Climate scenarios for fixed income investors

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Abstract

This paper offers a framework for building capital market assumptions for fixed income portfolios, including expected returns, standard deviations and conditional value-at-risk (CVaR), under diverse climate scenarios. First, it introduces climate risks and reviews the macro-financial models used to design climate scenarios, specifically by showcasing the use of Network for Greening the Financial System and National Institute Global Econometric Model (NGFS NiGEM) macroeconomic data to build financial scenarios for analysing asset classes with interest rates as underlying risk factors. Second, this paper presents a simple method to infer missing data in term structure models, with an application to the Dynamic Nelson-Siegel (DNS) model for both univariate and multivariate cases. Third, it applies the proposed framework to USD currency under six scenarios: Net Zero 2050, Below 2°C, Divergent Net Zero, Delayed Transition, Nationally Determined Contributions, and Current Policies. Expected returns and risk measures are computed for fixed income asset classes (government, corporate and inflation-linked bonds) for three different investment horizons.

Keywords: climate risks, climate conditional value-at-risk, capital market assumptions, asset allocation, scenario analysis, Nelson-Siegel.

JEL classification: G11, D81, C60.

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1. Introduction

Assessing the impact of climate change has become a key consideration for financial institutions, as climate change poses significant risks to asset values and investment returns. At the same time, governments and regulators are implementing new regulations and guidelines to encourage financial institutions to address the risks and opportunities posed by climate change. In 2019, the European Union introduced the Sustainable Finance Disclosure Regulation (SFDR), which requires financial market participants and advisers to disclose information on the integration of sustainability risks into their investment decision-making process.

In March 2022, the Securities and Exchange Commission proposed rule amendments requiring a domestic or foreign registrant to include certain climate-related information in its registration statements and periodic reports. This would include a "[. . .] *proposed definition of scenario analysis [that] both states that (i) when applied to climate-related assessments, scenario analysis is a tool used to consider how, under various possible future climate scenarios, climate related risks may impact a registrant's operations, business strategy, and consolidated financial statements over time; and that (ii) registrants might use scenario analysis to test the resilience of their strategies under future climate scenarios, including scenarios that assume different global temperature increases, such as, for example 3°C, 2°C, and 1.5°C above pre-industrial levels."*

The *Recommendations of the Task Force on Climate-Related Financial Disclosures* (TCFD (2017)) gives five reasons for using scenario analysis: (i) to help organisations consider issues, such as climate change, that are highly uncertain, with medium- to long-term outcomes and potentially disruptive effects; (ii) to enhance strategic conversations about the future and broaden decision-makers' thinking across a range of plausible scenarios; (iii) to help organisations frame and assess the potential range of plausible business, strategic, and financial impacts from climate change and associated management actions; (iv) to help organisations identify indicators for monitoring the external environment and adjust their strategies and financial plans accordingly; and (v) to assist investors in understanding the robustness of organisations' strategies and financial plans and in comparing risks and opportunities across organisations.

As defined in Batten (2018), physical risks arise from the increased vulnerability of current or unadaptable human and natural systems to climate-related hazards, such as gradual global warming and extreme weather events. In contrast, transition risks result from the transition to a low-carbon economy. From an economic perspective, physical risks can lead to unanticipated demand or supply shocks in the short or medium term while significantly affecting productivity and economic growth in the long term. Transition risks are shorter term and depend on the capacity to adapt; they can affect demand, supply and medium-term economic growth.

In recent decades, integrated assessment models (IAMs) have become the standard models for simulating the interactions between the economy and the environment. IAMs were first developed in the 1970s as a response to the growing concern over the environmental impacts of economic growth. They have since evolved to include various economic and environmental variables. Early models focused on the relationship between economic growth and resource depletion, but later models incorporate factors such as population growth, energy use, land use and climate change.

One of the most widely used IAMs is the Dynamic Integrated Climate-Economy (DICE) model developed by William Nordhaus in the 1990s. The model combines a neoclassical economic model with a climate model to simulate the impacts of climate change on economic growth. The model has been used to estimate the optimal carbon tax rate needed to limit global warming to 2°C above pre-industrial levels. Nordhaus developed a regional version, the Regional Integrated Model of Climate and the Economy (RICE), in the 2000s. RICE includes regional differences in both climate impacts and economic development. Since then, a myriad of models has been developed; Weyant (2017) reviews the use of IAMs over the previous 30 years. As pointed out by Pindyck (2013) and Hourcade et al (2021), IAMs present some pitfalls; one main challenge is uncertainty in the underlying data and assumptions.

Determining the impact of physical and transition risks on the performance of different asset classes has become a topic of interest. For example, Bowman et al (2022) study the climate change impact on sovereign bonds. They use forward-looking climate forecasts based on models reviewed by the Intergovernmental Panel for Climate Change (IPCC) and other published sources. Tokat-Acikel et al (2021) explore the implications of climate change for expected returns and strategic asset allocation of public asset classes. The International Actuarial Association (IAA) (2022) suggests using the scenarios for climate-related risk assessment devised by the Network for Greening the Financial System (NGFS)[2] to measure market risk vulnerabilities from both climate change and transitional effects on the economy. This scenario approach can be used with a bottom-up approach that considers the exposure of individual investments to climate-related risks and a top-down approach that estimates the impact of climate scenarios on macroeconomic parameters.

For instance, the European Central Bank (2021) evaluated the increasing credit and market risk for banks by assessing the impact on the probability of default, the loss-given-default, the revaluation of the trading book, and capital shortfalls. The authors use NGFS scenarios to identify that the Disorderly Transition and Hot House World scenarios imply higher loan defaults and asset valuation losses. Furthermore, Allen et al (2020) suggest a bottom-up climate-related risk assessment involving transition risks by examining the impact of increases in carbon prices and productivity shocks from the NGFS scenarios.

In particular, the effects of climate change on fixed income assets can be measured from market, credit and liquidity perspectives, accounting for the macroeconomic impacts of physical and transition risks. The contribution of this paper is twofold. First, it provides a methodology to simulate capital market assumptions for fixed income assets using term structure factors. Second, it proposes a simple imputation method to infer missing data, a problem arising with limited climate scenario data.

This paper's next section presents a detailed exposition of the three overarching classifications employed by NGFS to construct climate scenarios and their impact on key macroeconomic indicators. The third section then expands on the model employed in this paper to derive primary risk factors. The fourth section presents ways to translate the risk factors into capital market assumptions for three distinct fixed income assets, namely US Treasuries, US Treasury Inflation-Protected Securities (TIPS), and BBB-rated corporate

2 The Network for Greening the Financial System (NGFS), established in 2017, is a group of central banks and supervisors working to support the transition to a sustainable economy.

bonds denominated in US dollars. Finally, the concluding section summarises the main findings.

2. The data and scenarios

Defining relevant scenarios that represent physical and transition risks is pertinent to creating a robust narrative for assessing the many potential paths for fixed income returns. The Network for Greening the Financial System (NGFS)[3] has developed several climate scenarios to help financial institutions evaluate the potential impacts of climate change on their investments and develop strategies for managing climate-related risks. Using two dimensions – the amount of physical risk and amount of transition risk – NGFS establishes three categories: Orderly Transition, Disorderly Transition and Hot House World.

1. The **Orderly Transition** category assumes a smooth, gradual transition to a low-carbon economy with limited financial and economic disruptions. This scenario envisions policy actions that align with the goals of the Paris Agreement, including a significant increase in renewable energy investments and a phased-out use of fossil fuels. Thus, it represents a relatively low exposure to physical and transition risks. Within this category, two main scenarios are identified:
    - <u>Net Zero 2050:</u> This is the most optimistic scenario, with limited climate-related impact on GDP growth. The central assumption is that the world will achieve net-zero carbon emissions by 2050. The global temperature increases to 1.5°C above pre-industrial levels, as outlined in the Paris Agreement.
    - <u>Below 2°C:</u> This scenario assumes that the increase in global temperature is limited to below 2°C above pre-industrial levels without explicitly considering the achievement of net-zero emissions by 2050. This scenario would have additional physical risk but a slightly lower transition risk than the previous scenario.
2. The **Disorderly Transition** category assumes a sudden transition with severe financial and economic disruptions. This represents significant transition risk but low physical risk in the long term. The scenarios in this category envision a situation in which insufficient climate policies lead to abrupt and widespread changes in market conditions. These changes could lead to a sharp repricing of carbon-intensive assets, triggering widespread defaults and financial instability.
    - <u>Divergent Net Zero:</u> Similar to the Net Zero 2050 scenario, this scenario considers a world where net-zero emissions are achieved by 2050. Here, however, the change to a low-carbon economy is uneven and fragmented across regions and sectors. This scenario results in a significant divergence in the pace and nature of the changes, leading to substantial shocks in some macro variables.

[3] The NGFS scenarios can be found at www.ngfs.net/ngfs-scenarios-portal/. This paper uses the third set of NGFS scenarios, published in September 2022.

- Delayed 2°C: This scenario assumes that the world fails to limit the global temperature increase to below 2°C above pre-industrial levels and instead experiences a delay in the transition to a low-carbon economy. This delay might occur for various reasons, such as policy inaction, technological hurdles or political barriers. Contrary to the previous scenario, the Delayed 2°C scenario has higher physical risks, which lead to more significant economic and financial losses, but it presents a slightly lower transition risk.

3. The **Hot House World** category assumes a failure to limit global warming, resulting in severe physical impacts, such as more frequent and intense heat waves, droughts and storms. The scenarios in this category envision a world in which global warming exceeds 4°C above pre-industrial levels, causing significant damage to the environment, infrastructure and human health.

    - Nationally Determined Contributions (NDCs): This scenario considers a world in which countries fully implement their Nationally Determined Contributions (NDCs) under the Paris Agreement.[4] The NDCs submitted by governments, however, are insufficient to limit the global temperature increase to below 2°C or 1.5°C over pre-industrial levels. The physical risk is therefore significantly higher than in the previous scenarios. Still, given that the action to move to a lower-carbon economy is not sufficient, the transition risk is not very significant.
    - Current Policies: This scenario is the most adverse one for the environment, as it assumes that countries continue to implement their current policies and do not adopt any additional climate action measures beyond those currently in place. This scenario significantly increases greenhouse gas emissions, leading to severe physical risks and economic and financial losses. The transition risk is null, while the physical risk is substantial.

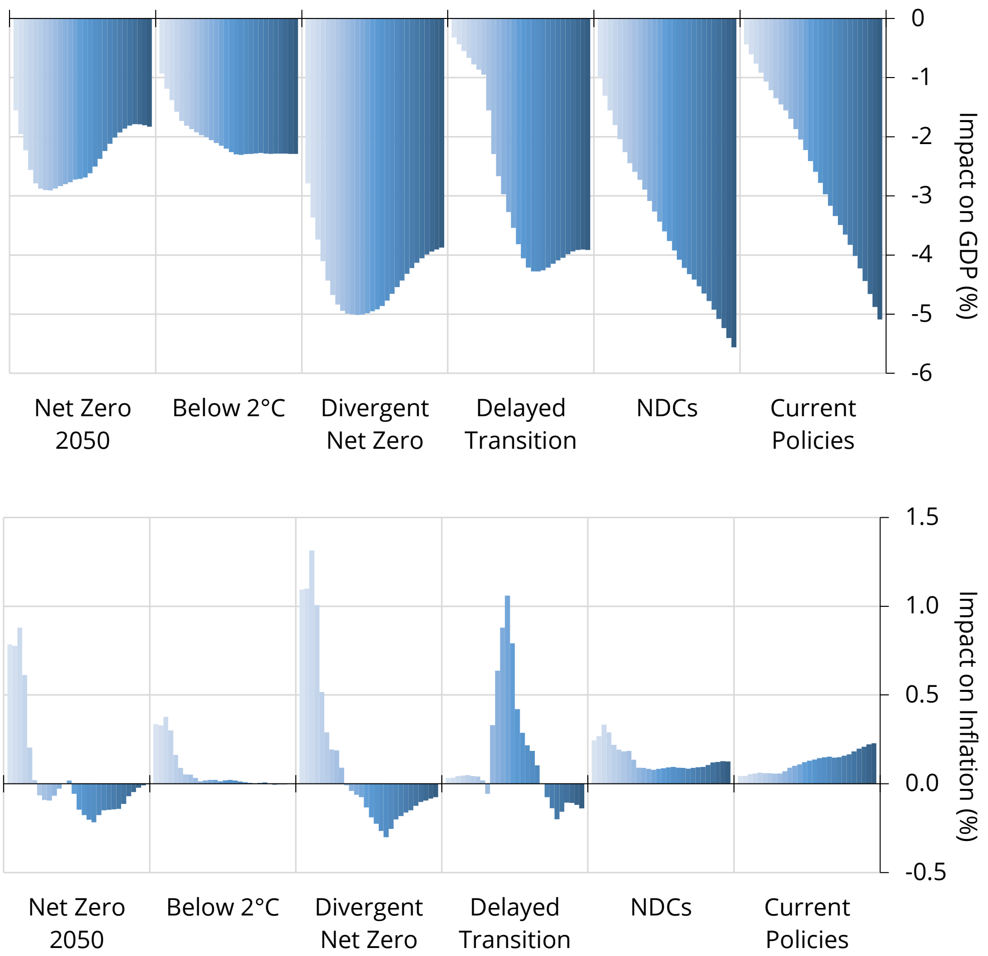
This paper will also focus on the six NGFS scenarios to define their final impact on US fixed income assets in the medium and long term, mainly by stressing the US yield curve. Several macroeconomic factors, such as inflation, GDP growth, unemployment and equity prices, will impact the yield curve. Graph 2.1 displays the evolution of GDP and inflation under different scenarios.

In the Orderly Transition category, inflation remains stable. In the Net Zero 2050 scenario, inflation is even lower in the medium and long term due to investments in energy efficiency, renewable energy and other low-carbon technologies. In the short term, some minor inflationary pressures are created, as transitioning to a low-carbon economy requires upfront investments and changes to production processes. In terms of GDP, the gradual transition to a low-carbon economy makes GDP growth relatively stable. Compared with the other scenarios, in the Net Zero 2050 and the Below 2°C scenarios, the transition to a low-carbon economy drives innovation and productivity gains,

[4] NDCs are pledges made by countries to reduce their greenhouse gas emissions and take other climate action measures. The Paris Agreement (Article 4, paragraph 2) requires each party to prepare, communicate and maintain the successive Nationally Determined Contributions (NDCs) that it intends to achieve.

contributing to GDP growth. Between the two, the Below 2°C scenario performs better in the short and medium term as it is less affected by transition risks. Still, long-term GDP growth is more robust for the Net Zero 2050 scenario as it is less vulnerable to future climate-related hazards.

Impact on GDP and inflation vs baseline scenario (%) Graph 2.1



Source: The Network for Greening the Financial System.

By contrast, in the Disorderly Transition category, inflation increases significantly in the short and medium term, with the Divergent Net Zero scenario being more severely impacted. This high inflation results from supply chain disruptions and increasing energy prices. Moreover, the higher risk premiums caused by financial instability also push up inflation. In the long term, inflationary pressures ease as the economy adapts to the low-carbon shift – but the same adverse factors GDP cause growth to contract as both production and consumption decrease. There is a slight recovery in the long term, as some physical risks are averted.

Finally, in the Hot House World category, the more frequent and intense extreme weather events disrupt agricultural production and other economic activities in the long term, leading to higher food prices and supply chain disruptions. The Current Policies and the NDCs scenarios will have the highest inflation by 2050. However, in the short and medium term, the inflationary pressures are not as extreme as those in the Disorderly Transition category. For GDP, these two scenarios present a gradual decline in GDP growth due to disruptions of economic activity, destruction of physical infrastructure, and adverse health impacts. GDP growth is significantly lower in the long term for these two scenarios as compared with the other four scenarios, which are much less vulnerable to physical risks.

3. The model

The expected returns and the standard deviations of the fixed income instruments are obtained through three steps.

First, we build the forward-looking term structure of nominal and real interest rates and corporate spreads through time (until the desired investment horizon) for each scenario using the NGFS macroeconomic variables. We then map the newly built variables onto risk factors using a Nelson-Siegel representation. Second, we simulate the risk factors using a constrained vector autoregressive (VAR) model. Third, we obtain the expected returns and standard deviations for US Treasuries, US Treasury Inflation-Protected Securities (TIPS), and BBB corporate bonds.

We initially select the financial variables of interest[5] – short-term and long-term rates – and map them on a Nelson-Siegel functional form.

By using the following Nelson and Siegel (1987) formula,[6] the level β_1 and the slope β_2 can be estimated with the two mentioned variables,

$$y(\tau) \quad = \beta_1 + \beta_2 \left[\frac{1 - e^{-\lambda\tau}}{\lambda\tau}\right] + \beta_3 \left[\frac{1 - e^{-\lambda\tau}}{\lambda\tau} - e^{-\lambda\tau}\right]$$

with τ the maturity and λ a fixed parameter. However, we have three parameters to estimate using two observed variables. This issue can be solved by modelling the distribution of the curvature β_3 conditionally on β_1 and β_2 based on historical data. With z a 3-dimensional vector, β_3 conditional on β_1 and β_2 is defined as follows:

5 The NGFS scenarios include estimates of the central bank intervention rate and the long-term interest rate. However, in the long term, the NGFS intervention and long-term rates converge, leading to a flattening of the yield curve. For this reason, we developed our own estimates of the short-term rate using a Taylor rule model. The Taylor rule, a monetary policy rule first proposed in 1993 by John Taylor to guide central banks in setting short-term interest rates, is based on the state of the economy. The formula is driven by the neutral interest rate (the rate appropriate in the absence of any inflation or output gap), the difference between the current inflation rate and the target inflation rate, and the output gap (the difference between actual and potential GDP). Likewise, the long-term rate is also driven by the potential output as an indicator of economic growth prospects, the inflation rate and inflation volatility to approximate inflation expectations, and the central bank policy rate.

6 Developed by Nelson and Siegel (1987) and further characterised by Diebold and Li (2006).

$$z = \begin{bmatrix} y \\ x \end{bmatrix}, \text{ where } y = \beta_3, \text{ and } x = \begin{bmatrix} \beta_1 \\ \beta_2 \end{bmatrix}$$

characterised as:

$$\mu = \begin{bmatrix} \mu_y \\ \mu_x \end{bmatrix}, \text{ where } \mu_y = \mu_3, \text{ and } \mu_x = \begin{bmatrix} \mu_1 \\ \mu_2 \end{bmatrix}$$

and:

$$\Sigma = \begin{bmatrix} \Sigma_{yy} & \Sigma_{yx} \\ \Sigma_{xy} & \Sigma_{xx} \end{bmatrix}.$$

The distribution of y conditional on $x = \hat{x}$, is a multivariate normal:

$$(y|x = \hat{x}) \sim N(\bar{\mu}, \bar{\Sigma})$$

where $\hat{x}$ refers to the projected climate scenario betas and:

$$\bar{\mu} = \mu_y + \Sigma_{yx}\Sigma_{xx}^{-1}(\hat{x} - \mu_x)$$

$$\bar{\Sigma} = \Sigma_{yy} - \Sigma_{yx}\Sigma_{xx}^{-1}\Sigma_{xy}.$$

The other risk factors, ie credit spreads for corporate bonds and real yields for TIPS, are estimated as follows. The interest rate of corporate bonds is a function of the current government rates, the slope of the yield curve, the equity price index and its volatility. Real yields are obtained by assuming that the most immediate inflation expectations follow the current inflation rate, while in the long term, they are aligned with the Fed's inflation target, with linear interpolation for intermediate values. These other risk factors are then estimated using a Nelson-Siegel model, ensuring a similar modelling framework as nominal interest rates.

Second, we simulate the risk factors using a constrained vector autoregressive (VAR) model, defined as follows:

$$\mathrm{B}_t = A + \Theta \mathrm{B}_{t-1} + e_t$$

with B_t the vector of risk factors: the three Nelson-Siegel factors (level, slope and curvature) for the nominal or real curves, plus the credit spread, e_t a random variable, and A and Θ the constant vector and the matrix of parameters to be estimated, respectively. The risk factors at time t are a function of the risk factors at time $(t-1)$ plus a constant and a random variable. The parameters are obtained through maximum likelihood estimation using 20 years of monthly historical data, assuming e_t follows a multivariate Gaussian distribution.[7] Then, the risk factors are simulated over the investment horizon (Monte Carlo) conditionally to the values of the risk factors under each NGFS scenario.[8]

Once the risk factors are simulated, we obtain the components of asset returns at each point in time, which allows us to build the distributions of asset returns for a given investment horizon. For US Treasuries and corporate bonds, the return is calculated by adding the price and coupon returns. The price return for each period (PR_t) is estimated by pricing a set of N par bonds with different maturities that represent the asset universe.

7 See Diebold and Li (2006) and Diebold and Rudebusch (2013) for a description of the methodology to estimate Dynamic Nelson-Siegel (DNS) models.

8 The simulation of the VAR model is constrained to ensure that the average of the risk factors equals the unconditional expectation at each scenario point in time. One possible criticism of this approach is that the VAR parameters and covariance structure are the same across different scenarios. Another option would be to consider a VAR with switching regimes or a Bayesian VAR for the estimation step.

This pricing (P) is a function[9] of the coupon (c), which corresponds to the respective tenor's yield at the beginning of the period, the maturity (m), and the yield (y), which is derived from the projected Nelson and Siegel factors. The price return is defined as follows:

$$PR_t = \sum_{i=1}^{N} \omega_i \left(\frac{P_i(y_{t,i}, c_{t-1,i}, m_i)}{100} - 1 \right)$$

with ω the percentage weight for each par bond that represents a segment of the fixed income asset class.

Similarly, the coupon return for each period (CR_t) is estimated as the weighted average of the coupon for a specific par bond:

$$CR_t = \sum_{i=1}^{N} \omega_i \left(\frac{c_{t-1}}{\Delta t} \right)$$

with Δt the chosen time period (one year for the empirical results).

The return of inflation-linked bonds is estimated similarly to the US Treasuries, with price and coupon returns, but using the real yield curve instead of the nominal yield curve. Additionally, there is a third component, the realised inflation return (IR_t) to calculate the total return:

$$R_t = (1 + RR_t)(1 + IR_t) - 1$$

with RR_t being the price plus coupon return estimated with real yields.

4. Capital market assumptions

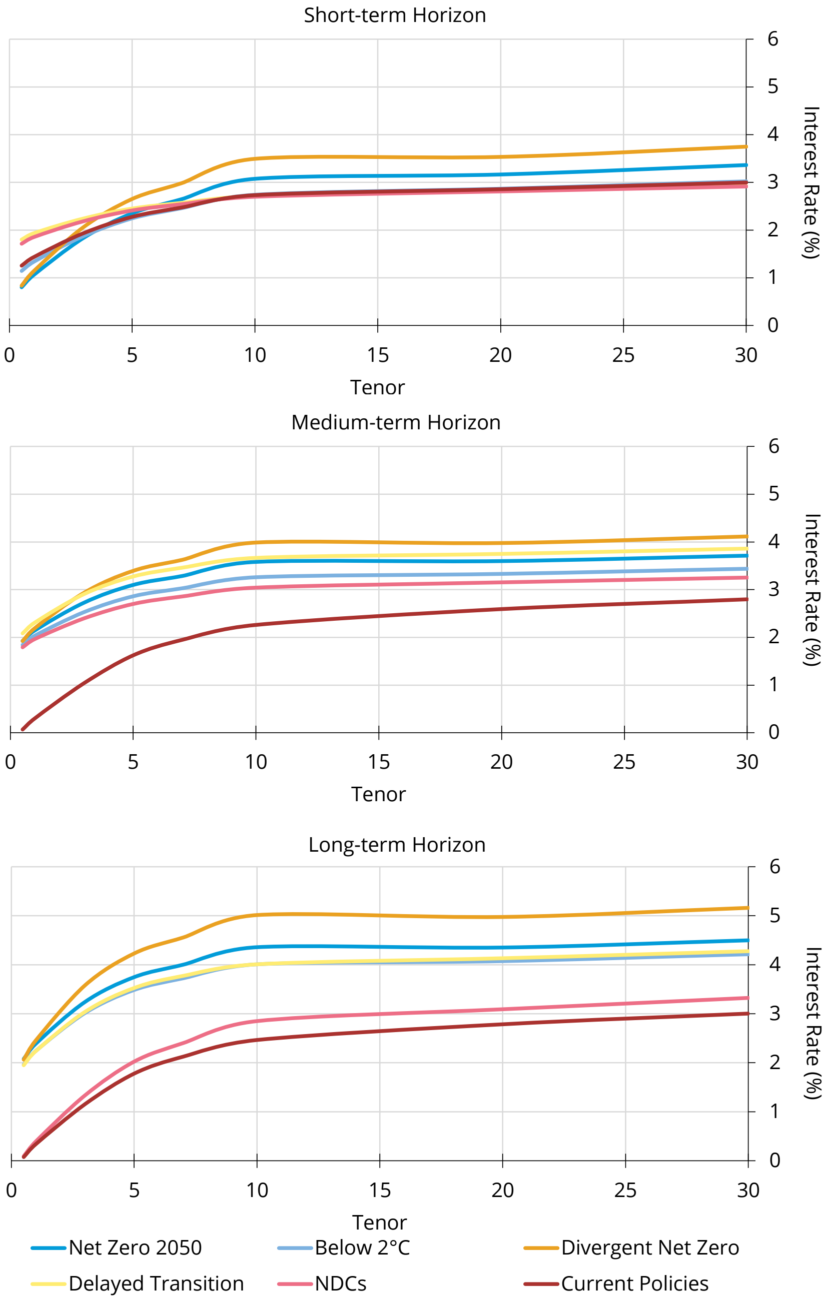
This section provides capital market assumptions based on fixed income risk factors derived from the NGFS climate scenarios. The fixed income risk factors consist of yield curves and credit spreads defined according to the methodology described in the previous section. The capital market assumptions are presented for three indices: US Treasury Bonds, US Treasury Inflation-Protected Securities (TIPS), and BBB corporate bonds.

The US Treasury Bonds index represents the issuance of US Treasuries with an average maturity of 8.3 years. The yield curve is the primary risk factor that will impact the return distribution of this asset class. The US TIPS index represents the issuance of US inflation-linked bonds with an average maturity of 7.8 years. The primary risk factors are the real yield curve and inflation. The BBB corporate bonds index represents corporate bonds issued in US dollars, with a credit rating between BBB– and BBB+ and an average maturity of 10.6 years. In addition to the yield curve, the credit spread is also a relevant risk factor. For the three indices, the asset price's sensitivity to changes in the yield curve, or credit spread if relevant, is assumed to remain constant over time. It should be noted that this analysis considers only market risk and does not take into account the impact of potential defaults.

9 For corporates, the pricing function takes into account the credit spread over the government yield curve.

To capture the impact of transition risk in the short and medium term and to consider the effect of physical risk in the long term, three investment horizons are analysed: a short-term horizon of five years, a medium-term horizon of 14 years, and a long-term horizon of 28 years. Graph 4.1 presents the nominal yield curve by the end of the three horizons for the six NGFS scenarios.

Forecasted nominal yield curves Graph 4.1



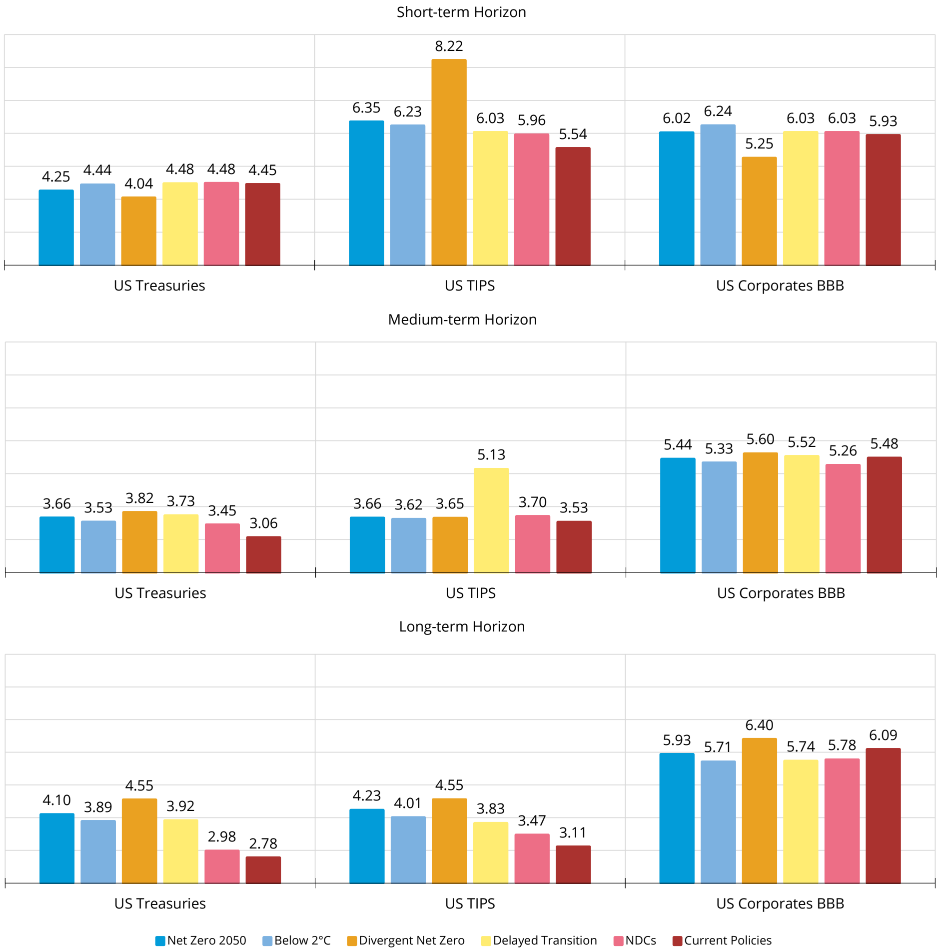
Source: Authors' calculations.

The impact of high inflation expectations in the Net Zero 2050 and Divergent Net Zero scenarios causes the yield curve to steepen more on the short-term horizon than in the other four scenarios. On the medium-term horizon, the effect of falling GDP growth in the yield curve of the Current Policies scenario is notable, resulting in significantly lower interest rates for all tenors than in the other five scenarios. Additionally, the Disorderly Transition scenarios show higher interest rates, given the increasing inflation in these scenarios. On the long-term horizon, the NDCs scenario is similar to the Current Policies scenario, with a low-yield and low GDP environment due to the additional physical risk of the Hot House World category.

With the specific yield curves for each period, a return distribution is built for the three asset classes with a VAR model adjusting the long-term mean of the risk factors to those expected under the six NGFS scenarios. The yield curves are represented by three parameters, namely the level, the slope and the curvature, following the Nelson and Siegel formula to facilitate the VAR model implementation.

The expected returns for the fixed income asset classes are reported in Graph 4.2. The impact of rising interest rates on the Net Zero 2050 and Divergent Net Zero scenarios, will influence the returns of US Treasuries and BBB corporate bonds in the short term. Nonetheless, in the medium and long term, with rates remaining high and stable, these scenarios demonstrate consistent and elevated returns for the aforementioned asset classes. Under the Disorderly Transition category, high inflationary periods positively impact nominal returns. For the Divergent Net Zero scenario, this occurs in the short term, thereby rendering the returns of TIPS particularly attractive. Conversely, in the Delayed Transition scenario, the high inflation period occurs in the medium term, influencing the return of TIPS. Notably, the Hot House World scenarios exhibit a long-term impact on the assets' returns, where low interest rates weaken the return of US Treasuries and TIPS compared with other scenarios. However, the heightened uncertainty associated with these scenarios increases the credit spreads, making the returns of corporates comparable with those in the other scenarios over the long term. It is pertinent to mention that the additional uncertainty may result in more defaults, a possible outcome that falls outside the purview of this analysis.

Expected returns | Graph 4.2
Annualised returns (%)



Source: Authors' calculations.

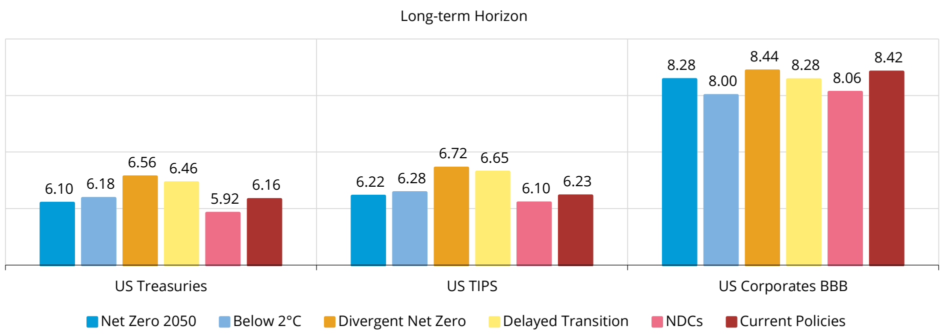
The present study employs a long-term analysis, thereby introducing significant uncertainty into the findings. To illustrate this point, Graph 4.3 showcases the annual volatility of the returns, which proves substantial for all scenarios and asset classes considered.[10] Among the various categories, the Disorderly Transition scenarios exhibit the highest volatility, due to pervasive transition risks that trigger sweeping changes in yield curves and credit spreads across the investment horizon. Conversely, the scenarios categorised under Hot House World display relatively lower volatilities due to the persistently low interest rates, which continue for most of the investment horizons. Nevertheless, the substantially low expected returns associated with low interest rates

[10] Figure 4.3 reports the time series volatility. We also computed the cross-sectional volatility for different horizons. We find that the cross-sectional volatility is lower than the time series volatility.

reflect a more negative Climate VaR[11] (with a confidence level of 95%) against the scenarios of the other categories (see Graph 4.4).

Expected volatility
(%)

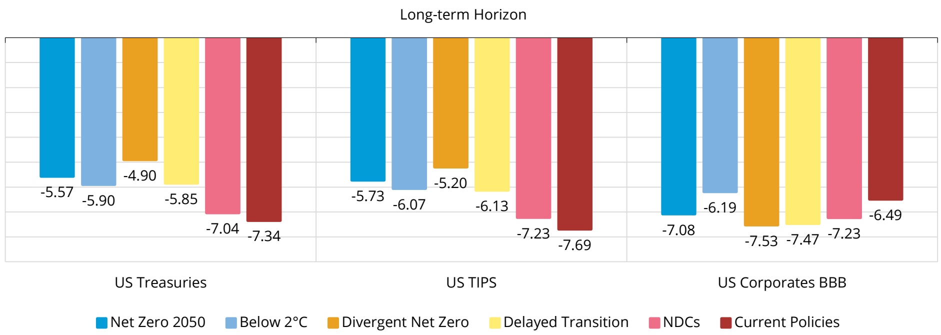
Graph 4.3



Source: Authors' calculations.

Climate VaR (95%)
(%)

Graph 4.4



Source: Authors' calculations.

Concluding remarks

The paper offers a framework for building capital market assumptions, including expected returns and standard deviations, for fixed income portfolios under varied climate scenarios. It provides an empirical application for US Treasuries, US TIPS, and US BBB

[11] The Climate VaR represents the worst 5% return outcome for all the simulations performed through the investment horizon.

corporate bonds for three investment horizons (short term, medium term, and long term). A possible extension would consist in building capital market assumptions for an expanded universe of asset classes, eg public equities, infrastructure, real estate, private equity and commodities.

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