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MODELING METHODOLOGY

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Authors
James Edwards – Director, Research
Rebecca Cui – Assistant Director, Research
Abhishek Mukherjee – Senior Research Analyst

Contact Us

Americas
+1.212.553.1658
clientservices@moodys.com

Europe
+44.20.7772.5454
clientservices.emea@moodys.com

Asia (Excluding Japan)
+85 2 2916 1121
clientservices.asia@moodys.com

Japan
+81 3 5408 4100
clientservices.japan@moodys.com

Assessing the Credit Impact of Climate Risk for Corporates

» **Moody's Analytics Climate-Adjusted EDF™ (Expected Default Frequency) framework provides a consistent, transparent, and customizable means for analyzing physical and transition risk's impact on public companies' credit risk.** This paper explains the functionality, methodology, and underlying data driving the Climate-Adjusted EDF framework for our physical and transition risk models. Resulting Climate-Adjusted EDF credit measures can be used for stress-testing, loan origination, credit monitoring, asset allocation, and disclosure.

» **The Physical Risk-Adjusted EDF model forecasts both direct and indirect effects of weather and climate events on businesses' infrastructure, operations, and markets.** Resulting credit measures account for acute physical events (e.g., hurricanes, wildfires, and floods) and chronic physical effects (e.g., sea level rise, heat stress, and water stress). For a range of possible warming paths, the methodology analyzes differential climate exposures based on the time horizon, location of a firm's physical assets and operations, and firm financial characteristics.

» **The Transition Risk-Adjusted EDF model forecasts the risks (and rewards) associated with the transition to a lower carbon economy.** The effects of carbon transition on a firm's financial and credit health may be driven by policies such as carbon taxation, variable technological growth, and/or socioeconomic trends. To capture the complicated economic drivers affecting firms, we employ an Integrated Assessment Model (IAM) to understand how a given transition future affects firm prices, quantities sold, and costs. We augment the IAM with a model of equilibrium firm-level competition to understand the effects of transition over time on firm earnings, firm valuations, and, ultimately, firm credit risk.

» **The Public Firm EDF model underlying our climate-adjusted framework enables rich and robust analysis of the credit risk implications of climate change.** The EDF structural model allows for effects that occur sequentially, stochastically, and at different intensities over time. Differing investor expectation assumptions can be added into the analysis, with important implications. Users can test sensitivity to parameter assumptions and examine the effects of transition and physical risk separately or in combination.

» **The Climate PD Converter allows users to adjust their own baseline PDs via the Climate-Adjusted EDF methodology.** Based on a firm's non-climate adjusted probability of default (PD) inputs and integral characteristics, the Converter outputs a full set of credit metrics conditional on a range of climate scenarios. This can be useful for analyzing unlisted names, measuring generic sectoral or regional risk, and adjusting internal ratings.

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1. Introduction

Moody's investment in climate risk analysis is motivated by scientific consensus that global warming poses a major risk to the stability of the international financial system and the world economy. Already, we see that a 1°C global warming above pre-industrial levels affects nearly every facet of the global economy — from infrastructure, agriculture, and real estate to human health and labor productivity.[1] Although fossil-free energy use is on the rise, and many governments have introduced carbon taxes and pledged to achieve net zero greenhouse gas emissions by 2050, the past decade was the warmest on record.[2]

The increasing pace of climate change and the increasing likelihood of major transition-related policy action have important implications for the financial health of firms across the globe. Firms may suffer direct damages to their physical assets or disruption to their business models due to weather and climate events. Carbon taxation, increasing energy prices, and new green technologies confront corporations with risks as well as rewards. Financial institutions with exposure to these firms must understand and carefully measure climate-related risks during loan origination, monitoring, asset allocation, stress-testing, and disclosure.

To quantify the corporate credit risks associated with climate change, Moody's Analytics has developed a climate-adjusted version of its Public Firm EDF (Expected Default Frequency) model. The Public Firm EDF model is a structural model of credit risk that has been used by global banks, insurers, corporates, and asset managers for more than 30 years. During that time, continuous updates and validation have shown the model's ability to accurately predict default events in diverse economic environments. The Public Firm EDF model provides a robust framework for understanding the effects of structural climate shocks on corporate credit risk.

To augment the Public EDF framework to account for climate risk, Moody's Analytics has developed a methodology to account for the effect of climate on the underlying drivers of EDF metrics. The climate-adjusted model integrates climate scenarios devised by the Network for Greening the Financial System (NGFS)[3] and state-of-the art data and assessment tools from Moody's affiliates Four Twenty Seven and V.E. (formerly Vigeo Eiris) to forecast the physical and transition risk credit impacts related to global warming.

Our Climate-Adjusted EDF models provide users with the following functionality:

» **30-year EDF term structures conditional on each NGFS baseline climate scenario:** For the 40,000 distinct names in the CreditEdge universe, the Climate-Adjusted EDF models produce a probability of default (PD) term structure that forecasts credit risk over time for each climate scenario. We currently offer output based on the NGFS baseline scenarios, a consensus set of possible climate futures employed by many central banks and financial supervisors. The NGFS baseline scenarios include the Orderly scenario (global carbon policy occurs immediately), the Disorderly scenario (global carbon policy commencing in 2030, with the delay necessitating an accelerated pace of carbon reduction), and the Hot House scenario (no additional carbon policy implemented). Figure 1 illustrates the emissions, temperature, and global damage paths underlying these scenarios. Note that for the Hot House scenario, we also provide results based on a 95% upper-tail damage estimate ("Hot House 95P"), so that users can understand "worst-case scenario" physical risk. EDF metrics can be calculated as Physical Risk-Adjusted Only, Transition Risk-Adjusted Only, or Total Climate Risk-Adjusted (physical and transition effects combined holistically, where cross-effects become important to the total credit risk impact).

» **Conditional valuation metrics for bonds issued by each firm:** For each bond issued by firms in the CreditEdge universe, we leverage the conditional PD term structures and the EDF Fair Value Spread™ model to calculate conditional valuation metrics. This includes conditional fair value bond spreads, fair value bond prices, and duration.

» **Ability to vary assumptions on physical damage levels, investor expectations, and discount rates in each scenario:** Climate modeling is, by necessity, built on assumptions and uncertainly measured parameters regarding the effects of climate change on firms. While we attempt to build this uncertainty directly into our risk metrics wherever possible,

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[1] Intergovernmental Panel on Climate Change, "Global Warming of 1.5°C," 2018. World Meteorological Organization, "Provisional Report on the State of the Global Climate 2020": https://library.wmo.int/index.php?lvl=notice_display&id=21804#.X_89fuhKg2x

[2] "2020 Was One of the Three Warmest Years on Record," World Meteorological Organization, January 15, 2021.

[3] Network for Greening the Financial System (NGFS) is a group of 87 central banks and supervisors and 13 observers committed to sharing best practices, contributing to the development of climate risk management in the financial sector, and mobilizing mainstream finance to support the transition towards a sustainable economy.

understanding sensitivity to the important drivers of the methodology remains crucial. The Climate-Adjusted EDF models allow users to vary which damage functions are selected to calculate global physical damages in each scenario or to provide customized physical damage paths. Users can choose to specify the extent to which expected climate costs are priced into firm valuations today, and how investor expectations change in the future. Finally, they can choose the discount rates employed to price future earnings and climate damages.

» **Climate adjustment of user-supplied PDs via the Climate PD Converter:** The Climate-Adjusted EDF model is an attractive framework for understanding climate scenario-conditioned credit risk, even when baseline (unconditional) PDs are derived from a model other than the Public EDF model. The Climate PD Converter module allows users to input a baseline PD and key characteristics of a custom entity; the Converter in turn returns climate-adjusted term structures and associated credit metrics for the name. The tool is useful for running unlisted and private names through the model, understanding generic sectoral and regional risk, and adjusting internal or reduced form PD models to account for climate risk.

This paper provides an overview of Moody's Analytics Climate-Adjusted EDF framework to determine financial and credit risk for publicly listed companies. Section 2 describes how the Public Firm EDF model stages and informs the modeling necessary to forecast physical and transition risk. Section 3 provides an overview of our modeling methodology for physical risk. Section 4 provides an overview of our modeling methodology for transition risk. Section 5 describes the Climate PD Converter for custom entities, unlisted firms, and user-provided unconditional probabilities of default. Section 6 provides a summary.

Figure 1 Carbon prices, CO2-equivalent emissions, temperature paths, and global damage estimates for NGFS scenarios.
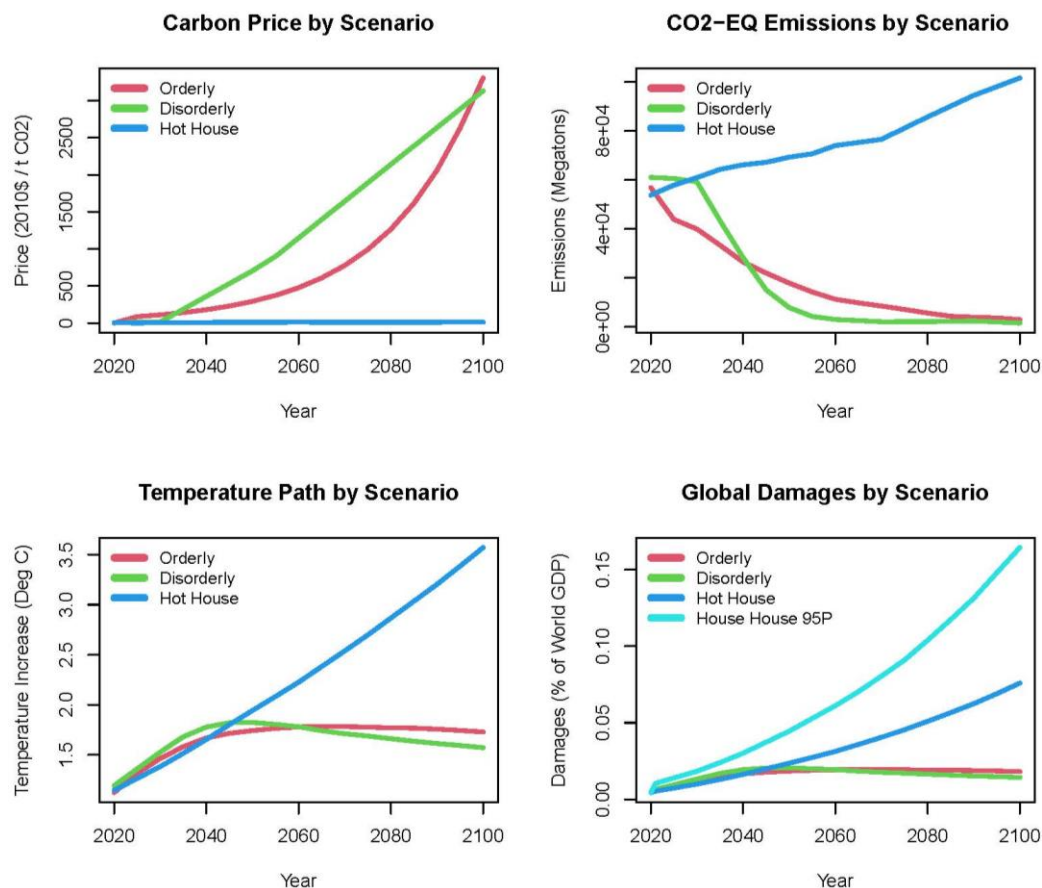
2. Measuring Climate Risk Within the Public Firm EDF Model

Moody's Analytics Climate-Adjusted EDF models follow the established taxonomy of climate risk, which falls into two broad categories: physical risk and transition risk.

» **Physical risk** encompasses the costs and risks arising from the *physical effects of climate change* on businesses' operations, workforce, markets, infrastructure, raw materials, and assets. Physical risks are further delineated as "acute" (e.g., extreme weather-driven events such as cyclones, hurricanes, or floods) or "chronic" (e.g., longer term climatic shifts that may cause changes in temperature, precipitation, water stress or sea level rise).

» **Transition risk** encompasses the costs and risks associated with the *transition to a lower carbon economy* and can include policy changes, such as carbon taxes or cap and trade, new regulations on goods and services, reputational impacts, and shifts in market preferences, norms, and technologies.

Levels of physical and transition risk can vary dramatically between firms. Firms with facilities in South East Asia, the Middle East, and the Caribbean — areas with high exposures to warming-related climate and weather events — will have relatively high physical risk. Firms in industrial sectors such as Coal, Oil & Gas, and Electricity Generation — which are highly exposed to carbon transition — will have relatively high transition risk.

Current best practice, influenced by both stress-testing conventions and climate science methods, is to discretize the continuous distribution of possible economic and climate futures into several representative climate scenarios. Each scenario represents a joint path of economic growth, emissions, and warming over a long period of time (typically, to the year 2100). By analyzing the effects of climate under these scenarios, practitioners can gain an understanding of the plausible physical and transitional impacts that global warming may have on the risk profiles of their exposures.

Once a specific climate scenario is selected for analysis (in our case, the NGFS baseline scenarios described above), we carry out several modeling steps to better understand the financial and credit effects of the future climate path in question. Figure 2 describes these steps. First, we model the relationship between raw climate risk drivers and the economic environment at any point of time within a given climate scenario path. Next, we analyze how modeled economic environments affect each firm's financial health within these environments. Finally, we translate each firm's financial position into credit risk forecasts at any point within the scenario.

Figure 2 Moody's Analytics climate-adjusted financial and credit impact analysis steps.
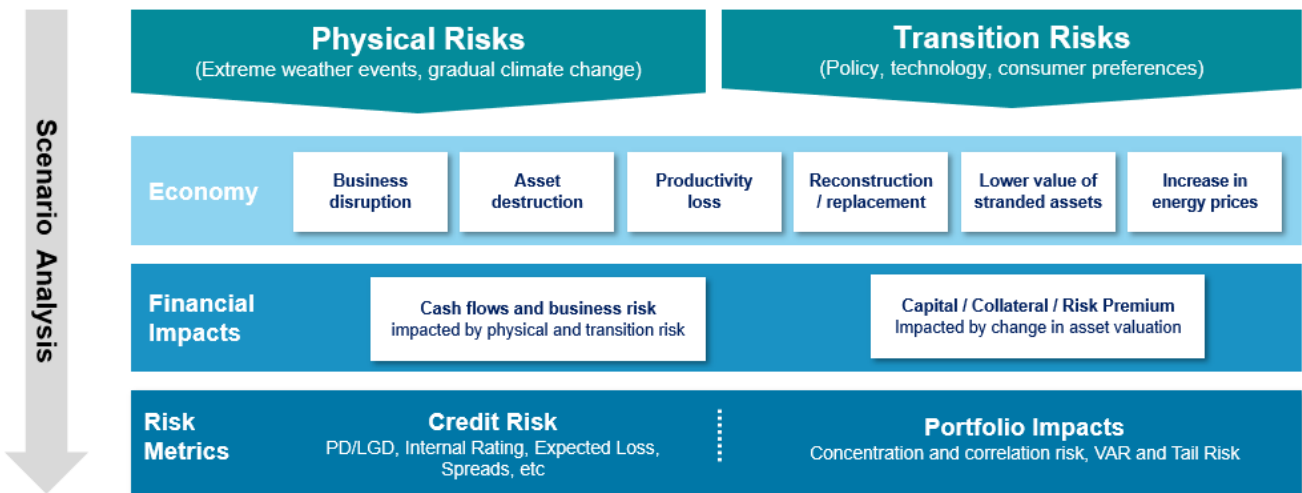
In this section, we describe how the Public EDF model is employed to translate between the firm's financial position and its credit risk. In the following sections, we will describe the modelling necessary to forecast the effects of physical and transition risk on the financial drivers of the Public EDF model.

The Public Firm EDF model[4] is a Merton-type structural model of credit risk. Structural credit risk models are defined by explicitly modeling the total firm asset value (enterprise value) process over time and by estimation of the likelihood of a firm's asset value falling below a lower bound (the default point) within a certain time horizon. If the firm asset value does in fact fall below this default point, the firm is considered insolvent, and it goes into default. Therefore, the likelihood of the firm's asset value falling below the default point is also the probability of default, labeled in CreditEdge as the Public EDF (Expected Default Frequency) value.

The left chart in Figure 3 illustrates the asset value process of a firm over a one-year period, starting from an analysis date of January 1. On January 1, the difference between the firm asset value and its default point represents the buffer a firm has between its current financial health and insolvency/default. The Public Firm EDF model estimates not only the current asset value of the firm and the default point, but also the distribution of possible paths of asset value over the course of the year. Based on this firm's asset value distribution (represented here by 50 possible paths of firm asset value), we can calculate the percentage of possible paths that fall below the default point. This percentage is the probability of default, or EDF credit measure, of the firm.

The light blue boxes on the right chart in Figure 3 illustrate the underlying drivers of both the firm asset value process and the firm default point: equity value, asset volatility, and liability value. First, we consider the effect of the firm's equity and liability values on its credit risk. The market value of the firm's equity (observed via stock prices) and the market value of its liabilities (risk-adjusted from the face value of liabilities in its financial statements) sum to equal the current market firm asset value. The default point of the firm is a function of its liability value. The ratio of market equity value to market liability value, or market leverage, is therefore the key driver of the buffer between the current firm asset value and its default point.

Figure 3   Structure of CreditEdge Public Firm EDF model.
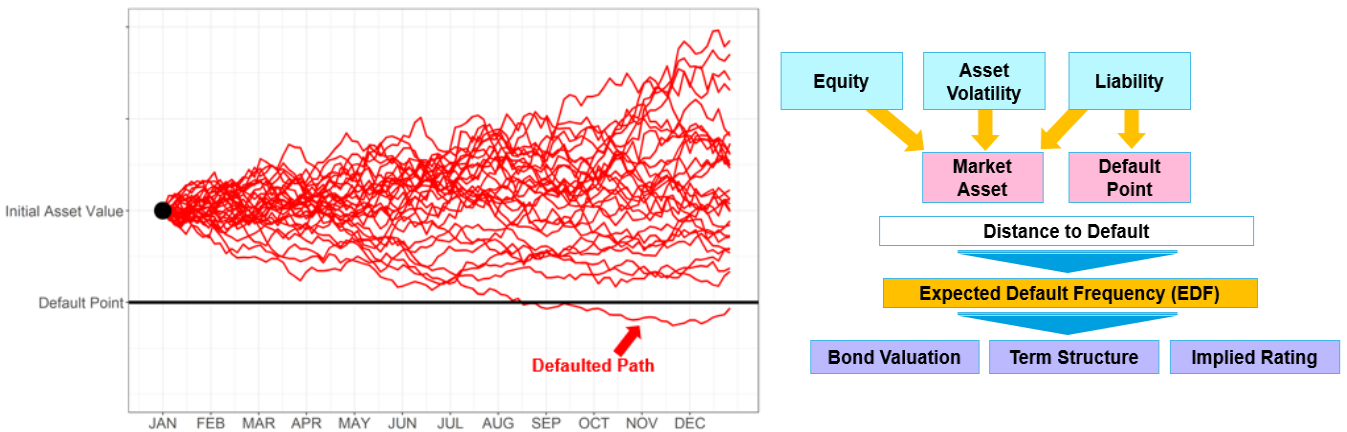
The third main driver of EDF value — an estimate of the firm's future asset volatility — is derived from both the firm's historical asset volatility and other firm and market data. The asset volatility estimate determines the extent that firm asset value is likely to change over the analyzed time horizon. The combination of market leverage and asset volatility (summarized in the distance-to-default metric) determines the firm's default probability.

The EDF model's output is an unconditional probability of default (PD) term structure for each firm, as shown for Chevron Corporation (a multinational energy company) in Figure 4. The EDF model also provides implied ratings and bond valuation metrics as a function of this term structure.

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[4] The Public Firm EDF model is a commercialized version of the KMV credit risk model. CreditEdge is the product name for the Public Firm EDF model.

Figure 4   Baseline probability of default term structure example (not climate-adjusted).

Baseline PD Term Structure
CHEVRON CORP.
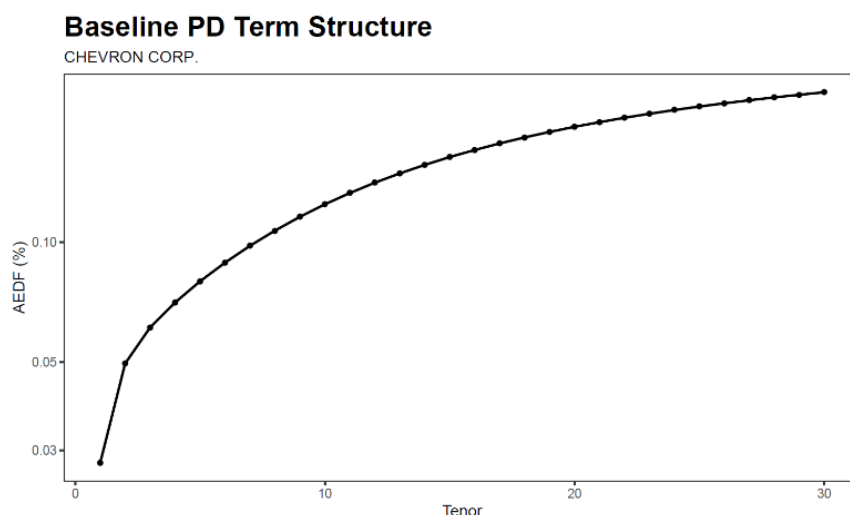
## 3. Modeling the Financial and Credit Impacts of Physical Risk

The Climate-Adjusted EDF models forecast the effect of climate change on firms' financial health as arising from climate-induced shocks on firms' market asset value. These shocks can arise from direct damage to a firm's physical assets or from business disruption that reduces a firm's ability to sell its products. In either case, the current valuation of the firm will be reduced. Given the expected characteristics of these shocks, we assume:

» There is uncertainty about when damaging climate events and their associated asset shocks will occur, even within specific climate scenarios and at specific future dates.

» Different geographic locations will have different exposure to damaging climate events, even for the same global temperature increase.

» The same damaging climate event has the potential to cause different magnitudes of asset depreciation for different firms, depending both on randomness and firm characteristics.

Figure 5 shows an example of the effect of these asset shocks within the EDF model. Consider an acute weather event that occurs with low probability but that causes a large depreciation of a firm's asset value. The weather event shown in the left chart occurs in late April during a potential future asset path (from the perspective of January 1) where there happened to be little asset value change during the previous four months.

If the negative shock is big enough to reduce asset value below the default point (it is not in this example), the shock can directly cause firm insolvency. Even if the weather event does not immediately precipitate insolvency, however, the shock reduces the buffer between asset value and the default point. This reduction means that the normal asset volatility the firm experiences over the remainder of the year is more likely to push the firm into default. From the perspective of January 1, therefore, the effect of the additional risk of marginal climate events is to increase the asset volatility of the firm within the year, increasing its probability of default.

Figure 5   Effect of physical risk on EDF value drivers.
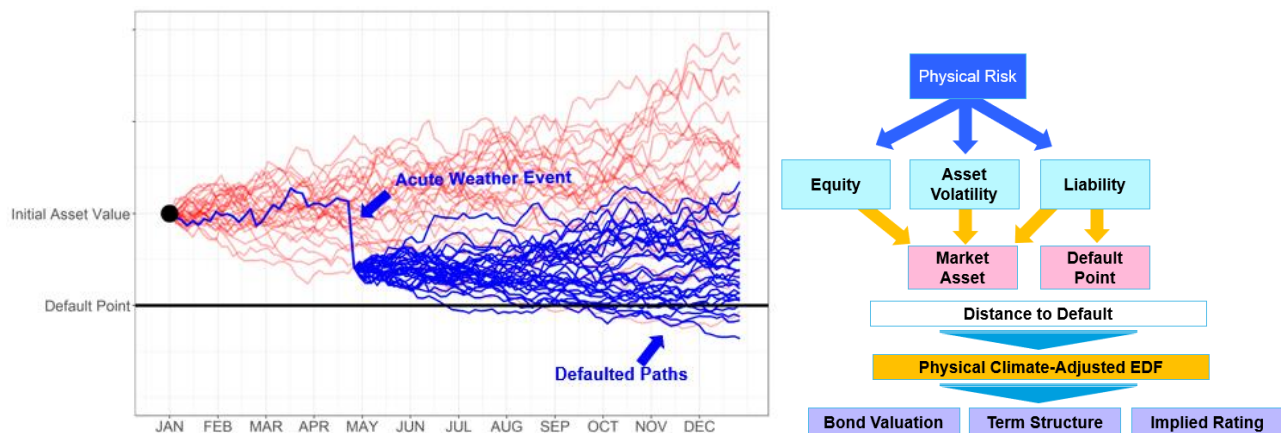
By treating the effects of physical climate-related events as a series of negative shocks to the firm's asset valuation, the financial forecasting problem has been reduced to modeling the frequency and magnitude of these shocks. We achieve this process by leveraging several data and modeling sources:

» **Forecasts of global economic damage paths:** For a given scenario, an estimate of the global damages associated with physical climate risk (as a percentage of global GDP) can be derived from a combination of an Integrated Assessment Model (which models the carbon emissions path associated with the scenario), a Global Circulation Model (which models the global temperature path resulting from the emissions path), and an Aggregated Damage Function (which forecasts global economic damages as a function of the temperature increase at any given time). Although we can run these models independently, the NGFS scenarios provide global damage estimates from an identical framework. We therefore employ the NGFS estimates as a starting point.

» **Economic damage path forecasts associated with a firm's location:** Given a global damage forecast, different locations will have highly differential exposures to physical damage. To forecast these differences, we employ Four Twenty Seven corporate climate scores, which rank a firm's relative physical climate risk from 0 to 100, based on climate hazard models and detailed data of the location of firm's facilities and operations. We calibrate these scores to forecast a firm's economic damage level for a given global damage level.

Figure 6   Physical modeling from global damage paths to EDF metrics.
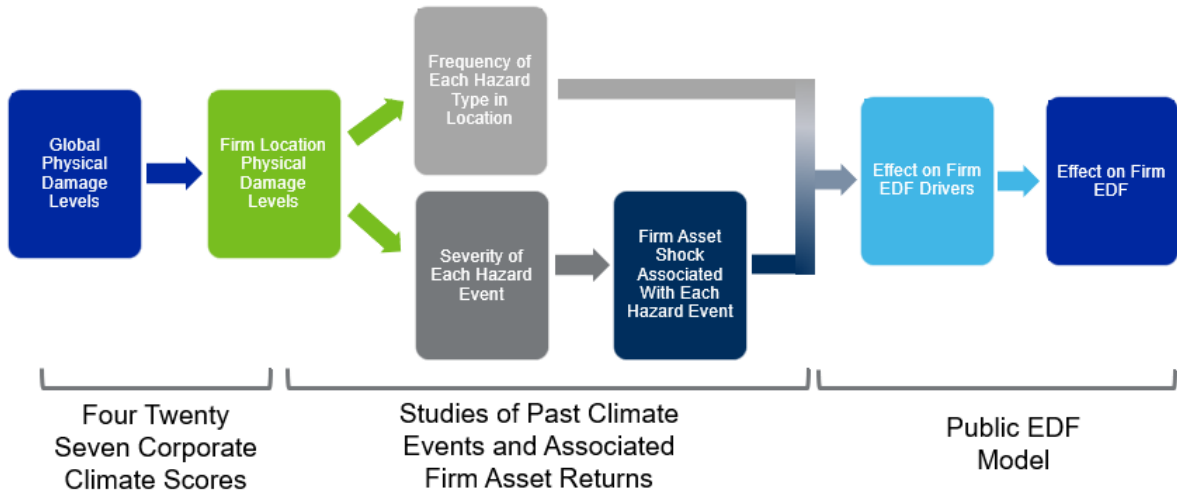
Figure 7   Example of Climate-Adjusted EDF term structures.
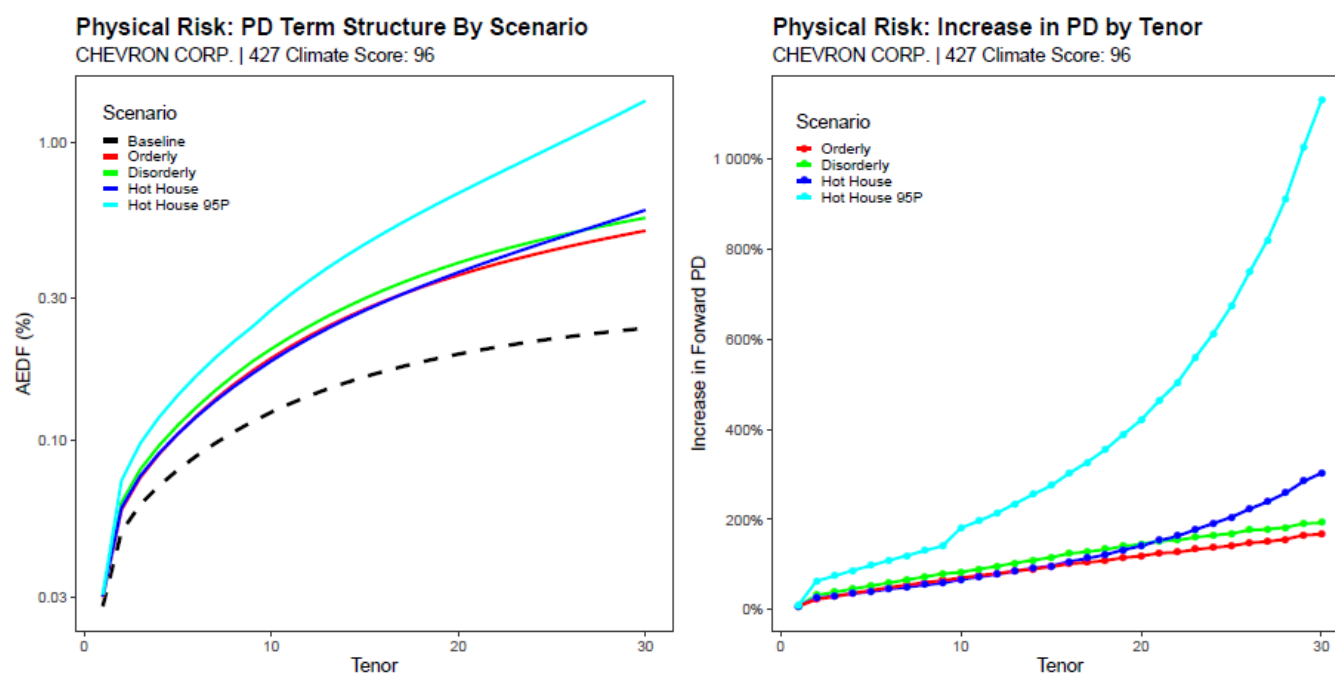
» **Converting economic damages to frequency and magnitude of asset shocks:** As a final step, we employ historical climate events to understand the typical severity of events and their effect on asset value. Because the Public Firm EDF model has been being estimated for more than 30 years, we already have asset return measurements for firms affected by historical climate-related events. This record allows us to convert between the economic damages of a certain hazard type and severity into a distribution of possible asset returns for each firm.

Figure 6 provides a summary of these modeling steps.[5] Figure 7 shows the analysis output: conditional PD term structures associated with each of the NGFS scenarios for a firm (in this case, Chevron Corporation). The methodology quantifies the effect of climate change over time on Chevron's credit risk. We see an immediate increase in risk as investors begin to price in future expected damages, and then increasing risk as more imminent physical damage causes additional volatility and further devaluation of the firm.

4.   Modeling the Financial and Credit Impacts of Transition Risk

Modeling the mechanics of an economy in energy transition, particularly when that transition is occurring concurrently with a warming world, is a complex exercise. While the headline assumption of any transition scenario is a forecast of government policy over time, we must make other key assumptions about population growth, productivity growth, and technology growth. Once we define a transition scenario, we model the effect of these assumptions on a cascade of linked economic drivers. These economic outcomes will affect the growth, competitiveness, and financial health of firms as they adapt to new risks and opportunities.

As with our physical risk methodology, our approach to measuring transition risk is to calculate its effects on the drivers of the Public Firm EDF model. Due to the complexity of the effects of transition on firms, however, it is necessary to go a step further and explicitly model the fundamentals driving the asset value process of the firm over time. The fundamentals that give a firm value are the discounted cash flows expected to be accrued by the firm over time; by modeling transition-adjusted cash flows, we can use properly discounted future earnings expectations to model transition-adjusted asset value processes. These asset value processes, in turn, dictate the expected paths of the Public Firm EDF drivers.

Figure 8 shows an example of the credit implications of such a shift in firm earnings expectations, once properly valued. From a current date of January 1, this example models a scenario where a new transition policy is announced mid-year. As is typical in

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[5] For further methodological details, see Edwards and Mukherjee, "Measuring the Credit Impact of Physical Risk for Corporates," Moody's Analytics, 2021.

climate change scenarios, the policy path is explicitly assumed, so the specific policy announcement happens with certainty on June 1. The certainty of the policy in our analyzed (conditional) scenario does not mean, however, that investors within the scenario must at every point expect such a conditional path to occur. In this simplified example, investors do not anticipate the policy announcement at all,[6] and only on June 1 do they begin accounting for it in their expected earnings forecasts and subsequent firm valuations.

Figure 8   Effect of transition risk on EDF drivers.
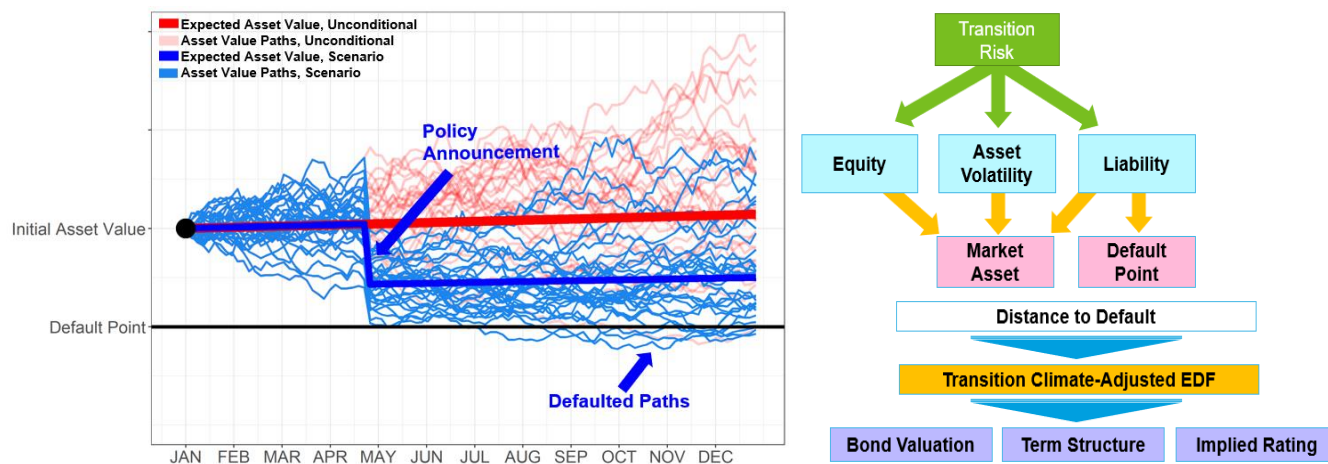
Since the policy announcement is certain, its effect on firm asset value impacts all possible paths of asset volatility up to June 1. (In this example, the shock is proportional to the original asset values at that date.) Note that for some paths where asset value has already depreciated due to normal business risk, this shock causes the firm to become insolvent (and thus default) immediately. Even in paths where the policy announcement does not immediately precipitate insolvency, the shock reduces the buffer between asset value and the default point, and the normal asset volatility the firm experiences over the remainder of the year is more likely to push the firm into default.

The bold horizontal red line in Figure 8 represents the unconditional path of expected firm asset value over the year, and the bold blue line represents the conditional path of firm asset value associated with the conditional climate policy scenario. Note that although volatility surrounds this expected asset value path in both the conditional and unconditional paths, the firm's higher default risk in the policy scenario is driven by changes in expected asset value, not any change in asset volatility around this path. This outcome occurs because the policy announcement is certain within the scenario, and thus drives the firm's *expected* asset value path over time.

To understand how earnings are affected by transition, it is necessary to model a scenario's effect on competitive equilibria both between the production of different good types and on firms producing the same good within each market. Figure 9 shows a more detailed look at how we move from a transition scenario to earnings paths, the asset value process, and finally transition risk-adjusted EDF metrics:[7]

» **Step 1A: Earnings projections on sectoral/regional level:** To understand the effect of the scenario on earnings in each sector/region combination, we leverage the General Change Asssessment Model (GCAM). GCAM is distinctive among Integrated Assessment Models used by the NGFS to generate scenario pathways for its highly detailed modeling of regions and industrial sectors, providing prices, production quantities, and itemized costs for over a thousand interlinked production technologies. This data enables us to calculate sectoral level earnings that account for scenario-conditioned supply and demand shocks arising from each transition future.

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[6] Alternatively, and with the same results, investors may expect an equal probability of a different policy announcement with *positive* effects on the future earnings of the firm. Users can specify different investor expectation functions within the framework.

[7] For further details about this methodology, see Edwards and Cui, "Measuring the Credit Impact of Transition Risk for Corporates," Moody's Analytics, 2021.

Figure 9   Structure for quantifying effect of transition scenarios on credit metrics.
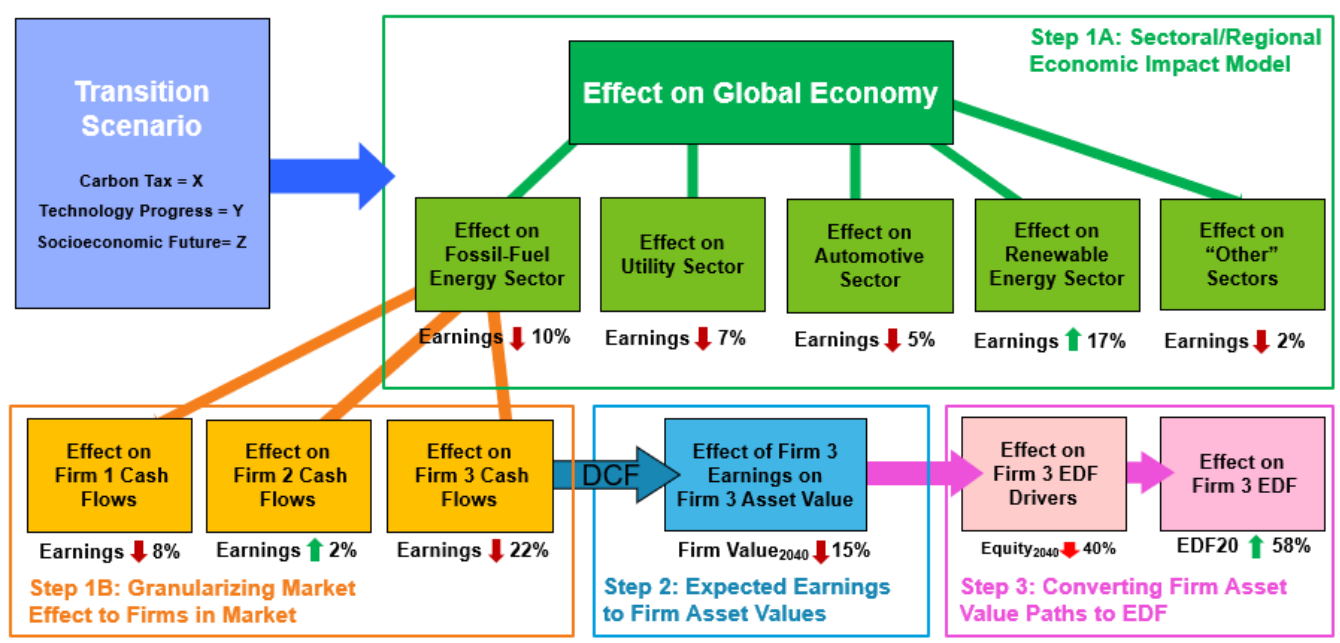
- » **Step 1B: Earnings projections on a firm level:** To forecast earnings on a firm level, we augment the GCAM framework with a model of firm competition within each market. Firms with potential differences in costs and non-price consumer preference set profit-maximizing output prices, leading to Nash Equilibrium market shares and earnings for each firm in the market. In addition to calibration on current market shares, the main driver of heterogeneity between firms are the emissions-intensity and energy-intensity of production. These different intensities, derived through firm's Scope 1 and Scope 2 emissions from V.E, cause relative costs to change over time as emissions and energy costs (typically) rise within a transition scenario. The result is a forecast on how each firm's market share and earnings will change over time as a result of its new level of economic competitiveness.

- » **Step 2: Converting earnings projections to asset value projections:** We employ standard discounted cash flow (DCF) techniques, while giving users full ability to vary discount factors to their own calibrations.

- » **Step 3: Measuring the effect of the scenario-conditional asset value process on EDF metrics:** The new asset value process links directly to the drivers of EDF, in turn giving a full term structure of scenario-conditional EDF metrics.

Figure 10   Transition scenario-conditional expected earnings, expected asset value, and EDF measures for Chevron Corporation.
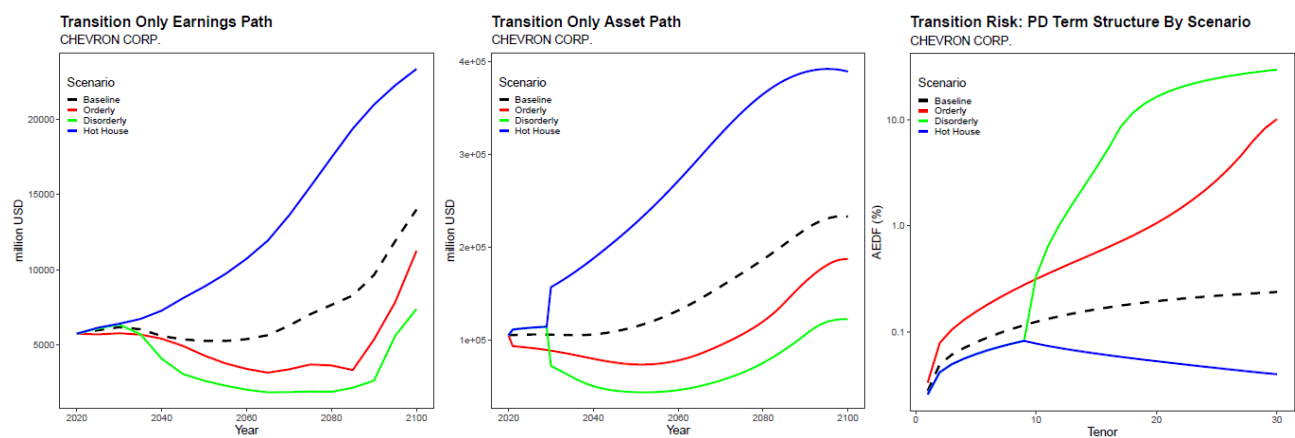
Figure 10 displays the climate scenario-conditional expected earnings paths, expected asset value paths, and EDF term structures for Chevron Corporation. Note that although earnings for each scenario are quite similar in the first 15 to 20 years for Chevron, the asset value path for Early Policy splits off immediately, and Late Policy and No Policy diverage dramatically in 2030. This is a result of the investor expectations path assumed in this example: investors gain updated expectations of the future likelihood of each earnings path when Early Policy is (or is not) announced in 2021, and Late Policy is (or is not) announced in 2030. The updated earnings expecations associated with the announcements result in immediate and material differences in valuation. As earnings continue to deviate over time, the asset path also deviates: the large differences in earnings are now being discounted at a lower rate, due to the shorter time to their realization. The total effect is conditional PDs that materially deviate immediately, and then continue to widen as time goes on.

5. Climate PD Converter

The Climate-Adjusted EDF methodology provides credit risk and valuation metrics for all firms in the CreditEdge universe (i.e., nearly all global publicly traded firms, over 40,000 listed companies). To further increase the coverage and usability of the framework, Moody's Analytics has built the Climate PD Converter. Figure 11 shows the converter's general approach.

Users provide a baseline unconditional one-year PD for each name, as well as some important characteristics of the firm associated with its climate exposure and long-term baseline risk. Based on this data, the converter constructs a custom entity, calculating expected values of any missing characteristics given the information provided. The custom name is then run through the physical and/or transition risk models to create full climate-adjusted PDs (and associated credit metrics) for the entity. This approach is useful for the following use cases:

» **Climate-adjusted risk for unlisted private names and small and medium enterprises (SMEs):** For private names, the structural Public EDF framework provides a more advantageous methodology for understanding the effects of climate change than many of the reduced form credit models standardly employed for the asset class. To take advantage of the Climate-Adjusted EDF methodology, Moody's Analytics provides climate-adjusted RiskCalc™ EDF credit measures for private names using the Climate PD Converter.

» **Custom entities and "generic firms" for an industry/region:** Users may be interested in understanding the relative climate-induced credit risk for hypothetical names based on certain characteristics. This can be especially useful for modeling on the sectoral and regional level, allowing measurement of "average" risk increase for a pool of similar exposures.

Figure 12 Structure of the Climate PD Converter.
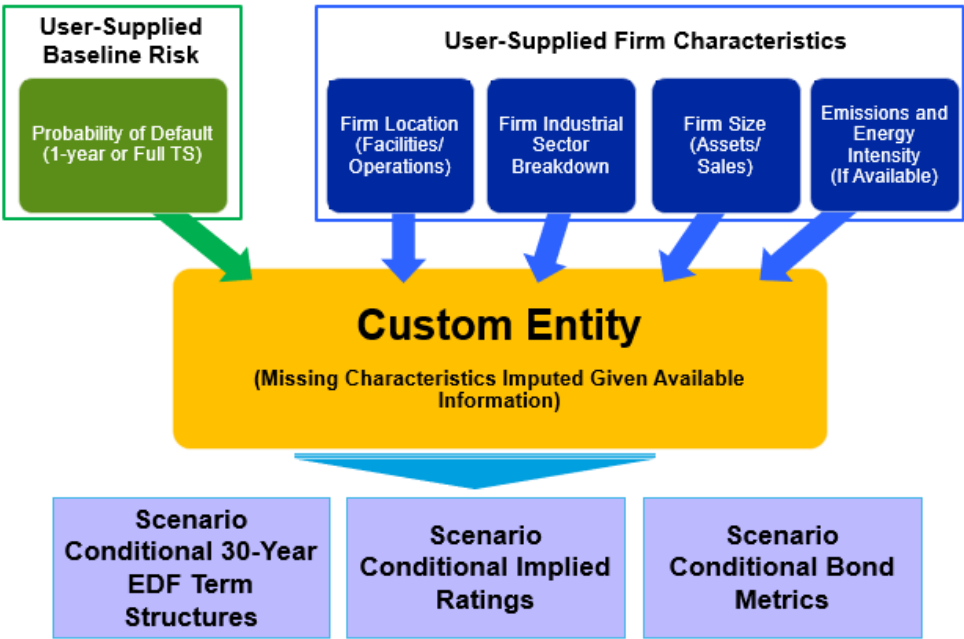
» **Employing user-provided unconditional PDs in the framework**: Users may have their own internal or reduced form credit model and may wish for the output of climate-stressed conditional PDs to be consistent with this input. The Climate PD Converter allows them to input their own baseline/unconditional PD and stress these risk values based on the values provided.

6. Summary

Institutions exposed to corporate climate risk have much to gain by moving quickly to analyze climate-related transition risks and the physical risks that are accumulating due to global warming. Gaining a nuanced understanding of exposures to physical and transition risks is a critical first step to managing them effectively. Practitioners must start with a detailed, data-driven assessment of the climate-induced risks affecting their exposures, of which credit risk is one of the most important. The Physical Risk-Adjusted EDF model incorporates effects stemming from climate-induced shocks on firms' asset values. The Transition Risk-Adjusted EDF model incorporates climate policy, technology, and market effects associated with firms' transitions to lower carbon economies. Whether used independently or in concert, the model outputs provide detailed analysis of climate's impact on credit risk, helping users better manage their resiliency to the perils of a warming world.

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