UNIMORE
UNIVERSITÀ DEGLI STUDI DI MODENA E REGGIO EMILIA
Dipartimento di Economia Marco Biagi

DEMB Working Paper Series

N. 237

Climate risk definition and measures: asset pricing models and stock returns

Alessio Capriotti[1], Andrea Cipollini[2], Silvia Muzzioli[3]

April 2024

[1] University of Modena and Reggio Emilia, Department of Economics "Marco Biagi"
Email: Alessio.capriotti@unimore.it
[2] Department of Economics, Management and Statistics, University of Palermo and CEFIN
Email: andrea.cipollini@unirc.it
[3] University of Modena and Reggio Emilia, Department of Economics "Marco Biagi" and CEFIN
Email: silvia.muzzioli@unimore.it

ISSN: 2281-440X online

Finanziato dall'Unione europea NextGenerationEU | Ministero dell'Università e della Ricerca | Italiadomani Piano Nazionale di Ripresa e Resilienza | UNIMORE Università degli Studi di Modena e Reggio Emilia

Climate risk definition and measures: asset pricing models and stock returns

Alessio Capriotti[a], Andrea Cipollini[b] and Silvia Muzzioli[c]

Abstract

The aim of this study is to examine the literature on climate risk definition and measures and the impact of climate risk on stock returns. We review how asset pricing models (and their testable implications) consider climate risk as a residual systemic risk driver in excess of either standard market risk factors or latent factors identified with business and financial cycles. Firms less exposed to transition risk, in equilibrium, should face a lower cost of equity financing, given an expected return lower than the one associated with pollutant firms. The existence of a recent outperformance of realized returns on green stocks can be reconciled with unexpected shifts in investors tastes for green assets. Finally, we identify some issues regarding the empirical approach and suggest several potential areas for future research.

---

[a] *Marco Biagi Department of Economics, University of Modena and Reggio Emilia, Italy. Email:* **alessio.capriotti@unimore.it**

[b] *Department of Economics, Management and Statistics, University of Palermo and CEFIN, Italy,* **andrea.cipollini@unipa.it.**

[c] *Corresponding author. Marco Biagi Department of Economics and CEFIN, University of Modena and Reggio Emilia, Italy. Email:* **silvia.muzzioli@unimore.it**

1. Introduction

Climate change has effects on the real economy and, consequently, on the financial system. Business activities and consumption patterns are influenced by physical risk and transition climate risk. Extreme weather events, with increasing frequency, have a strong impact on real economic activity through different transmission channels and require policymakers' action to mitigate and to adapt to climate change. Although the macroeconomic implications of climate risk have been highlighted 50 years ago by Nordhaus (1977), divergent positions expressed by various developing countries at COP28 held in 2023 still imply that it is a challenge nowadays to negotiate and coordinate, at global level, responding actions to contrast the systemic feature of climate risk. More recently, the literature on green finance has developed voluminously. In this review, we focus on the different studies exploring the contribution of investments in stock market to hedge climate risk and to finance the transition to a low carbon economy.

In Section 2 we present some evidence on extreme weather events related to climate change and greenhouse gas (GHG) emissions, the primary drivers of the ongoing change. In Section 3 we present the definition of climate risk in the financial context. In Section 4 we outline a definition of ESG, their usage, and their associated challenges. In Section 5 and in Section 6 we describe the main theoretical models and empirical methods, respectively, used to assess the climate risk impact on stocks differently exposed to transition to a low carbon economy. In Section 7 we review the implications of climate risk on financial stability. Section 8 concludes, suggesting future avenues of research.

2. Climate change: overview and data

Climate change refers to long-term changes in temperatures and weather patterns. These changes can be natural, resulting from variations in solar activity or major volcanic eruptions. However, since the 1800s, human activities have been the primary driver of climate change, mainly due to the use of fossil fuels such as coal, oil, and gas[1]. As reported by the Environmental Protection Agency (EPA) in 2023[2] most of the Earth's warming since 1950 has been caused by human emissions (accounting for over 95%) of greenhouse gases (GHG). Greenhouse gases result from various human activities, including the combustion of fossil fuels for heat and energy, deforestation, fertilisation of crops, waste disposal in landfills, livestock farming, and the production of certain types of industrial

---

[1] The definition is provided by United Nation, available at: https://www.un.org/en/climatechange/what-is-climate-change

[2] In recent times, EPA have concluded the last study, titled *Draft Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-2022*. The new article is available at the following link: https://www.epa.gov/ghgemissions/draft-inventory-us-greenhouse-gas-emissions-and-sinks-1990-2022.

products. EPA (2023) showed that – in the United States, using data updated to 2021, 28% of greenhouse gas emissions are attributed to the transportation sector, followed by the energy production industries at 25%. The industrial sector is responsible for 23%, the commercial and residential sector for 13%, and finally, the agricultural sector for the remaining 11%.

Figure 1 illustrates the historical evolution of the number of climate-related extreme events, based on a survey conducted by *EM-DAT: The International Disaster Database*. The original dataset contains information on the occurrence and impacts of over 26.000 mass disasters worldwide from 1900 to the present, categorised by individual countries, regional and continental membership. A "mass disaster" is defined as a situation or event that overwhelms local capacities, necessitating external support at the national or international level: in summary, an unforeseen and often sudden event that causes significant damage, destruction, and human suffering. The count includes climatological, hydrogeological, and meteorological phenomena, grouped by continent and excluding technological disasters. The disastrous events considered are related to droughts, extreme temperatures, floods, landslides, storms, fires and the empirical evidence points to a strong increasing trend in climate-related extreme events for some continents such as Africa, Asia, and the Americas. **Figure 2**, on the other hand, represents the evolution of some globally recorded climate-related extreme phenomena. The extreme events have become more frequent and persistent and the observations based on EM-DAT dataset have been modelled through a Poisson probability distribution by Hale (2022).

Figure 3 plots temperature anomalies (proxied by deviation from a long-term average) recorded from 1880 to 2023, showing that, since the '80s, the annual temperature deviation from the average has been consistently positive[3]. In particular, in 2023, the anomaly of the global temperature of the Earth's land and ocean surface reached 1.17 degrees Celsius above the 20th-century average.

While extreme events and weather anomalies are used to measure physical climate risk, greenhouse gases (GHGs) are used to measure transition climate risk. GHGs include carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), chlorofluorocarbons (CFCs), ozone (O_3), and water vapour (H_2O). CO_2 is the primary greenhouse gas resulting from the combustion of fossil fuels, industrial activities, and alterations in land use. In 2021, CO_2 accounts for approximately 75.32% of GHGs, according to *Our World in Data*[4] and, for this reason, it is typically used as a proxy for GHGs in empirical analysis.

---

[3] The data and other information are available at https://climate.nasa.gov/vital-signs/global-temperature/

[4] See: https://ourworldindata.org/greenhouse-gas-emissions

However, it is crucial to consider the classification made by *The Greenhouse Gas Protocol* regarding three different categories of emissions, defined as Scope 1, Scope 2, and Scope 3. Synthetically, Scope 1 refers to emissions originating from sources owned or controlled by the company and it includes emissions from combustion in owned or controlled equipment such as boilers, furnaces, vehicles, and chemical production processes. On the other hand, Scope 2 accounts for GHG emissions associated with the generation of purchased electricity consumed by the company. This includes electricity purchased or brought into the company's organisational boundary. Scope 2 emissions physically occur at the location where electricity is generated. Finally – residually – Scope 3 emissions result from the company's activities but originate from sources not owned or controlled by the company. For instance, Scope 3 activities are related to the extraction and production of purchased materials, transportation of purchased fuels, and the use of sold products and services.

As noted by Bolton e Kacperczyk (2021), only two data providers (Trucost and ISS ESG) store data related to Scope 3. Regardless of the classification, it is essential to emphasise that, whenever greenhouse gases (GHGs) or, more simply, CO_2 are used, they need to be normalized since in absolute terms, the values in tons of CO_2 emitted by the *i-th* company are not particularly informative. Therefore, a measure of the level of GHG or CO_2 emissions for a country is computed as the ratio between emissions and population (per capita emissions). **Figure 4** shows the evolution of CO_2 emission for countries belonging to BRICS and other advanced countries while **Figure 5** the CO_2 emissions per capita for the same countries. If it is true that Brazil, China, and India (developing countries) are experiencing a growing quantity of CO_2, and that China has surpassed the United States' emissions in the last decade - even though the United States, along with other advanced countries, is reducing CO_2 emissions - in relative terms, advanced countries have much higher emissions per capita compared to the BRICS, albeit with a decreasing trend.

3. Climate risk

Physical risk and transition risk are the main feature of climate risk. Physical risks are those associated with the (increasing) probability of extreme events related to climate change. They can be categorised into:

(a) Acute Physical Risk: refers to those driven by events, including the heightened severity of extreme weather events such as cyclones, hurricanes, heatwaves, cold spells, or floods.

(b) Chronic Physical Risk: relates to long-term changes in climate patterns (e.g., prolonged higher temperatures, sea level rise, changes in precipitation patterns) that can lead to chronic heat waves or rising sea levels.

Physical risks, especially acute, can have a strong negative effect on companies. For instance, a company operating in a flood-prone geographic area, once the extreme event occurs, will incur in losses of physical and human capital, disruption and/or slowdown of production activities, and damage to the company's reputation. Physical risks can have financial implications for organizations, manifesting as direct damages to capital and indirect impacts arising from supply chain disruptions or changes in the availability, sourcing, quality of water and food security. Furthermore, extreme temperature changes can affect the ergonomics of workplaces, the nature of activities undertaken, supply chains, transportation needs, and consequently, the safety of organizational employees.

Transition Risks are associated with the pace and extent to which an organization manages and adapts to internal and external changes to reduce greenhouse gas emissions and transition to renewable energy sources. Transition involves political, legal, technological, and market changes to address mitigation and adaptation requirements related to climate change. Depending on the nature, speed and goal of these changes, transition risks can entail varying levels of financial and reputational risk for organizations. Conversely, if an organization is a low-carbon footprint company operating in the renewable energy or climate transition market, it may experience market, technological, and reputational opportunities.

Four categories of transition risk can be identified:

- Political and regulatory risk: Political actions related to climate change continue to evolve, falling generally into two categories: policies attempting to limit actions contributing to negative climate change effects and policies promoting adaptation to climate change. The main challenge for policy makers is how to incentivize and promote the adoption of "green" technologies to make the use of fossil fuels less economically advantageous.

Two different types of active policies are distinguished:

(a) Adaptation Policies: These are actions aimed at anticipating the negative effects of climate change to prevent or minimize the damages they can cause, or to exploit the opportunities that may arise. Examples of adaptive measures include large-scale infrastructural changes, such as building defences to protect against sea level rise, as well as behavioural changes, such as individuals reducing food waste. Essentially, adaptation can be understood as the process of adjusting to the current and future effects of climate change.

(b) Mitigation Policies: This involves preventing or reducing the emission of greenhouse gases into the atmosphere to mitigate the severity of climate change impacts. Mitigation is achieved by reducing the sources of these gases – for example, increasing the share of renewable energy or implementing a cleaner mobility system – or by improving the storage of these gases, such as increasing the size of forests. In short, mitigation is a human intervention that reduces the sources of greenhouse gas emissions. The associated risk and financial impact of political changes depend on the nature and timing of the political shift. As the value of losses and damages from climate change increases, the risk of litigation is likely to rise. Reasons for such litigation include organizations' inability to mitigate climate change impacts, failure to adapt to climate change, and inadequate disclosure of material financial risks.

- Technological Risk: Technological advancements or innovations supporting the transition to a low-carbon and energy-efficient economic system can significantly impact organizations. As new technology replaces old systems and disrupts some aspects of the existing economic system, winners and losers will emerge from this process of "creative destruction." However, the timing of technology development and implementation represents a fundamental uncertainty in assessing technological risk.

- Market Risk: While the ways in which markets could be influenced by climate change are varied and complex, one of the primary ways is through changes in the demand and supply of specific goods, products, and services as climate-related risks and opportunities are increasingly considered.

- Reputational Risk: Climate change has been identified as a potential source of reputational risk related to changes in customer or community perception of an organization's contribution or penalty in transitioning to a low-carbon economy.

4. ESG as measure of climate risk exposure

Beyond company carbon emissions, the literature on the exposure of firms to climate transition risk focus on ESG scores. According to Matos (2020), the terms “responsible investing” and “sustainable investing” are interchangeable terms that denote the integration of environmental, social, and governance factors into investors' portfolio decisions. The environmental dimension (E) assesses a company's impact on the natural ecosystem, including its greenhouse gas emissions, efficient utilization of natural resources in production, pollution and waste management, and innovation in eco-friendly product design. The social dimension (S) encompasses a company's relationship with its employees, customers, and broader society, focusing on efforts to retain loyal employees (e.g. through quality employment and health benefits), to satisfy customers, and to contribute positively to the communities in which it operates. Last, the governance dimension (G) concerns the structures in place for management to act in the best interests of long-term shareholders encompassing the protection of shareholder rights, implementation of well-structured executive compensation policies, and avoidance of unethical practices.

In **Table 1** we present the factors that determine the ESG dimensions, according to EBA (2021) and Li et al. (2021). "E" dimension is usually used in empirical analysis to test the existence of a climate risk premium (see Alessi et al. (2021), Engle et al. (2020)). The principal data providers are Thomson Reuters, MSCI, Sustainalytics, KLD, Bloomberg and Inrate. Matos (2020) highlights how there has been a significant increase in access to ESG data in recent years, which has raised questions about the quality of the data, the absence of data for small firms along with the greenwashing phenomenon, a misrepresented or exaggerated representation of the extent to which investments are truly aligned with sustainability objectives. Potential biases in ESG ratings can be summarized as follows: size bias, geography bias and industry bias. Size bias is related to larger companies might obtain more favourable ESG evaluations due to their ability to allocate greater resources towards preparing and publishing ESG disclosures, as well as managing reputational risks. Geography bias is referred to the fact that ESG evaluations tend to be higher for companies located in regions with more stringent reporting requirements. Industry bias is linked to the fact that normalizing ESG ratings by industry can lead to oversimplification.

Moreover, ESG ratings may differ quite substantially across different data providers (see Chatterji et al. (2016), Escrig-Olmedo et al. (2019), Berg et al. (2019), Alessi et al. (2020)). Gibson et al. (2019) show that the average correlation between overall ESG ratings of different data providers is less than 50%. Assuming that firms with high ESG scores are "good" and firms with low ESG scores are "bad", Cornell and Damodaran (2020) notice that socially responsible firms have lower discount rates, resulting in lower expected returns for investors. Furthermore, the evidence indicates that bad performing firms are more likely to face consequences, such as higher discount rates or a higher frequency of disasters and shocks. However, the evidence supporting the integration of social responsibility into pricing by markets is weak, except for cases where companies are identified as bad performers.

5. Asset pricing and green stocks

In this section we review the equilibrium conditions for returns on stocks derived by asset pricing models which include investors and consumers with different (and time varying) tastes regarding environmental sustainability.

Pástor et al. (2021) develop an asset pricing model considering firms which differ in terms of sustainability in their business activity: "green" firms generate a positive externality for society, while "brown" firms a negative one. Agents also differ in their preferences for sustainability. First, agents get benefits from holding stocks of green firms and disutility from holding stocks of brown firms. The authors, relying on the assumption of dispersed tastes for green stocks, show that the expected returns (e.g. returns in equilibrium) are driven by market risk premium and green taste premium with positive and negative loading, respectively. The negative loading manifesting in stocks with low carbon footprint is motivated by the preference of green investors in holding low carbon emission stocks due to their climate risk hedging properties. The authors show how shifts in tastes imply returns deviation from their equilibrium values, and how adverse climate news raise the prices of green stocks, leading to unanticipated outperformance relative to brown stocks. This is motivated by the occurrence of a rising climate concern due to adverse climate news which increases investors' desire to hold green assets. This is associated to an upward revision in the expectations of future profits of green companies and a downward revision of expected profits of brown companies, due to raising expected sales of green products and an increasing likelihood of carbon taxes and regulations.

Zerbib (2022) considers not only sustainable integration practices (as in Pástor et al. (2021)), but also exclusion practices, when investing in stocks. In particular, the author considers regular investors that invest freely in all available assets which have mean–variance preferences and sustainable investors that prefer green stocks and exclude assets with high carbon footprint (sin stocks) with a high cost of externalities. Sustainable investors strategies imply that the equilibrium return on any asset is driven by two additional premia, beyond market risk premia: an exclusion-market premium, and a taste premium. On the other hand, the expected excess return on excluded assets is driven by three additional premia, beyond market risk premia: two exclusion premia (the exclusion-asset and exclusion-market premia) and a taste premium (direct and indirect).

Sauzet and Zerbib (2022) in a general equilibrium setting, model investors with preferences for green assets which also prefer consuming green goods. Preference for green goods add consumption premia to taste premium affecting expected returns. In particular, the authors show that consumption can offset the carbon premium, reducing the outperformance of brown stocks in terms of expected returns. This finding is motivated by acknowledging that brown assets can hedge consumption risk when green goods become expensive. Sauzet and Zebib (2022) show that an increase in consumption risk can be related to the election of a new government. For instance, the 2017 election of Trump in the U.S., led the US administration to the withdrawal from the Paris climate agreement. A rise in the consumption risk for green consumers can also be associated with a contraction of international trade due to the Covid-19 crisis which implied a 300% increase in the price of silicon (used as a factor of production of solar panels) and with the outbreak of the Ukraine war in 2022 implying global energy shortages.

6. Climate risk hedging portfolio

In this section we review the existing studies on portfolios used to hedge climate risk.

6.1. Portfolio sorting using carbon emissions and environmental scores

The performance of a Green Minus Brown Portfolio, that is a fund long on a green portfolio and short on a brown portfolio has been widely explored in the literature. The construction of a climate risk hedging portfolio relies on sorting stocks according to ESG scores and or GHG emissions, obtained from the main data providers (e.g. Bloomberg, Refinitiv, Trucost, Sustainalytics, etc).

A number of studies rely only on GHG emissions in a way similar to the study of Bolton and Kacperczyk (2021) investigating the presence of a carbon premium on stock returns in the US. Companies are categorized in terms of their heir carbon footprint, using Scope 1, Scope 2 and Scope 3 emissions and the authors distinguish among the level of emissions, their intensity (i.e. the ratio between total emissions and revenues) and the growth rate of emissions. Gimeno and Gonzalez (2022) focus both on the US and Europe and they construct a green minus polluter (GMP) factor as the ratio on the tons of CO2 equivalent emissions disclosed (Scope 1) per million of US dollars in income. Görgen, et al., (2020) focus is on the US and the authors combine multiple carbon-emission-related measures (related to value chain, public perception, and adaptability) to construct a "Brown-Green-Score" (BSG) factor as proxy of carbon risk. Alessi et al. (2021) focus is on Europe and the authors construct a "Synthetic greenness and transparency index" as a weighted average of the inverse of the ranking of different firms in terms of either emission intensity or E scores (using Bloomberg Environmental disclosure score). Alessi et al. (2021) sort firms according to the aforementioned index to construct portfolios with a different degree of greenness and transparency. Bua et al. (2022) use GHG emission (or GHG intensity) and E-scores to sort firms to create a green and brown portfolio. Bauer et al. (2022) focus on G7 countries companies and they distinguish between a size-adjusted and simple spread return. The former is the difference between the equal-weighted average of the returns for the "small-green" and "large-green" portfolios (based on the market capitalization in comparison to the median market capitalization) and the corresponding one for the brown portfolio return. The "simple spread" is the difference between the quintile portfolio returns (using either equal or value weights) with the highest and lowest emissions. Cassola et al. (2023), similar to Alessi et al. (2021), select firms according to a "Synthetic greenness and transparency index" and they build three value-weighted portfolios formed on size: a green portfolio of small, medium and large firms. As for the "high-carbon"/brown companies portfolio. The authors select firms that do not disclose environmental information and are active in high-carbon sectors (in line with the Climate-Policy Relevant Sectors classification in Battiston et al., 2017). Also, for high-carbon firms, the authors build three value-weighted portfolios formed on size: a high-carbon portfolio including small, medium, and large firms, respectively.

Pástor et al. (2022) compute stock-level environmental scores based on MSCI ESG Ratings using data for firm's weighted-average score across 13 environmental issues related to climate change, natural resources, pollution and waste, environmental opportunities (designed to measure a company's resilience to long-term environmental risks) and also the importance of environmental issues relative to social and governance issues within the same industry.

As Bolton and Kacperczyk (2021) point out, small companies, besides being less profitable, are more reluctant to provide data related to GHG emissions (see also Matos (2020), Cornel and Damodaran (2020)). Consequently, several studies rely on estimated CO2 emissions, provided by various third-party data sources, for companies that do not report their actual emissions. The empirical evidence by Aswani et al. (2022) suggest that using either reported or estimated emissions can have pronounced effects on the empirical results.

De Angelis and Monasterolo (2024) highlight "aggregate confusion" of ESG scores among data providers and rating agencies, and they point to poor transparency of ratings, negatively affecting the analysis of sustainability and financial performance of green investments and portfolios.

Given criticism regarding the use of ESG to sort portfolios, Zerbib (2022) prefer to measure green investors' private costs of environmental externalities, by identifying a large number of 453 green funds worldwide with investments in U.S. equities, focussing on their holding history on a quarterly basis. The cost of externalities for a given stock and on a given date is proxied by the relative difference between the weight of the stock in the market portfolio and its weight in the green funds, measure the degree of under(over) weighing relative to the market portfolio.

De Angelis and Monasterolo (2024) suggest constructing green and brown portfolios (from the STOXX Europe 600 constituents) based on the classification of the Climate Policy Relevant Sectors (CPRS) Main sectors. Starting with the "*Nomenclature statistique des activités économiques dans la Communauté européenne"* (NACE) classification (4 digit), these criteria yield six traditional CPRS Main sectors - fossil fuel, utility, energy-intensive, housing, transportation, agriculture - that can be further disaggregated considering the energy technologies that are relevant for the transition (e.g. fossil fuel/coal, fossil fuel/oil, fossil fuel/gas, electricity/renewable/wind, electricity/renewable/ solar, etc.). Then, companies' revenues are disaggregated into CPRS Granular sectors (Battiston et al. (2022)), providing the highest disaggregation level. In addition to the CPRS-based approach outlined above, the authors also consider the EU Taxonomy with the aim of identifying all the companies' revenue shares categorized as "taxonomy-aligned". An economic activity is taxonomy-aligned if: a) it makes a substantial contribution to at least one environmental objective considered in the Taxonomy Regulation; b) it does not significant harm any other environmental objective; c) it complies with minimum social safeguards and the technical screening criteria established by the European Commission through delegated acts (see Alessi et al. 2021). The authors rely on data for companies, that, since January 2023, fall under the scope of the Corporate Sustainability Reporting Directive (CSRD; Directive (EU) 2022/2464) which companies are obliged to report on the EU Taxonomy eligibility and alignment of their revenues, capital expenditures (CapEx) and operating expenditures (OpEx) for the previous calendar year. The focus is on Taxonomy-aligned activities such as electricity distribution and electricity transmission.

6.2. Portfolio sorting through textual factors

Another criterion to construct climate risk hedging portfolio is based on the estimation of climate sentiment index using text analysis (TA) which is the process of transforming unstructured text into a structured format to identify meaningful patterns and new insights (Blei et al. (2003), Gentzkow et al. (2019)). The main advantage of this approach is the possibility to evaluate the existence of climate risk premium for physical and transition risks, jointly.

The first study estimating climate news indices using text analysis is the one by Engle et al. (2020). The study focus on the US producing one index based on climate news in *The Wall Street Journal* (WSJ) and another one based on data from *Crimson Hexagon* (CH) which collects a massive corpus news articles and social media posts, filtering news on relevance of climate change. Engle et al. (2020) use E scores (from both MSCI and Sustainalytics) as a measure of climate risk exposure of each firm and construct a hedge portfolio for innovations in climate news. In particular, Engle et al. (2020) use a mimicking portfolio approach whose short-term returns hedge news about long run climate change over the holding period. The authors suggest that, in the short-run the portfolio differs from the Markowitz mean-variance efficient portfolio, exhibiting a lower Sharpe ratio, but in the long run the benefits of climate risk hedging will compensate investors. The time varying portfolio weights are obtained from a projection of climate change news (retrieved from text-based analysis) on stock returns interacting with Fama-French portfolios and an additional green factor obtained through sorting firms according to E-Scores provided by Sustainalytics and MSCI. For comparability, the authors also analyse the performance of hedge portfolios constructed using returns of the exchange-traded funds (ETFs) XLE and PBD instead of the returns of portfolios of stocks sorted by their E-Scores. XLE is the ticker of the Energy Select Sector SPDR ETF, which represents the energy sector of the S&P 500. PBD is the ticker of the Invesco Global Clean Energy ETF, which is based on the WilderHill New Energy Global Innovation Index including companies that focus on greener and renewable sources of energy and technologies facilitating cleaner energy. The empirical evidence shows that a mimicking portfolio approach can be successful in hedging innovations in climate change news both in sample and across a number of out-of-sample performance tests: in periods with more innovations in negative climate news, a portfolio that goes long firms with higher (more "green") E-Scores has relatively larger excess returns.

Bua et al. (2022) focus on Europe constructing two indices based on data from Reuters News: The Physical Risk Index (PRI) and Transition Risk Index (TRI). The authors use GHG emission or GHG intensity, as in Alessi et al. (2021) and Bolton and Kacperczyk (2021), and E-scores to sort firms to create a green and brown portfolio and then they estimate the exposure of the sorted portfolios to the climate risk factors retrieved through text analysis. Faccini et al. (2023) focus on the US and they use a textual and narrative analysis of Reuters climate-change news to create a monthly market-wide measure of both transition (climate policy) and physical climate risk. The authors estimate latent topics using the Latent Dirichlet Allocation (LDA) model developed by Blei et al. (2003). In Faccini et al. (2023) portfolio sorting is based on the beta coefficient, measuring the sensitivity of stock returns to the climate risk textual factor.

Ardia et al. (2022) construct a daily Media Climate Change Concerns index (MCCC), taking into account correlation among different topics (contrary to LDA method) by applying an increasing concave function to the average of the normalized source specific climate change concerns using news reported by newspapers and newswires in US. The authors construct the index focusing on different physical and transition risk topics, identifying four clusters of topics, such as Business Impact, Environmental Impact, Societal Debate, and Research.

Recently, Giglio et al. (2023) emphasize the role of preserving biodiversity, defined here as the sum total of genes, species, and ecosystems, given the extremely valuable impact for humans well-being. The authors construct a biodiversity news index by analyzing articles in the New York Times (NYT). The authors also construct a second index tracking public attention to biodiversity risks, hence they develop a "Google-Biodiversity Attention Index".

6.3. Expected returns

Asset pricing models study equilibrium returns, hence expected returns on stocks and systemic risk factors.

The empirical study of Acharya et al. (2022) focus only on heat stress (e.g on physical risk) to investigate the impact on model-free measures of conditional expected US stock returns (using option prices) and they find that an increase in corporate exposure to heat stress is associated with a higher expected return, only after 2013-2015.

The majority of papers investigates the impact of transition risk on stock returns. The focus is the study of the performance, in terms of expected returns, of portfolios hedging climate risk by exploring the contribution of climate change to the total risk premium, controlling for standard market risk factors. We can distinguish studies based on panel regression or on time series regression where the dependent variable is a portfolio return based on sorting stocks as described in the previous section. Panel studies focus on the estimation of expected return of individual stocks exploring their sensitivity of to a climate risk premium. The US based panel study of Bolton and Kacperczyk (2021) finds evidence of positive and statistically significant effect of a proxy of a climate risk factor (based on GHG emission level and its growth rate) on individual stock returns, while no effect is found for the intensity level of emissions. Görgen et al. (2020) find an insignificantly negative carbon premium for the US when using the Brown-Green-Score (BGS) factor to proxy climate risk using use a sample period running from 2010 to 2017.

Alessi et al. (2021) provide evidence, for Europe, on the existence of a negative and highly statistically significant "*Greenium*"- i.e. the climate premium transition risk- based on European individual stocks. Investors buy stocks of greener and more transparent firms accepting a ceteris paribus lower return, as a hedging strategy to reduce their exposure to climate risk. The *Greenium*, i.e. the risk premium for the green factor (obtained, as explained above, as the difference between the returns of the greener and more transparent portfolio and those of the brown portfolio), is estimated using as explanatory variable the green factor obtained through portfolio sorting entering a panel regression of European individual stocks including Fama-French factors as standard common systemic risk factors. The authors primary concern is whether climate risk is priced.

Time series regression analysis (see Pástor et al. (2022) study on the US, and that of Bauer et al. (2022) on companies of G7 countries) focus on the estimation of the alpha coefficient in asset pricing models capturing the expected return component in excess to the one related to systemic risk drivers (proxied by Fama-French factors). The alpha is the average residual component and it should be expected to be negative if the market acknowledges the climate risk hedging portfolio properties of a Green minus Brown portfolio (GMB). The expected return component for the US in Pástor et al. (2022) is obtained by estimating the implied cost of capital or by computing the difference between the observed one month return on a GMB portfolio and the unexpected component. The latter is the fitted value of a regression using the return on GMB portfolio as explanatory variable and proxies of the unexpected returns (such as earnings surprises and innovations to a climate news index) as explanatory variable.

The empirical evidence for US is resumed in the following. Zerbib (2022) shows, for investable industries, a statistically significant positive taste premium, driving expected returns, associated especially with stocks with high carbon footprint in industries more exposed to transition risk (the taste premium remains statistically significant and positive regardless of the portfolio sorting criteria used, either industry-sorted or industry-size double-sorted). Regarding sin stocks, the author finds that the exclusion premia significantly impact the excess returns and it increased sharply during the 2007–2008 crisis. Sauzet and Zerbib (2023) investigate the role played by consumption-premia (after controlling for standard market risk and taste premium factors) driving expected returns in the US showing its role in explaining the limited impact of green investing on the cost of capital of polluting firms.

The empirical evidence for Europe is resumed in the following. Cassola et al. (2023) focus on the European stock market, based on Alessi et al. (2023), retrieve both a long term and a short-medium term common systemic risk drivers, identified as financial and business cycle factors (in alternative to Fama French Factors). The authors break down the Green minus Brown portfolio return into the business and financial cycle factors and a residual component, orthogonal to the first two, identified as green factor which is found to be correlated with major climate risk events using step dummies in panel regression. The analysis is also extended at the industry and at the individual company level. In particular, at the industry level, climate risks are negatively priced in sectors with a high carbon footprint, and, at the firm level, the authors find a conditional association between a green-risk company beta and the green score of Alessi et al. (2023).

The studies based on text analysis estimation of climate risk can discriminate between the role played by physical and transition risk on expected returns. The beta coefficient of green and brown portfolios (obtained through sorting using GHG or ESG scores) to a climate risk factor (retrieved from text-based analysis) is estimated in the studies of Bua et al. (2022) for Europe and of Faccini et al. (2021) for the US. In particular, Bua et al. (2022) investigate the presence of climate risk premium related to both physical and transitional factors in the Euro area equity market, performing a time-series regression of the returns on a GMB portfolio on the Fama-French five factor regression model, augmented with PRI (or TRI) index of climate risk obtained through text-based analysis. The authors show that the climate risk premia for transition and physical climate risk have increased since the Paris Agreement (PA) (see also Monasterolo and De Angelis (2020), Bolton and Kacperczyk (2021)). Faccini et al. (2023) investigate the existence of the climate risk premium in the US stock market using regression analysis of a GMB portfolio return on the Fama-

French five factors, augmented with the green factor obtained through text-based analysis. The authors find that only the transition (climate-policy) risk is priced.

Recently, Giglio et al. (2023) sort equity portfolios according to biodiversity risk exposures. The empirical evidence shows that portfolios, holding long positions in industries with low biodiversity risk and short positions in industries with high biodiversity risk, hedge biodiversity risk.

6.4. Unexpected returns

Recently, the realized return on green portfolios constructed using the sorting criteria discussed in the previous section have been higher than those for brown portfolios. The overperformance of green portfolios has been highlighted by Pástor et al. (2022) and by Ardia et al. (2022) for the US, and almost for all other G7 countries, with Italy being the exception, by Bauer et al. (2022). The recent overperformance of green stocks have lead a numbers of studies to explore the unexpected returns dynamics.

A number of event studies investigate the performance of stocks related to ESG news. Monasterolo and de Angelis (2020) consider different equity holding indices from US, EU, and global financial markets, discriminating between low-carbon and carbon-intensive stock indices and find that, following the announcement of the Paris Agreement, PA, the market has regarded many low-carbon indices as less risky, making them more attractive for investment opportunities. Moreover, although not statistically significant, most of the low-carbon indices analysed demonstrate an overall rise in mean returns after the PA. Bansal et al. (2021) investigate the time variability of abnormal returns from socially responsible investing (SRI) and find that high rated SRI stocks outperform low rated SRI stocks during good economic times (for example, periods with high market valuations or aggregate consumption) but underperform during bad times (such as recessions). This variation in abnormal returns of high-SR stocks vis-à-vis low SR stocks is consistent with a wealth-dependent investor preference for SR stocks that leads to an increased (decreased) demand for SRI during good (bad) times.

Capelle-Blancard and Petit (2019) investigating the effects of ESG (ordinary and not extreme) news on stock market, find that shareholders respond to the release of ESG news. On average, the change in the firm's market value over a 3-day period surrounding the publication of negative ESG news is approximately 0.1%, whereas the effect of positive ESG news is scarcely noteworthy. The impact of negative ESG events is reduced when the affected companies have previously revealed more favourable ESG information compared to their competitors and when the industry has a positive ESG reputation. Conversely, the impact is heightened when the news is quantitatively and economically focused, and when there is a sense of emotional proximity between the event and the company. Yu et al. (2023) points at the correlation between ESG news sentiment and the risk of a stock price crash, emphasising the importance of accurately measuring the sentiment related to ESG factors. Gimeno and Gonzales (2022) construct a portfolio green minus polluter (GMP) that is long on the green companies and short on polluter companies (both for the US and for Europe) and it is used as an additional systemic risk factor beyond the Fama-French factors. The authors find that the green factor, e.g. the GMP portfolio return explains the stock market excess returns to a higher extent than Fama French factors and they also show the rising relevance of the factor since the Paris Agreement. In particular, the consistent positive performance after PA, holds in both geographical areas where the political decisions regarding climate and the development of regulations have different paces of developments. Borghesi et al. (2022), sorting stocks listed in the "STOXX 100 All Europe" according to MISCI environmental score, estimate cumulative abnormal returns (CARs) both in the green and brown sectors in relation to green policy announcements made by major European governments in 2020. The empirical findings point at a stronger sentiment effect in the green sector than in the brown sector.

As explained in the previous section, the alpha obtained from time series regression of climate risk hedging portfolio on common systemic risk drivers is interpreted to be a proxy of average climate risk. However, if there has been a sequence of unexpected shocks which do not average out over sufficiently long sample periods (e.g. one-sided shocks producing unexpected shifts in perceptions and beliefs about the size of climate risk) then the unexpected return component of stocks and portfolio cannot be ignored. Realized returns on green stocks can differ substantially from expected returns if risk perceptions or preferences shift unexpectedly over time, as described by Ardia et al. (2022) and Pástor et al. (2022). As shown in Section 5, Pástor et al. (2021) provide a theoretical framework that explains such a divergence via increased investor demand for green assets and increased consumer demand for green products. Pástor et al. (2022) and Ardia et al. (2022) focus on green and brown stocks of the US stock market to retrieve the role played by the unexpected component of a GMB portfolio in shaping the dynamics of realized returns. The unexpected component is driven by shocks to climate concern proxied by the estimated residuals of an AR(1) model fitted to a Media Climate Change index, MCCC, developed by Ardia et al. (2021). While Pástor et al. (2022) use the monthly MCCC developed by Ardia et al. (2021), Ardia et al. (2022) focus on daily observations. The empirical evidence from both studies is capable to reconcile the observed overperformance of green stocks with their underperformance, in terms of expected cumulative returns, relative to brown stocks. Pástor et al. (2022), after controlling the expected return component, through earning announcement and forecast, find a positive and statistically significant contribution of innovation to climate concern on realized returns. Ardia et al. (2022) focus is on panel regression and the empirical evidence points at a statistically significant and positive effect of carbon emission intensity interacting with a proxy of innovation to climate concern. Moreover, Ardia et al. (2022), retrieving the MCCC for different topics related to physical and transition risk, show that there is significant exposure to almost all topics discussing climate change transition risk, but only a subset of physical risk topics explain the performance of green versus brown firms. Finally, Ardia et al. (2022) find that high unexpected changes in climate change concerns increase (decrease) the discount factor of brown (green) firms but do not find evidence of a cash flow effect. Bauer et al. (2022) suggest that more data and research are needed to draw a complete picture of the relation between expected and realized returns of green and brown assets pointing at the recent example highlighting the crucial role of unexpected shocks for the performance of green and brown stocks which is the energy crisis just before and following the Russian invasion of Ukraine in early 2022, showing, during the first half of 2022, a much stronger returns for brown over green stocks.

The empirical evidence in Zerbib (2022) shows that unexpected shifts in green tastes affect positively the performance of green stocks reducing the overall risk premium underlying the overperformance of stocks with high carbon footprint in terms of expected returns. Moreover, during the crisis period, there is evidence of an increase in the exclusion premia rising the expected return of sin stocks.

7. Financial Stability

The impact of climate risk on the returns of individual companies or on a portfolio of stocks can be useful for financial investors interested in the performance of green funds and, also, for a borrowing firm, more interested in the cost of finance through equity. A number of studies provide useful information to policymakers more interested in the implications of climate risk for financial stability. This requires the use of macroprudential indicators such as Marginal Expected Shortfall (MES). Alessi et al. (2021) analysis, uses data on the exposure of different financial institutions to climate policy relevant sectors and compute MES. The latter is defined as the equity loss for a financial institution portfolio due to particular scenarios (varying in terms of portfolio decarbonization). Caporin et al. (2023) study the transition risk spillovers (proxied by individual stock carbon premium) among six major financial markets from 2013 to 2021. The authors distinguish between simultaneous and non-simultaneous spillovers. While the former refers to the construction of a proxy of global transition risk, the latter refers to the estimation of directional connection indices (see Diebold and Yilmaz, 2014) for different quantiles of transition risk, using the generalized forecast error variance decomposition (GFEVD), after controlling for a global factor, based on a quantile VAR (QVAR) model framework, proposed by Lanne and Nyberg (2016). The focus on a common driver underlying worldwide stock returns in the first stage of the analysis is in line with the empirical evidence of Bolton and Kacperczyk (2023) focussing on a cross-section of 14,400 firms in 77 countries, finding higher stock returns associated with higher levels and growth rates of carbon emissions. In particular, the highest carbon premia related to emissions growth are observed for firms located in countries with lower economic development, larger energy sectors, and less inclusive political systems. The highest premia related to emission levels are observed in countries with stricter domestic climate policies.

8. Conclusions

In this study we review the literature on climate change and stock returns. After reviewing the main definition regarding the distinction between physical and transition climate risk and describing how the environmental dimension is incorporated in ESG scores, we have distinguished the causal linkages between climate risk and expected and unexpected stock returns. Most of the empirical studies focus on the impact of climate risk on expected stock returns and the empirical evidence is ambiguous: there is no wide consensus on the stock market acknowledging the climate risk hedging role of green stocks implying investors willing to pay a premium for environmentally friendly firms, hence lowering their expected return and the cost of capital.

One of the main reasons of contrasting empirical result regarding the expected return performance of green stocks compared to brown is related to the different approaches sorting stocks in terms of their carbon footprint: a text-based approach computing news-based indices of climate risk and composite indices using data for ESG-scores and GHG emissions. We argue that the information gathered through a text-based approach are more exhaustive to retrieve estimates of the climate risk premium accounting jointly for physical and transition risks.

The literature leaves some open issues setting up a future research agenda. First, it is important to observe that most of the literature focus on the US, and future research should therefore focus on the European stock market and more generally on financial markets of developing countries that are more vulnerable to climate risks. Second, we argue that it is necessary to retrieve climate risk indices for each company relying on a combination of different ESG scores from different data provider, based on estimation methods, such as machine learning regression techniques enabling to select a model that strikes a balance between adaptability and simplicity by incorporating only the most influential variables. Third, the empirical analysis should take into account the availability of mixed frequency data for proxies of physical and transition risk (data for weather and extreme events are available on daily basis, while ESG scores or CO2 emissions are typically sampled at annual frequency). Fourth, we argue that the forward-looking content of option prices and the use of implied moments (see Ilhan et al. (2020)) is another promising avenue of research to capture transition risk. Fifth, as pointed by Battiston et al. (2020), the interconnectedness of among different investors, firms and policymakers plays a key role in how climate change materializes: policy intervention which might be look optimal at the individual level might lead to sub-optimal outcomes at the system level. One fruitful avenue of research would rely on the use of cooperative game theory to study the implication of climate risk for the stability of the whole financial system. Recently, Ciano et al. (2021), using cooperative games theory, analyse the implication of events such as the Kyoto Protocol and the Paris Agreement on countries payoffs. Finally, the analysis of spillovers (with a particular focus on equities) can also be used to assess the financial stability implications of climate risk. As suggested by Battiston et al. (2020), in the modelling of spillovers we should acknowledge the main features of transition to a low carbon economy, that is: systemic risk, nonlinearity and endogeneity (given that climate risk impact is conditional on perception of risk of the agents involved and their reaction).

Funding

This work was funded by European Union under the NextGeneration EU Programme within the Plan “PNRR - Missione 4 “Istruzione e Ricerca” - Componente C2 Investimento 1.1 “Fondo per il Programma Nazionale di Ricerca e Progetti di Rilevante Interesse Nazionale (PRIN)” by the Italian Ministry of University and Research (MUR), Project title: “Climate risk and uncertainty: environmental sustainability and asset pricing”. Project code "P20225MJW8" (CUP: E53D23016470001), MUR D.D. financing decree n. 1409 of 14/09/2022.

The work was supported also by the University of Modena and Reggio Emilia for the FAR2022 and FAR2023 projects.

Conflict of interest

The authors declare that they have no conflict of interest.

Availability of data and materials

Not applicable.

Code availability

Not applicable.

Reference

Acharya, V. V., Johnson, T., Sundaresan, S., & Tomunen, T. (2022). Is Physical Climate Risk Priced? Evidence from Regional Variation in Exposure to Heat Stress. National Bureau of Economic Research Working Paper Series, 30445, http://www.nber.org/papers/w30445

Alessi, L., E. Ossola, and R. Panzica (2020). The greenium matters: greenhouse gas emissions, environmental disclosures, and stock prices. European Commission, Joint Research Centre, Working Papers in Economics and Finance, 2019/12.

Alessi, L., Ossola, E., & Panzica, R. (2021). What greenium matters in the stock market? The role of greenhouse gas emissions and environmental disclosures. Journal of Financial Stability, 54. doi: https://doi.org/10.1016/j.jfs.2021.100869.

Alessi, L., Ossola, E., Panzica, R., (2023). When Do investors go green? Evidence from a time-varying asset-pricing model. International Review of Financial Analysis. Forthcoming.

Ardia, D., Bluteau, K., Boudt, K., & Inghelbrecht, K. (2022). Climate Change Concerns and the Performance of Green Versus Brown Stocks. Management Science, 69(12), 7607-7632. doi: http://dx.doi.org/10.2139/ssrn.3717722

Aswani, Jitendra and Raghunandan, Aneesh and Rajgopal, Shivaram, Are Carbon Emissions Associated with Stock Returns? (February 23, 2023). Review of Finance, forthcoming, Available at SSRN: https://ssrn.com/abstract=3800193 or http://dx.doi.org/10.2139/ssrn.3800193

Bansal, Ravi; Wu, Di (Andrew); Yaron, Amir, Socially Responsible Investing in Good and Bad Times, The Review of Financial Studies, Volume 35, Issue 4, April 2022, Pages 2067–2099, https://doi.org/10.1093/rfs/hhab072

Battiston, S., Mandel, A., Monasterolo, I. et al. A climate stress-test of the financial system. Nature Clim Change 7, 283–288 (2017). https://doi.org/10.1038/nclimate3255

Battiston, Stefano and Dafermos, Yannis and Monasterolo, Irene, Climate Risks and Financial Stability (December 14, 2020). Available at SSRN: https://ssrn.com/abstract=3748495 or http://dx.doi.org/10.2139/ssrn.3748495

Battiston, Stefano and Monasterolo, Irene and van Ruijven, Bas and Krey, Volker, The NACE – CPRS – IAM mapping: A tool to support climate risk analysis of financial portfolio using NGFS scenarios. (September 19, 2022). Available at SSRN: https://ssrn.com/abstract=4223606 or http://dx.doi.org/10.2139/ssrn.4223606

Bauer, M. D., Huber, D., Rudebusch, G. D., & Ole, W. (2022). Where is the carbon premium? Global performance of green and brown stocks. Journal of Climate Finance, 1. doi: https://doi.org/10.1016/j.jclimf.2023.100006

Berg, Florian F.; Kölbel, Julian F; Rigobon, Roberto, Aggregate Confusion: The Divergence of ESG Ratings, Review of Finance, Volume 26, Issue 6, November 2022, Pages 1315–1344, https://doi.org/10.1093/rof/rfac033

Blei, D. M., Ng, Y., Andrew, & Jordan, M. I. (2003). Latent dirichlet al.location. J. Mach. Learn. Re, 993–1022.

Bolton, P. and Kacperczyk, M. (2023), Global Pricing of Carbon-Transition Risk. J Finance, 78: 3677-3754. https://doi.org/10.1111/jofi.13272

Bolton, P., & Kacperczyk, M. (2021). Do investors care about carbon risk? Journal of Financial Economics, 142(2), 517-549. doi: https://doi.org/10.1016/j.jfineco.2021.05.008.

Borghesi, S., Castellini, M., Comincioli, N., Donadelli, M., Gufler, I., Vergalli, S. (2022). European green policy announcements and sectoral stock returns. ENERGY POLICY, 166, 1-27 [10.1016/j.enpol.2022.113004].

Bua, G., Kapp, D. R., & Rognone, L. (2022). Transition versus physical climate risk pricing in European financial markets – A text-based approach. European Central Bank. doi: doi/10.2866/583769

Capelle-Blancard, G., & Petit, A. (2019). Every Little Helps? ESG News and Stock Market Reaction. Journal of Business Ethics, 157(2), 543-565. doi: https://doi.org/10.1007/s10551-017-3667-3

Caporin Massimiliano; Jiménez-Martin, Juan-Angel; Yang Runfeng, Measuring Climate Transition Risk Spillovers, Review of Finance, Volume 28, Issue 2, March 2024, Pages 447–481, https://doi.org/10.1093/rof/rfad026

Cassola, N., Morana, C., & Ossola, E. (2023.). Green Risk in Europe. University of Milan Bicocca Department of Economics, Management and Statistics, Working Paper No. 526. doi: http://dx.doi.org/10.2139/ssrn.4562028

Chatterji, A.K., Durand, R., Levine, D.I. and Touboul, S. (2016), Do ratings of firms converge? Implications for managers, investors and strategy researchers. Strat. Mgmt. J., 37: 1597-1614. https://doi.org/10.1002/smj.2407

Ciano, T., Ferrara, M., Gangemi, M., Merenda, D. S., & Pansera, B. A. (2021). Climate Change Sustainability: From Bargaining to Cooperative Balanced Approach. Games, 12(2). doi: https://doi.org/10.3390/g12020045

Cornell, B., & Damodaran, A. (2020, March 20). Valuing ESG: Doing Good or Sounding Good? NYU Stern School of Business. doi: http://dx.doi.org/10.2139/ssrn.3557432

De Angelis, Luca and Monasterolo, Irene, Greenness Confusion and the Greenium (February 7, 2024). Available at SSRN: https://ssrn.com/abstract=4719166 or http://dx.doi.org/10.2139/ssrn.4719166

Delforge, D., & al. (2023). EM-DAT: The Emergency Events Database. Preprint. doi: https://doi.org/10.21203/rs.3.rs-3807553/v1

Diebold, Francis and Yilmaz, Kamil, (2014), On the network topology of variance decompositions: Measuring the connectedness of financial firms, Journal of Econometrics, 182, issue 1, p. 119-134.

EBA. (2021). EBA Report on Management and Supervision of ESG Risks for Credit Institutions and Investment Firms. https://www.eba.europa.eu/sites/default/files/document_library/Publications/Reports/2021/1015656/EBA%20Report%20on%20ESG%20risks%20management%20and%20supervision.pdf

Engle, R. F., Giglio, S., Kelly, B., Lee, H., & Stroebel, J. (2020). Hedging Climate Change News. The Review of Financial Studies, 33(3). doi: https://doi.org/10.1093/rfs/hhz072

EPA. (2023). Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-2021. U.S. Environmental Protection. https://www.epa.gov/ghgemissions/inventory-us-greenhouse-gas-emissions-and-sinks-1990-2021

Escrig-Olmedo, E.; Fernández-Izquierdo, M.Á.; Ferrero-Ferrero, I.; Rivera-Lirio, J.M.; Muñoz-Torres, M.J. Rating the Raters: Evaluating how ESG Rating Agencies Integrate Sustainability Principles. Sustainability 2019, 11, 915. https://doi.org/10.3390/su11030915

Faccini, R., Matin, R., & Skiadopoulos, G. (2023). Dissecting climate risks: Are they reflected in stock prices? Journal of Banking & Finance, 155. doi: https://doi.org/10.1016/j.jbankfin.2023.106948

Fama, E. F. (2015). A five-factor asset pricing model. Journal of Financial Economics, 116(1), 1-22. doi: https://doi.org/10.1016/j.jfineco.2014.10.010

Financial Task Force on Climate-related. (2017). Recommendations of the Task Force on Climate-related Financial Disclosures.

Gentzkow, M., Kelly, B., & Taddy, M. (2019). Matt Text as Data. Journal of Economic Literature, 57(3), 535-74, https://www.aeaweb.org/articles?id=10.1257/jel.20181020

Gibson, R., Krueger, P., Riand, N., & Schmidt, P. (2019, 01 01). ESG Rating Disagreement and Stock Returns. SSRN Electronic Journal. doi:10.2139/ssrn.3433728

Giglio, S., Kelly, B., & Stroebel, J. (2021, 11 01). Climate Finance. Annual Review of Financial Economics. doi:10.1146/annurev-financial-102620-103311

Giglio, S., Kuchler, T., Stroebel, J., & Zeng, X. (2023). Biodiversity risk (No. w31137). National Bureau of Economic Research.

Giglio, S., Maggiori, M., Rao, K., Stroebel, J., & Weber, A. (2021, August). Climate Change and Long-Run Discount Rates: Evidence from Real Estate. The Review of Financial Studies, 34(8), 3527–3571. doi: https://doi.org/10.1093/rfs/hhab032

Gimeno, R., & Gonzales, C. I. (2022, March 23). The Role of a Green Factor in Stock Prices. When Fama & French Go Green. Banco de Espana Working Paper(2207). doi: http://dx.doi.org/10.2139/ssrn.4064848

Görgen, M., Jacob, A., Nerlinger, M., Riordan, R., Rohleder, M., & Wilkens, M. (2020, August 10). Carbon Risk. SRNN. doi: http://dx.doi.org/10.2139/ssrn.2930897

Hale, G. (2022). Climate risks and exchange rates. Annual Research Conference (ARC) of the IMF.

Ilhan, E., Sautner, Z., & Vilkov, G. (2020). Carbon Tail Risk. The Review of Financial Studies, 34(3), 1540-1571.doi: https://doi.org/10.1093/rfs/hhaa071

Lanne, M. and Nyberg, H. (2016), Generalized Forecast Error Variance Decomposition for Linear and Nonlinear Multivariate Models. Oxf Bull Econ Stat, 78: 595 603. https://doi.org/10.1111/obes.12125

Li, T.-T., Wang, K., Sueyoshi, T., & Wang, D. (2021). ESG: Research Progress and Future Prospects. Sustainability, 13. doi: https://doi.org/10.3390/su132111663

Matos, P. (2020, August 7). ESG and Responsible Institutional Investing Around the World: A Critical Review. CFA Institute Research Foundation Literature Reviews. doi: https://dx.doi.org/10.2139/ssrn.3668998

Monasterolo, I. (2020, 10 05). Climate Change and the Financial System. Annual Review of Resource Economics, 12(1). doi:doi: 10.1146/annurev-resource-110119-031134

Monasterolo, I., & de Angelis, L. (2020). Blind to carbon risk? An analysis of stock market reaction to the Paris Agreement. Ecologic Economics, 170. doi: https://doi.org/10.1016/j.ecolecon.2019.106571.

Nordhaus, W. (1977). Economic Growth and Climate: The Carbon Dioxide Problem. The American Economic Review, 67(1), 341-346, http://www.jstor.org/stable/1815926

Pástor, Ľ., Stambaugh, R. F., & Taylor, L. A. (2021). Sustainable investing in equilibrium. Journal of Financial Economics, 142(2), 550-571. doi: https://doi.org/10.1016/j.jfineco.2020.12.011

Pástor, Ľ., Stambaugh, R. F., & Taylor, L. A. (2022). Dissecting green returns. Journal of Financial Economics, 146(2), 403-424. doi: https://doi.org/10.1016/j.jfineco.2022.07.007

Ritchie, H., & Rosado, P. (2020). Greenhouse gas emissions. (OurWorldInData.org) https://ourworldindata.org/greenhouse-gas-emissions

Sauzet, Maxime and Zerbib, Olivier David, When Green Investors Are Green Consumers (November 17, 2022). Proceedings of the EUROFIDAI-ESSEC Paris December Finance Meeting 2022, Available a SRN: https://ssrn.com/abstract=4098124 or http://dx.doi.org/10.2139/ssrn.4098124

WBCSD/WRI. (2004). Greenhouse Gas Protocol: a Corporate Accounting and Reporting Standard. doi:10.13140/RG.2.2.34895.33443.

Yu, H., Liang, C., Liu, Z., & He, W. (2023). News-based ESG sentiment and stock price crash risk. International Review of Financial Analysis, 88. doi: https://doi.org/10.1016/j.irfa.2023.102646.

Zerbib, O. D. (2022). A Sustainable Capital Asset Pricing Model (S-CAPM): Evidence from Environmental Integration and Sin Stock Exclusion. Review of Finance, 1345-1388. doi: https://doi.org/10.1093/rof/rfac045

Figures

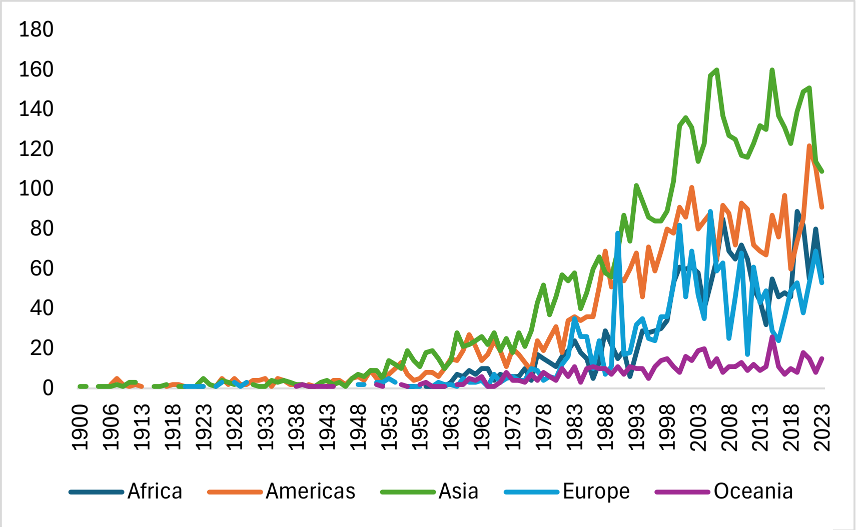

Figure 1. *Number of extreme events climate related in the different continents. EM-DATA 2024.*

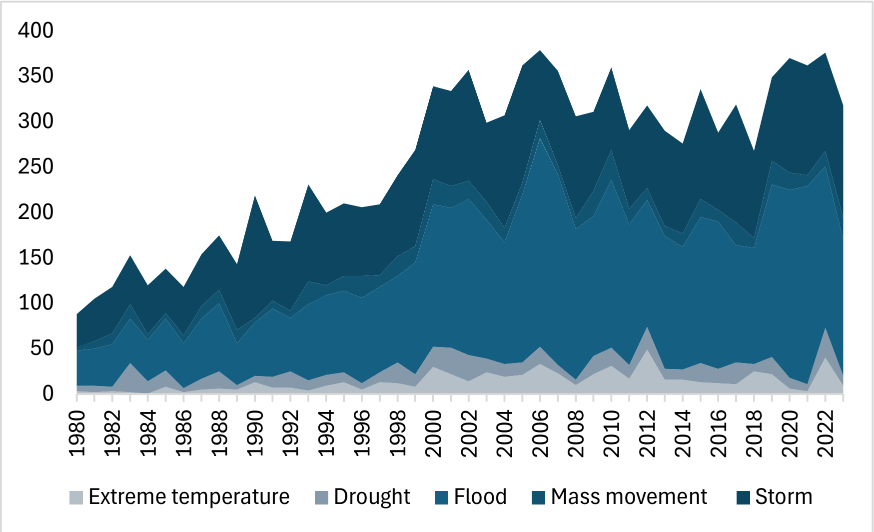

Figure 2. *Number of extreme climate events (global) related to certain phenomena. EM-DATA 2024.*

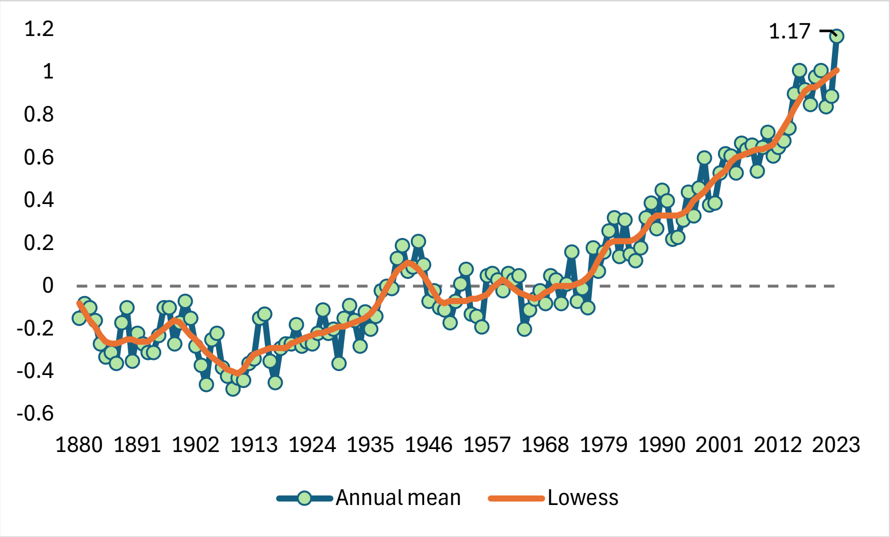

Figure 3. *Global land-ocean temperature index. NASA's Goddard Institute for Space Studies (GISS), 2023.*

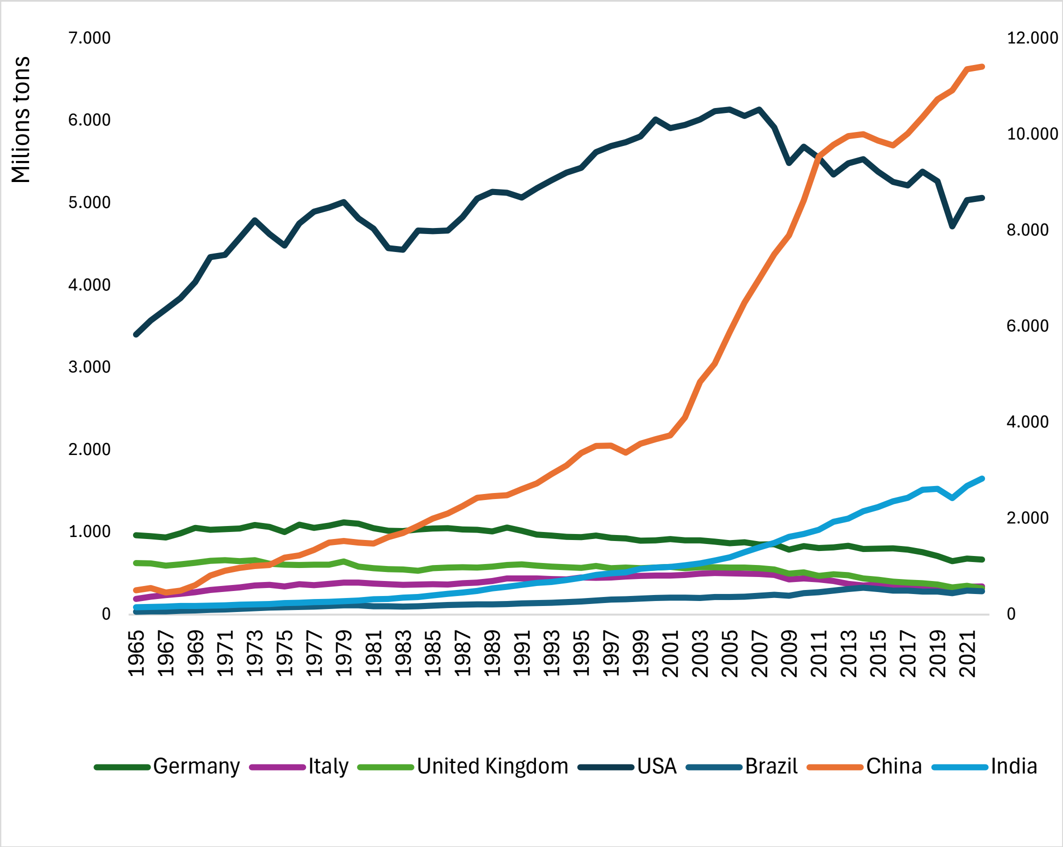

Figure 4. *CO_2 emission for different country. Our World in data, 2023.*

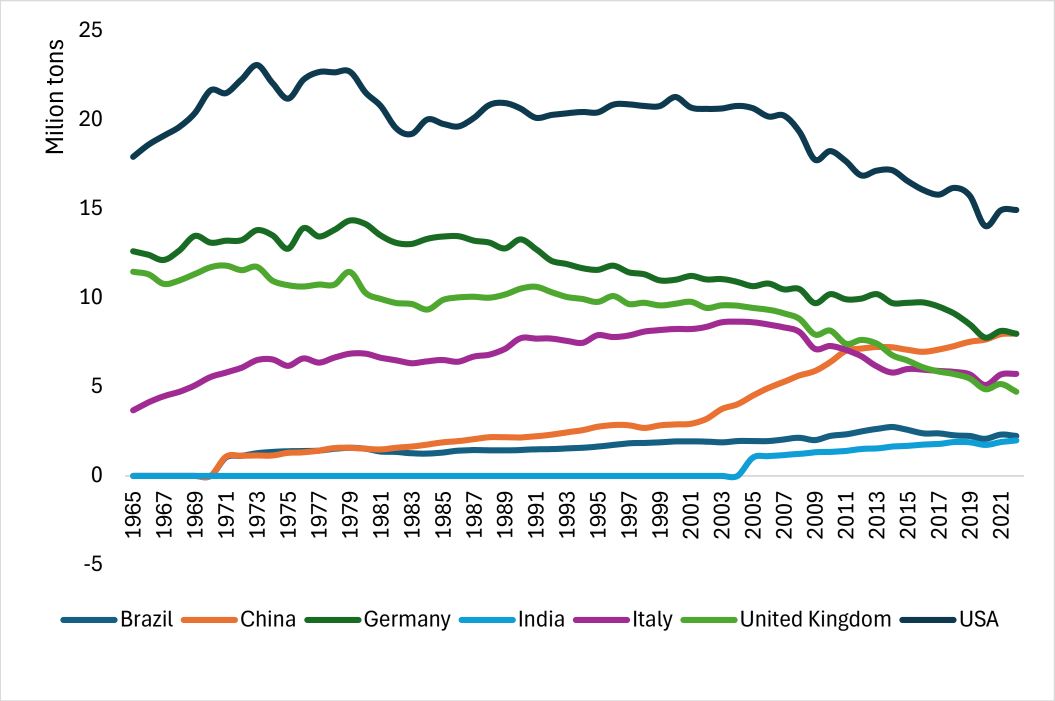

Figure 5. *CO_2 emission per capita for different country. Our World in data, 2023.*

Tables

Table 1. *International Framework of ESG dimensions factors. Elaboration based on the EBA report on ESG risk management and supervision*

E	● GHG emissions ● Energy consumption and efficiency ● Air pollutants ● Water usage and recycling ● Waste production and management (water, solid, hazardous) ● Impact and dependence on biodiversity ● Impact and dependence on ecosystems ● Innovation in environmentally friendly products and services
S	● Workforce freedom of association ● Child labour ● Forced and compulsory labour ● Workplace health and safety ● Customer health and safety ● Discrimination, diversity and equal opportunity ● Poverty and community impact ● Supply chain management ● Training and education ● Customer privacy ● Community impacts
G	● Codes of conduct and business principles ● Accountability ● Transparency and disclosure ● Executive pay ● Board diversity and structure ● Bribery and corruption ● Stakeholder engagement ● Shareholder rights

Table 2. Main result of the empirical analysis

Author	**Type of climate risk texted**	**Measure of climate risk tested**	**Results**
Acharya et al. (2022)	Physical risk	SEAGLAS (Spatial Empirical Adaptive Global-to-Local Assessment System). Probabilistic projections of daily temperature and precipitation change under different RCP (Representative Concentration Pathway).	They find that an increase in corporate exposure to heat stress is associated with a higher expected return. These effects are significant only after 2013-2015.
Alessi et al. (2021)	Transition risk	"Synthetic greenness and transparency index" $G_{i,t} = \gamma K_{i,t} + (1-\gamma)E_{i,t}$ Where $E_{i,t}$ is the ranking of firm i in term of E (Bloomberg transparency index-ESG) and $K_{i,t}$ is the inverse of the ranking of firm i in term of emission intensity (GHG or CO2).	The study provides evidence on the existence of a negative *Greenium* based on European individual stock
Bolton and Kacperczyk (2021)	Transition risk (carbon risk)	GHG emission (Scope 1, 2, 3 and their transformation).	They find a robust, persistent, and significant carbon premium at the firm level for all three categories of emission levels and growth rates while the carbon premium cannot be explained through a sin stock divestment effect

			and there is not a carbon premium associated with emission intensity.
Bua et al. (2022)	Transition and physic risks	Climate textual factor to create two novel indices: TRI (transitional risk index) and PRI (physical risk index). E scores and GHG for sort portfolio.	The climate risk premia for transition and physical climate risk have increased since the Paris Agreement. Firm level information appears to be used as a gauge for transition risk (since 2015); sectoral classification may be employed as gauge firm's exposures to physical risk.
Faccini et al. (2023)	Transition and physic risks	Climate textual factor, constructed using the LDA.	Only the risks stemming from U.S. climate policy debate are priced, a recent phenomenon driven by 2012-2018 period (a segmentation of the time span has been implemented).
Gimeno and Gonzales (2022)	Transition risk (carbon risk)	GMP (green minus polluter).	The outcome is a boost in the prices of environmentally friendly stocks.
Görgen, et al., (2020)	Transition risk (carbon risk)	BGS (Brown-Green-Score).	There is no evidence of a risk premium associated with carbon risk.
Ilhan et al. (2020)	Transition risk (carbon risk)	Scope 1 disclosure's firm.	A one-standard-deviation increase in a firm's log industry carbon intensity increases the implied volatility slope, which captures protection against downside tail risk.

Hong et al. (2019)	Physical risk	Potential loss resulting from extreme weather events such as storms, floods.	There is a negative correlation between climate risk and corporate earnings, coupled with a positive association with earnings volatility. Furthermore, firms tend to rely less on short-term loans and more on long-term loans and pay out lower cash dividends.
Monasterolo and de Angelis (2020)	Transition risk (carbon risk)	Different green and brown indices for monthly data (i.e. *Nasdaq Clean Edge Green Energy*, *Wilderhill Clean Energy*, *STOXX Global ESG ENV Leaders* etc.).	The overall performance of the low-carbon indices has increased after the PA due to a significant reduction in the index risk level. The level of systematic risk (beta) associated to the low-carbon indices has significantly decreased after the PA both in the US and EU, as well as globally.