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ARE INVESTORS SENSITIVE TO CLIMATE-RELATED TRANSITION AND PHYSICAL RISKS? EVIDENCE FROM GLOBAL STOCK MARKETS

Key points

- *With climate change posing significant uncertainties to firms' future cash flows, financial regulators have expressed growing concern over the extent to which climate risks are reflected in the prices of financial assets, as abrupt shifts in investor expectations or sentiment could trigger disorderly market repricing.*

- *In this study, we construct news-based indices capturing public perception of climate-related physical and transition risks – the highs and lows of which can match with major global climate events. We then explore whether equity prices react to changes in the perceived climate risks, and if so, whether this sensitivity depends on firms' environmental performance or the domicile of the firms' headquarters.*

- *Estimates show that global stock prices respond negatively to increases in both types of climate risk, and being "green" ("brown") is rewarded (penalised) by the market. Subsample analyses further reveal that these findings are driven primarily by firms headquartered in advanced economies (AEs), with the stock prices of emerging market (EME) firms yielding modest if not insignificant responses to changes in climate-related risks and their interactions with environmental performance.*

- *As EMEs are more vulnerable to the devastating impacts of climate change and less able to afford its consequences, this raises the concern of disruptive financial market repricing when investors eventually come to terms with the very real threats climate change poses to firms in these economies.*

- *In Hong Kong, rapid improvement in emissions disclosure has coincided with heightened investor scrutiny of firms' carbon disclosure and intensity, suggesting ESG integration has facilitated the assessment of climate-related risks.*

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I. INTRODUCTION

The 2010s constituted the hottest decade on record – accompanied by intensifying floods, droughts, heat waves and water scarcity, with immense social and economic impacts (FAO (2021)). Tackling climate change, consequently, has moved to the forefront of international policy agendas. In 2015, over 190 countries adopted a legally-binding international treaty on climate change – the Paris Agreement, and more recently, countries pledged to phase down the use of coal at the 2021 UN Climate Change Conference ("COP26"). These developments highlight the significant "physical risks" and "transition risks" of climate change confronting the global economy.[1] These risks, with the potential to affect the future payoffs of a wide range of financial assets, raise an important question of whether they are adequately reflected in asset prices – a growing concern among global financial regulators.[2] If not, this situation represents a vulnerability to financial stability as abrupt changes in investor expectations or sentiment over these risks might trigger disorderly financial market repricing.

Given the difficulty of quantifying climate risks, however, empirical evidence on the asset pricing implications is, at best, mixed. In theory, to test whether the risks of climate change are priced into financial markets, one needs to measure time-varying physical and transition risks, as well as firm-level exposures to such risks, which can be a daunting task. The former requires probabilities of various future climate developments and policy scenarios while the latter requires in-depth granular analysis of a firm's assets and business models. Earlier studies have tended to focus on carbon emissions metrics (e.g. Bolton and Kacperczyk (2020)), measures involving spatiotemporal weather data (e.g. Bansal, Kiku and Ochoa (2016)), or event studies of policy events (e.g. Qian, Suryani and Xing (2020)), none of which can simultaneously capture the multifaceted and time-varying nature of climate risks and firms' varying degrees of exposure to such risks.

In this study, therefore, we use natural language processing techniques to construct global, news-based measures capturing public awareness of climate-

[1] "Physical risks" refer to the potential damage to asset values, productive capacity and overall economic activity caused by natural disasters induced by climate change, while "transition risks" result from climate policy changes, unanticipated or otherwise, during the transition towards a greener economy that may cause some sectors to face impairment of asset values and/or higher business costs.

[2] See, for example, the FSB's 2020 stocktake on financial authorities' experience in including physical and transition climate risks as part of their financial stability monitoring: https://www.fsb.org/2020/07/stocktake-of-financial-authorities-experience-in-including-physical-and-transition-climate-risks-as-part-of-their-financial-stability-monitoring/.

related transition and physical risks since the early 2000s.[3] Combining our news indices with a variety of firm-level measures of "greenness" (such as carbon efficiency, ESG score, and implementation of an emissions target) as proxies for exposure to transition risk, we then examine whether global equity investors are sensitive to climate risks, and whether this sensitivity differs across different types of economies. An important caveat is that *actual* physical and transition risks facing a firm may differ from public *perception* of global climate risks in general. That being said, if equity returns fail to react to shifts in public perception of climate risks, we may infer that investors may not be paying sufficient attention to them.

Our results provide evidence that equity prices react significantly and negatively to increases in both types of climate risks. Environmental outperformance also acts as a financial market hedge during periods of heightened climate concern, with "green" ("brown") firms being rewarded (punished) by the market when perceived climate risks increase. The effect, however, is driven primarily by AE corporates. Subsample analyses reveal that the stock prices of EME firms (including those in emerging Asia (EM Asia)) yield modest if not insignificant responses to changes in climate risk and their interactions with environmental performance. As EMEs are arguably more vulnerable to climate change, this raises the concern of a climate 'Minsky moment' in the financial markets when investors finally come to terms with the severity of the threats associated with global warming. In the case of Hong Kong, however, indicators of emissions disclosure and efficiency are important drivers of stock returns when perceived climate risks increase, likely reflecting the economy's sharp improvement in carbon disclosure in recent years.

The rest of this paper is organised as follows. Section 2 describes the data and our climate indices, Section 3 outlines the equity returns model and discusses the findings, and Section 4 concludes.

II. DATA

2.1 Firm sample

Our sample consists of publicly-listed firms in the Refinitiv Global Developed and Global Emerging Markets Indices, which are designed to serve as

[3] While a rapidly growing branch of the literature leveraging textual analysis techniques to capture climate risks has recently emerged, studies have focused on US climate news reporting and firms (e.g. Engle et al. (2020) and Ardia et al. (2021)), whereas our paper takes a global focus.

broad market benchmarks to track the performance of liquid equities worldwide[4]. We match these firms using their ISIN identifiers to the S&P Capital IQ database, from which we extract corporate balance sheet and market data. This gives us a final sample of 11,888 firms (out of an original 12,012 firms), covering over 60 AE and EME economies (in terms of firm headquarters) across the five geographical regions and the eleven Global Industry Classification Standard (GICS) sectors (see Chart A1 in the Appendix for a detailed breakdown).

2.2 Environmental data

For firms' environmental data, we rely on two sources – Refinitiv Eikon and S&P Global Trucost. Eikon offers a wide variety of different ESG metrics, and we focus on three in particular: 1) Target Emissions – a binary variable indicating whether a company has set targets or objectives to be achieved on emissions reduction, 2) Policy Emissions – a binary variable indicating whether a company has a policy to improve emissions reduction, and 3) ESG score – an overall company score based on self-reported information in the environmental, social and corporate governance pillars.

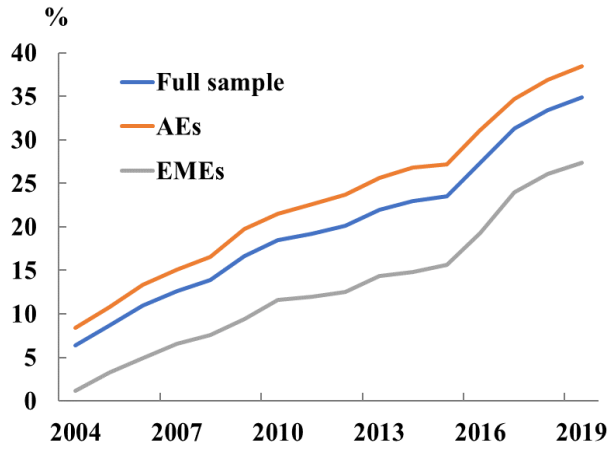
For data relating to the magnitude of GHG emissions, we rely on Trucost, which provides annual measures of all three scopes of firm-level emissions following the GHG Protocol – a global standardised framework for emissions accounting. Scope 1 emissions are from directly emitting sources that are owned or controlled by a company, while scope 2 emissions are from the consumption of purchased electricity, steam, or other sources of energy generated from a company's direct operations. And scope 3 emissions encompass all other emissions associated with a company's operations that are not directly owned or controlled by the company, including sources in the company's supply chain. For our purposes, we normalise emission levels by revenue to arrive at a measure of carbon intensity.

We also make use of Trucost's weighted GHG disclosure score, which measures the extent of emissions disclosure by a company. As Trucost has one of the widest coverages of firm-level emissions data, we assume that missing data under this measure is equivalent to a disclosure score of 0. Chart 1 provides a breakdown of non-zero emissions disclosure by economy type for our sample of firms. While disclosure has improved significantly over the past two decades, only about a third

[4] See https://www.refinitiv.com/content/dam/marketing/en_us/documents/methodology/global-equity-index-methodology.pdf for details. We also add members of the CSI 300 Index (which includes the top 300 stocks traded on the Shanghai and Shenzhen Stock Exchanges), as the Refinitiv indices exclude Mainland China's exchanges.

of the firms in our sample have provided some form of emissions-related information as of 2019, with the share for EME firms (27%) significantly lower than for AE corporates (38%), suggesting a relatively low level of ESG integration among EMEs.

Chart 1: Emissions disclosure, sample share



Sources: Trucost and author's estimates.
Note: figures represent the share of active firms with a non-zero Trucost weighted GHG disclosure score – see Table A1 in Appendix II for a detailed description of the disclosure score.

2.3 News-based climate indices

Frequently used measures of climate-related risks in the literature, such as temperature and drought indicators and events studies of policy actions, are unable to capture both the multifaceted and constantly evolving nature of climate risks. While the physical and transition aspects of climate change are interrelated, the two types of risk often move independently from one another. For example, US climate policy risk was arguably relatively low under President Trump, who rolled back more than 100 environmental regulations by the end of his four-year term, while physical risks increased sharply amid a historic number of billion-dollar climate disasters across the US in the years under his administration[5].

With this in mind, we construct indices of climate transition risk and physical risk using information embodied in more than 100,000 climate-related news articles published since 2000 in The New York Times (NYT) and The Guardian – two major daily news platforms with leading international readership. Our indices capture public awareness of climate-related risks, with the underlying assumption

[5] See: https://www.climate.gov/news-features/blogs/beyond-data/2018s-billion-dollar-disasters-context, https://www.climate.gov/news-features/blogs/beyond-data/2020-us-billion-dollar-weather-and-climate-disasters-historical and https://www.nytimes.com/interactive/2020/climate/trump-environment-rollbacks-list.html.

that intensified news reporting occurs when events containing relevant information take place and increases the perceived relevance of such risks in the eyes of the public. We refer to these indices as measures of climate risk for simplicity. To quantify the extent of news coverage on our topics of interest, we look for occurrences of terms related to transition and physical risks using lexicons which we compile by looking through the words and word combinations in our sample of articles.

Our climate physical risks lexicon comprises of 199 terms related to: i) extreme climate and weather conditions and natural disasters (e.g. "*flood*", "*extreme weather*", "*record heat*"), ii) slower-moving physical phenomenon related to global warming (e.g. "*sea levels rising*", "*melting glaciers*", "*temperatures rising*"), and iii) broad references to the damaging impacts of climate change (e.g. "*environmental destruction*", "*climate hazard*", "*climate instability*"). Meanwhile, our climate transition risks lexicon comprises of 634 terms related to: i) general actions targeting climate change (e.g. "*climate action*", "*reduce emissions*", "*cut greenhouse"*), ii) specific mechanisms and policy / legal terms (e.g. "*climate change bill*", "*cap-and-trade system*", "*carbon pricing*"), iii) adjectives relating to environmental improvement (e.g. "*green*", "*renewable*", "*energy efficiency*"), and iv) references to climate-related summits / conferences (e.g. "*Kyoto protocol*", "*climate conference*", "*Paris agreement*"). Charts 2 and 3 provide a visualisation of the top terms in our lexicons in the form of word clouds, where term size is proportional to the frequency of appearance in the corpus of articles.

Chart 2: Climate physical risks lexicon

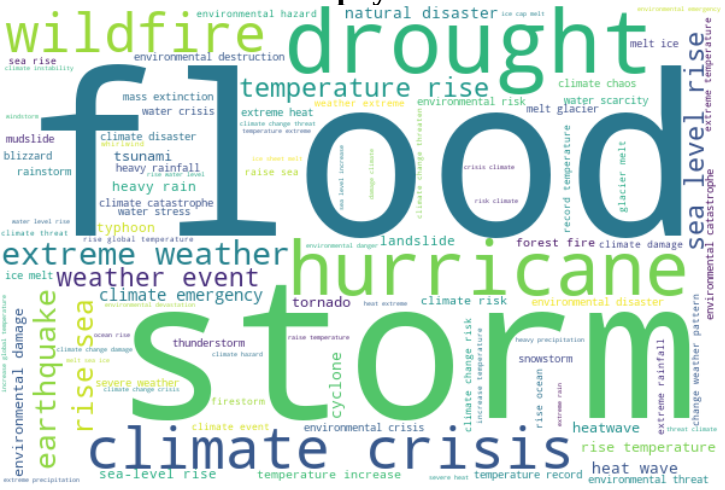
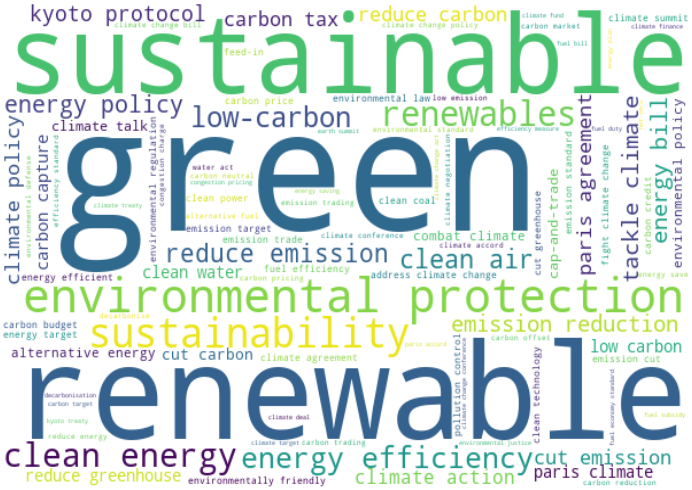


Chart 3: Climate transition risks lexicon



Sources: The New York Times, The Guardian, and author's estimates.
Note: term size is proportional to frequency of appearance in the corpus of articles; words are first lemmatised (e.g. temperatures rising → temperature rise); only the most frequent 100 words in each lexicon are shown for simplicity.

Charts 4 and 5 present our indices of physical risks and transition risks, respectively. The physical risks index shows large spikes during months when major

natural disasters occurred around the world, such as floods in Europe, drought in East Africa, hurricanes and wildfires in the US, and typhoons in Asia. Attention-grabbing extreme weather events often serve as wake-up calls alerting the public to climate change risks (Choi, Gao and Jiang (2021)), despite the difficulty of attributing any individual natural disaster directly to climate change. Similarly, the transition risks index exhibits visible peaks during months of significant events with implications for global climate policy, such as international agreements on climate change in Copenhagen and Paris, and the US's withdrawal from the Kyoto and Paris treaties.

Chart 4: Climate physical risks index

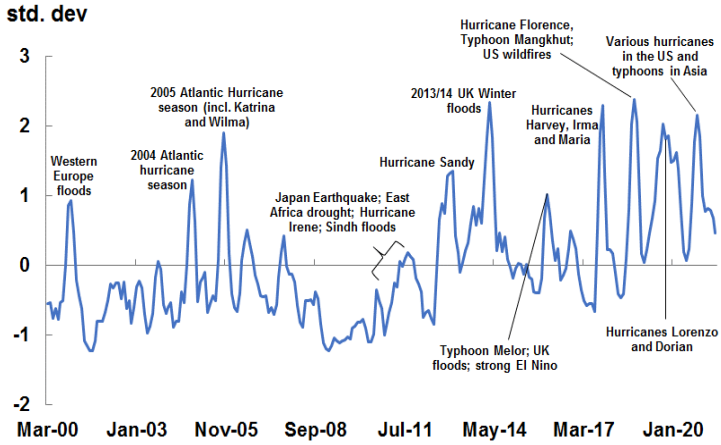
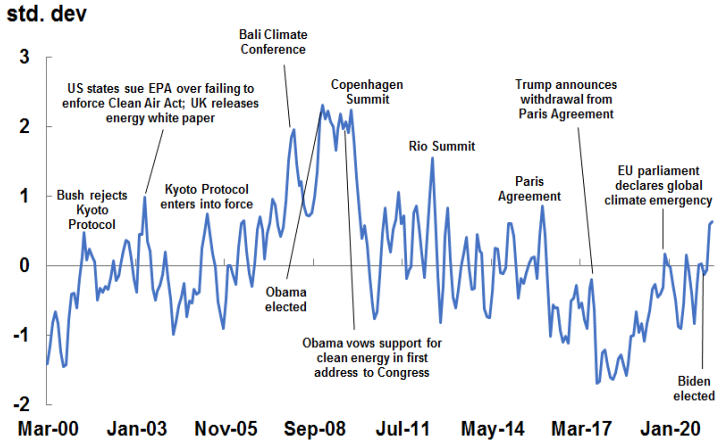


Chart 5: Climate transition risks index



Sources: The New York Times, The Guardian, and author's estimates.
Note: indices shown are normalised and in 3-month moving averages.

It should be noted that a higher level of the transition risks index represents heightened public awareness of policy risks, but does not necessarily translate into tighter climate policy (although this is most often the case). For example, the index features a small spike in the month when President Trump announced the US's withdrawal from the Paris Agreement, marking a move towards looser climate policy in the US. However, this event also arguably boosted global awareness of climate policy risks as it invited widespread condemnation from political leaders, business executives and environmentalists around the world, and increased discussion of climate policy-related topics in the news[6]. Similarly, a higher level of the physical risks index represents heightened public awareness of the physical risks of climate change, but does not necessarily indicate an increase in future physical risks faced by firms.

These indices are intended to be measures of global, rather than location- or firm-specific, perceived transition and physical risks, as reporting by The

[6] See, for example: https://www.nytimes.com/2017/06/01/climate/trump-paris-climate-agreement.html and https://www.nytimes.com/2017/06/02/climate/paris-climate-agreement-trump.html.

NYT and The Guardian is targeted at an international audience. We focus on major developments around the world rather than domestic ones only reported in local newspapers due to the global nature of climate change and the importance of multilateral efforts (e.g. the UN Climate Change Conferences) in driving national climate policies. Furthermore, it is conceivable that physical phenomenon related to climate change reported in The NYT and The Guardian could increase one's perception of physical risks even if they do not take place in one's home country. For example, The NYT and The Guardian's reporting of record-breaking heatwaves in North America and rainfall in China in the summer of 2021 likely raised awareness of the physical risks associated with climate change around the world. As pointed out by Ardia et al. (2021), most people do not directly experience the physical impacts of climate change, and media plays an important role in communicating the informational content about climate change to the public.

III. ASSESSING INVESTOR SENSITIVITY TO CLIMATE RISKS

3.1 Methodology

Using the indices outlined above, we estimate a stock returns model with monthly equity price data from January 2000 to May 2021 to explore whether investors are sensitive to changes in climate-related physical and transition risks, and whether they distinguish between "green" versus "brown" firms. Specifically, we estimate the following panel regression, including company fixed effects to control for any time-invariant firm characteristics that could be correlated with environmental performance and equity returns:

$$\begin{aligned} \textit{Firm return}_{i,t} = \alpha_i + \beta_1 \Delta\textit{Transition risks index}_t + \beta_2 \Delta\textit{Physical risks index}_t + \\ \beta_3 \textit{Environmental activity}_{i,t-12} + \beta_4(\Delta\textit{Transition risks index}_t * \textit{Environmental activity}_{i,t-12}) + \\ \beta_5(\Delta\textit{Physical risks index}_t * \textit{Environmental activity}_{i,t-12}) + \beta_6 \textit{Controls}_{i,t} + \varepsilon_{i,t} \end{aligned} \quad (1)$$

Where $\textit{Firm return}_{i,t}$ is firm i's equity return in month t, α_i is the firm fixed effect, and $\Delta\textit{Transition risks index}_t$ and $\Delta\textit{Physical risks index}_t$ are changes in the indices of climate transition risks and physical risks, respectively, between month t-1 and t. $\textit{Environmental activity}_{i,t-12}$ is a generic term representing firm i's lagged environmental activity, taking the form of six dummy variables that we construct using annual data from Refinitiv Eikon and Trucost: i) emissions disclosure dummy (representing firms with non-zero emissions disclosure), ii) target emissions dummy, iii) policy emissions dummy, iv) high ESG score dummy (representing firms with an

ESG score in the upper quartile), v) carbon efficient dummy (representing firms with total emissions intensity in the lower quartile), and vi) carbon inefficient dummy (representing firms with total emissions intensity in the upper quartile)[7].

The first three environmental activity dummy variables represent firms' environmental efforts, whether it be disclosing some form of emissions data or implementing an emissions target or policy. Meanwhile, the last three dummy variables are related to firms' actual environmental performance – notably, the ESG score and emissions intensity. For emissions intensity, we look at both the lower and upper quartiles representing less and more carbon-intensive firms, respectively. Therefore, the first five dummy variables act as proxies for whether a firm is "green", as a value of 1 indicates firms' efforts or outperformance in relation to environmental factors, while the final variable proxies for whether a firm is "brown". See Table A1 in the Appendix for a detailed description of the variables used in our estimation, including controls.

Our coefficients of interest are β_4 and β_5, which represent the elasticity of asset prices to climate transition and physical risks, respectively, for firms with varying degrees of environmental activity. As the environmental measures can proxy for firms' exposure to climate transition risks, we expect green firms to outperform brown ones when perceived transition risks increase (i.e. a positive β_4) due to investors readjusting their expectations of firms' cash flows resulting from potential revisions to government policy that may favour (penalise) green (brown) firms. On the other hand, as the measures cannot proxy for firms' exposure to climate physical risks, the discrepancy between green versus brown firms when perceived physical risks increase is expected to be less apparent. That being said, green firms may outperform brown ones in response to rising physical risks if, for example, heightened concern over the physical impacts of climate change lead investors to shift their preferences towards greener firms (Pastor, Stambaugh and Taylor (2021)), leading to a positive β_5.

Our model aims to explore the overall sensitivity of equity returns to climate risks, rather than explicitly measure the presence of any mispricing of climate risk. As our sample is comprised of companies from a number of different economies featuring different degrees of financial segmentation and frictions, we opt for a characteristic-based approach following Bolton and Kacperczyk (2020), as opposed

[7] We transform continuous variables such as the ESG score and GHG emissions intensity into quartile dummies to facilitate interpretation of the coefficients on the interaction terms; this quartile-split is done by sector (and year) to avoid the results being driven entirely by the highest emitting sectors.

to a risk factor-based portfolio approach which has been commonly used in the literature to measure risk premia in a single economy. Furthermore, empirically confirming a climate risk premium requires disentangling unexpected climate shocks from the realised returns, which is notoriously difficult; failure to account for the unexpected component may lead to inaccurate classification of mispricing (Pastor, Stambaugh and Taylor (2021))[8].

3.2 Equity prices fall in response to rising climate risks, with green firms outperforming

We first estimate the model outlined in equation (1) *excluding indicators of environmental performance*, to explore the unconditional effects of climate risks on equity prices using our indices. Increases in both climate indices are statistically significantly associated with negative stock returns, on average, as shown by the solid-coloured (representing a statistically significant effect), negative blue and orange bars in Chart 6, providing evidence that investors are sensitive to global transition and physical risks. The reaction to changes in physical risks (in orange), however, is modest compared to its policy counterpart (in blue), potentially due to investors placing greater importance on local rather than global climate physical risks as our index only captures the latter.

With evidence of global equity prices reacting negatively to climate-related risks, we next explore whether this relationship is influenced by firms' environmental performance. Chart 7 shows estimates from our model with indicators of environmental activity and their interactions with the climate indices now included. Each pair of blue and orange bars represents equity return sensitivity to increases in the transition and physical risks indices, respectively, for firms in the green/brown categories specified along the x-axis (β_4 and β_5 from equation (1)). For example, the leftmost pair of bars shows the equity return sensitivity to changes in the two climate indices for firms that have set an emissions target. We can see from the positive and solid-coloured bars for green firms that environmental efforts are rewarded by the market when perceived climate risks increase. Simply the act of disclosing emissions

[8] Ex-post realised returns are commonly used in the literature as a proxy for expected returns, neglecting the unexpected component that can significantly impact green / brown firms' realised returns. As theory predicts lower (higher) expected returns for green (brown) stocks which are better (worse) climate hedges, green (brown) stocks outperformance (underperformance) may be incorrectly interpreted as mispricing when it is really reflecting reactions to unanticipated increases in environmental concerns. Insofar as changes in our indices can capture climate concern shocks, the coefficient on environmental performance (β_3) can be interpreted as a proxy of the climate risk premium. Indeed, our findings show that while green (brown) firms tend to underperform (outperform) during normal times (periods with no changes in climate concerns as captured by our indices) in line with theory, green (brown) firms outperform (underperform) in response to rising perceived climate risks, highlighting the importance in disentangling the two effects.

information and setting emissions targets and policies (regardless of actual performance) distinguishes some companies from others, as shown by the leftmost three pairs of bars. More sustainable firms characterised by higher ESG scores (shown in the fourth set of bars) also outperform when there are changes to climate-related transition risks.

Chart 6: Equity return sensitivity to increases in the climate risk indices

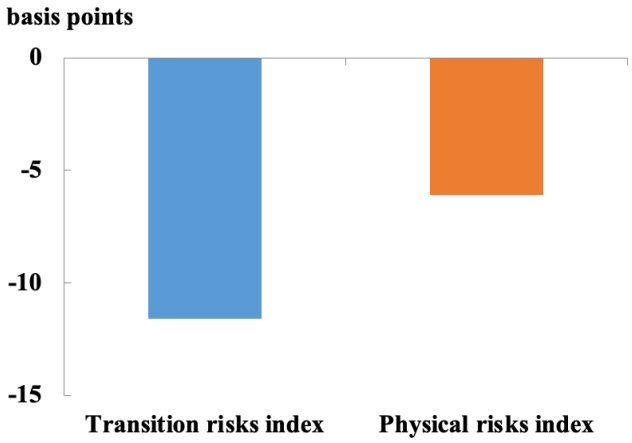
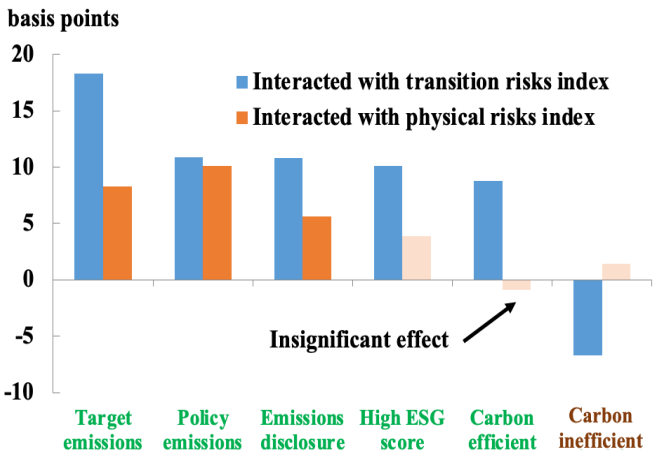


Chart 7: Equity return sensitivity to increases in the climate risk indices: green versus brown firms



Note: statistically significant (at 5% or above) results are shown in solid colours, while insignificant results are shown in shaded/more transparent colours; % change in climate indices are normalised.

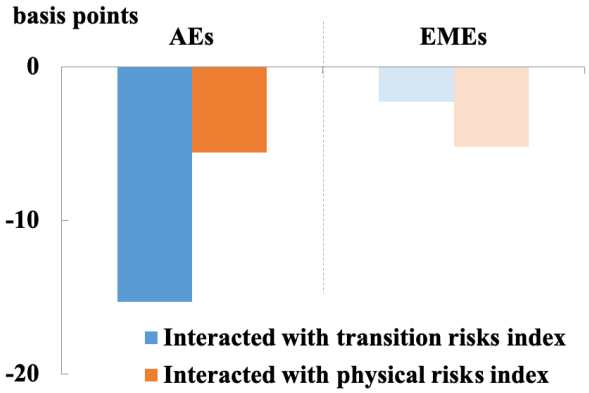
Emissions intensity is another important driver of stock price movements, but only when interacted with changes in the transition risk index, consistent with investors updating their expectations about firms' future cash flows resulting from potential government regulation (e.g. an emissions tax) when perceived policy risks increase. Carbon inefficient / "brown" companies (shown in the rightmost pair of bars) are penalised by the market with their stock prices underperforming when transition risks increase, while carbon efficient ones (shown in the fifth pair of bars) outperform, in line with the findings of Ardia et al. (2020) and others. As carbon efficiency differs substantially across industries, a natural concern could be that our results are driven disproportionately by sectors that are traditionally viewed as "dirty", such as Utilities and Energy (Bolton and Kacperczyk (2021)). Re-running our regressions excluding these two sectors shows that our findings continue to hold, suggesting the empirical relationships we document are not exclusive to the highest-emitting sectors[9].

[9] Results not shown by brevity, but are available upon request.

3.3 Investor sensitivity to climate risks and environmental performance is modest in EMEs compared to AEs

If we break down our sample by firms headquartered in AEs versus EMEs, it becomes apparent that the full-sample stock price reaction to climate risks documented in Chart 6 is driven by AE companies. Chart 8 shows the equity return sensitivity of AE and EME firms to changes in the global transition and physical risks indices. While the impact is negative and significant for AE firms, there appears to be no significant effect for EME corporates (as shown by the shaded / more transparent bars on the right hand side), pointing to a relatively low level of climate risk sensitivity among investors in EME markets. This result is not driven by differences in the industrial composition of AE and EME firms, as our AE and EME sub-samples are both broadly distributed across all eleven GICS sectors.

Chart 8: Equity return sensitivity to increases in the climate risk indices: AEs vs. EMEs



Note: statistically significant (at 5% or above) results are shown in solid colours, while insignificant results are shown in shaded/more transparent colours; % change in climate indices are normalised.

We next compare the equity pricing implications of being green versus brown for firms headquartered in the two types of economies. Chart 9 presents our main findings for AE firms; we can see that indicators such as GHG disclosure, emissions targets and policies, ESG scores and emissions intensity are all important determinants of how the stock prices of AE firms react to changing climate risks, with the significance and sign of the bars more or less mirroring the full sample results. For EMEs shown in Chart 10, however, outperformance (underperformance) of green (brown) firms is modest when compared to their AE peers, with most measures of environmental activity registering an insignificant effect. One common theme across AE and EME markets is the higher stock price penalty incurred by carbon inefficient firms during periods of rising transition risks (the solid-coloured,

negative rightmost blue bar in each chart), suggesting the traditional "brown" measure of high carbon intensity acts as an important indicator of firm susceptibility to transition risk.

Chart 9: *AE* firms' equity return sensitivity to increases in the climate risk indices: green versus brown firms

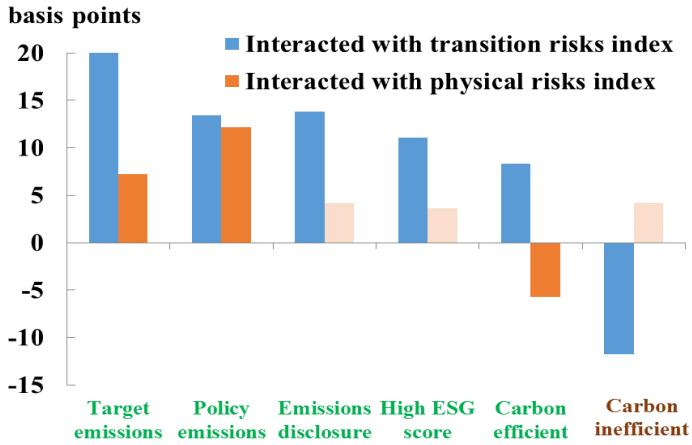
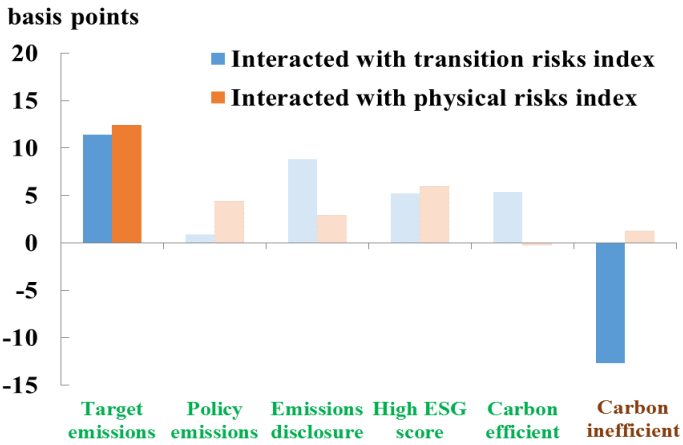


Chart 10: *EME* firms' equity return sensitivity to increases in the climate risk indices: green versus brown firms



Note: statistically significant (at 5% or above) results are shown in solid colours, while insignificant results are shown in shaded/more transparent colours; % change in climate indices are normalised.

If we break down this carbon inefficient dummy using its respective scope measures, we can see that investors in AE firms are sensitive to not only the direct emissions (scope 1), but also emissions that are not directly controlled by the firm such as those resulting from upstream supply chain activities (scope 3) which often account for the largest quantity of a company's emissions footprint (Chart 11). In the case of EMEs, however, while high *direct* emissions are heavily scrutinised, investors appear to overlook firms' scope 3 emissions (Chart 12). This raises concerns of greenwashing in EMEs, as firms could simply outsource their high-emitting activities to improve their environmental footprint in the eyes of investors.

Chart 11: *AE* firms' equity return sensitivity to increases in the climate risk indices: carbon inefficiency

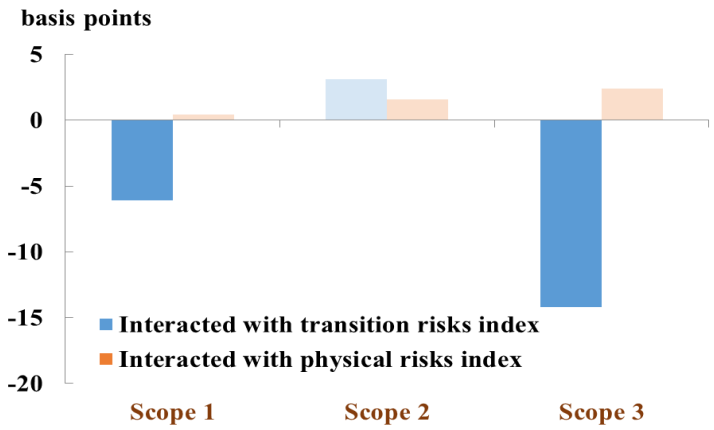
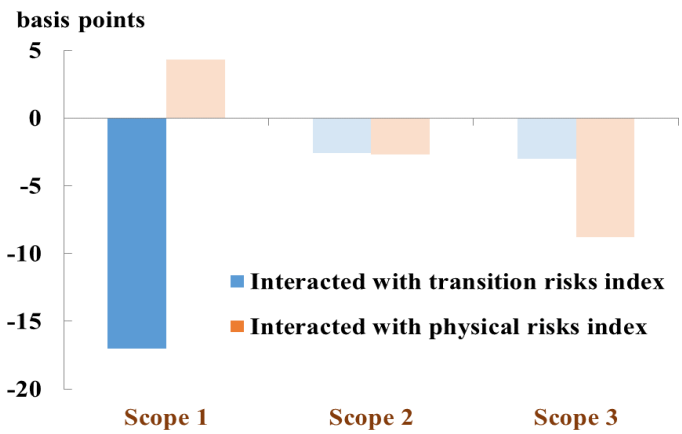


Chart 12: *EME* firms' equity return sensitivity to increases in the climate risk indices: carbon inefficiency



Note: statistically significant (at 5% or above) results are shown in solid colours, while insignificant results are shown in shaded/more transparent colours; % change in climate indices are normalised.

Taken together with our earlier findings, our results point to a relatively low level of climate-risk sensitivity among investors in EME markets, where firms remain in the early stages of ESG integration (recall Chart 1). However, EMEs are arguably more vulnerable to climate change, with limited public disaster relief funds, fiscal constraints, and a lack of well-developed insurance markets. Figures from the IMF show that the average share of uninsured losses from climate-related disasters between 2009-2018 was nearly 90% in emerging market developing economies ('EMDEs') compared to around 30% in AEs, suggesting emerging markets face significantly greater physical risks associated with climate change (Chart 13). Furthermore, international efforts to combat global warming present significant challenges to EMEs' fossil-fuel dependent industries. Although the situation has improved over the last 15 years, EME corporates still tend to be less carbon efficient than their AE peers, making the low-carbon transition more difficult (Chart 14).

While all of these factors suggest investors in EME firms should be paying closer attention to climate-related risks, our findings provide only limited evidence of climate-risk sensitivity in EME stock markets. This could reflect investors placing greater emphasis on *local* climate developments, as our indices tend to capture *global* events spearheaded by major AEs. Even if this is the case, however, climate-related physical and policy developments on the global stage, and in AEs, are nonetheless highly relevant to EME corporates, as they influence domestic policy direction and local awareness of climate risks, as well as international capital flows and trade. As such, our findings suggest that EME equity prices may not be reflecting the extent of climate-related risks that firms in these economies face.

Chart 13: Share of uninsured losses from climatic disasters, 2009-2018 average

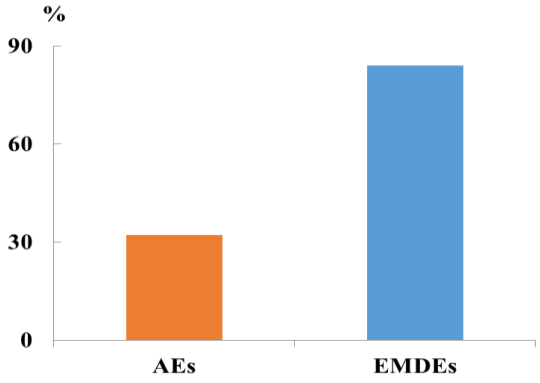
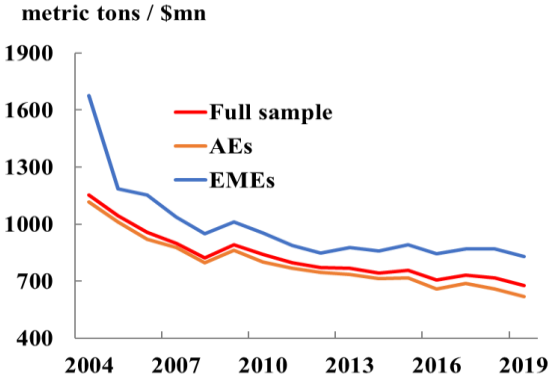


Chart 14: Emissions intensity, sample median



Sources: IMF April 2020 GFSR, Trucost, Capital IQ, and author's calculations.

This represents a potential vulnerability for financial stability, as a sudden shift in investor expectations or sentiment over these risks could trigger sharp financial losses across a broad range of financial assets. Our findings therefore highlight the need for increased effort to boost awareness of climate-related risks among investors of EME firms. Furthermore, climate-sensitive investors may avoid EME markets if they face greater hurdles in allocating capital in a sustainable manner, as these economies may lack the resources needed to break their dependency on cheaper fossil fuels and often have other important priorities. As green solutions and tackling climate change increasingly dominate the agendas of global investors, however, scaling up integration of environmental factors will also be crucial for EMEs to broaden their investor base and achieve their sustainable development goals.

3.4 Case study: EM Asia, Hong Kong SAR, and Singapore

If we narrow our scope to EM Asia, we find that, similar to the overall EME case, equity investors exhibit limited sensitivity to climate-related risks and their interactions with environmental activity, suggesting room for improvement in terms of ESG integration[10]. Focusing on the traditional emissions disclosure and carbon intensity indicators, results show that disclosing emissions data and the level of carbon intensity have little to no bearing on the stock price fluctuations of EM Asian corporates when climate-related risks increase.

In the region's leading financial centres – Hong Kong and Singapore, Hong Kong firms disclosing emissions information are rewarded by the market and carbon inefficient firms are penalised when transition risks increase, while investors in Singaporean firms appear insensitive to these indicators (Chart 15). This discrepancy likely reflects Hong Kong's significant improvements in emissions disclosure in recent years (Chart 16), following the Paris Agreement and the implementation of a new Companies Ordinance in 2014, which required all Hong Kong incorporated companies to include a discussion of their environmental performance in their annual reports[11]. These developments arguably reduced information asymmetry and facilitated the assessment of carbon transition risk among investors in Hong Kong firms.

[10] Results (unreported for brevity) are based on an expanded sample of firms headquartered in South Korea, Mainland China, Taiwan, Thailand, Malaysia, Indonesia, Vietnam, and the Philippines.

[11] Meanwhile, the Singapore Exchange introduced sustainability reporting on a 'comply-or-explain' basis to its listing rules in 2016. See: https://www.hkex.com.hk/-/media/HKEX-Market/News/Market-Consultations/2011-to-2015/July-2015-Consultation-Pape/Consultation-paper/cp201507.pdf, https://www.sgx.com/regulation/sustainability-reporting, and https://www.arx.cfa/-/media/regional/arx/post-pdf/2019/08/04/esg-disclosures-in-asia-pacific.ashx.

Chart 15: Hong Kong and Singaporean firms' equity return sensitivity to increases in the climate risk indices

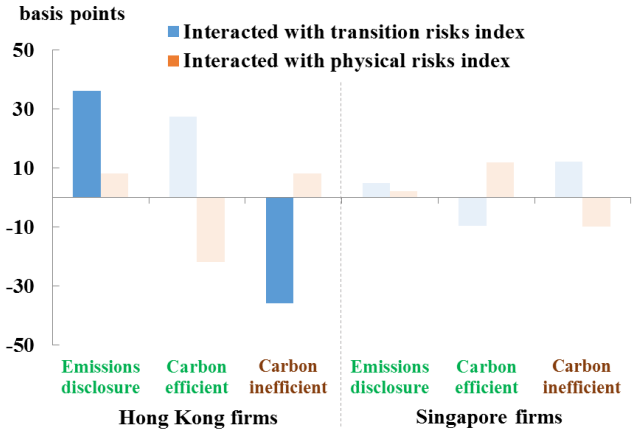
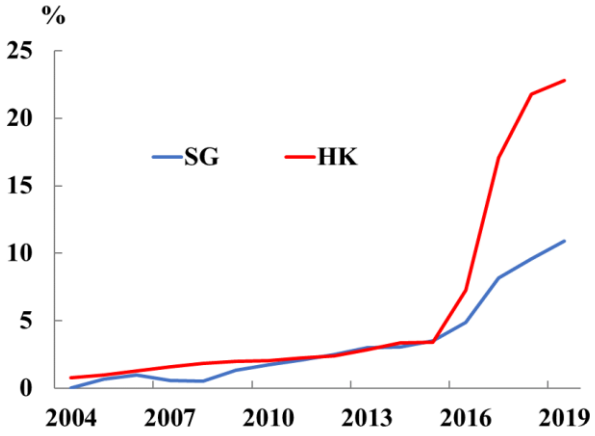


Chart 16: Emissions disclosure, sample share: Hong Kong (HK) versus Singapore (SG)



Sources: Trucost and author's estimates.
Notes: statistically significant (at 5% or above) results are shown in solid colours, while insignificant results are shown in shaded/more transparent colours; % change in climate indices are normalised.

IV. CONCLUSION

Using news-based indices of climate-related transition and physical risks, this paper explores the sensitivity of global equity market investors to different types of climate risk and whether this relationship depends on firms' environmental activity and performance. We find that increases in the public's perceived level of either type of risk are associated with negative equity returns. Being "green" ("brown") is also rewarded (penalised) by the market, with investors scrutinising firms' environmental efforts and performance during periods of shifting climate risks. Simply the act of disclosing emissions information and setting emissions targets or policies, regardless of actual performance, distinguishes certain firms from others. Meanwhile, ESG ranking and emissions intensity are important drivers of stock market fluctuations, with higher-ESG-scoring and more-carbon-efficient firms yielding positive equity returns relative to other firms when climate-related risks increase. The market also penalises high-emitting companies, with less carbon-efficient firms underperforming.

Subsample analyses reveal that these findings are mainly driven by AE companies, with the stock prices of EME firms only modestly sensitive (if not insensitive) to climate-related risks and their interactions with environmental performance. This stands in stark contrast to the fact that EMEs are most at risk of the consequences of climate change, raising concerns of disorderly financial market repricing when investors eventually come to terms with the very real threat that global warming poses to firms in these economies. Our results highlight the importance for EMEs to scale up ESG integration and boost awareness of the virtues

of "green" efforts and performance among investors of EME firms. Indeed, in the case of Hong Kong, rapid improvement in emissions disclosure has coincided with heightened investor scrutiny of firms' carbon disclosure and intensity, suggesting corporate disclosure and dissemination of environmental data can facilitate the assessment of climate-related risks.

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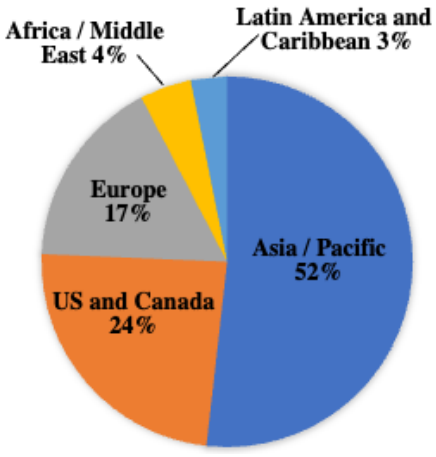
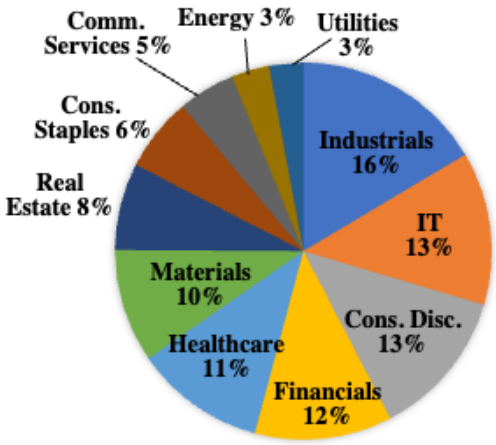
APPENDIX

Chart A1: Sample characteristics

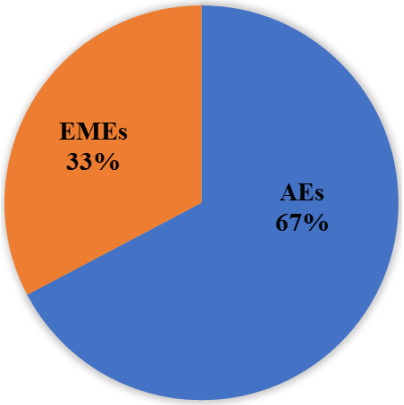
i. Region breakdown



ii. Sector breakdown



iii: Economy type breakdown



Sources: Capital IQ and author's estimates.

Table A1: Variable Descriptions

Variable	Description	Data source
Firm return	Monthly % change in firm's equity last sale price	Capital IQ
Controls		
Market Return	Monthly % change in equity benchmark index	Bloomberg
Market cap	Log of monthly average of firm's market capitalisation	Capital IQ
PBV	Monthly average of firm's price-to-book value ratio, winsorised	Capital IQ
ROA	Quarterly firm's return-on-assets (%), winsorised	Capital IQ
Leverage	Quarterly firm's ratio of total liabilities to total assets, winsorised	Capital IQ
Capex-assets	Quarterly firm's ratio of capital expenditures to total assets (%), winsorised	Capital IQ
Momentum	Firm's cumulative stock return over previous one-year period, winsorised	Capital IQ
Volatility	Standard deviation of firm's returns based on past 12 months of monthly returns, winsorised	Capital IQ
Environmental indicators		
Emissions disclosure dummy	Dummy = 1 if the firm has a non-zero weighted GHG disclosure score. The weighted GHG disclosure score represents the proportion of scope 1 emissions external costs which are disclosed by the company. If a company discloses its scope 1 emissions (e.g. 2,000 tCO2e emissions) but not its scope 2 emissions (so Trucost estimates them as, e.g., 18,000 tCO2e emissions), the company's carbon weighted disclosure would be 10% (i.e. 10% of the company's carbon emissions are disclosed).	Trucost
Target emissions dummy	Dummy = 1 if the firm has set targets or objectives to be achieved on emission reduction.	Refinitiv Eikon
Policy emissions dummy	Dummy = 1 if the firm has a policy to improve emissions reduction.	Refinitiv Eikon
ESG score upper-quartile dummy	Dummy = 1 if the firm's ESG score is in the upper quartile compared to firms in the same sector.	Refinitiv Eikon

	The ESG score is an overall company score constructed by Refinitiv based on self-reported information in the environmental, social and corporate governance pillars.	
Total emissions intensity upper(lower)-quartile dummy	Dummy = 1 if the firm's total (scope 1, 2 and 3-upstream) emissions as a share of revenue (in tonnes per million) is in the upper(lower) quartile compared to firms in the same sector	Trucost
Scope 1 emissions intensity upper(lower)-quartile dummy	Dummy = 1 if the firm's scope 1 emissions as a share of revenue is in the upper(lower) quartile compared to firms in the same sector. Scope 1 emissions comprise of GHG emissions from sources that are owned or controlled by the company (categorised by the greenhouse gas protocol).	Trucost
Scope 2 emissions intensity upper(lower)-quartile dummy	Dummy = 1 if the firm's scope 2 emissions as a share of revenue is in the upper(lower) quartile compared to firms in the same sector. Scope 2 emissions comprise of GHG emissions from consumption of purchased electricity, heat or steam by the company (categorised by the GHG protocol).	Trucost
Scope 3 emissions intensity upper(lower)-quartile dummy	Dummy = 1 if the firm's scope 3 upstream emissions as a share of revenue is in the upper(lower) quartile compared to firms in the same sector. Scope 3 upstream emissions comprise of GHG emissions from other upstream activities not covered in scope 2 (categorised by the GHG protocol).	Trucost