for the period Jan 2005-Oct 2021. Standard error in parenthesis.

Table 3: GHG emissions level and intensity, E score, and ESG score data

Panel a) Number of firms with data				
Year	log-GHG_E	log-GHG_{EI}	E score	ESG score
2005	259	254	537	686
2006	341	336	584	717
2007	423	413	706	777
2008	463	445	756	805
2009	547	518	776	823
2010	587	548	817	852
2011	626	583	833	874
2012	659	608	859	897
2013	689	634	880	913
2014	734	670	900	939
2015	773	707	945	978
2016	811	732	962	994
2017	857	767	1,011	1,044
2018	907	797	1,056	1,089
2019	944	818	1,074	1,105
2020	953	811	1,087	1,115
2021	949	793	1,081	1,116
Panel b) Threshold				
25th Percentile	4.45	0.97	34.55	38.15
75th Percentile	6.00	2.14	76.46	69.56

Note: Exposure data as number of firm with data coverage over time (from 2005 to 2021) for the EuroStoxx 600 Index constituents (panel a) and the threshold levels to construct green and brown portfolios (panel b) for log-GHG emissions levels (GHG_E), log-GHG emissions intensity (GHG_{EI}), Environmental score (E score), and Environmental, Social, and Governance score (ESG score). Environmental, ESG, and GHG emissions data are sourced from Refinitiv.

Table 4: EuroStoxx 600 Index historical constituents' sectoral composition

	NACE code - sector	No.	log GHG_E	log GHG_{EI}	ESG	E	GHG_E contribution Index	GHG_E contribution EU
D	Electricity, gas, steam and air conditioning supply	37	17.09	7.77	56.73	60.4	41%	28%
B	Mining and quarrying	48	16.52	6.95	59.27	59.29	23%	2%
M	Professional, scientific and technical activities	150	15.62	7.64	51.74	48.04	9%	1%
H	Transportation and storage	37	15.36	6.16	55.75	55.93	7%	14%
C	Manufacturing	309	15.36	6.09	56.15	53.57	7%	26%
N	Administrative and support service activities	36	14.87	4.86	47.65	40.75	4%	1%
E	Water supply; sewerage, waste management and remediation activities	9	14.43	6.08	61.2	61.19	3%	5%
F	Construction	35	13.84	4.76	58.88	65.16	2%	2%
G	Wholesale and retail trade; repair of motor vehicles and motorcycles	81	13.66	4.83	51.48	47.81	1%	3%
I	Accommodation and food service activities	16	13.18	5.71	57.7	55.2	1%	1%
K	Financial and insurance activities	252	12.67	3.84	50.67	53.52	0%	0%
J	Information and communication	109	12.53	3.36	50.74	41.76	0%	0%
A	Agriculture, forestry and fishing	1	12.12	4.07	54.92	39.16	0%	16%
S	Other service activities	6	11.81	4.42	45.04	42.05	0%	0%
Q	Human health and social work activities	9	11.67	4.21	47.1	39.97	0%	1%
O	Public administration and defence; compulsory social security	4	11.19	3.08	41.36	41.53	0%	1%
R	Arts, entertainment and recreation	12	10.67	3.55	47.08	39.91	0%	0%
L	Real estate activities	47	10.38	4.30	48.02	49.79	0%	0%

Note: EuroStoxx 600 Index historical constituents sectoral (NACE code - sector) composition over the period Jan 2005-Oct 2021, number of companies per sector (No.), average environmental score (E score), environmental, social, and governance score (ESG score), log-GHG emissions levels (log GHG_E), log-GHG emissions intensity (log GHG_{EI}). Per-year average GHG emission contribution of each EuroStoxx 600 Index NACE sector to the total EuroStoxx 600 Index emissions (GHG_E contribution Index), and the per-year average GHG emissions of the full NACE sector to the total European Union GHG emission (GHG_E contribution EU) as from EU27 sourced from Eurostat. The table is sorted according to descending greenhouse gas emissions. The lighter the colour the 'greener' the sector, the darker the colour, the 'browner' the sector according to each metric (E score, ESG score, GHG_{EI}, GHG_E). Environmental, ESG, and GHG emissions data are sourced from Refinitiv.

Table 5: Green and brown E, ESG, GHG_{EI}, GHG_E portfolios composition

Panel a)		E score		ESG score		log-GHG_{EI}		log-GHG_E	
		Green	Brown	Green	Brown	Green	Brown	Green	Brown
Metric average		85.64	19.89	78.77	25.42	0.92	6.47	8.69	15.67
Number of assets		456	708	524	696	396	285	409	241
Panel b) Sectoral composition (%)									
NACE code - sector									
A	Agriculture, forestry and fishing	0.00	0.14	0.19	0.14	0.00	0.00	0.00	0.00
B	Mining and quarrying	4.82	3.95	4.58	3.45	1.01	12.63	1.47	11.62
C	Manufacturing	28.73	26.55	30.73	27.16	14.65	33.68	16.87	34.44
D	Electricity, gas, steam and air conditioning supply	4.17	2.97	3.82	2.59	0.51	9.82	0.98	11.62
E	Water supply; sewerage; waste management and remediation activities	0.88	0.56	0.95	0.29	0.00	2.11	0.24	2.07
F	Construction	5.48	2.97	3.82	2.73	3.28	3.51	3.42	4.15
G	Wholesale and retail trade; repair of motor vehicles and motorcycles	5.26	7.91	5.53	6.61	5.05	2.81	5.87	6.64
H	Transporting and storage	3.51	2.40	3.44	2.87	1.26	7.02	1.71	7.05
I	Accommodation and food service activities	1.75	1.69	1.53	1.29	1.26	1.40	0.98	0.83
J	Information and communication	5.48	9.75	7.82	8.91	13.89	2.11	12.71	2.90
K	Financial and insurance activities	24.12	19.63	18.32	20.98	39.65	4.56	33.50	5.39
L	Real estate activities	3.29	3.25	3.24	4.17	3.79	3.51	7.33	0.00
M	Professional, scientific and technical activities	9.87	12.15	12.98	11.78	10.10	13.68	9.54	11.62
N	Administrative and support service activities	1.75	2.82	1.53	3.30	3.28	1.75	2.93	1.66
O	Public administration and defence; compulsory social security	0.22	0.56	0.19	0.57	0.51	0.00	0.49	0.00
Q	Human health and social work activities	0.00	0.56	0.38	0.72	0.25	0.35	0.24	0.00
R	Arts, entertainment and recreation	0.22	1.41	0.57	1.58	1.26	0.35	1.47	0.00
S	Other services activities	0.44	0.71	0.38	0.86	0.25	0.70	0.24	0.00

Note: We sort the EuroStoxx 600 Index historical constituents on environmental score (E score), environmental, social and governance score (ESG score), greenhouse gas emissions intensity (GHG_{EI}), greenhouse gas emissions (GHG_E) and we create individual green and brown portfolios. This table reports each portfolio metric average (E, ESG, GHG_{EI}, or GHG_E), the number of assets, and the relative NACE sectoral (%) composition over the period Jan 2005-Oct 2021. Environmental, ESG, and GHG emissions data are sourced from Refinitiv.

Table 6: Portfolios sorted on transition and physical climate betas

Panel a) Transition risk beta portfolios									
Full sample TRI	Quintiles			Deciles			25 Percentiles		
	L	H	LMH	L	H	LMH	L	H	LMH
E(R)-Rf (%)	11.93	12.53	-1.17	10.78	10.19	-0.10	8.46	5.71	1.96
σ (%)	18.97	19.35	5.78	20.11	20.58	8.25	22.35	22.47	13.05
SR	0.63	0.65	-0.20	0.54	0.50	-0.01	0.38	0.25	0.15
Before 2015 TRI	Quintiles			Deciles			25 Percentiles		
	L	H	LMH	L	H	LMH	L	H	LMH
E(R)-Rf (%)	10.21	12.99	-3.81	9.40	11.66	-3.38	8.32	10.21	-3.08
σ (%)	19.77	20.28	5.94	20.97	21.40	8.06	23.53	23.16	12.76
SR	0.52	0.64	-0.64	0.45	0.54	-0.42	0.35	0.44	-0.24
After 2015 TRI	Quintiles			Deciles			25 Percentiles		
	L	H	LMH	L	H	LMH	L	H	LMH
E(R)-Rf (%)	14.53	11.97	2.74	12.88	8.18	4.81	8.68	-0.41	9.61
σ (%)	17.77	18.16	5.95	18.83	19.37	8.51	20.57	21.46	13.44
SR	0.82	0.66	0.46	0.68	0.42	0.57	0.42	-0.02	0.71
Panel b) Physical risk beta portfolios									
Full sample PRI	Quintiles			Deciles			25 Percentiles		
	L	H	LMH	L	H	LMH	L	H	LMH
E(R)-Rf (%)	11.78	13.31	-1.98	10.98	10.58	-0.28	7.08	5.94	0.43
σ (%)	19.23	19.35	5.78	20.37	20.51	8.00	22.83	23.07	13.29
SR	0.61	0.69	-0.34	0.54	0.52	-0.04	0.31	0.26	0.03
Before 2015 PRI	Quintiles			Deciles			25 Percentiles		
	L	H	LMH	L	H	LMH	L	H	LMH
E(R)-Rf (%)	11.66	12.82	-2.40	10.22	11.60	-2.61	6.11	8.71	-3.75
σ (%)	20.16	20.11	5.75	21.43	21.26	7.86	23.71	23.62	12.91
SR	0.58	0.64	-0.42	0.48	0.55	-0.33	0.26	0.37	-0.29
After 2015 PRI	Quintiles			Deciles			25 Percentiles		
	L	H	LMH	L	H	LMH	L	H	LMH
E(R)-Rf (%)	12.14	14.11	-1.29	12.33	9.26	3.26	8.47	2.10	6.71
σ (%)	17.84	18.23	5.83	18.77	19.42	8.19	21.51	22.26	13.80
SR	0.68	0.77	-0.22	0.66	0.48	0.40	0.39	0.09	0.49

Note: This table shows the performances of the 5, 10, 25 low (L) and high (H) portfolios sorted according to their sensitivity to the Transition Risk Index (TRI) and Physical Risk Index (PRI), alongside the low-minus-high (LMH) transition and physical risk spread returns portfolios. We report the portfolios percentage annualised excess returns(E(R)-Rf), standard deviations (σ), and the Sharpe ratios (SR), for three periods (full sample, Jan 2005-Oct 2021; before 2015, Jan 2005-Dec 2014; and after 2015, Jan 2015-Oct 2021) considering the EuroStoxx 600 Index constituents.

Table 7: Climate risk premia

Panel a): Physical risk premiun

Full sample	Quintiles L	Quintiles H	Quintiles LMH	Deciles L	Deciles H	Deciles LMH	25 Percentiles L	25 Percentiles H	25 Percentiles LMH
α_{FF5}	8.33	10.12	-2.26	8.07	7.96	-0.54	5.14	4.54	-0.07
[t]	5.90	6.30	-1.55	4.14	3.88	-0.27	1.69	1.65	-0.02
MKT_t	1.01	1.01	0.00	1.04	1.04	-0.01	1.08	1.09	0.00
[t]	106.37	81.28	0.07	68.77	73.09	-0.37	48.63	62.59	-0.18
SMB_t	0.43	0.44	-0.01	0.50	0.52	-0.02	0.63	0.66	-0.03
[t]	20.19	15.05	-0.20	15.96	15.14	-0.71	12.67	16.92	-0.68
HML_t	0.12	0.15	-0.03	0.17	0.19	-0.02	0.23	0.25	-0.02
[t]	6.41	4.87	-0.90	6.15	4.78	-0.50	5.50	5.50	-0.49
CMA_t	0.12	0.10	0.02	0.12	0.10	0.02	0.11	0.09	0.02
[t]	5.31	3.72	0.48	4.19	3.27	0.61	2.40	2.32	0.39
RMW_t	-0.13	-0.10	-0.03	-0.15	-0.14	-0.02	-0.19	-0.23	0.04
[t]	-9.32	-4.97	-1.10	-8.04	-5.55	-0.54	-6.33	-7.01	1.16
Before 2015									
α_{FF5}	8.26	9.44	-2.45	7.06	8.35	-2.57	3.15	6.06	-4.09
[t]	4.21	4.53	-1.36	2.85	3.05	-1.00	0.85	1.64	-0.98
MKT_t	1.02	1.01	0.01	1.06	1.04	0.01	1.11	1.09	0.01
[t]	76.56	70.00	0.67	65.73	65.50	0.56	47.64	57.01	0.51
SMB_t	0.42	0.39	0.02	0.47	0.46	0.01	0.57	0.57	0.00
[t]	13.94	11.15	0.74	13.11	11.66	0.38	10.88	12.01	0.02
HML_t	0.12	0.17	-0.05	0.15	0.20	-0.05	0.19	0.25	-0.06
[t]	4.16	3.97	-1.15	4.17	3.93	-0.99	3.57	3.90	-0.88
CMA_t	0.13	0.13	0.00	0.13	0.13	0.00	0.13	0.13	0.01
[t]	4.08	4.26	0.03	3.46	4.01	-0.04	2.54	2.74	0.11
RMW_t	-0.17	-0.11	-0.06	-0.21	-0.15	-0.06	-0.25	-0.25	0.00
[t]	-9.15	-3.82	-1.79	-8.83	-4.19	-1.82	-6.95	-5.55	-0.07
After 2015									
α_{FF5}	9.18	12.05	-2.13	10.51	8.54	2.27	9.85	3.95	6.14
[t]	4.75	5.05	-0.83	3.80	3.04	0.68	2.15	0.97	1.15
MKT_t	0.98	0.99	-0.01	0.99	1.02	-0.03	1.02	1.05	-0.03
[t]	97.83	56.43	-0.78	56.91	51.15	-1.71	35.85	41.03	-1.19
SMB_t	0.49	0.53	-0.04	0.57	0.64	-0.07	0.76	0.82	-0.06
[t]	25.57	20.70	-1.32	19.28	20.02	-1.52	14.92	21.77	-1.08
HML_t	0.11	0.10	0.01	0.17	0.13	0.04	0.24	0.21	0.03
[t]	6.35	3.58	0.22	6.54	3.70	0.80	5.89	5.27	0.59
CMA_t	0.10	0.06	0.04	0.13	0.06	0.07	0.11	0.06	0.05
[t]	4.96	1.66	1.04	4.22	1.24	1.15	2.00	0.99	0.64
RMW_t	-0.06	-0.09	0.03	-0.07	-0.13	0.07	-0.09	-0.22	0.13
[t]	-3.50	-4.33	1.10	-2.89	-4.87	1.95	-2.45	-4.99	2.53

Panel b): Transition risk premium

Full sample	Quintiles L	Quintiles H	Quintiles LMH	Deciles L	Deciles H	Deciles LMH	25 Percentiles L	25 Percentiles H	25 Percentiles LMH
α_{FF5}	8.46	9.20	-1.32	7.67	7.46	-0.45	6.10	3.94	1.42
[t]	5.96	6.11	-0.91	4.23	3.84	-0.22	2.19	1.51	0.46
MKT_t	1.00	1.01	-0.01	1.03	1.04	-0.02	1.06	1.07	-0.02
[t]	111.53	65.17	-0.84	90.10	52.62	-0.86	63.70	44.24	-0.73
SMB_t	0.43	0.42	0.01	0.48	0.50	-0.02	0.54	0.58	-0.04
[t]	18.46	13.78	0.36	15.41	12.17	-0.43	13.93	12.00	-0.71
HML_t	0.11	0.15	-0.04	0.15	0.18	-0.03	0.21	0.21	0.00
[t]	5.84	5.59	-1.43	6.31	5.38	-1.00	6.91	5.54	-0.06
CMA_t	0.11	0.11	0.00	0.12	0.11	0.01	0.12	0.08	0.04
[t]	5.09	4.53	-0.03	4.47	3.52	0.28	3.05	1.99	0.72
RMW_t	-0.13	-0.10	-0.03	-0.16	-0.13	-0.02	-0.20	-0.20	0.00
[t]	-8.59	-5.30	-1.59	-8.23	-5.82	-0.86	-7.50	-6.03	-0.08
Before 2015									
α_{FF5}	6.82	9.55	-3.85	6.05	8.33	-3.46	5.22	6.98	-3.01
[t]	3.39	4.94	-2.14	2.37	3.41	-1.35	1.36	2.06	0.77
MKT_t	1.01	1.01	-0.01	1.04	1.05	-0.01	1.10	1.09	0.00
[t]	73.88	59.53	-0.39	61.41	54.77	-0.43	49.70	52.10	0.06
SMB_t	0.43	0.38	0.05	0.46	0.44	0.02	0.51	0.51	0.00
[t]	11.39	12.03	1.53	9.05	11.43	0.42	7.19	11.80	0.02
HML_t	0.10	0.16	-0.06	0.12	0.19	-0.06	0.16	0.17	-0.01
[t]	3.34	4.79	-1.87	3.29	4.79	-1.81	3.24	3.81	-0.12
CMA_t	0.10	0.15	-0.05	0.12	0.16	-0.04	0.12	0.15	-0.04
[t]	3.32	5.06	-1.24	3.21	4.87	-1.01	2.13	3.42	-0.51
RMW_t	-0.16	-0.12	-0.04	-0.19	-0.17	-0.02	-0.23	-0.24	-0.24
[t]	-7.28	-4.95	-1.45	-6.64	-6.18	-0.72	-6.37	-6.38	0.04
After 2015									
α_{FF5}	11.14	9.86	1.61	10.75	7.79	3.20	8.63	1.92	7.05
[t]	6.00	4.40	0.69	4.24	2.64	1.01	2.10	0.49	1.41
MKT_t	0.98	0.99	-0.02	0.99	1.02	-0.02	0.98	1.01	-0.04
[t]	102.34	42.22	-0.57	86.54	33.29	-0.65	47.75	27.23	-1.15
SMB_t	0.46	0.51	-0.05	0.54	0.61	-0.08	0.64	0.70	-0.06
[t]	25.73	16.30	-1.45	22.46	13.20	-1.37	17.56	11.20	-0.85
HML_t	0.12	0.10	0.02	0.18	0.13	0.05	0.25	0.22	0.03
[t]	7.40	3.88	0.71	6.84	3.56	1.14	5.69	5.08	0.50
CMA_t	0.13	0.06	0.07	0.14	0.04	0.11	0.16	0.02	0.14
[t]	5.80	2.15	1.92	3.72	0.87	1.76	2.66	0.27	1.99
RMW_t	-0.08	-0.07	-0.02	-0.11	-0.09	-0.02	-0.14	-0.15	0.01
[t]	-4.43	-3.32	-0.55	-3.90	-3.01	-0.39	-3.66	-3.20	0.15

Note: This table shows the estimated abnormal returns (αFF5) and coefficients to the market factor (MKT), size factor (SMB), value factor (HML), the investment factor (CMA) and the profitability factor (RMW) of the portfolios sorted according to their sensitivity to the Transition Risk Index (TRI), alongside the low-minus-high (LMH) transition and physical risk spread returns portfolios, considering a Fama and French (2015) five factor (FF5) asset pricing model specification. Eurostoxx 600 Index historical constituents are used and results are reported for three periods (full sample, Jan 2005-Oct 2021; before 2015, Jan 2005-Dec 2014; and after 2015, Jan 2015-Oct 2021).

Table 8: Sensitivity of green and brown E, ESG, GHG_{EI}, GHG_E portfolios to PRI and TRI

Full sample	E score				ESG score				GHG_{EI}				GHG_E			
	Brown		Green		Brown		Green		Brown		Green		Brown		Green	
Intercept	0.038***	0.038***	0.022***	0.022***	0.040***	0.040***	0.021***	0.021***	0.029***	0.029***	0.044***	0.044***	0.029***	0.029***	0.046***	0.046***
[t]	7.285	7.349	6.789	6.838	6.357	6.431	7.381	7.329	4.994	4.991	7.211	7.212	5.915	5.920	8.244	8.204
MKT	0.960***	0.960***	1.029***	1.029***	0.922***	0.922***	1.016***	1.016***	1.024***	1.024***	1.047***	1.047***	1.018***	1.017***	1.008***	1.008***
[t]	104.020	103.918	125.059	125.438	89.915	90.097	145.915	148.181	95.980	96.076	74.323	74.183	119.278	119.423	80.639	80.872
SMB	0.451***	0.451***	0.101***	0.101***	0.398***	0.398***	0.082***	0.082***	0.230***	0.229***	0.264***	0.264***	0.151***	0.150***	0.467***	0.467***
[t]	22.770	22.987	5.242	5.330	18.266	18.441	5.161	5.431	8.227	8.237	8.921	8.935	6.295	6.303	20.994	20.907
HML	-0.010	-0.010	0.253***	0.253***	-0.001	-0.001	0.161***	0.161***	0.105***	0.105***	0.372***	0.372***	0.127***	0.128***	0.173***	0.173***
[t]	-0.568	-0.567	17.833	18.073	-0.048	-0.043	16.861	17.002	3.459	3.465	10.436	10.447	5.306	5.317	5.839	5.790
RMW	-0.059***	-0.059***	-0.067***	-0.067***	-0.111***	-0.111***	-0.043***	-0.043***	-0.139***	-0.139***	-0.041*	-0.041*	-0.085***	-0.085***	-0.001	-0.001
[t]	-4.208	-4.225	-5.486	-5.535	-7.209	-7.268	-4.562	-4.604	-7.103	-7.100	-1.649	-1.647	-4.999	-4.991	-0.047	-0.043
CMA	0.183***	0.183***	-0.008	-0.009	0.192***	0.192***	-0.025**	-0.025**	0.049	0.049	0.092***	0.092***	-0.033	-0.033	0.199***	0.199***
[t]	9.498	9.543	-0.629	-0.644	9.227	9.305	-1.969	-1.997	1.607	1.610	3.442	3.446	-1.323	-1.326	9.005	8.970
TRI	0.095		0.145		0.170		0.276**		-0.031		0.005		0.040		0.055	
[t]	0.529		1.202		0.866		2.488		-0.145		0.023		0.215		0.268	
PRI		-0.269		0.010		-0.087		-0.072		-0.249		-0.019		-0.312		-0.123
[t]		-1.353		0.068		-0.381		-0.548		-0.985		-0.075		-1.468		-0.535
Before 2015	E score				ESG score				GHG_{EI}				GHG_E			
	Brown		Green		Brown		Green		Brown		Green		Brown		Green	
Intercept	0.028***	0.029***	0.021***	0.021***	0.029***	0.030***	0.017***	0.018***	0.033***	0.033***	0.036***	0.035***	0.030***	0.030***	0.038***	0.038***
[t]	4.594	4.744	4.711	4.832	4.430	4.617	4.584	4.916	4.486	4.519	4.872	4.873	5.090	5.259	5.469	5.570
MKT	0.978***	0.978***	1.038***	1.038***	0.958***	0.958***	1.015***	1.015***	1.039***	1.039***	1.056***	1.056***	1.007***	1.007***	1.029***	1.030***
[t]	93.189	93.319	111.193	111.521	100.705	100.708	113.891	113.882	78.573	78.984	62.179	62.370	94.196	93.987	59.989	59.455
SMB	0.453***	0.453***	0.045**	0.045**	0.450***	0.450***	0.009	0.009	0.137***	0.137***	0.252***	0.252***	0.046**	0.046**	0.511***	0.511***
[t]	18.773	18.789	2.415	2.418	17.683	17.686	0.550	0.564	4.341	4.373	8.436	8.444	2.039	2.041	20.194	20.274
HML	0.051**	0.051**	0.266***	0.266***	0.063***	0.062***	0.160***	0.160***	0.005	0.005	0.533***	0.534***	0.011	0.011	0.293***	0.293***
[t]	2.376	2.376	15.096	15.110	2.762	2.761	13.576	13.567	0.144	0.148	16.091	16.141	0.480	0.477	9.501	9.575
RMW	-0.052***	-0.052***	-0.087***	-0.087***	-0.085***	-0.085***	-0.053***	-0.054***	-0.164***	-0.164***	-0.028	-0.027	-0.124***	-0.125***	0.042	0.042
[t]	-3.006	-3.018	-5.943	-5.944	-4.825	-4.847	-4.257	-4.284	-6.820	-6.886	-0.899	-0.892	-7.358	-7.373	1.613	1.621
CMA	0.151***	0.151***	0.003	0.003	0.155***	0.155***	-0.023	-0.023	0.114***	0.114***	0.043	0.044	0.028	0.028	0.154***	0.154***
[t]	6.335	6.322	0.155	0.156	6.399	6.381	-1.490	-1.496	3.216	3.253	1.359	1.373	1.135	1.131	5.768	5.823
TRI	0.148		0.047		0.307		0.308**		-0.050		-0.138		0.108		0.040	
[t]	0.657		0.302		1.375		2.245		-0.196		-0.517		0.518		0.143	
PRI		-0.022		0.171		0.178		0.137		0.112		0.376		-0.076		0.172
[t]		-0.087		0.863		0.680		0.815		0.387		1.130		-0.334		0.568
After 2015	E score				ESG score				GHG_{EI}				GHG_E			
	Brown		Green		Brown		Green		Brown		Green		Brown		Green	
Intercept	0.049***	0.047***	0.029***	0.027***	0.052***	0.051***	0.031***	0.029***	0.033***	0.032***	0.056***	0.053***	0.038***	0.036***	0.053***	0.051***
[t]	6.237	6.514	5.863	5.623	5.420	5.413	6.576	6.258	3.784	3.821	7.895	8.051	4.735	4.742	7.861	8.141
MKT	0.926***	0.926***	0.996***	0.996***	0.873***	0.873***	0.995***	0.995***	0.975***	0.975***	1.020***	1.020***	1.010***	1.009***	0.981***	0.980***
[t]	70.400	71.267	100.968	102.227	67.682	67.457	103.725	110.242	86.887	85.273	64.946	65.476	86.060	85.419	82.930	83.117
SMB	0.528***	0.527***	0.231***	0.230***	0.411***	0.410***	0.219***	0.218***	0.352***	0.351***	0.417***	0.416***	0.244***	0.243***	0.504***	0.503***
[t]	23.411	23.372	13.456	13.554	15.574	15.649	13.882	14.417	14.119	14.212	15.100	15.135	9.711	9.727	19.735	19.479
HML	-0.113***	-0.112***	0.205***	0.206***	-0.099***	-0.099***	0.144***	0.145***	0.222***	0.224***	0.105***	0.106***	0.283***	0.285***	-0.013	-0.012
[t]	-6.452	-6.441	15.675	15.814	-4.894	-4.897	11.520	12.126	11.838	11.932	5.869	5.979	15.624	16.018	-0.830	-0.760
RMW	-0.047**	-0.046**	-0.035***	-0.034**	-0.122***	-0.121***	-0.031***	-0.029***	-0.132***	-0.131***	-0.016	-0.014	-0.064***	-0.063***	-0.031	-0.029
[t]	-2.471	-2.427	-2.605	-2.531	-5.899	-5.822	-2.744	-2.660	-6.576	-6.641	-0.916	-0.805	-3.314	-3.322	-1.574	-1.500
CMA	0.191***	0.192***	-0.017	-0.017	0.187***	0.187***	-0.002***	-0.002	0.039	0.040*	0.069***	0.069***	-0.022	-0.021	0.176***	0.177***
[t]	7.532	7.631	-1.121	-1.104	6.502	6.405	-0.149	-0.118	1.567	1.649	3.515	3.541	-0.927	-0.876	7.744	7.745
TRI	0.156		0.330*		0.059		0.345*		-0.166		0.521*		-0.095		0.284	
[t]	0.484		1.716		0.150		1.931		-0.456		1.902		-0.283		1.014	
PRI		-0.463		-0.160		-0.313		-0.298		-0.921***		-0.260		-0.765**		-0.330
[t]		-1.475		-0.789		-0.791		-1.595		-2.642		-1.010		-2.376		-1.109

Note: We group EuroStoxx 600 Index historical constituents stocks into brown and green portfolios according to their environmental score (E), environmental, social and governance score (ESG), greenhouse gas emissions intensity (GHG_{EI}) calculated as the sum of scope 1 and 2 divided by net revenue, and greenhouse gas emissions (GHG_E) calculated as the sum of scope 1 and 2. We perform time-series regressions of the brown and green portfolios excess returns on the Fama-French five factors (market, MKT; size, SMB; value, HML; profitability, RMW; and investment, CMA) plus Physical Risk Index (PRI) or Transition Risk Index (TRI) for the period Jan 2005-Oct 2021 (Full sample), Jan 2005-Dec 2014 (Before 2015), and Jan 2015-Oct 2021 (After 2015). t-statistics ([t]), and Newey-West standard are adopted. * $p < 0.1$; ** $p < 0.05$; *** $p < 0.01$. Environmental, ESG, and GHG emissions data are sourced from Refinitiv.

Table 9: Sensitivity of NACE to TRI

Full sample	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	Q	R	S
Intercept	0.061	0.034**	0.033***	0.044***	0.037***	0.013	0.040***	0.032***	0.018*	0.037***	0.041***	0.022**	0.041***	0.041***	0.022*	0.068***	0.023*	-0.006
[t]	1.465	1.994	6.606	4.778	3.008	1.552	5.951	4.238	1.745	7.120	8.271	2.264	7.284	5.356	1.946	4.856	1.731	-0.450
MKT	0.919***	1.156***	0.933***	0.780***	0.696***	1.084***	0.908***	0.951***	1.068***	0.866***	0.950***	0.747***	0.915***	1.055***	0.986***	0.663***	0.824***	0.827***
[t]	15.604	39.596	60.647	35.638	35.224	47.997	78.261	55.310	45.394	124.048	74.829	33.050	76.782	55.300	26.580	40.358	43.674	32.875
SMB	-0.070	0.523***	0.403***	0.015	0.235***	1.055***	0.813***	0.998***	1.365***	0.514***	0.393***	0.646***	0.383***	0.919***	1.141***	0.408***	1.115***	0.893***
[t]	-0.423	5.990	17.580	0.379	4.859	23.723	28.388	22.929	15.660	22.307	13.224	11.394	13.044	21.943	20.960	7.667	17.154	14.510
HML	-0.051	0.359***	-0.043	-0.125***	-0.194***	0.444***	-0.046	0.195***	0.349***	-0.101***	0.462***	0.171***	-0.027	-0.021	-0.038	-0.239***	-0.086**	0.321***
[t]	-0.396	4.915	-1.643	-3.296	-5.691	10.271	-1.462	5.758	6.058	-5.764	18.719	4.762	-0.989	-0.457	-0.625	-6.789	-2.266	5.779
RMW	-0.658***	-0.170**	-0.111***	-0.226***	0.166***	0.174***	0.106***	0.070**	0.431***	-0.080***	-0.105***	-0.126***	-0.184***	0.141***	0.399***	-0.221***	0.117***	0.205***
[t]	-4.802	-2.456	-6.958	-7.617	3.746	5.256	4.574	2.237	8.379	-4.373	-5.358	-3.781	-10.523	4.148	8.556	-5.352	2.711	4.144
CMA	0.493***	0.367***	0.138***	-0.067*	-0.094*	0.290***	0.113***	0.013	0.101*	0.047**	0.006	0.289***	0.177***	0.147***	0.016	0.238***	0.197***	0.115*
[t]	3.097	3.870	6.493	-1.740	-1.860	8.617	4.459	0.341	1.719	2.055	0.211	6.836	6.035	4.686	0.282	5.434	4.568	1.792
TRI	-3.045*	0.004	0.474**	-0.589	-0.121	0.424	0.207	0.561*	0.127	0.024	0.063	0.624	0.268	0.391	0.422	0.665	-0.369	0.119
[t]	-1.847	0.008	2.380	-1.532	-0.233	1.262	0.853	1.734	0.292	0.111	0.338	1.482	1.252	1.252	0.712	1.113	-0.643	0.207
Before 2015	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	Q	R	S
Intercept	0.108*	0.060***	0.033***	0.056***	0.045***	0.015	0.019**	0.025***	0.008	0.037***	0.039***	0.015	0.045***	0.037***	0.029**	0.072***	0.002	0.006
[t]	1.728	3.153	4.823	5.081	2.915	1.324	2.304	2.625	0.536	5.628	6.767	1.299	5.598	3.857	2.007	3.807	0.122	0.326
MKT	1.030***	1.156***	0.915***	0.732***	0.673***	1.090***	0.887***	0.899***	1.036***	0.863***	0.912***	0.724***	0.909***	1.040***	0.920***	0.670***	0.760***	0.814***
[t]	12.510	36.493	45.507	29.713	27.602	30.652	74.889	55.238	39.407	104.128	63.404	42.851	54.799	60.177	18.917	31.210	34.319	22.558
SMB	-0.058	0.117	0.443***	-0.009	0.338***	1.035***	0.852***	0.835***	1.179***	0.596***	0.360***	0.677***	0.389***	0.970***	1.127***	0.440***	0.930***	0.814***
[t]	-0.234	1.325	15.736	-0.196	6.523	21.279	27.204	20.551	16.535	19.150	12.881	15.178	10.298	23.818	14.585	6.103	12.829	11.308
HML	-0.219	0.014	0.022	-0.093*	-0.154***	0.557***	0.082***	0.220***	0.445***	-0.039*	0.517***	0.252***	0.023	0.090*	-0.052	-0.175***	-0.025	0.372***
[t]	-1.142	0.166	0.606	-1.781	-3.176	8.783	2.578	6.245	6.452	-1.822	17.021	6.618	0.645	1.867	-0.558	-3.514	-0.523	4.492
RMW	-1.037***	-0.161**	-0.107***	-0.203***	0.131**	0.170***	0.146***	0.074**	0.473***	-0.122***	-0.158***	-0.197***	-0.186***	0.173***	0.397***	-0.218***	0.080	0.218***
[t]	-5.256	-2.443	-4.702	-5.752	2.196	3.526	4.912	2.054	8.670	-5.003	-6.321	-4.710	-7.786	4.227	6.243	-3.917	1.429	2.994
CMA	0.563***	0.727***	0.132***	-0.092*	-0.144**	0.259***	0.073**	0.057	0.110*	-0.022	0.043	0.226***	0.181***	0.164***	0.174***	0.173***	0.248***	0.175**
[t]	2.615	8.265	4.663	-1.942	-2.156	6.303	2.237	1.509	1.766	-0.738	1.326	4.922	4.608	5.397	2.842	3.047	4.821	2.111
TRI	-4.337*	-0.056	0.841***	-0.900*	-0.405	0.341	0.468	0.827**	0.484	0.029	-0.099	0.760	0.298	0.498	0.993	1.017	-0.223	-0.129
[t]	-1.951	-0.091	3.121	-2.032	-0.657	0.793	1.567	2.256	0.883	0.116	-0.427	1.516	0.990	1.281	1.260	1.288	-0.312	-0.172
After 2015	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	Q	R	S
Intercept	0.018	0.017	0.023***	0.027*	0.024	0.007	0.064***	0.041***	0.028	0.032***	0.039***	0.027*	0.032***	0.042***	0.004	0.051***	0.055**	-0.020
[t]	0.510	0.662	3.691	1.659	1.319	0.547	6.961	2.866	1.603	4.026	6.767	1.831	4.543	3.260	0.205	2.750	2.562	-0.992
MKT	0.754***	1.136***	0.958***	0.853***	0.739***	1.063***	0.934***	1.016***	1.094***	0.873***	0.912***	0.779***	0.920***	1.069***	1.079***	0.652***	0.899***	0.833***
[t]	13.133	33.200	73.758	29.179	21.313	49.199	64.873	42.316	28.970	69.284	63.404	19.525	66.340	31.827	35.161	28.689	33.336	29.325
SMB	0.044	0.753***	0.379***	-0.001	0.080	1.246***	0.858***	1.211***	1.737***	0.469***	0.360***	0.687***	0.423***	0.926***	1.004***	0.451***	1.408***	1.055***
[t]	0.278	7.908	12.589	-0.013	0.780	19.967	22.017	20.215	12.750	15.722	12.881	6.550	11.930	11.638	14.552	5.597	14.069	13.782
HML	-0.049	0.714***	-0.134***	-0.085*	-0.160***	0.171***	-0.245***	0.143***	0.101	-0.163***	0.517***	0.075	-0.135***	-0.236***	0.018	-0.344***	-0.222***	0.143**
[t]	-0.308	10.171	-5.915	-1.689	-3.031	3.719	-10.107	2.885	1.538	-6.900	17.021	1.579	-5.071	-5.315	0.296	-6.672	-3.492	2.451
RMW	-0.200	-0.336***	-0.103***	-0.232***	0.260***	0.164***	0.071**	0.053	0.344***	0.012	-0.158	0.010	-0.185***	0.093*	0.396***	-0.213***	0.159**	0.150***
[t]	-1.494	-4.639	-4.540	-4.845	4.359	4.183	2.527	1.084	4.087	0.449	-6.321	0.190	-7.080	1.941	6.529	-3.557	2.502	2.610
CMA	0.223	0.129	0.097***	0.064	0.005	0.156***	0.058*	0.004	0.006	0.096***	0.043***	0.335***	0.104***	-0.021	-0.129	0.258***	0.130*	-0.062
[t]	1.478	1.489	3.633	0.967	0.070	3.139	1.799	0.070	0.064	2.946	1.326	4.903	3.937	-0.432	-1.528	3.760	1.742	-0.777
TRI	-2.601	-0.553	-0.308	0.006	0.384	0.284	0.236	0.292	-0.449	-0.038	-0.099	0.464	0.014	0.227	-0.753	-0.311	-0.084	0.210
[t]	-1.503	-0.499	-1.110	0.008	0.422	0.530	0.577	0.421	-0.575	-0.101	-0.427	0.672	0.050	0.422	-0.915	-0.396	-0.086	0.242

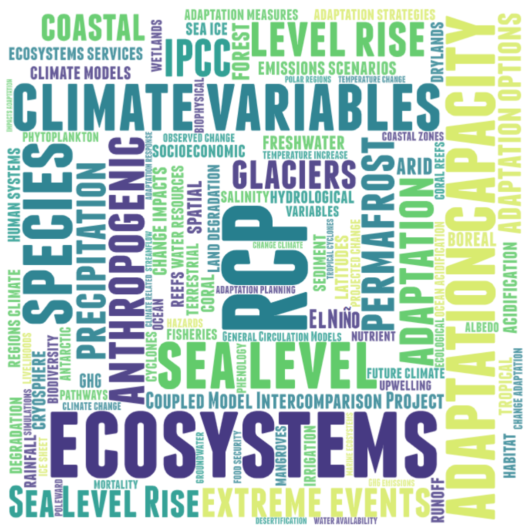
Note: We group the EuroStoxx 600 Index historical constituents into NACE sectors: Agriculture, forestry and fishing (A), Mining and quarrying (B), Manufacturing (C), Electricity, gas, steam and air conditioning supply (D), Water supply; sewerage, waste management and remediation activities (E), Construction (F), Wholesale and retail trade; repair of motor vehicles and motorcycles (G), Transportation and storage (H), Accommodation and food service activities (I), Information and communication (J), Financial and insurance activities (K), Real estate activities (L), Professional, scientific and technical activities (M), Administrative and support service activities (N), Public administration and defence; compulsory social security (O), Human health and social work activities (Q), Arts, entertainment and recreation (R), Other service activities (S). We perform time-series regressions of the NACE sectors excess returns on the Fama-French five factors (the market factor, MKT; the size factor, SMB; the value factor,HML; the profitability factor, RMW; and the investment factor, CMA) plus Transition Risk Index (TRI) over the period Jan 2005-Oct 2021 (Full sample), Jan 2005-Dec 2014 (Before 2015), and Jan 2015-Oct 2021 (After 2015). t-statistics ([t]), and Newey-West standard are adopted. * $p < 0.1$; ** $p < 0.05$; *** $p < 0.01$.

Table 10: Sensitivity of NACE to PRI

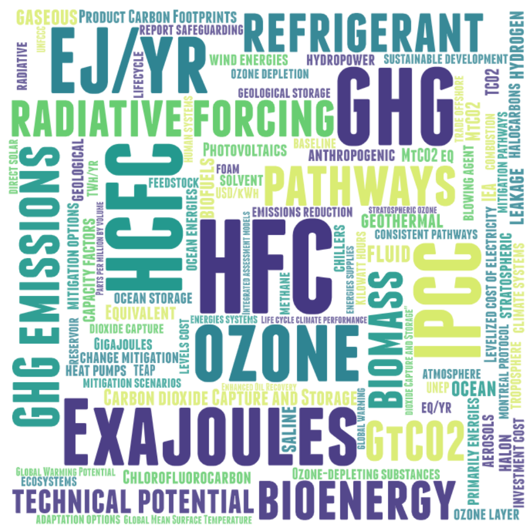
Full sample	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	Q	R	S
Intercept	0.061	0.034**	0.033***	0.044***	0.037***	0.013	0.040***	0.032***	0.018*	0.037***	0.041***	0.022**	0.041***	0.041***	0.022*	0.068***	0.023*	-0.006
[t]	1.466	1.992	6.581	4.750	3.037	1.554	5.976	4.242	1.746	7.132	8.319	2.270	7.289	5.369	1.947	4.876	1.728	-0.450
MKT	0.920***	1.155***	0.933***	0.780***	0.697***	1.083***	0.908***	0.951***	1.068***	0.865***	0.950***	0.746***	0.915***	1.054***	0.987***	0.663***	0.824***	0.826***
[t]	15.741	39.588	60.500	35.631	34.818	47.971	77.954	55.223	45.335	123.484	75.016	33.020	76.784	55.286	26.585	40.543	43.658	32.995
SMB	-0.068	0.522***	0.402***	0.014	0.235***	1.054***	0.813***	0.997***	1.365***	0.513***	0.394***	0.645***	0.383***	0.918***	1.142***	0.407***	1.116***	0.891***
[t]	-0.410	5.994	17.480	0.353	4.825	23.717	28.412	22.885	15.640	22.288	13.346	11.357	13.034	21.867	20.967	7.588	17.115	14.580
HML	-0.051	0.359***	-0.043	-0.125***	-0.194***	0.444***	-0.046	0.195***	0.349***	-0.101***	0.462***	0.171***	-0.027	-0.021	-0.038	-0.239***	-0.086**	0.321***
[t]	-0.392	4.918	-1.640	-3.285	-5.621	10.263	-1.459	5.749	6.059	-5.748	18.915	4.755	-0.991	-0.457	-0.628	-6.837	-2.267	5.815
RMW	-0.659***	-0.170**	-0.111***	-0.226***	0.166***	0.174***	0.106***	0.070**	0.431***	-0.079***	-0.105***	-0.126***	-0.184***	0.141***	0.399***	-0.221***	0.117***	0.206***
[t]	-4.825	-2.454	-6.973	-7.621	3.721	5.254	4.580	2.245	8.373	-4.372	-5.390	-3.769	-10.512	4.153	8.548	-5.399	2.698	4.149
CMA	0.497***	0.367***	0.137***	-0.066*	-0.094*	0.290***	0.113***	0.012	0.100*	0.047**	0.005	0.288***	0.177***	0.146***	0.016	0.237***	0.198***	0.115*
[t]	3.148	3.871	6.443	-1.708	-1.859	8.584	4.445	0.321	1.717	2.063	0.208	6.798	6.032	4.671	0.270	5.399	4.586	1.802
PRI	-0.981	-0.248	-0.107	-0.935**	0.217	0.181	-0.164	-0.184	0.081	-0.559**	0.326*	0.102	0.145	0.071	0.483	0.173	0.100	-0.633
[t]	-0.564	-0.366	-0.506	-2.260	0.400	0.482	-0.585	-0.525	0.152	-2.421	1.708	0.244	0.596	0.198	0.846	0.280	0.165	-0.954
Before 2015	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	Q	R	S
Intercept	0.094	0.059***	0.036***	0.055***	0.044***	0.016	0.021**	0.027***	0.010	0.038***	0.038***	0.017	0.045***	0.038***	0.031**	0.074***	0.001	0.006
[t]	1.525	3.109	5.297	4.848	2.791	1.399	2.509	2.895	0.695	5.766	6.681	1.421	5.712	3.999	2.185	3.899	0.057	0.363
MKT	1.030***	1.157***	0.915***	0.732***	0.673***	1.090***	0.887***	0.900***	1.036***	0.863***	0.912***	0.725***	0.909***	1.041***	0.920***	0.671***	0.760***	0.813***
[t]	12.599	36.547	45.192	29.763	27.119	30.676	74.532	54.994	39.334	104.057	63.883	42.482	54.786	60.116	18.928	30.981	34.362	22.520
SMB	-0.051	0.119	0.441***	-0.010	0.339***	1.035***	0.851***	0.835***	1.177***	0.595***	0.362***	0.678***	0.389***	0.970***	1.128***	0.441***	0.930***	0.813***
[t]	-0.208	1.336	15.511	-0.208	6.469	21.259	27.032	20.246	16.577	19.123	12.892	14.957	10.301	24.065	14.610	6.139	12.808	11.268
HML	-0.215	0.014	0.021	-0.092*	-0.153***	0.556***	0.082**	0.219***	0.445***	-0.039*	0.517***	0.252***	0.022	0.089*	-0.053	-0.177***	-0.025	0.373***
[t]	-1.134	0.165	0.582	-1.762	-3.115	8.784	2.523	6.138	6.438	-1.821	17.163	6.547	0.635	1.822	-0.572	-3.508	-0.521	4.493
RMW	-1.032***	-0.161**	-0.108***	-0.201***	0.131**	0.169***	0.145***	0.073**	0.472***	-0.121***	-0.158***	-0.198***	-0.187***	0.172***	0.396***	-0.219***	0.080	0.218***
[t]	-5.231	-2.449	-4.758	-5.712	2.177	3.521	4.890	2.021	8.668	-5.029	-6.336	-4.754	-7.807	4.196	6.224	-3.914	1.436	2.999
CMA	0.567***	0.727***	0.131***	-0.090*	-0.143**	0.259***	0.073**	0.055	0.109*	-0.022	0.043	0.224***	0.181***	0.164***	0.173***	0.171***	0.248***	0.176**
[t]	2.665	8.283	4.601	-1.891	-2.129	6.276	2.208	1.455	1.764	-0.733	1.330	4.847	4.616	5.347	2.812	3.040	4.824	2.121
PRI	-0.452	0.711	0.010	-0.946*	0.064	0.241	0.010	0.442	-0.345	-0.408	0.475**	0.686	0.441	0.511	1.094	0.994	0.161	-0.623
[t]	-0.176	0.968	0.036	-1.882	0.096	0.489	0.028	0.981	-0.500	-1.453	2.071	1.355	1.343	1.124	1.416	1.163	0.223	-0.735
After 2015	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	Q	R	S
Intercept	0.026	0.014	0.024***	0.024	0.023	0.006	0.062***	0.037***	0.032*	0.031***	0.046***	0.024	0.031***	0.039***	0.006	0.050***	0.057***	-0.024
[t]	0.722	0.571	4.023	1.539	1.309	0.479	7.075	2.709	1.954	4.021	5.724	1.625	4.620	3.288	0.334	2.704	2.783	-1.187
MKT	0.755***	1.136***	0.958***	0.852***	0.739***	1.063***	0.933***	1.015***	1.095***	0.873***	0.999***	0.778***	0.920***	1.068***	1.080***	0.651***	0.899***	0.833***
[t]	13.344	33.262	74.030	28.942	21.414	49.206	64.928	42.411	28.881	68.577	79.506	19.546	66.847	31.856	35.489	28.781	33.132	29.225
SMB	0.042	0.749***	0.379***	-0.002	0.081	1.246***	0.857***	1.209***	1.738***	0.468***	0.464***	0.686***	0.422***	0.925***	1.003***	0.449***	1.408***	1.053***
[t]	0.262	7.902	12.527	-0.039	0.782	19.910	22.024	20.210	12.794	15.726	12.040	6.474	11.840	11.528	14.835	5.550	14.059	13.529
HML	-0.047	0.714***	-0.133***	-0.085*	-0.160***	0.171***	-0.245***	0.142***	0.101	-0.163***	0.360***	0.075	-0.135***	-0.236***	0.018	-0.344***	-0.222***	0.143**
[t]	-0.305	10.233	-5.927	-1.681	-3.033	3.716	-10.127	2.886	1.547	-6.903	13.536	1.565	-5.089	-5.341	0.303	-6.732	-3.494	2.409
RMW	-0.205	-0.338***	-0.104***	-0.233***	0.261***	0.164***	0.072**	0.053	0.344***	0.012	-0.028	0.010	-0.185***	0.093*=	0.394***	-0.214***	0.159**	0.150***
[t]	-1.540	-4.669	-4.566	-4.857	4.367	4.185	2.529	1.083	4.079	0.428	-1.126	0.195	-7.105	1.945	6.454	-3.572	2.497	2.598
CMA	0.228	0.130	0.098***	0.064	0.005	0.155***	0.057*	0.003	0.007	0.096***	-0.081***	0.334***	0.104***	-0.022	-0.128	0.259***	0.130*	-0.063
[t]	1.497	1.495	3.657	0.958	0.061	3.120	1.786	0.057	0.076	2.928	-2.597	4.861	3.929	-0.446	-1.499	3.769	1.743	-0.766
PRI	-2.184	-2.420**	-0.299	-1.006	0.464	0.065	-0.122	-1.058*	0.826	-0.697**	0.452	-0.574	-0.364	-0.564	-0.615	-1.124	0.361	-0.868
[t]	-1.151	-2.392	-0.963	-1.438	0.574	0.123	-0.289	-1.828	0.990	-2.012	1.345	-0.841	-1.090	-1.008	-0.698	-1.308	0.358	-0.840

Note: We group the EuroStoxx 600 Index historical constituents into NACE sectors: Agriculture, forestry and fishing (A), Mining and quarrying (B), Manufacturing (C), Electricity, gas, steam and air conditioning supply (D), Water supply; sewerage, waste management and remediation activities (E), Construction (F), Wholesale and retail trade; repair of motor vehicles and motorcycles (G), Transportation and storage (H), Accommodation and food service activities (I), Information and communication (J), Financial and insurance activities (K), Real estate activities (L), Professional, scientific and technical activities (M), Administrative and support service activities (N), Public administration and defence; compulsory social security (O), Human health and social work activities (Q), Arts, entertainment and recreation (R), Other service activities (S). We perform time-series regressions of the NACE sectors excess returns on the Fama-French five factors (the market factor, MKT; the size factor, SMB; the value factor,HML; the profitability factor, RMW; and the investment factor, CMA) plus Physical Risk Index (PRI) over the period Jan 2005-Oct 2021 (Full sample), Jan 2005-Dec 2014 (Before 2015), and Jan 2015-Oct 2021 (After 2015). t-statistics ([t]), and Newey-West standard are adopted. * $p < 0.1$; ** $p < 0.05$; *** $p < 0.01$.

Figure 1: Word clouds summary for physical and transition risk vocabularies



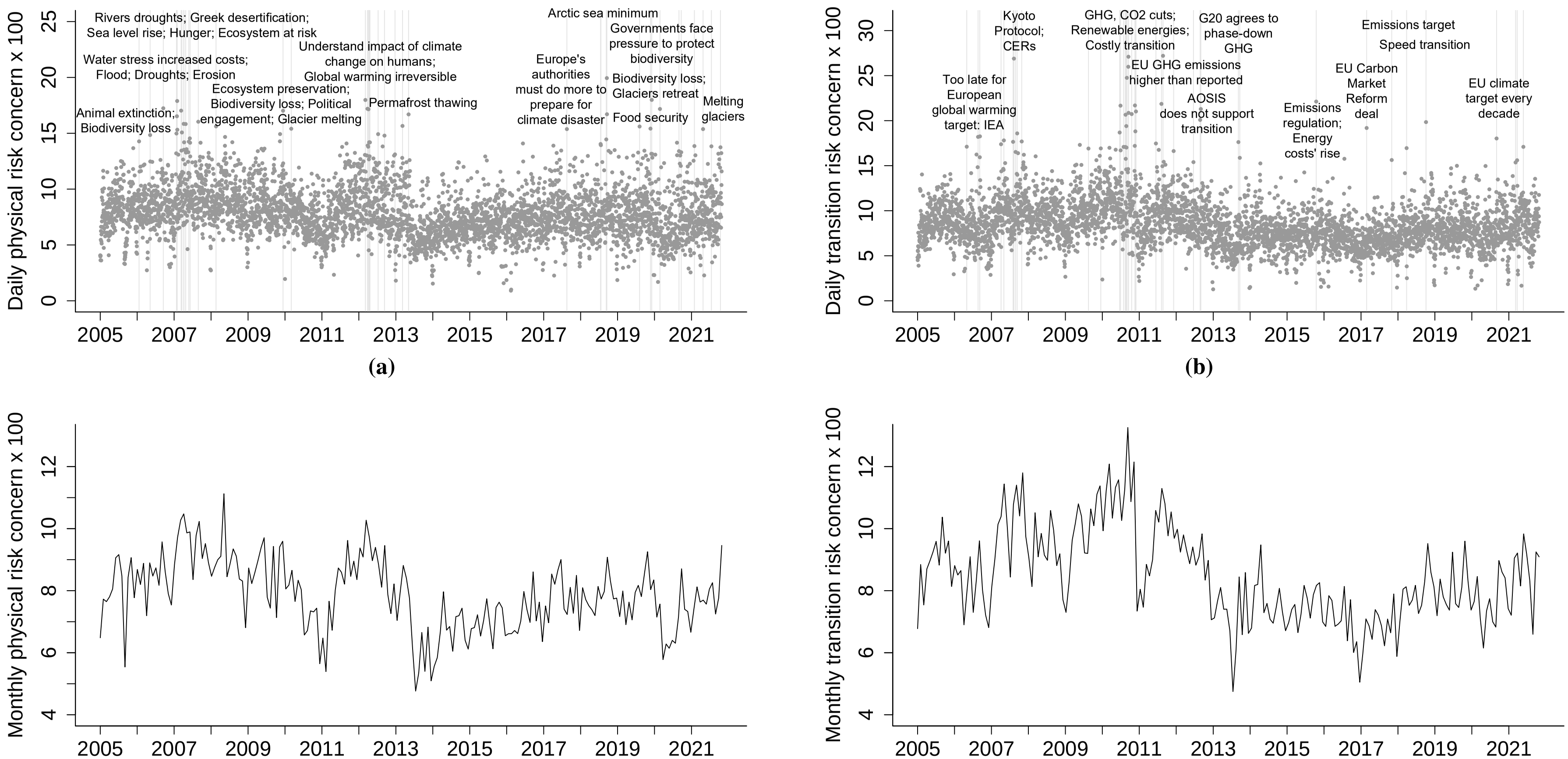
(a) Physical risk vocabulary



(b) Transition risk vocabulary

Note: Word cloud summaries for the physical risk (a) and transition risk (b) vocabularies. Term sizes depend on the relative importance of the term according to the individual term frequency-inverse document frequency, tf-idf, score. Reported terms are the reconstructed stemmed terms. Major acronyms: Representative Concentration Pathways (RCP), hydrofluorocarbon (HFC), hydrochlorofluorocarbon (HCFC). Table A2 reports the full list of acronyms.

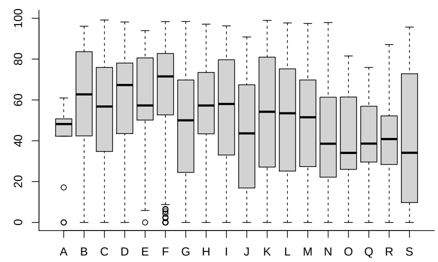
Figure 2: Physical and transition risk concern timeseries 2005-2021



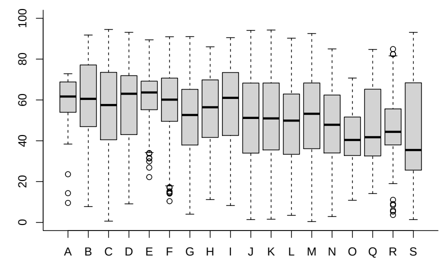
(a) (b) (c) (d)

Note: Daily physical risk (a) and transition risk (b) concern time series as scatter plots together with the major risk shock topics (vertical bars) for the period Jan 2005-Oct 2021. Monthly average physical (c) and transition (d) risk concern time series.

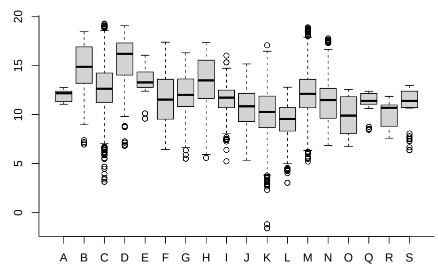
Figure 3: Distribution of exposure metrics



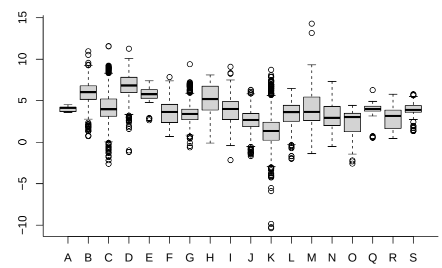
(a) Environmental score



(b) ESG score



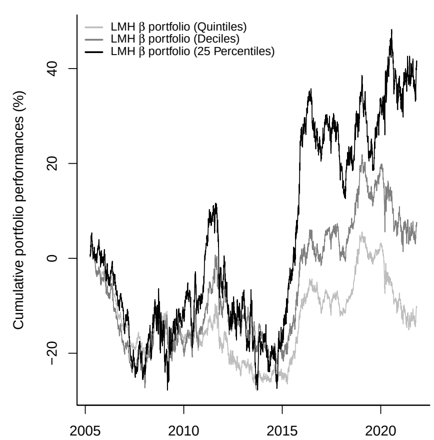
(c) GHG emissions



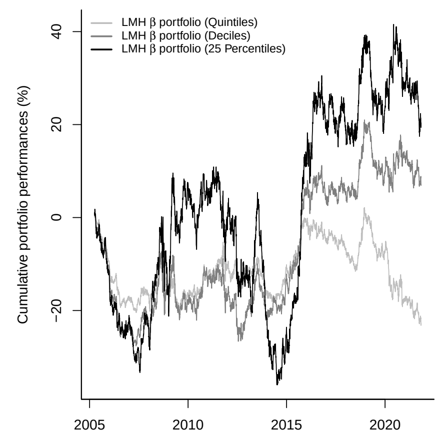
(d) GHG emissions intensity

Note: Environmental score (a), ESG score (b), GHG emissions (c), and GHG emissions intensity (d) boxplots for the NACE Rev. 2 sectors: Agriculture, forestry and fishing (A); Mining and quarrying (B); Manufacturing (C); Electricity, gas, steam and air conditioning supply (D); Water supply, sewerage, waste management and remediation activities (E); Construction (F); Wholesale and retail trade, repair of motor vehicles and motorcycles (H); Accommodation and food service activities (I); Information and communication (J); Financial and insurance activities (K); Real estate activities (K); Professional, scientific and technical activities (M); Administrative and support service activities (N); Public administration and defence, compulsory social security (O); Human health and social work activities (Q); Arts, enterteinment and recreation (R); Other services activities (S). Environmental, ESG, and GHG emissions data are sourced from Refinitiv.

Figure 4: Cumulative performances of portfolios sorted on TRI and PRI



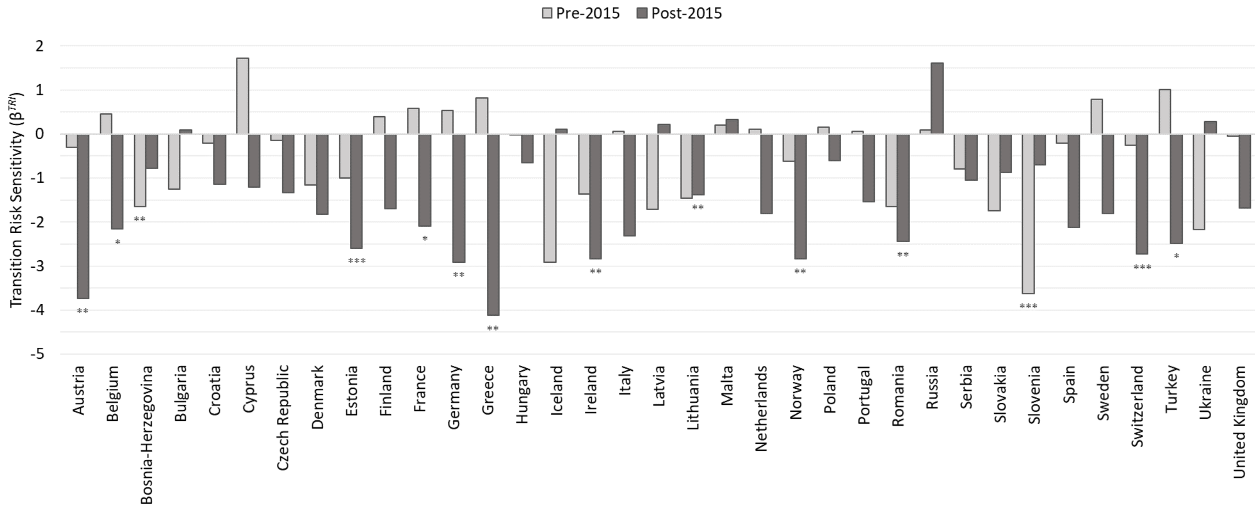
(a) Transition LMH beta portfolios



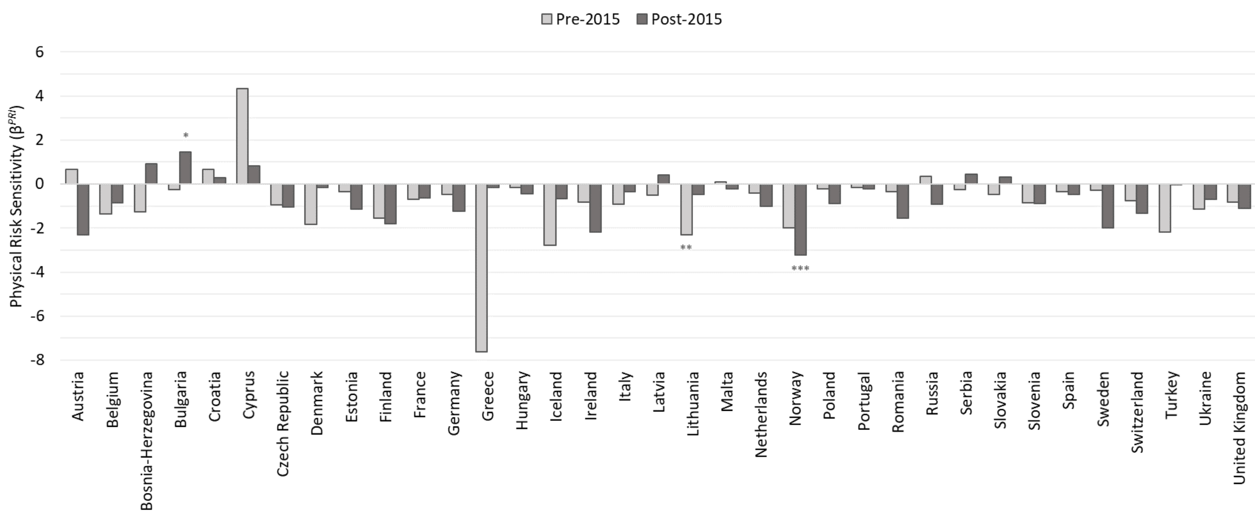
(b) Physical LMH beta portfolios

Note: Cumulative daily performances of the low-minus-high (LMH) quintiles (light-grey lines), deciles (grey lines) and 25 percentiles (black lines) transition (a) and physical (b) climate beta portfolios considering EuroStoxx 600 Index historical constituents stocks over the period Jan 2005-Oct 2021.

Figure 5: Stock market index sensitivity to climate risks by country pre- and post-2015



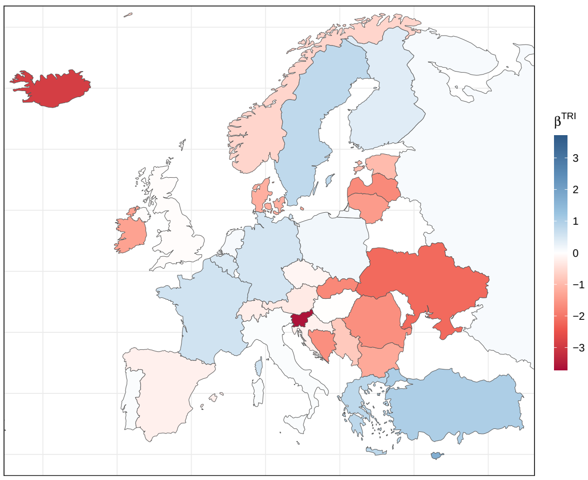
(a) Countries sensitivity to transition climate risk (β^{TRI})



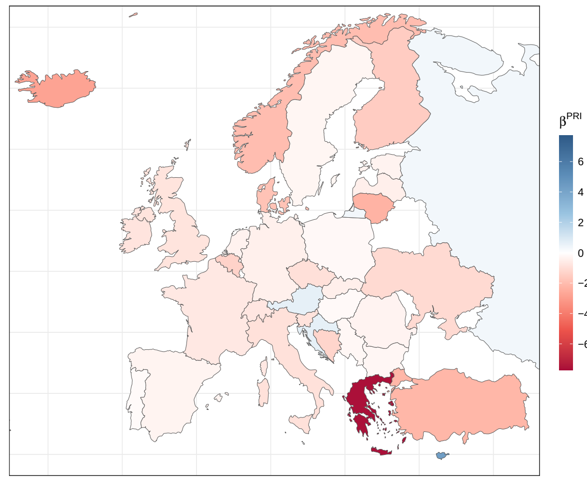
(b) Countries sensitivity to physical climate risk (β^{PRI})

Note: Stock market index returns beta sensitivity to the Transition Risk Index, TRI (a) and Physical Risk Index, PRI (b) for Austria, FTSE Austria (FTWIAUTE); Belgium, BEL 20 (BFX); Bosnia-Herzegovina, BIRS (BIRS1); Bulgaria, BSE SOFIX (SOFIX); Croatia, CROBEX (CRBEX); Cyprus, Cyprus Main Market (CYMAIN); Czech Republic, PX (PX); Denmark, OMX Copenhagen 20 (OMXC20); Estonia, Tallinn SE General (OMXTGI); Finland, OMX Helsinki 25 (OMXH25); France, CAC 40 (FCHI); Germany, DAX (GDAXI); Greece, Athens General Composite (ATG); Hungary, Budapest SE (BUX); Iceland, ICEX Main (OMXIPI); Ireland, ISEQ Overall (ISEQ); Italy, FTSE MIB (FTMIB); Latvia, Riga General (OMXRGI); Lithuania, Vilnius SE General (OMXVGI); Malta, MSE; Netherlands, AEX (AEX); Norway, Oslo OBX (OBX); Poland, WIG20 (WIG20); Portugal, PSI (PSI20); Romania, BET (BETI); Russia, MOEX Russia (IMOEX); Serbia, Belex 15 (BELEX15); Slovakia, SAX (SAX); Slovenia, Blue-Chip SBITOP (SBITOP); Spain, IBEX 35 (IBEX); Sweden, OMX Stockholm 30 (OMXS30); Switzerland, SMI (SSMI); Turkey, BIST 100 (XU100); Ukraine, PFTS (PFTSI); United Kingdom, FTSE 100 (FTSE). Pre- and post-2015 sample periods are analysed for each country. ***, **, * indicate p-value< 0.01, p-value< 0.05, and p-value< 0.10, respectively.

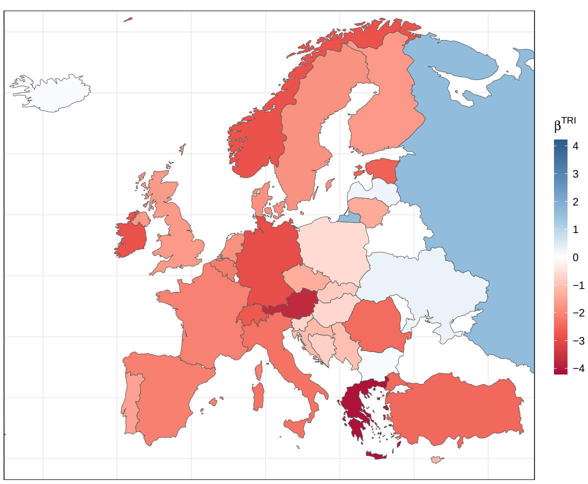
Figure 6: Stock market index sensitivity to climate risks map by country pre- and post-2015



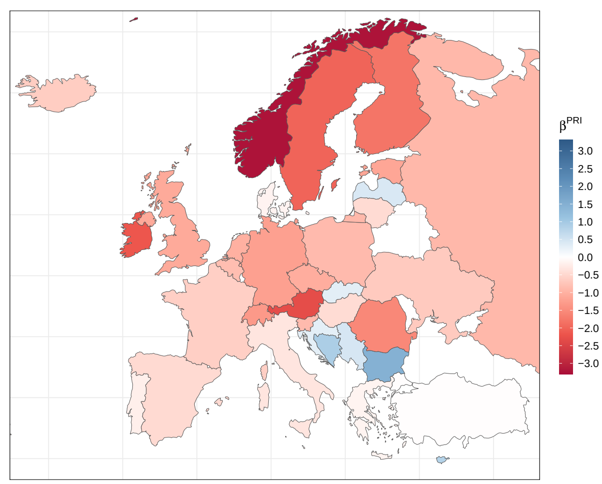
(a) Countries sensitivity to TRI pre-2015



(c) Countries sensitivity to PRI pre-2015



(b) Countries sensitivity to TRI post-2015



(d) Countries sensitivity to PRI post-2015

Note: Countries' stock market sensitivity to transition risk, TRI, pre-2015 (a) and post-2015 (b). Countries' stock market sensitivity to physical risk, PRI, pre-2015 (c) and post-2015 (d). See the stock market indices list from Figure 5.

Appendix

Table A1: List of climate change white papers for transition and physical risk

Year	Source	Title	Transition	Physical
1990	IPCC	IPCC Synthesis Report 1990	115-148p	
1990	IPCC	Climate change: The IPCC Impacts Assessment		Entire
1992	IPCC	Climate change: The IPCC 1990 and 1992 Assessments		87-113p
1999	IPCC	IPCC Special Report: Aviation and the global atmosphere	Entire	
2000	IPCC	IPCC Special Report: Methodological and technological issues in technology transfer	Entire	
2001	IPCC	IPCC Synthesis Report 2001	302-354p	
2001	IPCC	Climate change 2001: Impacts, adaptation and vulnerability		Entire
2005	IPCC	IPCC Special Report: Carbon dioxide capture and storage	Entire	
2005	IPCC	IPCC Special Report: Safeguarding the ozone layer and the global climate system: Issues related to hydrofluorocarbons and perfluorocarbons	Entire	
2007	IPCC	IPCC Synthesis Report 2007	55-70p	
2007	IPCC	Climate change 2007: Impacts, Adaptation and Vulnerability		Entire
2011	IPCC	IPCC Special Report: Renewable energy sources and climate change mitigation	Entire	
2012	IPCC	IPCC Special Report: Managing the risks of extreme events and disasters to advance climate change adaptation		Ch. 2-4
2014	IPCC	IPCC Synthesis Report 2014	75-112p	
2014	IPCC	Climate change 2014: Impacts, adaptation and vulnerability		Part A & B
2018	UNEP FI	Navigating a new climate. Part 2: Physical risks and opportunities		Entire
2019	IPCC	IPCC Special Report: Global warming of 1.5C	Ch. 2 & 4	Ch. 3
2019	IPCC	IPCC Special Report: Climate change and land		Ch. 1-5
2019	IPCC	IPCC Special Report: The ocean and cryosphere in a changing climate		Entire
2020	IMF JM	The effects of weather shocks on economic activity: What are the channels of impact?		Entire
2020	MGI	Climate risk and response: Physical hazards and socioeconomic impacts		Entire
2020	SRI	Natural catastrophes in times of economic accumulation and climate change		Entire

Note: This table reports the year of publication, source, title of the list of texts used to construct the physical and transition risk vocabularies. List of acronyms: IPCC, Intergovernmental Panel on Climate Change; IMF JM, International Monetary Fund - Journal of Macroeconomics; UNEP FI, United Nations Environment Programme Finance Initiative; MGI, McKinsey Global Institute; SRI, Swiss Re Institute.

Table A2: Physical risk and transition risk vocabularies list of acronyms

Physical risk vocabulary acronyms	
GHG	Greenhouse gas
RCP	Representative Concentration Pathway
IPCC	Intergovernmental Panel on Climate Change
Transition risk vocabulary acronyms	
EJ/yr	Exajoules per-year
MtCO2	Megatonne of carbon
eq/yr	Equivalent per-year
MtCO2 eq	Megatonne of carbon equivalent
GHG	Greenhouse gas
TCO2	Tonne of carbon
GtCO2	Gigatonne of carbon
TEAP	Technology and Economic Assessment Panel
HCF	Hydrofluorocarbon
TWh/yr	Terawatt hours/year
HCFC	Hydrochlorofluorocarbon
UNEP	United Nations Environment Programme
IPCC	Intergovernmental Panel on Climate Change
UNFCCC	United Nations Framework Convention on Climate Change
IEA	International Energy Agency
USD/kWh	United States Dollar/Kilowatt hour

Note: Physical risk and transition risk summary vocabularies as in figure 1 list of acronyms.

A2. Common Metrics for Firms' Climate Risk Exposure: A Review

A2.1. Transition Risk

Academics, practitioners, and supervisors typically use GHG emissions or GHG emissions intensity (GHG emissions scaled by some organization-specific metric) to proxy a firm's exposure to transition risk, motivated by the fact that carbon-intensive activities are likely affected by GHG emissions reduction policies (Ardia et al. 2023; Bolton and Kacperczyk 2023; In et al. 2019; NGFS 2020). However, empirical findings based on these measures are not conclusive. Bolton and Kacperczyk (2023) provide evidence of the existence of a carbon premium while considering both emissions levels and changes, but no relation with carbon intensity exists. Also Bolton and Kacperczyk (2021) and Ramelli et al. (2021) find that transition risks related to carbon emissions are priced. In contrast, In et al. (2019) find that green firms outperform brown firms when considering carbon intensity and Hsu et al. (2023) show that a long-short portfolio constructed from firms with high versus low emission intensity generates a positive excess return.

Other potential measures of climate exposure are E and ESG scores, which aim to measure the environmental, or environmental, social and governance-related performance of a company.[25] A number of academic studies rely on E/ESG scores (possibly in combination with other company-specific metrics) to identify climate-sensitive companies. Görgen et al. (2020), for example, build a "greenness" score based on carbon intensity, ESG scores and an adaptability score. Alessi et al. (2021) combines ESG disclosure scores with quantitative measures on emissions, while Engle et al. (2020) focus exclusively on the E score.

Other studies consider sectoral classifications and define climate-sensitive companies as those belonging to high GHG emissions sectors. This approach is particularly relevant in contexts where the lack of transparent indicators (e.g. ESG ratings) may limit the ability of investors to understand to steer their investment toward climate-hedged portfolios (Bolton and Kacperczyk 2021). As such, Choi et al. (2020) finds that the sectors identified as major emitters by the Intergovernmental Panel on Climate Change (IPCC) earn lower stock returns than other firms. Bolton and Kacperczyk (2023) argue that relying on a sectoral analysis may facilitate the detection of climate-risky investments, whereas such an approach may ignore relevant intra-sectoral differences. Batten et al. (2016) document the impact of transition risk on the energy sector and concludes that only renewable energy companies generate abnormal returns.

A2.2. Physical Risk

Measuring firms' exposure to physical risk is challenging as physical risk arises from the interaction of hazard (occurrence, or probability of occurrence, of a physical event), exposure (presence of elements in areas and settings that could be adversely affected), and vulnerability (predisposition of exposed elements to suffer damages due to the hazardous event). Such dimensions typically depend on both

[25] The exact information contained in any ESG score depends on the methodology used to calculate it, which, in turn, differs across credit/rating providers. Existing research documents large differences between ESG ratings (Chatterji et al. 2016; Gibson Brandon et al. 2021) and elaborates on the possible reasons for these Berg et al. (2022).

local/specific and macro factors. Currently, most of the information on physical risk exposure is provided by some public sources (e.g. EC JRC Risk Data Hub) and private data providers. These databases, however, are not fully comparable as they focus on different risk aspects, types of hazard and types of entities. Due to data limitations, studies that explore the consequences of physical risks on asset prices mainly focus on specific physical events and/or consider only some dimensions of physical risk (see Addoum et al. (2020); Hong et al. (2019); Kruttli et al. (2021)). Alternatively, as is the case for transition risk, sectors can be used to proxy physical risk exposure. While all sectors can suffer from natural disasters, some sectors, including energy, transportation, and telecommunications, are expected to be more exposed to climate hazards through their infrastructure assets (ECB 2021). Primary economic activities, including agriculture, forestry, fishing, mining and quarrying, are exposed through the natural and/or food systems on which they depend. Among services, the insurance sector, tourism and health care might be particularly sensitive to physical risk (IPCC 2014).

While E, ESG, and GHG emissions have mainly been used to capture exposure to transition, rather than physical risk, this distinction is not always clear and these metrics' potential to capture physical exposure has been largely unexplored. In this study, we decided to test all of the above-mentioned exposure metrics in light of their potential use for investors to hedge against physical and/or transition risks.