

A Scientific Portfolio Publication

Beyond Carbon Price: a Scenario-Based Quantification of Portfolio Financial Loss from Climate Transition Risks

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Abstract

This paper addresses climate transition risks in portfolio management by introducing a model that integrates firm-specific 'green' revenues, aligned with the European taxonomy, with economic and energy variables from adverse transition scenarios. Unlike short-term climate stress tests focusing on carbon pricing, our model incorporates operational cost and revenue transmission channels to derive a *conditional transition loss* metric. Applied to 1,287 listed companies, our analysis reveals significant implications for equity portfolio risk management. Aggregate portfolio impacts range from 0.5-6%, with sector-specific losses as high as 10-60% in vulnerable sectors such as Utilities. Integrating such forward-looking scenario analysis results with backward-looking financial factor models offers a promising avenue to capture shifts in investor perceptions and enhance equity portfolio risk management.

Key takeaways:

- Climate transition risks, driven by shifts in policy, technology, and consumer preferences, present significant challenges for portfolio management. Existing short-term climate stress tests focus predominantly on carbon pricing and its impact on operational costs, often neglecting longer-term transmission channels related to demand-driven changes in firm revenue dynamics.
- This paper introduces a model that integrates firm-specific 'green' revenues, aligned with the European taxonomy, with economic and energy variables derived from adverse transition scenarios. By capturing the interplay between revenue and operational cost transmission channels, the model derives a *conditional transition loss* metric.
- Applied to the 1,287 constituents of the MSCI World Index, the analysis highlights three main results: revenue impacts are as influential as carbon pricing in shaping transition risks; heterogeneous effects within sectors show some firms benefiting under ambitious transition scenarios; and uncertainty around socio-economic pathways significantly affects conditional transition loss estimates.

Keywords:

- Greenhouse gas emissions, portfolio decarbonisation, attribution analysis

Introduction

Introduction

Climate-related transition risks, which encompass the economic and financial challenges associated with the shift to a low-carbon economy, are increasingly central to equity portfolio management. These risks, driven by policy changes, technological innovations and evolving consumer preferences, pose potential disruptions while offering opportunities for firms strategically aligned with climate goals. For equity portfolio managers, transition risks are not merely theoretical concerns but material considerations affecting valuations, sectoral dynamics and risk-return profiles. Understanding and quantifying these risks are crucial for portfolio allocation.

Over the past decade, academic research and financial industry practitioners have increasingly recognised the importance of transition risks. Early contributions, such as the Carbon Tracker Initiative's identification of the 'carbon bubble', highlighted the financial implications of unburnable fossil fuel reserves (Leaton, 2011). This was followed by Mark Carney's landmark speech¹ in 2015, which underscored the systemic consequences of climate-related risks, including transition risks. The establishment of the Task Force on Climate-related Financial Disclosures (TCFD) in 2017 formalised these risks and catalysed further research.

The existing literature provides mixed evidence on the pricing of transition risks in equity markets. Studies such as Bolton and Kacperczyk (2021) have identified a carbon risk premium, whereby firms with higher greenhouse gas (GHG) emissions are valued with a discount. Conversely, other studies, such as Bernardini et al. (2021) and Bauer et al. (2022), suggest that green stocks have outperformed brown stocks, indicating that transition risks may not be uniformly priced. These contradictions are often attributed to differences in realised versus expected returns, as highlighted by Ardia et al. (2023) and Pástor et al. (2022). The latter emphasise that unexpected shifts in climate concerns can lead to a revaluation of assets, benefiting green firms while penalising brown ones. Furthermore, reviews by Campiglio et al. (2023) and Thomä and Chenet (2017) reveal structural barriers to pricing transition risks, including inadequate risk models and intertemporal inconsistencies.

Long-term scenario analysis has emerged as a critical complementary tool for addressing these challenges, offering forward-looking insights into how transition risks might materialise under different climate policy and technological pathways (Campiglio et al., 2023). While short-term climate stress tests focus primarily on carbon pricing and its impact on operational costs, long-term scenario methodologies extend the analysis to include demand shifts across activity segments and broader economic and energy interdependencies. Recent efforts by regulatory bodies such as the Network for Greening the Financial System (NGFS) have advanced integrated assessment models that capture both direct and indirect effects of transition drivers. However, these approaches often lack granularity at the firm level, particularly in differentiating impacts within the same sector. This analysis therefore aims to address the following research question: How might firms be affected by both the opportunities and costs associated with the climate-related transition, and how does this impact differ both across and within sectors?

1 - Breaking the tragedy of the horizon – climate change and financial stability – speech by Mark Carney, given at Lloyd's of London in 2015. Available at: <https://www.bankofengland.co.uk/speech/2015/breaking-the-tragedy-of-the-horizon-climate-change-and-financial-stability>.

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This paper contributes to the literature in two ways:

- First, it introduces a model that integrates firm-level revenue data, ‘green’ revenues from the European taxonomy, alongside carbon intensity metrics. By linking the firm revenue dependencies to variables derived from NGFS scenarios, the model captures the effects of demand fluctuations on firm revenues, providing a more nuanced and comprehensive perspective compared to traditional models that rely solely on emissions intensity metrics.
- Second, it evaluates the sensitivity of the resulting *conditional transition loss* to the choice of scenario, time horizon, and model uncertainties, acknowledging the significant influence of these parameters on outcomes (Bingler et al., 2022b; Campiglio et al., 2023). To this end, the analysis considers both medium-term (2030) and long-term (2050) horizons across four scenarios and three models.

The analysis of the 1,287 companies in the MSCI World Index highlights three main results:

- First, the revenue transmission channel, often underexplored, plays a critical role in shaping transition risks, both for sectors with low direct emissions, such as Healthcare and Technology, and for transition-sensitive sectors like Energy and Utilities.
- Second, incorporating both revenue and carbon cost effects uncovers heterogeneous impacts within sectors, with some firms benefiting from the transition while others face significant losses. This heterogeneity underscores the limitations of using carbon intensity as a standalone proxy for transition risk.
- Third, the sensitivity analysis shows that transition risk impacts are highly dependent on scenario and time horizon assumptions, while the choice of the integrated assessment model has a limited impact.

Based on these results, several recommendations can be made for academics, regulators, and practitioners.

- First, forward-looking metrics that incorporate both revenue and operational cost transmission channels should be prioritised to enhance risk assessment frameworks.
- Second, given the uncertainty surrounding socio-economic pathways of the energy transition, utilising a set of complementary scenarios allows for a relevant estimation of potential transition outcomes and their implications for equity valuations, that can serve as the starting point of a risk management strategy.
- Third, the sensitivity analysis reveals that most transition risks materialise from cash flows beyond 2030, despite the mitigating effects of discounting. This finding suggests that the ‘tragedy of the horizon’ is not an inherent flaw of the discounting principle but rather a reflection of the prevalent focus on short-term horizons in current risk assessments.

The rest of this paper is organised as follows. In Section 1, we review the existing literature on transition risks, highlighting how this analysis aims to extend existing results by focusing on the interplay between carbon cost and revenue transmission channels. Section 2 introduces the model and data, detailing the integration of firm-level revenue data with sectoral variables derived from NGFS scenarios and the calibration of key parameters. Section 3 presents the results, highlighting the significance of the revenue transmission channel, the heterogeneous impacts within sectors, and the sensitivity of outcomes to scenario design, time horizon, and model uncertainties.

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Finally, Section 4 concludes by discussing these results in light of the current literature and offering recommendations for future research.

1. Literature Review

1. Literature Review

Financial investors, regulators, and researchers began addressing transition risks during the 2010s, giving rise to a burgeoning field of study. In 2011, the Carbon Tracker Initiative highlighted the risk of a ‘carbon bubble’ in the fossil fuel sector, stemming from reserves that are currently financially valued but whose exploitation and anticipated revenues would conflict with international climate mitigation objectives (Leaton et al., 2011). Subsequently, in 2015, the former Governor of the Bank of England, Mark Carney, delivered a seminal speech cautioning financial institutions about the systemic consequences of climate-related physical and transition risks. The formalisation of these climate-related financial risks occurred in 2017 with the establishment of the Task Force on Climate-related Financial Disclosures (TCFD) by the Financial Stability Board. Since then, significant research efforts have concentrated on climate transition risks. In this section, we first review the theoretical channels driving transition risks, and then discuss recent developments and findings following the distinction introduced by Campiglio et al. (2023) and Daumas (2024) between backward-looking studies, which analyse the historical impact of transition risks on financial asset prices, and forward-looking studies, which utilise scenario-based approaches to estimate potential future changes in asset prices².

1.1 The Transition Risk Drivers and Their Theoretical Impacts on Financial Performance

Transition risks arise from the interplay of three key drivers³: policy risk, technology risk, and preference change (Semieniuk et al., 2021). Policy risk encompasses the risks and opportunities linked to the implementation of climate mitigation measures, including regulations, taxes, trading mechanisms, public subsidies, and public investments. Technology risk pertains to the emergence of innovations that facilitate the transition from fossil fuels to low-carbon energy sources. Preference changes operate through two distinct channels: shifts in consumer demand for green products and services driven by evolving preferences, and changes in investor preferences towards green assets, motivated by either risk-return considerations or social responsibility objectives.

These drivers are interdependent, as policy incentives can accelerate technological adoption, while policy and technological advancements can shape consumer demand for green products⁴. From a qualitative perspective, transition risks may affect financial institutions and their portfolios through multiple channels. The Basel Committee (2021) differentiates between microeconomic transmission channels, which influence financial counterparties directly, and macroeconomic transmission channels, which influence financial counterparties through broader factors such as global growth and labour productivity. Whether through micro- or macroeconomic channels, transition drivers affect both the flows and stocks of a company, resulting in alterations to its income statement, cash flow statement, and balance sheet. In terms of flows, the primary impacts may involve revenues (e.g., fluctuations in sales volumes or prices), operating costs⁵ (e.g., environmental taxes, energy, or raw material price volatility), financial costs (e.g., higher interest rates for risky projects), and investments (e.g., capital for production or innovation). Regarding stocks, significant impacts may include the devaluation of tangible assets due to reduced

2 - Daumas (2024) consider three fields specifically related to low-carbon transition risks: the asset stranding literature, the direct assessment of transition risks through prospective models – which corresponds to the ‘forward-looking’ literature and the financial empirics of the low-carbon transition – which corresponds to the ‘backward-looking’ literature.

3 - Originally, the TCFD defined transition risks as policy and legal, technology, market and reputation risks.

4 - Although challenging to quantify, transition risks can also be influenced by liability or litigation risks. These risks arise from the potential for costly legal actions targeting greenhouse gas-intensive industries or financial institutions that fail to adapt to climate-related developments. As of October 2024, about 230 ‘strategic climate cases’ have been filed against companies since 2015. This includes ‘climate-washing’, ‘polluter pays’, ‘corporate framework’, and ‘transition risk’ cases (Setzer and Higham, 2024).

5 - Empirical evidence confirms in particular that firms with high carbon emission intensity tend to exhibit lower profitability, even after controlling for industry effects (Oestreich et al., 2024).

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profitability (e.g., stranded assets) and variations in intangible assets such as patents or brands sensitive to consumer preferences.

1.2 Mixed Evidence on the Integration of Transition Risks by the Financial Markets

Despite the numerous theoretical channels through which transition risks can impact financial portfolios, the empirical evidence regarding their effect on asset prices remains inconclusive. For instance, Bolton and Kacperczyk (2021) show that firms with higher GHG emissions are valued at a discount, suggesting that investors demand compensation for their exposure to transition risks (the 'carbon risk premium'). On the other hand, Bernardini et al. (2021) and Bauer et al. (2022) find that green stocks have generally provided higher returns than brown stocks for much of the past decade. Finally, other studies such as those by Gorgen et al. (2021) and Amenc et al. (2021), do not find any carbon or green premium to be statistically significant.

An interpretation of these conflicting findings is offered by Pástor et al. (2022) and Ardia et al. (2023) by emphasising the distinction between realised and expected returns. Unexpected changes in climate concerns can prompt a revaluation, resulting in higher returns for green stocks and lower returns for brown firms. Pástor et al. (2021) explain this mechanism through a theoretical model where increasing investor demand for green assets drives this divergence. As a result, green stocks' realised returns may have exceeded those of brown stocks, even if their expected returns remain lower.

In their review, Campiglio et al. (2023) conclude that 'the literature tends to tilt towards the opinion that climate-related risks are inefficiently priced, and financial markets underreact to them' (p. 963). Thomä and Chenet (2017) attribute this mispricing to inadequacies in risk modelling frameworks, which fail to account for the uncertainties associated with climate change, and to inter-temporal inconsistency, described by Carney as the 'tragedy of horizons'. Silver (2017) further highlights that portfolio managers' decisions about transition risks are influenced by cultural factors, misaligned incentives, and the conventional practice of measuring and managing risks relative to benchmarks.

1.3 Towards Integrated Forward-Looking Scenario Analysis

The inconclusive findings on the effect of transition risks on asset prices, combined with the limitations of existing risk management frameworks in capturing these risks, underscore the need for alternative approaches. Forward-looking methodologies, such as short-term climate stress tests and long-term scenario analyses, have been developed to quantify the potential materialisation of transition risks and their implications for financial markets (Campiglio et al., 2023).

Short-term climate stress tests are designed to simulate sudden, unexpected shocks related to transition risks, often in the form of a sharp increase in carbon pricing. For example, Barker et al. (2015) propose an 'aggressive' scenario where carbon prices in six major markets rise to USD50–75 per tonne by 2025. They estimate the resulting changes in firms' profit before tax as a proxy for

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potential losses in equity market value. Similarly, Reinders et al. (2023) assess the impact of EUR100 and EUR200 carbon tax shocks on the market values of equity and debt instruments, applying their model to the exposures of Dutch banks. A key challenge in such exercises is capturing the impact of carbon pricing on indirect emissions, including those from energy consumption (Scope 2) and the broader upstream and downstream value chain (Scope 3). Additionally, second-order effects, such as the pass-through effect – the ability of firms to transfer part of the carbon tax burden to consumers – must be considered. Environmentally extended input-output models are a leading method for estimating both the impact of indirect emissions and the pass-through potential of each sector. For example, leveraging the World Input-Output Database, which captures interdependencies among 55 sectors, Adenot et al. (2022) and Desnos et al. (2023) examine the ‘cascading’ effects of carbon price increases. They show that while sectors such as energy, materials, and utilities are the most directly impacted by carbon pricing mechanisms, incorporating second-order effects reveals significant shocks in other industries, including consumer staples, consumer discretionary, and information technology. The authors also underline the importance of the uncertainty regarding the pass-through parameter.

Short-term climate stress tests focus on carbon pricing mechanisms, such as taxes or emissions trading schemes, as the primary transition driver, with their impact on firms’ operational costs as the main transmission channel through which transition risks result in financial devaluation. As a result, these stress tests do not account for long-term dynamics, including the opportunities associated with the growth and development of green activities. To address this limitation, long-term scenario analyses have been developed by both practitioners and ESG data providers, as well as by financial regulatory institutions. Binger et al. (2022a) conducted a comparative analysis of 16 forward-looking climate transition risk tools, primarily developed by ESG data providers. Their findings indicate that many of these tools extend the scope of transition risk drivers beyond the carbon price by incorporating factors such as input substitution (eight out of 16 methodologies) and potential economic gains (11 out of 16 methodologies). However, the study highlights a significant lack of methodological transparency, with only two out of the 16 methodologies rated as having high public transparency, creating substantial challenges for replicability.

Since 2019, financial regulatory institutions have actively developed similar long-term scenario methodologies to conduct climate risk sensitivity analyses at micro- and macroprudential levels, particularly under the framework of the Central Banks and Supervisors Network for Greening the Financial System (NGFS) (Acharya et al., 2023; D’Orazio et al., 2024). Regarding transition risks, this framework relies primarily on process-based integrated assessment models, which take into account the interactions between the economic and energy sectors, capturing indirect effects of both political and technological shocks. For example, the 2022 climate stress test for institutions for occupational retirement provision conducted by the European Insurance and Occupational Pensions Authority relies on the variables generated by the REMIND-MAgPIE integrated assessment model (part of the NGFS framework), while more granular sectoral and country-level economic and financial variables are derived from a structural macro-econometric model (EIOPA, 2022). However, a limitation in portfolio

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management applications lies in the inability to distinguish between companies within the same sector, as the variables typically affect sector-level stock market indices. The European Central Bank has addressed this issue in its first two EU-wide climate stress tests by introducing a methodology that incorporates company-specific sensitivities to shocks (ECB, 2021; 2023). This is accomplished by assessing the historical sensitivities of firms' asset values, operating expenses, and debt levels to macroeconomic variables (e.g. inflation) and adjusting these factors based on companies' direct and indirect emissions as well as their decarbonisation objectives.

The approach proposed in this paper aligns with this long-term scenario analysis framework recently advanced by financial regulators, utilising outputs from NGFS integrated assessment models. The first contribution to the literature is an improved understanding of how companies within the same sector can experience different impacts, achieved by quantifying the relative contributions of the 'revenue' and 'operating cost' transmission channels. Instead of relying solely on Scope 1 and 2 emissions, which neglect indirect effects like those related to product sales, or Scope 3 emissions, which often suffer from data quality issues, this methodology integrates 'green' revenue data derived from the EU taxonomy for sustainable activities. This enables a more refined analysis of the revenue impacts of adopting specific technologies and the operational cost effects of their implementation. The second contribution is an evaluation of the sensitivity of these results to variations in scenario design, time horizon, and model uncertainties. As noted by Bingler et al. (2022b) and Campiglio et al. (2023), such choices have a significant influence on outcomes. To this end, the analysis considers a set of four distinct scenarios, two time horizons (2030 and 2050), and three integrated assessment models.

2. Model and Data

2. Model and Data

The price of equity assets associated with a firm can fluctuate due to shifts in investors' perceptions of the firm's future expected cash flows or changes in the discount rate applied to assess the present value of those cash flows (Pástor et al., 2021). Transition risk drivers can influence these cash flows, potentially harming 'brown' firms or benefiting 'green' firms. The approach proposed here seeks to model a *conditional transition loss* in equity value caused by changes in expectations surrounding climate transition scenarios, focusing on the impact of changes in expected cash flows. This section introduces the model, and its calibration.

2.1 A Discounted-Cash Flow Model for Transition Risk Channels

The analysis employs a discounted cash flow model that considers the impact of two key transmission channels for each firm. The first channel relates to revenue, which is affected differently across companies based on the contribution of various activities to the firm's total revenue. Each activity segment's revenue is driven by a corresponding scenario variable. For instance, the revenue segment linked to 'conventional transportation' would align with the trend of the scenario variable 'Final Energy|Transportation|Liquids'. The second channel concerns operating costs, which depend on the firm's direct emissions (Scope 1) intensity and the carbon price specified in the scenario.

Let $CF_{i,t}$ denote the cash flows of firm i at time t , under the expected (*baseline*) transition scenario. We assume the following cash flow structure:

$$CF_{i,t} = Y_{i,t}(1 - \omega_{i,t} - \theta - \tau - \rho)$$

where $Y_{i,t}$ represents revenue, $\omega_{i,t}$ the carbon costs rate, θ the operating cost rate, τ is the tax rate, and ρ the (net) investments rate⁶. Firm revenue, $Y_{i,t}$, is the sum of revenue its activity segments, denoted by s . The dynamic of revenue is driven by a growth factor specific to each activity segment:

$$Y_{i,t} = \sum_s Y_{i,s,0} \times \frac{Y_{s,t}}{Y_{s,0}}$$

where $Y_{i,s,0}$ is the initial sales of product s for stock i , and $\frac{Y_{s,t}}{Y_{s,0}}$ is the growth factor of the product's demand over time, determined by the scenario.

The carbon costs rate is modelled as the product of the direction emissions (Scope 1) of the firm and the carbon price of the scenario. Indirect emissions, whether related to energy consumption (Scope 2) or the entire value chain (Scope 3), are not considered to directly affect the carbon cost rate. This assumption is based on the premise that their impact is already integrated at the sectoral level through the integrated assessment model, and their repercussions on the firm cash flows are captured through the revenue channel. For example, a car manufacturer may have minimal Scope 1 emissions, but significant Scope 3 emissions associated with its products' use. Rather than directly applying a carbon price to these Scope 3 emissions – which are often challenging to quantify – the integrated assessment model is assumed to account for the effects of a carbon tax on the demand for conventional vehicles, resulting in reduced demand. For the car manufacturer, this indirect impact is therefore reflected in the revenue segment.

⁶ - Every rate is expressed as a fraction of the sales. It allows us to factorise the sales in the cash-flows formula.

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Finally, to avoid negative cash flows, the carbon cost rate is capped such that the sum of the carbon cost rate, tax rate, operating cost rate, and investment rate does not exceed 1:

$$\omega_{i,t} = \min(\sigma_i \times \Lambda_t, 1 - \tau - \theta - \rho)$$

where σ_i is the carbon intensity of the stock i and Λ_t is the carbon price.

Once the cash flows are projected between the reference date and the analysis horizon, they are discounted by weighted average cost of capital (WACC):

$$DCF_{i,t} = \frac{CF_{i,t}}{(1 + WACC)^t}$$

These discounted cash flows are summed to compute the total firm value V_i :

$$V_i = \sum_t^T DCF_{i,t}$$

The *conditional transition loss* is finally computed as the relative change in the stock value compared to the value in the baseline scenario:

$$L_i = -\left(\frac{\Delta V_i}{V_i^{baseline}}\right)$$

2.2 Decomposing the Revenue and Carbon Cost Effects on Conditional Transition Loss

The transmission channels of revenue, driven by growth in different activity segments, and operational costs, influenced by carbon costs, are interconnected. Since carbon costs are proportional to a firm's carbon intensity, the absolute operating cost depends on the level of activity, which is itself determined by the firm's revenue. To better understand the relative contribution of each transmission channel, this relationship is further analysed. Specifically, we calculate the sensitivity of DCF to changes in carbon cost rate $\omega_{i,t}$ and projected sales $Y_{i,t}$:

$$\begin{aligned}\frac{\partial DCF_{i,t}}{\partial \omega_{i,t}} &= -\frac{Y_{i,t}}{(1 + WACC)^t} \\ \frac{\partial DCF_{i,t}}{\partial Y_{i,t}} &= \frac{(1 - \omega_{i,t} - \tau - \theta - \rho)}{(1 + WACC)^t}\end{aligned}$$

These partial derivatives give us the sensitivity of the discounted-cash-flows to the carbon costs rate and sales:

$$\frac{\partial^2 DCF_{i,t}}{\partial \omega_{i,t} \partial Y_{i,t}} = -\frac{1}{(1 + WACC)^t}$$

The impact on the discounted-cash-flows of the stock i due to the climate scenarios can thus be described as:

$$\begin{aligned}\Delta DCF_{i,t}^Y &= \frac{\partial DCF_{i,t}}{\partial Y_{i,t}} \times \Delta Y_{i,t} \\ \Delta DCF_{i,t}^\omega &= \frac{\partial DCF_{i,t}}{\partial \omega_{i,t}} \times \Delta \omega_{i,t} \\ \Delta DCF_{i,t}^{Y \times \omega} &= \frac{\partial^2 DCF_{i,t}}{\partial \omega_{i,t} \partial Y_{i,t}} \times \Delta \omega_{i,t} \Delta Y_{i,t}\end{aligned}$$

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where $\Delta Y_{i,t}$ and $\Delta \omega_{i,t}$ are the differences in the projected sales and the carbon costs rate between the initial expected transition scenario and the new market expectations. The total impact of the transition scenario on firm i 's discounted cash flows can thus be expressed as:

$$\Delta DCF_{i,t} = \Delta DCF_{i,t}^Y + \Delta DCF_{i,t}^\omega + \Delta DCF_{i,t}^{Y \times \omega}$$

The change in stock value due to unexpected transition concerns is:

$$\Delta V_i = \Delta V_i^Y + \Delta V_i^\omega + \Delta V_i^{Y \times \omega}$$

The loss from each factor is computed as a ratio to the baseline stock value:

$$\begin{aligned} L_i^Y &= -\left(\frac{\Delta V_i^Y}{V_i^{\text{baseline}}}\right) \\ L_i^\omega &= -\left(\frac{\Delta V_i^\omega}{V_i^{\text{baseline}}}\right) \\ L_i^{Y \times \omega} &= -\left(\frac{\Delta V_i^{Y \times \omega}}{V_i^{\text{baseline}}}\right) \end{aligned}$$

where V_i^{baseline} is the value of the stock in the initially expected transition scenario. The loss from net carbon tax is computed as the loss from carbon netted from the interaction term:

$$L_i^{\omega^{net}} = L_i^\omega + L_i^{Y \times \omega}$$

The total loss of the stock i can therefore be expressed as:

$$L_i = L_i^Y + L_i^{\omega^{net}}$$

This decomposition allows us to understand the repricing effects of unexpected change in transition concerns through two main dimensions: the net carbon tax effect and the revenue effect.

2.3 Model Calibration

The growth factors – specific to each activity segment – and the carbon price are calibrated based on the Network for Greening the Financial Systems (NGFS) scenarios database⁷.

The Current Policies scenario is considered as the reference scenario, and the Net Zero 2050 scenario as our main 'adverse' transition scenario⁸. Certain activity segments are particularly vulnerable to transition risks, such as the climate policy-relevant sectors identified by Battiston et al. (2017). For these specific segments, relevant NGFS scenario variables have been selected as proxies to estimate the growth factor influencing revenue trends (Exhibit 1). The growth factor is defined as $\frac{Y_{s,t}}{Y_{s,0}}$, where $Y_{s,t}$ is the demand of the product s at time t and $Y_{s,0}$ is the demand of the product s at the base year (2020).

7 - These scenarios are based on three Integrated Assessment Models (IAMs): GCAM 6.0 NGFS, MESSAGEix-GLOBIOM 1.1-M-R12 and REMIND-MAgPIE 3.2-4.6. We focus on the MESSAGEix-GLOBIOM 1.1-M-R12 model for results presentation.

8 - The additional scenarios Below 2°C, Delayed transition, and Fragmented World are considered in the sensitivity analysis.

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Exhibit 1: Activity segments and scenario variables

Activity segment	NGFS Variable used to calibrate the growth factor
Other	GDP MER Counterfactual without damage
Fossil Fuels Electricity	Secondary Energy Electricity Coal
	Secondary Energy Electricity Gas
	Secondary Energy Electricity Oil
Low Carbon Electricity	Secondary Energy Electricity Biomass
	Secondary Energy Electricity Geothermal
	Secondary Energy Electricity Hydro
	Secondary Energy Electricity Solar
	Secondary Energy Electricity Wind
	Secondary Energy Electricity Nuclear
Fossil Fuels	Primary Energy Coal
	Primary Energy Gas
	Primary Energy Oil
	Secondary Energy Gases
	Secondary Energy Liquids
Hydrogen	Secondary Energy Hydrogen
Alternative Transportation	Final Energy Transportation Electricity
	Final Energy Transportation Hydrogen
Conventional Transportation	Final Energy Transportation Liquids

Note: This table presents the mapping between specific segment activities and the corresponding NGFS scenario variables used to proxy the revenue trend of each segment.

The initial revenue for each activity segment, $Y_{i,s,0}$, is determined using a dataset derived from the European Sustainable Taxonomy (Moody's Product & Services dataset) in conjunction with the NACE classification⁹. The Weighted-Average Cost of Capital (WACC), Tax Rate (τ), Operating Costs Rate (θ), and Net Investments Rate (ρ) are calibrated based on the global version of the Damodaran Online database¹⁰, at TRBC sector level¹¹ (Exhibit 2).

Exhibit 2: Calibrated Parameters by TRBC Sector

Sector	WACC	τ	θ	ρ
Industrials	0.091	0.201	0.116	0.071
Basic Materials	0.094	0.140	0.090	0.038
Cyclical Consumer	0.091	0.138	0.308	-0.005
Energy	0.086	0.136	0.068	0.022
Financials	0.075	0.036	0.232	-0.032
Non-Cyclical Consumer	0.073	0.174	0.241	0.122
Technology	0.107	0.079	0.270	0.026
Telecoms	0.077	0.178	0.309	0.016
Utilities	0.082	0.141	0.190	0.116
Total	0.064	0.125	0.221	0.032

Note: This table presents the calibrated parameters for different TRBC sectors, including Weighted-Average Cost of Capital (WACC), Tax Rate (τ), Operating Costs Rate (θ), and Net Investments Rate (ρ). The WACC is calibrated using the field Cost of Capital, while the tax rate (τ) is derived from the Tax Rate field. The operating costs rate (θ) is calculated by subtracting the Pre-tax, Pre-stock compensation Operating Margin from the Gross Margin. The net investments rate (ρ) is calibrated using the field Net Capex/Sales.

9 - The following process is applied for each stock: for each activity segment with an available information in Moody's dataset, that percentage is assigned to the corresponding segment, b) the remaining revenue percentage is allocated to the segment corresponding to the NACE code of the firm. For NACE activities not explicitly mapped, revenue is assigned to the 'Other' segment.

10 - https://pages.stern.nyu.edu/~adamodar/New_Home_Page/data.html

11 - Stocks that do not have a TRBC sector are assigned to the Total sector, calibrated with the total market. Due to the lack of data, we assign the stocks from the Healthcare sector to the Total sector.

3. Results

3. Results

The model is applied to the 1,287 largest listed companies in the world¹². The results demonstrate that the revenue transmission channel is significant and, on average, has an impact comparable to that of the carbon price transmission channel. Additionally, incorporating both transmission channels reveals heterogeneous impacts within transition-sensitive sectors. Furthermore, we show that the conditional transition loss provides additional insights beyond the carbon intensity typically used as a proxy for transition risk. Lastly, the sensitivity of these findings to the choice of scenario and time horizon is discussed.

3.1 The revenue transmission channel as a key driver

While most short-term climate stress test exercises on equity portfolios focus on the impact of carbon pricing mechanisms on firms' operating costs, this long-term scenario analysis incorporates dynamics related to demand shifts across different activity segments. The analysis reveals that aggregate impact of this transmission channel is more important than the impact on carbon price for most of the sectors, both for sectors with low direct emissions (such as Healthcare, Telecoms and Technology), whose revenue are impacted by the global GDP trajectory, and for transition-sensitive sectors where specific 'green' activity segments are developing and 'brown' activity segments are declining (Utilities, Energy, Industrials). Overall, Utilities, Energy, Basic Materials¹³ and Industrials suffer the greatest losses, with Utilities facing a potential value loss of up to 58% (Exhibit 3).

Exhibit 3: Conditional transition loss per sector

Sector	Total (%)	From net carbon tax (%)	From revenue (%)	Revenue impact / carbon tax impact ratio
Utilities	57.9	22.2	35.6	1.6
Energy	33.1	12.4	20.7	1.7
Basic Materials	22.0	20.1	1.0	0.1
Industrials	9.8	4.9	5.0	1.0
Non-Cyclical Consumer	4.7	3.0	1.8	0.6
Financials	3.1	1.2	1.9	1.5
Healthcare	2.5	0.7	1.7	2.5
Telecoms	2.1	0.3	1.8	6.3
Technology	1.8	0.3	1.5	4.6
Cyclical Consumer	-1.6	1.7	-3.3	1.9
MSCI World	5.9	2.9	3.0	1.0

Note: The table presents the weighted average conditional transition loss for each sector, decomposed into total loss, loss from net carbon tax, and loss from revenue under the Net Zero 2050 scenario using the MESSAGEix-GLOBIOM 1.1-M-R12 model. The 'Revenue impact / carbon tax impact ratio' compares the magnitude of revenue-driven losses to losses from net carbon tax for each sector. A ratio greater than 1, shown in bold, indicates that the impact of revenue shifts is more significant than the impact of the carbon tax, while a ratio below 1 suggests the opposite. Negative values in the total loss indicate net gains for a sector.

3.2 Heterogeneous impact for firms within the climate sensitive sectors

Existing transition risk scenario analyses based on integrated assessment models provide financial impact assessments with sector-level granularity. However, for portfolio managers, it is equally critical

12 - Constituents of the MSCI World Index.

13 - Interestingly, Basic Materials displays a revenue-to-carbon-tax ratio of only 0.05, making it almost immune to the revenue dimension. This contrasts with its heavy exposure to carbon taxes, likely due to the minimal expected changes in demand for this sector under transition scenarios. The sector's potential decarbonisation appears to depend more on shifts in the energy supply chain (Energy and Utilities) than on demand-side transformations.

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to understand both the sectoral and intra-sectoral dimensions of transition risks. Incorporating the revenue transmission channel alongside carbon pricing reveals significant heterogeneity in impacts among companies that belong to the same transition-sensitive sectors. Unlike stress tests that focus solely on carbon pricing, this approach shows that transition can result in positive revaluation for some companies. This is particularly visible in the Energy and Utilities sectors where both ‘winners’ (stocks with negative losses) and ‘losers’ are observed (Exhibit 4).

Exhibit 4: Summary statistics by sector

a) Conditional transition lost (total) (%)								
Sector	Nb. of stocks	Mean	Std dev	Min	Max	Q1	50%	Q3
Utilities	69	51.8	27.3	-97.5	71.1	49.5	58.9	67.3
Energy	59	30.8	22.1	-84.6	57.1	27.4	33.3	43.8
Basic Materials	88	22.0	20.2	-0.7	66.7	5.1	15.2	33.0
Industrials	215	8.4	13.1	-13.7	65.1	1.9	2.5	7.8
MSCI World	1287	9.2	17.0	-97.5	71.1	1.8	2.2	5.3
b) Loss from net carbon tax (%)								
Sector	Nb. of stocks	Mean	Std dev	Min	Max	Q1	50%	Q3
Utilities	69	22.4	25.4	0.0	138.0	5.1	16.9	30.2
Energy	59	12.7	10.3	0.1	33.9	4.9	9.5	18.4
Basic Materials	88	20.3	20.3	0.1	64.3	4.0	13.6	32.0
Industrials	215	4.2	10.6	0.0	63.4	0.3	0.7	1.5
MSCI World	1287	4.7	11.7	0.0	138.0	0.1	0.4	2.3
c) Loss from revenue (%)								
Sector	Nb. of stocks	Mean	Std dev	Min	Max	Q1	50%	Q3
Utilities	69	29.3	31.9	-97.9	49.0	20.2	46.5	48.9
Energy	59	18.0	16.1	-85.0	340.0	23.2	23.3	23.3
Basic Materials	88	1.6	3.1	-17.4	21.9	1.6	1.6	1.6
Industrials	215	4.2	6.5	-15.2	18.4	1.7	1.7	1.7
MSCI World	1287	4.6	11.3	-97.9	49.0	1.7	1.7	1.8

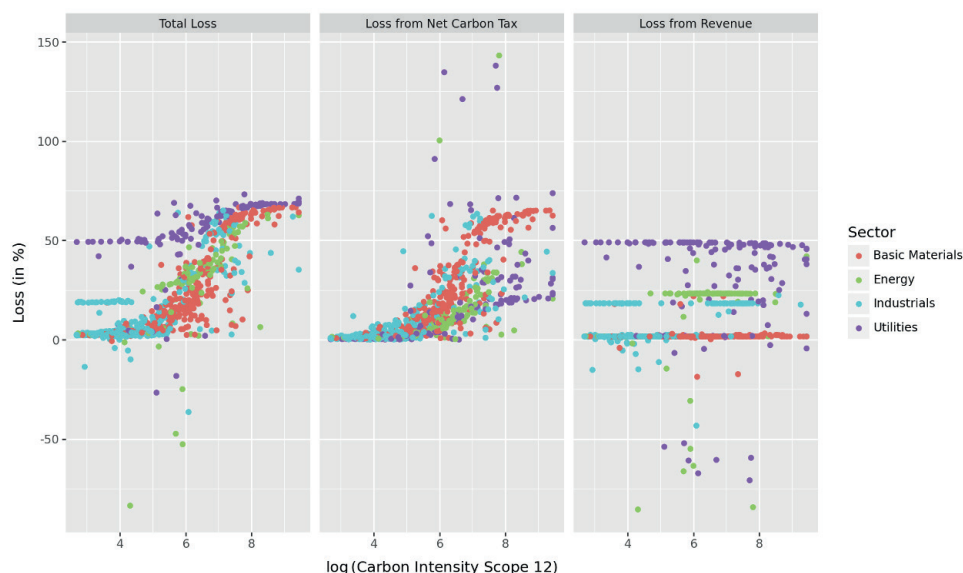
Note: Summary statistics for total loss, loss from net carbon tax, and loss from revenue are presented by sector, covering Utilities, Energy, Basic Materials, and Industrials, along with the overall MSCI World index under the Net Zero 2050 scenario using the MESSAGEix-GLOBIOM 1.1-M-R12 model. The statistics include the mean, standard deviation, minimum, maximum, and quartile values (Q1, median (50%), Q3) across each sector. The total loss reflects the combined impact of transition risks, while the loss from net carbon tax and loss from revenue separately illustrate the effects of carbon pricing and revenue changes. Negative values indicate cases where stocks experienced gains rather than losses.

3.3 A limited overlap between the carbon intensity and the conditional transition loss

Carbon intensity, defined as a company’s emissions divided by its revenue or enterprise value, has been widely used as a proxy for transition risks, particularly in studies examining whether transition risks are priced by the equity market. While the conditional transition loss metric is related to carbon intensity, the analysis reveals significant divergence for many companies due to the influence of the revenue dimension, especially in the Utilities sector (Exhibit 5).

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Exhibit 5: Relationship between carbon intensity and conditional transition loss



Note: The graphics display the relation between carbon intensity and different types of losses across the selected sectors – Utilities, Energy, Basic Materials, and Industrials – under the Net Zero 2050 scenario using the MESSAGEix-GLOBIOM 1.1-M-R12 model. Each plot presents the loss sensitivity to carbon intensity levels, measured as the logarithm of Scope 1+2 intensities. The subplots illustrate the total loss, loss from net carbon tax, and loss from revenue for each sector. The use of winsorisation at the 1st and 99th percentiles reduce the influence of extreme carbon intensity values, and the log transformation allows for a more balanced visualisation of the data.

3.4 Sensitivity analysis to scenario, model, and horizon

Long-term scenario analysis differs from traditional risk management practices for portfolio managers in two key dimensions: first, it extends the time horizon to as far as 2050; second, it incorporates multiple scenarios without assigning probabilities to them. Consequently, it is crucial to assess the sensitivity of the analysis to these two primary parameters.

Regarding scenarios, all transition scenarios result in significantly lower conditional transition losses compared to the Net Zero 2050 scenario (Exhibit 6). For the aggregate universe, the loss ranges from 0.4% under the Fragmented World scenario to 6.2% under the Net Zero 2050 scenario. While the relative differences are substantial, these results offer a useful approximation of the potential range of impacts arising from transition risks.

Exhibit 6: Conditional transition loss sensitivity to scenario

Sector	Net Zero 2050	Below 2°C	Delayed transition	Fragmented World	Max-Min
Utilities	57.9	26.6	21.7	9.9	47.9
Energy	33.1	9.8	7.5	3.3	29.8
Basic Materials	22.0	2.9	2.7	1.1	20.9
Industrials	9.8	2.6	2.0	1.2	8.6
MSCI World	6.2	1.2	1.0	0.4	5.8

Note: This table displays the of sectoral losses to different transition scenarios, including Net Zero 2050, Below 2°C, Delayed transition, and Fragmented World. The values represent the percentage loss for each sector under each scenario. The Max-Min column indicates the difference between the maximum and minimum losses across scenarios, capturing the range of sensitivity to transition risks for each sector. Higher values in the Max-Min column suggest greater sensitivity to the choice of transition pathway, while lower values indicate a more consistent loss impact across scenarios.

3. Results

The time horizon also plays a significant role, as the conditional transition loss for the aggregate universe increases from 2.5% when considering 2030 as the horizon to 6.2% when extending the horizon to 2050. This indicates that, despite the discounting factor reducing the influence of long-term cash flows on present valuations, the majority of transition risks arise from cash flows occurring after 2030 (Exhibit 7).

Exhibit 7: Conditional transition loss sensitivity to horizon

Sector	2030	2050	2030/2050	Max-Min
Utilities	29.3	57.9	0.5	28.5
Energy	12.5	33.1	0.4	20.6
Basic Materials	9.0	22.0	0.4	13.0
Industrials	3.1	9.8	0.3	6.8
MSCI World	2.5	6.2	0.4	3.7

Note: This table presents the sensitivity of sectoral losses to different time horizons, specifically 2030 and 2050. The values represent the percentage loss for each sector at each time point. The 2030/2050 column shows the ratio of losses in 2030 relative to those in 2050, indicating the proportion of near-term impacts compared to longer-term outcomes. The Max-Min column indicates the difference between the maximum and minimum losses across the two horizons, highlighting the extent of change in losses over time. Higher Max-Min values suggest greater variation in sectoral losses between 2030 and 2050, while lower values indicate more stability across time.

More specifically, the analysis reveals that the relative contribution of the revenue mechanism versus the carbon price transmission channel shifts with the time horizon. In the medium term (2030), losses are primarily driven by the carbon tax. However, after 2030, the revenue segments become the dominant driver of losses (Exhibit 8).

Exhibit 8: Revenue impact / carbon tax impact ratio

Sector	2030	2050
Utilities	0.7	1.6
Energy	0.9	1.7
Basic Materials	0.1	0.1
Industrials	0.6	1.0
MSCI World	0.7	1.0

Note: This table displays the Revenue impact / carbon tax impact ratio for each sector across the time horizons 2030 and 2050. The ratio compares the magnitude of the revenue impact relative to the carbon tax impact. A ratio greater than 1 indicates that the revenue impact is more significant than the carbon tax impact, while a ratio less than 1 suggests the carbon tax impact is dominant. Changes in the ratio between 2030 and 2050 reflect how the relative importance of revenue shifts and carbon tax impacts evolves over time for each sector.

Finally, our results exhibit a limited sensitivity to the uncertainties related to the integrated assessment model used to project economic and energy variables. For the aggregate universe, switching from one model to another would lead to a maximum difference in conditional transition loss of 1.2% (from 6.2% to 5.1%) (Exhibit 9).

Exhibit 9: Conditional transition loss sensitivity to model

Sector	MESSAGEix-GLOBIOM 1.1-M-R12	GCAM 6.0 NGFS	REMIND-MagPIE 3.2-4.6	Max-Min
Utilities	57.8	51.1	56.5	6.7
Energy	33.1	22.7	26.3	10.4
Basic Materials	22.0	12.2	13.2	9.8
Industrials	9.8	5.9	5.0	4.8
MSCI World	6.2	5.2	5.1	1.2

Note: This table shows the sensitivity of sectoral losses to different climate-economy models, including MESSAGEix-GLOBIOM 1.1-M-R12, GCAM 6.0 NGFS, and REMIND-MagPIE 3.2-4.6. The values represent the percentage loss for each sector as estimated by each model, with the Net Zero 2050 transition scenario. The Max-Min column indicates the difference between the maximum and minimum losses across the models, reflecting the range of variability in model outcomes for each sector.

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Combining the sensitivities to each parameter indicates that the conditional transition loss is predominantly influenced by the choice of scenario and time horizon, while model uncertainties have a smaller impact (Exhibit 10).

Exhibit 10: Conditional transition loss sensitivity to the main parameters

Sector	Max-Min Scenario	Max-Min Horizon	Max-Min Model
Utilities	47.9	28.5	6.7
Energy	29.8	20.6	10.4
Basic Materials	20.9	13.0	9.8
Industrials	8.6	6.8	4.8
MSCI World	5.8	3.7	1.2

Note: This table presents the sensitivity of sectoral losses to different calibration settings, including variation across scenarios (Max-Min Scenario), time horizons (Max-Min Horizon), and integrated assessment models (Max-Min Model). The values represent the difference between the maximum and minimum losses for each sector under each calibration setting, indicating the range of potential outcomes.

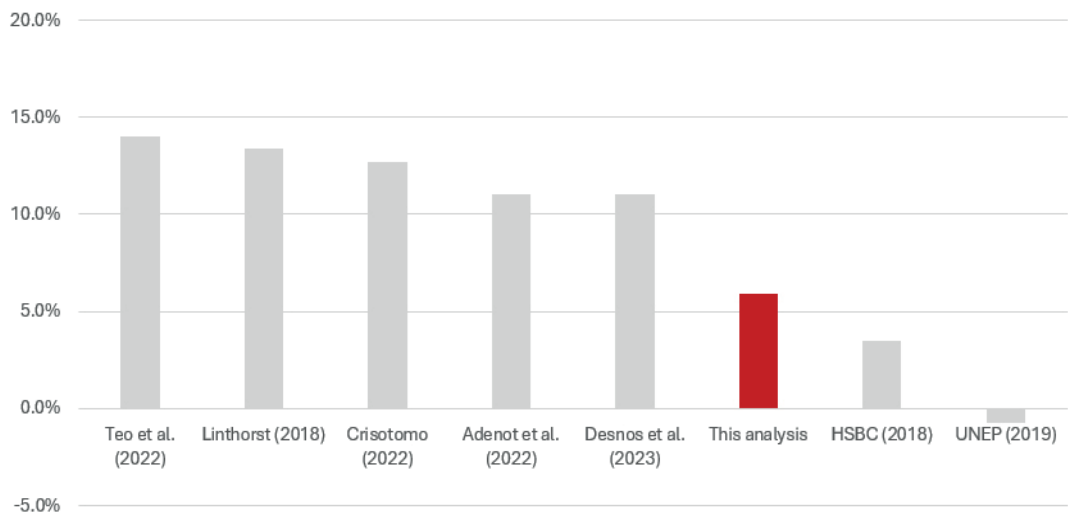
Discussion and Conclusion

Discussion and Conclusion

This study contributes to the understanding of climate transition risks by integrating firm-level data within a long-term scenario analysis to quantify financial impacts in equity portfolios. By incorporating the revenue transmission channel (shifts in demand) alongside the operational cost transmission channel (increasing carbon price), the analysis highlights the significant heterogeneity in transition risk exposure among firms within the same sector. Climate-related sectors like Utilities show varied impacts, with some firms benefiting from transition opportunities while others face substantial losses. These findings underscore the limitations of traditional carbon intensity metrics as proxies for transition risks.

The results of long-term forward-looking scenario analyses are challenging to compare due to the numerous differing assumptions. At an aggregate level, our findings are slightly lower than those reported in existing studies (Exhibit 11). This difference is primarily attributable to our consideration of the positive effects of the transition, in contrast to most studies, which focus solely on potential losses. Among the most sensitive sectors, Energy and Utilities, our results rank in the upper half in terms of transition losses (Exhibit 12). While the literature demonstrates significant variability in conditional transition loss estimates, sector-dependent ranges can be identified. For a diversified portfolio, estimated losses range between 0-15%. In contrast, the ranges are considerably broader for sector-specific losses: 10-50% for Energy and 10-80% for Utilities. These findings underscore the substantial sectoral heterogeneity in transition risks.

Exhibit 11: Comparison of aggregate conditional transition loss in the literature



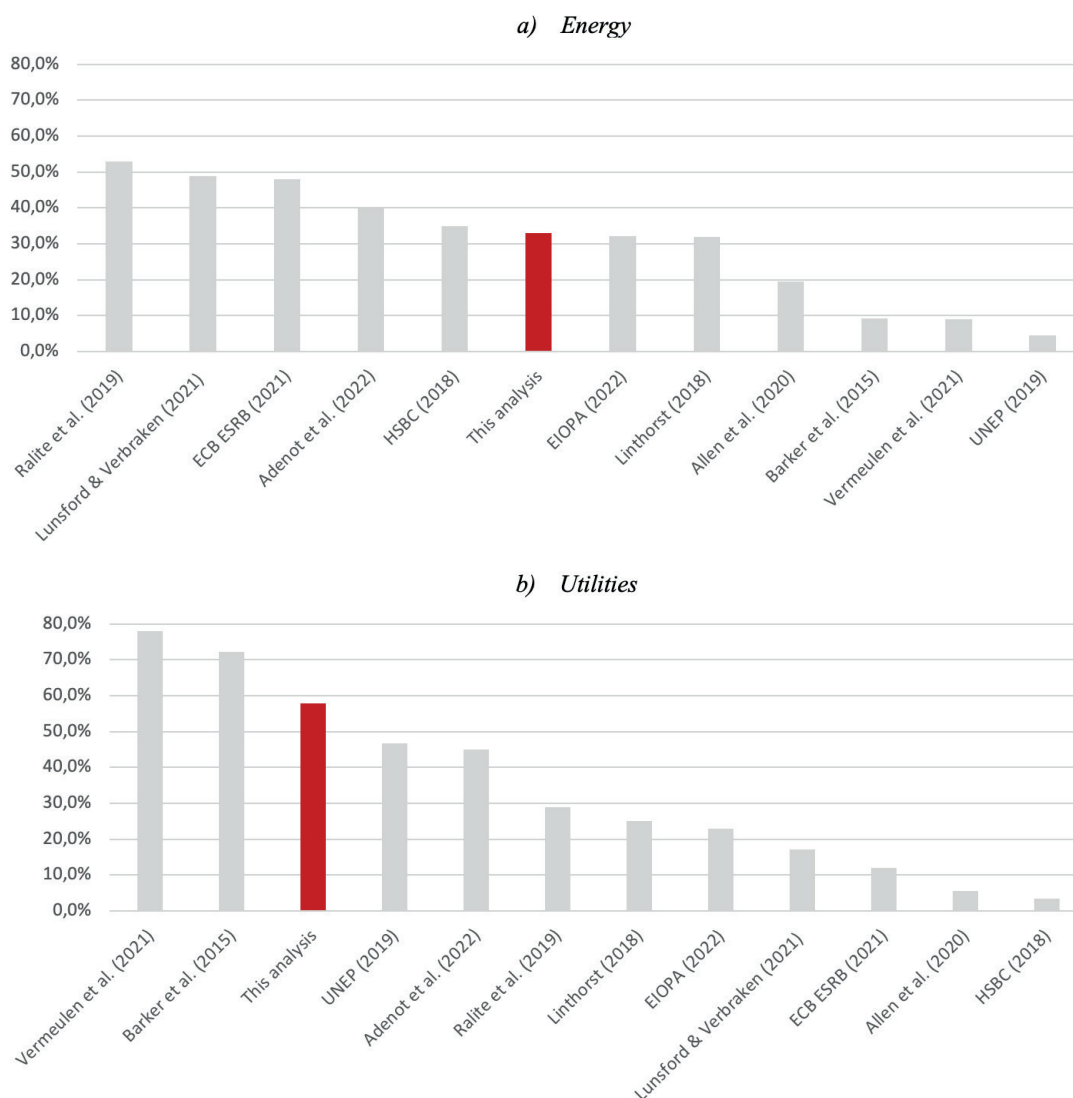
Note: The exhibit displays the conditional transition loss for a diversified portfolio. For each study, the most stringent scenario is presented. The chosen horizon aligns with either the default horizon of the study or the one producing the most adverse outcomes.

The sensitivity analysis highlights the significant influence of scenario design and time horizon on transition risk financial impact. Regarding the horizon, despite the mitigating effect of discounting, the majority of the conditional transition loss originates from cash flows beyond 2030, underscoring the necessity of forward-looking approaches that move beyond short-term stress tests. For practitioners

Discussion and Conclusion

and regulators, this research emphasises the importance of adopting integrated methodologies that incorporate both revenue and operational cost impacts while leveraging complementary scenarios and models to capture a broader range of potential outcomes.

Exhibit 12: Comparison of conditional transition loss in the literature



Note: The exhibit displays the total loss per sector for a diversified portfolio. For each study, the most stringent scenario is presented. The chosen horizon aligns with either the default horizon of the study or the one producing the most adverse outcomes. Studies originally classified results using differing sector classifications; these have been mapped to the most relevant TRBC sectors—Energy and Utilities. Where aggregation across studies was necessary, the median value was used.

These results open several avenues for future research. One of them involves refining the model to incorporate the forward-looking behaviour of firms, such as the dynamics on capital expenditures. However, this approach may require further maturity in the underlying data, as green capital expenditure remains sparsely reported.

Discussion and Conclusion

Another promising direction is to explore the integration of transition risk management into equity portfolio construction by bridging the results from such ‘forward-looking’ approach with the ‘backward-looking’ approaches based on traditional financial factor models. While scenario analysis is a critical first step in understanding the range of potential financial impacts of transition risks, asset prices, as highlighted by Pástor et al. (2021), may also react to changes in discount rates associated with expected cash flows. Using factor models calibrated on historical asset price data could capture potential shifts in investor perceptions and provide a foundation for hedging against these risks.

This would necessitate the development of specific transition risk factors beyond carbon intensity, focusing on broader drivers such as shifts in demand for carbon-intensive products and services. In this context, recent developments in climate-related and transition-related news indicators¹⁴ present a promising avenue to enhance the evaluation of financial instruments’ sensitivity to shift in investor perceptions of climate-related transition risks.

14 - See for example Apel et al. (2023).

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