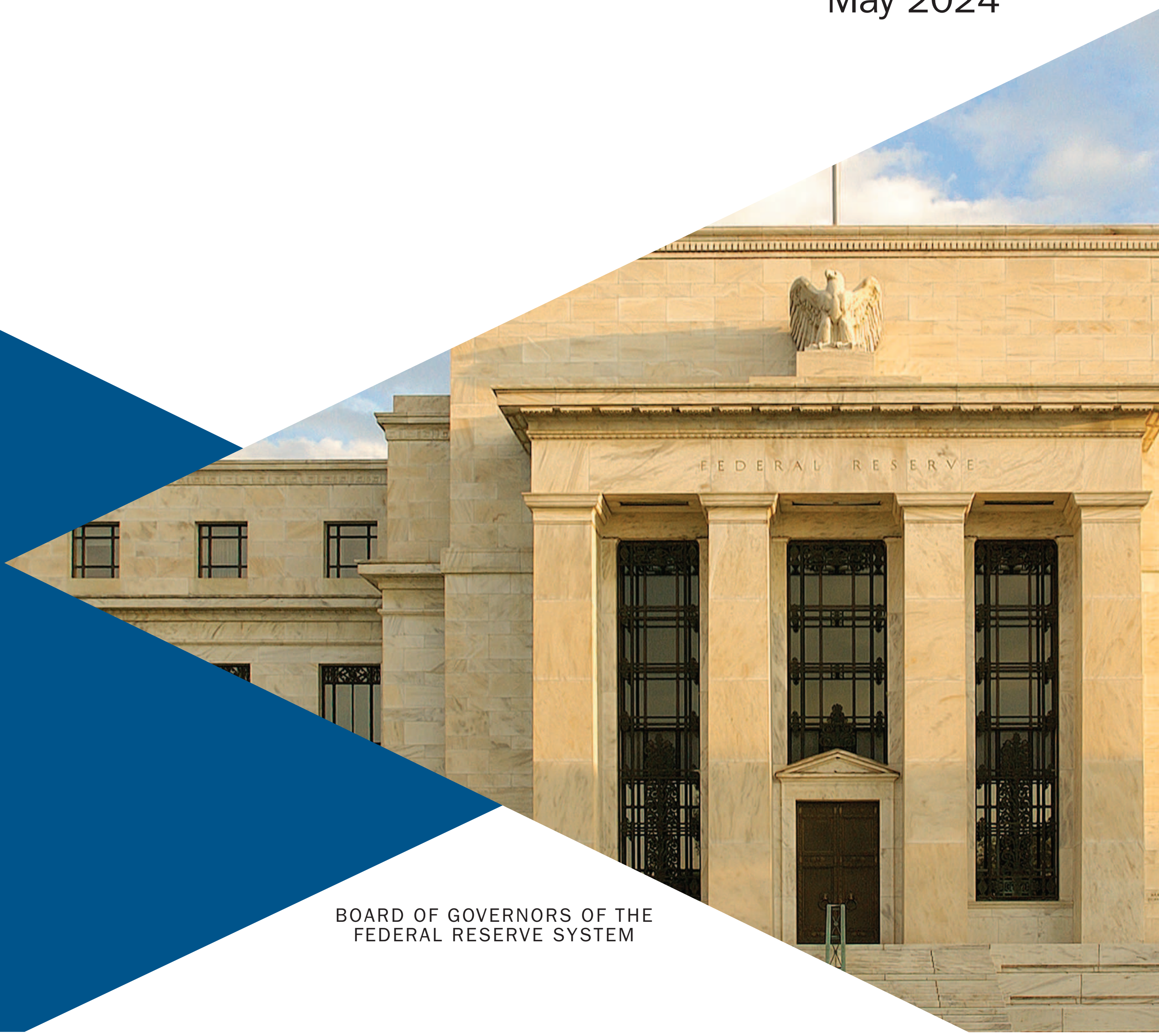
Pilot Climate Scenario Analysis Exercise

Summary of Participants' Risk-Management Practices and Estimates

May 2024



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Abbreviations

bps	Basis points
CRE	Commercial real estate
CSA	Climate scenario analysis
DSCR	Debt-service-coverage ratios
FEMA	Federal Emergency Management Agency
GDP	Gross domestic product
GHG	Greenhouse gas
GVA	Gross value added
LGD	Loss given default
LTV	Loan-to-value
MEV	Macroeconomic variables
MSA	Metropolitan statistical area
NFIP	National Flood Insurance Program
NGFS	Network of Central Banks and Supervisors for Greening the Financial System
NOI	Net operating income
PD	Probability of default
RCP	Representative Concentration Pathway
RRE	Residential real estate
SFHA	Special Flood Hazard Area
SSP	Shared Socioeconomic Pathway

Executive Summary

The Federal Reserve conducted a pilot climate scenario analysis (CSA) exercise in 2023 to learn about large banking organizations' climate risk-management practices and challenges and to enhance the ability of large banking organizations and supervisors to identify, estimate, monitor, and manage climate-related financial risks. The exercise was conducted with six large bank holding companies: Bank of America Corporation; Citigroup Inc; The Goldman Sachs Group, Inc.; JPMorgan Chase & Co.; Morgan Stanley; and Wells Fargo & Company (together, "participants"). The pilot CSA exercise was exploratory in nature and does not have consequences for bank capital or supervisory implications.

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The pilot CSA exercise provided the following insights:

- Participants used climate scenario analysis to consider the resiliency of their business models to a range of climate scenarios and to explore potential vulnerabilities across short- and longer-term time horizons.
- Participants took different approaches to construct the detailed physical and transition risk scenarios used in the pilot CSA exercise and to translate those scenarios into estimates of climate-adjusted credit risk parameters. Differences in approach were driven largely by participants' business models, views on risk, access to data, and prior participation in climate scenario analysis exercises in foreign jurisdictions.
- Most participants relied on existing credit risk models to estimate the impact of physical and transition risks on their portfolios and assumed that historical relationships between model inputs and outputs continue to hold as the climate and the structure of the economy evolve.
- Participants reported significant data and modeling challenges in estimating climate-related financial risks. For example, participants noted a lack of comprehensive and consistent data related to building characteristics, insurance coverage, and counterparties' plans to manage climate-related risks. In many cases, participants relied on external vendors to fill data and modeling gaps.
- Participants reported that better understanding and monitoring of indirect impacts (e.g., disruptions to local economies) and chronic risks (e.g., sea level rise) are important for managing climate-related financial risks.

- Participants highlighted the important role that insurance plays in mitigating the risks of climate change for consumers, businesses, and banks. They noted the need to monitor changes across the insurance industry, including changes in insurance costs over time, and the impacts of those changes on consumers and businesses in specific markets and segments.
- Participants identified key design choices that meaningfully impacted the insights drawn from the exercise. These included choices related to the scope of the shocks, scenario severity, the starting point of the exercise, insurance assumptions, and balance sheet assumptions.
- Participants suggested that climate-related risks are highly uncertain and challenging to measure. The uncertainty around the timing and magnitude of climate-related risks made it difficult for participants to determine how best to incorporate these risks into their risk-management frameworks on a business-as-usual basis.
- While not the focus of the pilot CSA exercise, participants' estimates of climate-adjusted credit risk parameters, such as probability of default (PD), showed significant heterogeneity in impact across sectors, regions, and counterparties.[1]

The report includes the following sections:

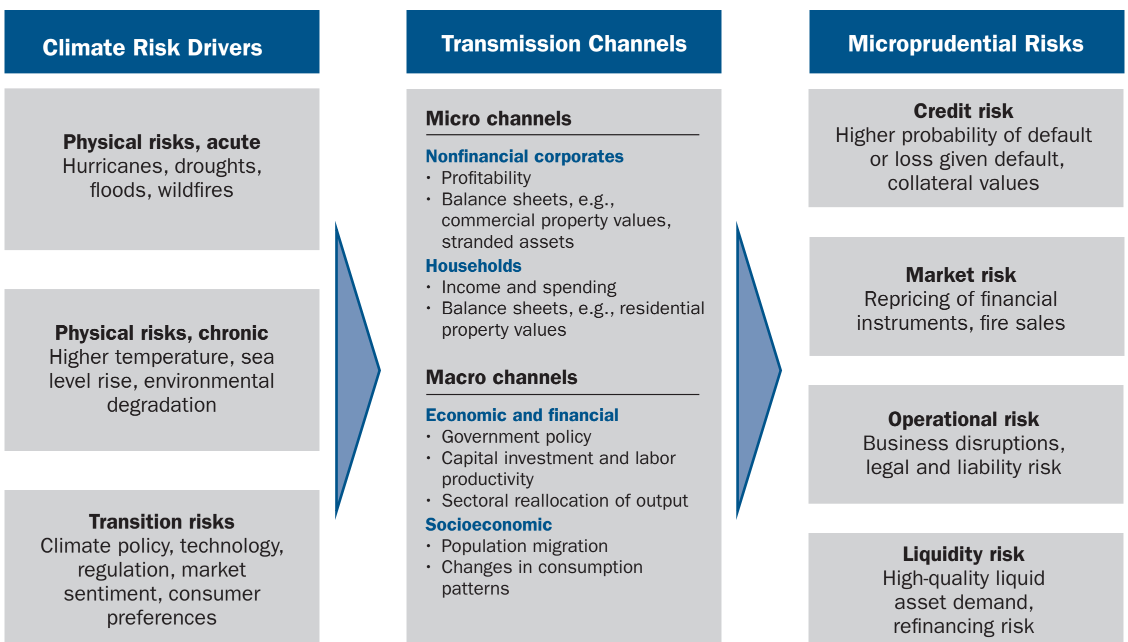
- Overview of the Pilot CSA Exercise, which discusses the transmission channels through which climate-related risk drivers could impact large banking organizations and describes the overall design of the pilot CSA exercise.
- Pilot CSA Exercise Insights, which summarizes key takeaways from the exercise related to participants' climate-related financial risk-management practices, exposures to climate-related risks, and lessons learned.
- Physical Risk Module, which looks in detail at participants' approaches to physical risk scenario design, measurement methodologies, and estimates.
- Transition Risk Module, which looks in detail at participants' approaches to transition risk scenario design, measurement methodologies, and estimates.
- Governance and Risk Management, which discusses participants' governance and risk-management processes.
- Appendix, which provides notes on calculation methodologies.

[1] The Federal Reserve did not independently estimate the impact on risk parameters. All reported results are based on estimates provided by participants.

Overview of the Pilot CSA Exercise

Large banking organizations and the broader financial system are exposed to climate change through macroeconomic and microeconomic transmission channels associated with physical and transition risk drivers. Physical risks refer to the harm to people and property arising from acute, climate-related events, such as hurricanes, wildfires, floods, heatwaves, and droughts as well as longer-term chronic phenomena, such as higher average temperatures, changes in precipitation patterns, sea level rise, and ocean acidification. Transition risks refer to stresses to certain institutions, sectors, or regions arising from the shifts in policy, consumer and business sentiment, or technologies associated with the changes that would be part of a transition to a lower carbon economy.

Figure 1. Climate risk drivers manifest as prudential risks



Note: Examples are indicative and not exhaustive.

Source: *Participant Instructions*.

Figure 1 describes the transmission channels through which climate-related risk drivers could impact large banking organizations. Physical and transition risk drivers associated with climate change may affect households, communities, businesses, and governments through damages to property, shifts in business activity, or changes in the values of assets and liabilities. These effects could manifest as traditional prudential risks to large banking organizations, including credit, market, operational, and liquidity risk.

Pilot CSA Exercise Objectives

The 2023 pilot CSA exercise had two primary objectives:

- To learn about large banking organizations' climate risk-management practices and challenges; and
- To enhance the ability of large banking organizations and supervisors to identify, estimate, monitor, and manage climate-related financial risks.

The pilot CSA exercise comprised a physical risk module and a transition risk module. Each module described forward-looking risk scenarios, including core climate, economic, and financial variables, where appropriate. The scenarios selected for the pilot CSA exercise were neither forecasts nor policy prescriptions. They did not necessarily represent the most likely future outcomes or a comprehensive set of possible outcomes. Rather, they were chosen to represent a range of plausible future outcomes that could help build understanding of how certain climate-related financial risks could manifest for large banking organizations and how these risks may differ from the past.

Each participant estimated the effect of these scenarios on a relevant subset of credit exposures. The physical risk module focused on estimating the effect of common and idiosyncratic shocks of varying levels of severity on residential real estate (RRE) and commercial real estate (CRE) loan portfolios over a one-year horizon in 2023. The Federal Reserve set broad parameters around the severity of physical hazards by selecting a future point in time on specific Shared Socioeconomic Pathways (SSPs) or Representative Concentration Pathways (RCPs) presented by the Intergovernmental Panel on Climate Change and a specific return period loss.[2] The transition risk module focused on estimating the effect of different transition pathways, as described by the Network of Central Banks and Supervisors for Greening the Financial System (NGFS), on corporate and CRE loan portfolios over a 10-year horizon from 2023-32. Participants assumed that balance sheets remained static over the relevant projection horizon.

The Federal Reserve collected qualitative and quantitative information from the six participants and engaged with the participants throughout the exercise to understand the data and methodological challenges that they faced in measuring and managing the financial risks of climate change.

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[2] For example, a 100-year return period loss is a loss that has a 1 percent chance (1 in 100 years) of being equaled or exceeded in a given year.

Table 1 summarizes the general design elements, while table 2 provides additional detail for the physical risk and transition risk modules.

Table 1. General design elements of the pilot CSA exercise

Element	Description
Risk drivers	Physical risks and transition risks modeled independently in separate modules
Estimation	Participants estimate loan-level estimates for select credit portfolios
Balance sheet assumption	Static
Key risk parameters	Probability of default and loss given default
Bank submissions	Data templates, supporting documentation, and responses to qualitative questions
As-of date	December 31, 2022

Source: *Participant Instructions*.

Table 2. Module-specific elements of the pilot CSA exercise

Element	Physical risk module	Transition risk module
Scenarios	Range of severity of shocks	NGFS: Current Policies and Net Zero 2050
Type of shock	Common hazard specified by the Federal Reserve Idiosyncratic hazard chosen by each participant	
Projection horizon	1 year: 2023	10 years: 2023–32
Loan portfolios	Residential real estate Commercial real estate	Corporate Commercial real estate
Potential mitigants	Insurance	Obligor transition capacity

Source: *Participant Instructions*.

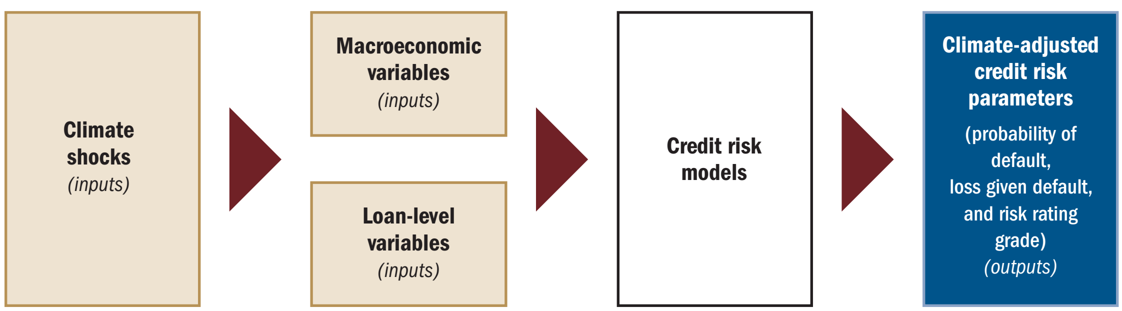
For more detailed information related to the design of the exercise, please see the *Pilot Climate Scenario Analysis Exercise: Participant Instructions* (*Participant Instructions*), available at https://www.federalreserve.gov/publications/files/csa-instructions-20230117.pdf.

Pilot CSA Exercise Insights

This section summarizes the key insights from the pilot CSA exercise. Observations and conclusions apply to only the six participants and are not necessarily indicative of practices at other banking organizations.

Participants use climate scenario analysis to consider the resiliency of their business models to a range of climate scenarios and to explore potential vulnerabilities across short- and longer-term time horizons. Many participants had conducted climate scenario analysis exercises prior to the pilot CSA exercise to identify risks and vulnerabilities, facilitate internal dialogue, inform strategic planning, or meet supervisory expectations in foreign jurisdictions. At a high-level, participants followed the stylized approach to model climate-related risks shown in figure 2.

Figure 2. Stylized modeling approach for climate-related risks



Source: Federal Reserve summary of CSA participant submissions.

Participants' approaches to the pilot CSA exercise varied significantly. Participants used different approaches to develop the physical and transition risk scenarios and to translate these scenarios into climate-adjusted credit risk parameters. Differences in approach were driven largely by participants' business models, views on risk, access to data, and prior participation in climate scenario analysis exercises in foreign jurisdictions. In constructing the common physical hazard shock, for example, some participants used external vendors to run simulations of thousands of potential hurricane events consistent with the severity parameters provided. Others studied historical hurricane events and created bespoke storm paths tailored to hit areas with material exposures.

Participants generally used existing credit models to estimate the impact of climate-related risks on credit risk parameters. In both the physical and transition risk modules, most participants adjusted inputs to their existing credit risk model frameworks to better capture climate-related risks, rather than adjusting the models themselves. They then used the climate-adjusted inputs in their existing credit risk models to generate climate-adjusted credit risk parameters. Some participants acknowledged that reliance on existing models assumes that historical relationships between model inputs and outputs continue to hold in future states even as the climate and the structure of the economy evolve. Some suggested that models could be enhanced to better capture climate transmission channels and associated impacts going forward.

Participants faced data challenges as they conducted the exercise. As summarized in table 3, participants noted a range of data gaps, including gaps related to real estate exposures, insurance, obligors' transition risk management, and infrastructure. Participants filled these gaps by sourcing data from third-party vendors or public sources or by using proxies to provide an estimate. Going forward, participants reported plans to capture additional data from clients, to source data from vendors, and to use proxies where necessary.

Table 3. Examples of participant-identified data gaps

Topic	Examples
Real estate exposures	Property location, square footage, number of floors, construction materials, renovations, age, energy efficiency ratings, municipal regulatory data and retrofitting costs.
Insurance	Levels and types of coverage, deductibles and replacement cost values.
Transition risk	Obligor emissions and transition risk management.
Infrastructure	Critical infrastructure, adaptation estimates, flood defense and community resiliency.

Source: Federal Reserve summary of CSA participant submissions.

Most participants worked with third-party vendors to conduct the pilot CSA exercise. For the physical risk module, some participants used catastrophe models provided by third-party vendors to simulate a large number of physical risk events and related damages to individual properties under the pilot CSA exercise scenarios, while others used vendors to estimate the property damage caused by their internally-generated, bespoke scenarios.[3] For the transition risk module, most participants used external databases or vendors to help expand and customize the scenario variables, to access greenhouse gas (GHG) emissions data, and/or to capture the impact of transition risk on corporate financial statements or ratings. Participants noted that the lack of historical data and the proprietary nature of vendor models inhibited their ability to independently

[3] A catastrophe model is a computerized process that simulates a large number of potential catastrophic events in order to assess losses due to the events.

assess model performance.[4] Some indicated a desire to further develop in-house modeling capabilities in order to reduce reliance on third-party vendors, while others plan to continue to explore vendor solutions.

Most participants considered indirect impacts and/or chronic risks in the physical risk module but faced modeling challenges. Most participants attempted to estimate at least one indirect impact, although this was not required as part of the exercise. Some participants made adjustments to macroeconomic variables (MEVs), such as county- or state-level gross domestic product (GDP), unemployment, or real estate prices. Some considered the effects of higher insurance premiums or elevated labor and raw material costs associated with rebuilding efforts.

Participants noted the importance of understanding insurance market dynamics when modeling the impact of physical risk hazards on credit exposures. The pilot exercise considered the credit impact of physical hazards assuming current insurance coverage and assuming no insurance coverage. While exploring these cases can be helpful, some participants noted the importance of developing a more nuanced understanding of insurance markets, including understanding the evolution of insurance pricing and its impact on property prices and obligors' cashflows, in order to manage climate-related risks.

Some participants conducted deep dive analysis to understand how obligors expect to manage transition risks over time, although this was not required as part of the exercise. Participants noted that information obtained through public disclosures, engagement with obligors, and/or third-party vendors led to a more nuanced understanding of potential transition risk effects on obligors' business strategies, profitability, and capital needs.

Participants intend to incorporate climate scenario analysis into their risk-management processes over time. Participants plan to continue to invest in data, models, and expertise to better identify, estimate, and monitor climate-related financial risks through the use of scenario analysis exercises and other tools. Participants' specific plans for future investments include acquiring more granular climate and exposure data, enhancing modeling capabilities, designing more customized scenarios that are better suited to test participants' unique business models and vulnerabilities, and shifting from vendor models to in-house solutions. Participants identified the high degree of uncertainty inherent to climate risk modeling, as well as the challenges created by such uncertainty in reliably and consistently quantifying the impact of climate-related risks, as factors impacting how the results of climate scenario analysis exercises could be used going forward.

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[4] The *Participant Instructions* stated that the pilot CSA exercise was designed to build capacity. Thus, participants were not prohibited from using models that had not been fully integrated into their model risk-management framework, including those that had not yet been subject to comprehensive model validation, unless participants also relied on a model used in this exercise for business-as-usual decisionmaking or to estimate risks on a regular basis.

Designing climate scenario analysis exercises requires consideration of tradeoffs. Standardized scenarios built on a consistent set of assumptions and variable pathways—for example, common storm paths, wind speeds, precipitation levels, or sea level rise—may result in greater consistency and comparability of specific estimates across participants. However, participants are uniquely exposed to different types of physical and transition risks, and standardization limits their ability to tailor scenarios to risks most material to their portfolios. Similarly, greater prescription in methods and data foster comparability of estimates but could obscure idiosyncratic risks and stifle innovation as practices continue to evolve.

Participants pointed to key design choices that impacted their approaches and estimates. These include

- **Scope of the shock.** The pilot CSA exercise physical risk module focused primarily on estimating the direct impacts of a single, acute hazard on RRE and CRE exposures over a one-year time horizon, limiting consideration of the longer-term impacts of the hazard.[5] The exercise did not require participants to capture indirect impacts, such as damage to critical infrastructure (e.g., bridges and power stations) or supply chain disruptions, that could lead to prolonged disruption to local economies. In addition, the exercise did not require participants to capture the effects of chronic risks like sea level rise or higher average global temperatures. Participants noted that consideration of different types of physical risk shocks, the cumulative effects of multiple hazards over time, or a more comprehensive incorporation of indirect impacts and chronic effects, could meaningfully affect the nature of the exercise and the channels through which physical risks could impact their portfolios.
- **Scenario severity.** For the physical risk module, participants described the scenarios (e.g., a 200-year return period loss consistent with SSP 8.5/RCP 8.5) as relatively severe acute physical hazard events, particularly when assuming no insurance coverage. By contrast, most participants viewed the two scenarios used in the transition risk module (i.e., Current Policies and Net Zero 2050) as orderly, rather than stress, scenarios, and they noted the limited differentiation between the scenarios over the 10-year horizon. As credit risk parameters are sensitive to the macroeconomic environment, the benign MEVs included in the NGFS scenarios resulted in limited aggregate impact across the transition risk scenarios despite the significant increase in the carbon price in the Net Zero 2050 scenario.
- **Starting point.** The pilot CSA exercise focused on the impact of the scenarios on participants' 2022:Q4 exposures. Climate-estimated impacts were applied at a point of the credit cycle when credit quality was strong and loan-to-value (LTV) ratios were low across the portfolios, acting as a credit risk mitigant. As with other external shocks, the effects of adverse climate shocks could be different if the shocks were to occur during an economic downturn.

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[5] The *Participant Instructions* stated that the review would focus primarily on the direct impacts of physical risks. Participants were encouraged, but not required, to incorporate indirect impacts of the event where possible.

- **Insurance assumptions.** Financial protections, such as effectively functioning insurance markets, can limit the credit risk that large banking organizations face from climate-related physical risks in their real estate portfolios. To consider the sensitivity of the physical risk impact to insurance assumptions, the exercise asked participants to estimate the credit impact of physical hazards assuming no public or private insurance coverage, including no coverage from the National Flood Insurance Program (NFIP). An assumption of no insurance coverage may help to understand tail risk scenarios, but it represents an extreme outcome.
- **Balance sheet assumptions.** The pilot CSA exercise prescribed a static balance sheet approach. Static balance sheet assumptions hold the size and risk characteristics of the balance sheet constant over the projection horizon. This approach can build capacity around the measurement of potential risks by isolating the scenario impacts on measurements of PD and loss given default (LGD) for current exposures, but it does not account for management actions that could reduce the impact of climate risks. Participants noted their ability to rebalance their portfolios over the forecast horizon could significantly mitigate risk.

Additional investment and analysis could improve participants' risk-management capabilities. For example, participants faced challenges in modeling indirect impacts, chronic risks, and insurance dynamics related to physical risks. Participants also reported challenges in modeling the broader macroeconomic and sectoral implications of various transition pathways. Participants' modeling approaches varied significantly across these areas, and their estimates suggested that some of these factors could meaningfully magnify or mitigate credit risk impacts. Further research in these and other areas would help participants better understand their potential exposure to climate-related financial risks.

Highly uncertain risks are challenging to measure, and thus hard to incorporate into risk-management frameworks. The degree of uncertainty around the timing and magnitude of climate-related risks is high, making it difficult for participants to determine how best to account for and manage these risks on a business-as-usual basis. Those uncertainties can generate considerable variation in estimates of expected impacts, which complicates use of some common risk-management tools, such as quantitative risk limits, and strategic decisions. The high degree of uncertainty is a significant factor in considering how participants could use the insights gained from climate scenario analysis going forward.

Physical Risk Module

The physical risk module required participants to estimate the credit risk impact of different types of acute physical hazards of varying degrees of severity on their RRE and CRE portfolios in certain National Climate Assessment (NCA) regions. The *Participant Instructions* prescribed a common shock for all participants as a hurricane in the Northeast region. Participants selected an idiosyncratic shock based on the materiality to their business model and exposures. Table 4 provides a summary of the six iterations of the physical risk shocks considered in the exercise. See the *Participant Instructions* for details on the severity parameters for each iteration.

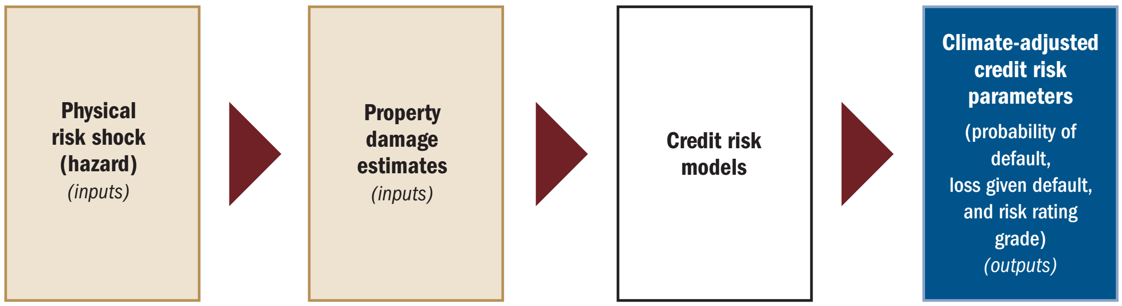
Table 4. Summary of physical risk shocks

Iteration	Severity			Impact		Mitigant
	Climate pathway	Return period loss	Year of shock	Hazard	Geography	Insurance
Common shock						
1	SSP2-4.5/RCP 4.5	100-year	2050	Severe hurricane(s)	Northeast NCA region	Existing coverage
2	SSP5-8.5/RCP 8.5	200-year	2050	Severe hurricane(s)	Northeast NCA region	Existing coverage
3	SSP5-8.5/RCP 8.5	200-year	2050	Severe hurricane(s)	Northeast NCA region	No coverage
Idiosyncratic shock						
4	SSP2-4.5/RCP 4.5	100-year	2050	Participant chosen	Participant chosen NCA Region	Existing coverage
5	SSP5-8.5/RCP 8.5	200-year	2050	Participant chosen	Participant chosen NCA Region	Existing coverage
6	SSP5-8.5/RCP 8.5	200-year	2050	Participant chosen	Participant chosen NCA Region	No coverage

Source: *Participant Instructions*.

Translating physical risk shocks into credit risk parameters for real estate exposures is a complex, multi-step process. As illustrated in figure 3, participants projected future physical shocks under changing climate conditions, estimated the vulnerability of their in-scope exposures to these physical shocks, and estimated the credit risk impact, including the impact on PD, LGD, and internal risk rating grade (where applicable). The following sections discuss how participants approached each of these steps.

Figure 3. Stylized modeling approach for physical risk estimation



Source: Federal Reserve summary of CSA participant submissions.

Define Physical Risk Shock

The first step of the exercise involved identifying the physical hazard and its detailed characteristics (left side of figure 3). Given the complexity of modeling physical climate systems and related financial impacts, most participants relied on external vendor models to define physical shocks consistent with the severity parameters outlined in the *Participant Instructions* and to forecast property-level damages caused by the physical shocks. While there was wide variation in approach among the participants, several participants used external catastrophe models for this step. Catastrophe models simulate a large number of extreme events to quantify the financial impact of a range of potential disasters.

Common Shock Selection

The *Participant Instructions* defined the common shock to be a hurricane event (or series of events) in the Northeast at varying degrees of severity, but each participant determined the precise characteristics of the hurricane, such as the geographic path, wind speed, storm surge, or precipitation level.

Participants took a range of approaches in the design of the physical risk shocks. Approaches were largely a function of the capabilities that participants had onboarded or previously developed internally. The design of the physical risk shock determined the geographic path and footprint of the selected hazard event, such as a hurricane, the severity of the hazard, and its specific characteristics, such as wind speed and storm surge at points along that path. The design determined the level of damages to individual properties and reported credit risk parameters.

Participants that onboarded catastrophe models typically used these models to select specific hazard events (e.g., a hurricane) from a catalogue of simulated events in the relevant region.

These participants used the catastrophe models to design hazards consistent with the future climate parameters provided by the *Participant Instructions*. When designing a hurricane shock, for example, some participants selected a single hurricane event that produced aggregate damages consistent with the prescribed return periods. Other participants selected multiple hurricane events within the region, each with levels of aggregate damages within a narrow range around the specified return period, and then averaged the damage estimates across hurricanes. Participants took this approach to reflect the uncertainty associated with climate modeling and to account for the variation of different hurricane characteristics. Participants noted that hurricanes with similar levels of aggregate damages in a region may have very different footprints and impact different properties within the region.

Participants' generally selected hazard events impacting geographic areas in which they have concentrations of loans. Participants' approaches varied in whether they applied the same or different hazard events across their CRE and RRE portfolios. Practices ranged from selecting a single hazard event (e.g., a hurricane path) based on aggregate exposures across both CRE and RRE portfolios to selecting different hazard events for each portfolio in order to recognize the differences in geographic concentrations of CRE versus RRE.

Participants that did not use catastrophe models to simulate hurricane events relied on other approaches to design a hurricane event with the prescribed characteristics. One approach was to combine historic hurricane paths in the region with an external climate vendor projection of physical risks, such as coastal flooding, river flooding, and wind. In this approach, historic hurricane paths were adjusted so the hypothetical path of the event covered areas where participants had concentrations of RRE and/or CRE loans.

Depending on the approach taken, participants used different levels of granularity of hazard estimates, typically ranging from property-level estimates to zip code-level estimates. The level of granularity affected the participant's ability to consider the local geography in the damage estimation process.

Where participants did not use a catastrophe model, they differed in how they derived flood and wind damages caused by the hurricane. In some cases, participants modeled flood and wind damages separately and aggregated them. In other cases, participants only modeled flood damages and added a scaler for assumed wind damage. The share of damage caused by flood versus wind for selected hurricane events varied significantly across participants.

Idiosyncratic Shock Selection

For the idiosyncratic shock, participants were asked to select a hazard event and an NCA region based on materiality to their business models and exposures.[6] The *Participant Instructions* prescribed certain features that determined the severity of the shock.

The number and types of hazards that participants considered for the idiosyncratic shock was largely a function of participants' modeling capacity. Most participants considered multiple hazards, such as hurricanes, floods, wildfires, convective storms, and winter storms, while others limited consideration to fewer hazards. When selecting the hazard and region for the idiosyncratic shock, most participants estimated property-level damages across NCA regions for properties securing RRE and CRE loans and selected the hazard-region combination with the highest aggregate damages.

Some participants based their choice of idiosyncratic hazard on damage estimates for the most severe scenario, while others used a combination of severities. Most participants used estimates of total property damage without insurance protection as the metric by which they chose the idiosyncratic shock. Another approach was to convert estimated property damages into expected loan losses to identify the hazard-region combination that resulted in the highest expected loan losses.

For the idiosyncratic shock, participants chose hurricanes, extensive flooding, or wildfires in either the Southeast or Southwest geographic regions.

Consideration of Future Climate Conditions in Year 2050

As prescribed by the pilot CSA exercise, all participants considered future climate conditions in the year 2050 when modeling their physical risk shocks, although participants employed different methods to estimate these conditions. All methods relied on climate models for future climate estimates based on specific SSP/RCP pathways. In cases where participants utilized catastrophe models, vendors used climate model outputs to generate climate-conditioned simulated events reflecting future climate conditions rather than conditions based on historical data. In other cases, external climate vendors downscaled climate estimates from climate models for specific hazards and regions, or participants used climate model outputs directly in their internal models to project future hazard risk factors without relying on third-party vendors.

In the design of hurricane events consistent with possible future climate conditions in 2050, most participants included global and regional sea level rise, temperature increases, and changes to wind speeds. All participants considered how future climate conditions could impact the severity of physical shocks used for the exercise. For example, approaches included considering the

[6] Participants were directed to select a geographic region other than the Northeast region, which was used in the common shock.

impact of sea level rise on storm surge, permanent inundation of coastal properties outside of the direct path of the storm, or heat stress and precipitation on CRE business interruption.[7]

Estimate Property Damages

After identifying a specific hazard event, participants used different approaches to model the resultant damages (middle left of figure 3). Vendors that provided property-level damage estimates derived those estimates from hazard intensity parameters at the property location and key building characteristics, such as year built, occupancy codes, number of floors, and building materials.

Most participants reported data gaps around building characteristics and largely relied on national or regional “default” property characteristics from their vendors. Where third-party vendors were not used, or where third-party vendor data were limited, participants based the damage estimates on academic studies of historic events.

When estimating damages, participants made different assumptions about the decomposition of property value into building structure value and land value. Some participants estimated land value based on expert judgment or county records, others made implicit assumptions of land value based on the property value, and others used external estimates at the zip code level. When estimating damages to the building structure, some participants assumed that land value depreciated, while others assumed that damages would impact only the building structure. In the latter case, land value could serve as a mitigant to the level of damages applied to property value.

Credit Risk Models

After constructing the common and idiosyncratic shocks and estimating the physical damages to their real estate portfolios, participants calculated climate-adjusted credit risk parameters (right side of figure 3). Participants focused primarily on estimating the impact of damages to properties in the path of the physical hazard with less work on indirect impacts or broader impacts from chronic changes in climate conditions.

Direct Impacts

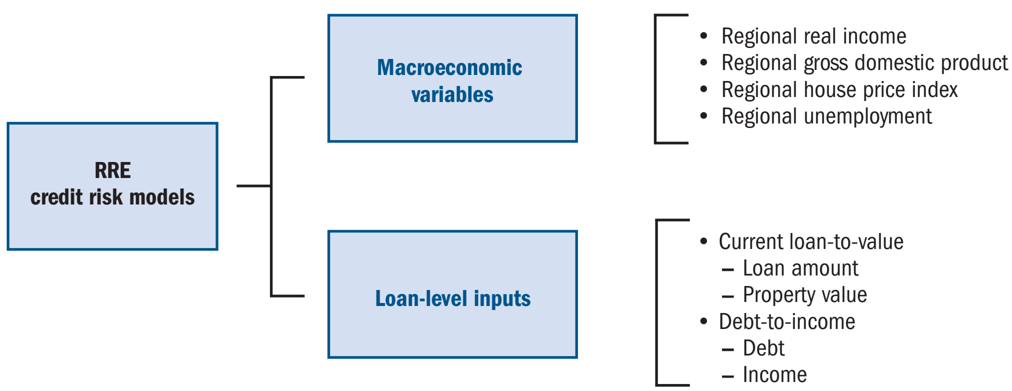
Most participants largely relied on existing credit risk modeling frameworks used in stress testing and regulatory capital requirements to estimate the direct impacts of acute physical shocks on credit risk parameters, such as PD and LGD, at the loan level. Participants generally modified key inputs into existing credit risk parameter estimation models, rather than changing the models themselves. Participants noted that reliance on existing models assumes that historical relation-

[7] Some of the analysis described was not included in the credit risk parameters submitted by participants for the exercise because it was not required as part of the exercise.

ships between model inputs and outputs continue to hold in future states as the climate and structure of the economy evolve.

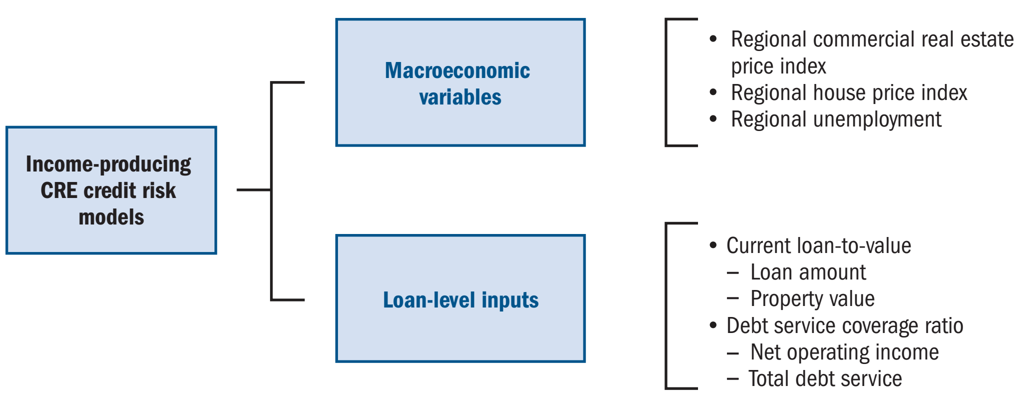
Figures 4 and 5 show stylized models for estimating impacts on credit risk parameters for RRE and CRE, respectively. These credit models combine MEVs and loan-level inputs, such as LTV ratios to estimate the PD and LGD of a given exposure. The primary adjustments for the physical risk shocks were through LTVs for RRE, and through LTVs and debt-service-coverage ratios (DSCRs) for CRE.

Figure 4. Stylized inputs for RRE credit risk models in the physical risk module



Source: Federal Reserve summary of CSA participant submissions.

Figure 5. Stylized inputs for CRE credit risk models in the physical risk module



Source: Federal Reserve summary of CSA participant submissions.

For both RRE and CRE, most participants translated climate shocks to estimates of PD and LGD by decreasing property values by the amount of uninsured damages from the event, thus increasing LTV ratios. Another approach assumed that obligors take on additional debt to cover uninsured or underinsured structure damage repair costs, increasing loan values and LTVs, and increasing debt-to-income ratios. For CRE, in addition to incorporating the impact from property damage on LTVs, some participants also assumed that climate shocks would impact the amount of time that an income-producing property was out of service. DSCRs were therefore adjusted to reflect declines in net operating income (NOI) due to damage-related business interruption. Another approach estimated the impact of repair costs on borrower cashflows in cases where repair costs were significant due to deductibles or when assuming no insurance coverage.

Indirect Impacts

In addition to estimating direct impacts of physical hazards on in-scope portfolios, participants were encouraged, but not required, to incorporate indirect impacts of the event where possible. Examples of indirect impacts could include, but are not limited to, impacts on the local economy, infrastructure, pricing effects, and supply chains, all of which could impact credit risk parameters.

Participants took varying approaches in considering indirect impacts. Given the optional nature of indirect impacts in the pilot CSA exercise and the challenges around estimating their impact, some participants either did not estimate indirect impacts or considered them in a separate analysis that was not included in the formal submission of credit risk parameters. Other participants incorporated one or more of the indirect impacts listed in table 5 in their PD and LGD submissions. These indirect impacts were captured either through adjustments to state- or metropolitan statistical area (MSA)-level MEVs included in credit models or through loan-level inputs.

Insurance Assumptions and Modeling

For the pilot CSA exercise, participants were asked to estimate the credit impact of physical hazards in both the common and idiosyncratic shock with two different assumptions: (1) assuming current insurance coverage, and (2) assuming no public or private insurance coverage, including no coverage from the NFIP. For purposes of the pilot CSA exercise, most participants assumed that insurance markets would operate effectively and that insurance payouts would be sufficient to rebuild damaged properties. Participants noted that the no insurance shocks naturally involved uncertainty, since the available historical data do not contain relevant examples of widespread damage not covered by insurance and/or government assistance.

See box 1 for background information on the types of insurance relevant for banks' RRE and CRE portfolios.

Table 5. Indicative examples of indirect impacts in the physical risk module

Indirect impacts considered	Description	Variables impacted
Disruption to local economy	Localized macroeconomic impacts related to climate shocks, primarily based on academic studies of historic events and some forward-looking estimates of home values	RRE and CRE: County, metropolitan statistical area, or state-level macroeconomic variables, such as personal income, gross domestic product, house price index, or unemployment
Increase in insurance premiums	Increased insurance premiums in response to the physical events for all properties in the region	RRE: Debt-to-income impact, or property value shock translated to house price index impact CRE: Net operating income impact, or property value shock translated to house price index impact
Inflationary effects	Cost of repair increases and supply shortages from surge in demand for labor and materials needed to complete repairs given widespread regional impact immediately following a natural catastrophe event	RRE: Debt-to-income impact, or property value shock translated to loan-to-value CRE: Net operating income impact, or property value shock translated to loan-to-value
Guarantor liquidity and net-worth impact	Guarantor rating downgrades to capture liquidity and net-worth impacts	CRE: Guarantor ratings downgrades

Source: Federal Reserve summary of CSA participant submissions.

Box 1. The Role of Insurance

Banks typically set property insurance requirements in real estate underwriting and credit monitoring procedures. The insurance requirements may include criteria for acceptable insurers, type and amount of coverage, and maximum deductibles allowed. Banks may rely on insurance companies (for residential) or third-party appraisers (for commercial) to estimate the replacement costs of the mortgage collateral.

Banks require borrowers to purchase and maintain standard hazard insurance (e.g., homeowners insurance), which covers fire and wind damage, but not flood damage. In high-risk hurricane zones, windstorm/hurricane coverage may be excluded from standard property insurance policies and purchased via policy endorsement at additional costs.

Flood insurance is purchased separately. In the U.S., the Flood Disaster Protection Act requires flood insurance on all originations, renewals, increases, or extensions of credit that are secured by an interest in improved real estate in the Special Flood Hazard Area (SFHA) covered by the Federal Emergency Management Agency's (FEMA's) NFIP. Flood insurance regulations apply to loans that are made by regulated lenders and loans purchased by government-sponsored enterprises and other agencies that provide government guarantees. FEMA provides flood insurance coverage of up to $250,000 for RRE and up to $500,000 for CRE. For real estate properties outside of the SFHA, flood insurance can be purchased on a voluntary basis.

Insurers can adjust policies at the time of renewal. For RRE, the policy is reset annually. In some cases, insurers have either raised premiums sharply or exited markets altogether. Policy adjustments can take place in a wider region than the areas directly hit by a natural disaster in the past.

Banks can obtain required insurance (e.g., mandatory flood insurance in the SFHA, homeowners insurance) on borrowers' behalf in the case of an insurance policy lapse.

All participants reported data gaps related to insurance, including insurance coverage details, replacement cost value, and deductibles, particularly for CRE (see table 6). While participants have some level of hazard insurance information, it is not always consistently recorded or easily aggregated. As a result, participants generally had to rely on assumptions to estimate the degree of insurance mitigation for physical risk shocks.

Table 6. Participant-identified data gaps and assumptions around insurance

Description	Participant practices
Flood insurance	Most participants assumed FEMA flood insurance coverage for properties in designated SFHA areas. Outside of SFHA areas, some participants assumed no coverage due to lack of data and others relied on underlying coverage data.
Other hazard insurance	For RRE, half of the participants used homeowners insurance data. For CRE, all participants noted data challenges related to CRE insurance coverage and deductibles. When data were not systemically available, participants relied on assumptions based on underwriting standards, sample of insurance policies, or force placed insurance. Most participants assumed wind damage would be fully covered.
Insurance deductibles	Half of the participants considered insurance deductibles in the CSA exercise for at least one portfolio. These were based on assumptions, such as policy-required minimum deductibles.
Business interruption insurance for CRE	Some participants reduced the impacts of business interruption due to physical damage for CRE portfolio by assuming business interruption insurance coverage.

Source: Federal Reserve summary of CSA participant submissions.

In the scenarios that assumed existing insurance coverage for RRE and CRE portfolios, insurance generally mitigated LTV shocks. Similarly, for CRE, business interruption insurance mitigated the NOI impact from downtime caused by physical damage for some participants. In the no-insurance shocks, this mitigation was removed.

Most participants noted that the pilot CSA exercise did not require that participants capture the impact of an increase in insurance premiums over time. Participants noted that an increase in insurance costs, which some participants voluntarily included as indirect impacts, could lead to increased financial burden for obligors, potentially impacting obligors' disposable income and overall credit profile. For CRE, rising insurance premiums could cause NOI shocks, which could drive rent increases if higher costs were passed on to renters.

Impact Estimates from Participants

This section summarizes estimates of average loan-level PDs across participants for the physical risk module.[8] Estimates were produced by participants using their own models and assumptions and submitted to supervisors as part of this exercise. Basic quality control checks were performed, but the data were not independently verified by supervisors, and the Federal Reserve did not independently estimate the impact on risk parameters. Given the goals and design of the exer-

[8] See the appendix for more detail.

cise, the quantitative estimates should be interpreted with an understanding that broad variation in approach makes comparison and aggregation of estimates across participants difficult.

For the common shock of the physical risk module, participants estimated the impact of a hurricane in the Northeast NCA region on in-scope CRE and RRE portfolios. For the idiosyncratic shock, participants were asked to select a hazard event and an NCA region based on materiality to their business models and exposures. See table 4 for a summary of the shocks.

To provide some scale of the portfolio coverage, table 7 shows the aggregate number of CRE and RRE loans across participants in the common shock. A similar table for the idiosyncratic shock is not included given the variation in regions selected by participants. More than 1,000 CRE loans and more than 238,000 RRE loans in the Northeast NCA region were impacted by the most severe common shock (200-year, no insurance). This represents about 20 and 50 percent of participants' total Northeast NCA region CRE and RRE loan counts, respectively.

Table 7. Physical risk common shock summary

Loans	Commercial real estate	Residential real estate
	Aggregate number of loans	Aggregate number of loans
Total		
All U.S.	33,879	2,200,504
Northeast NCA region	5,314	471,157
Impacted loans		
100-year	1,154	212,010
200-year	991	219,194
200-year no insurance	1,055	238,644

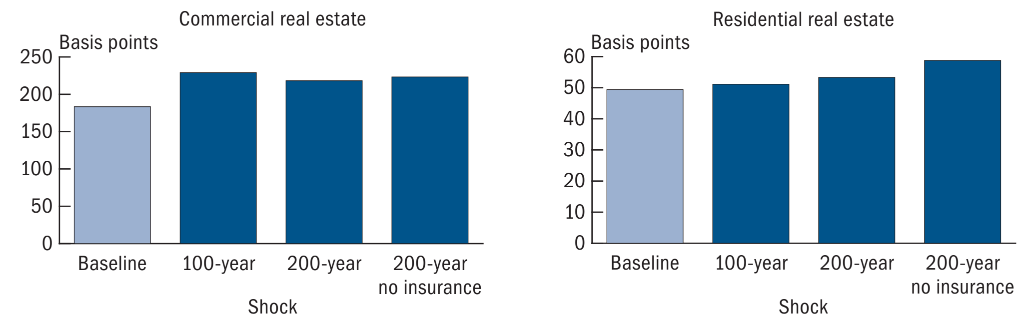
Note: "All U.S." is aggregated across six participants. "Northeast NCA region" and "Impacted loans" are aggregated across five participants. "Impacted loans" includes all loans with a change in the probability of default in the associated scenario. See the appendix for more detail.

Source: CSA participant submissions, Federal Reserve FR-Y14Q Schedule H.2, and FR-Y14M Schedules A.1 and B.1 as of December 31, 2022.

As reported in figures 6 and 7, participants estimated that PDs generally increased with the severity of the shocks, e.g., moving from SSP2-4.5 (or RCP 4.5) pathways with a 100-year return period loss to SSP5-8.5 (or RCP 8.5) pathways with a 200-year return period loss and to the no insurance shock.[9] In the common shock, estimates of average PDs across participants for properties in the Northeast region increased by about 40 basis points (bps) for CRE and about 10 bps for RRE in the most severe iteration (200-year, no insurance) relative to the baseline (figure 6).[10] In the idiosyncratic shock, average PDs across participants for properties in the selected NCA

[9] The majority of participants show an increase in the estimated impact from the 100-year shock to the 200-year shock.
[10] See the appendix for more detail.

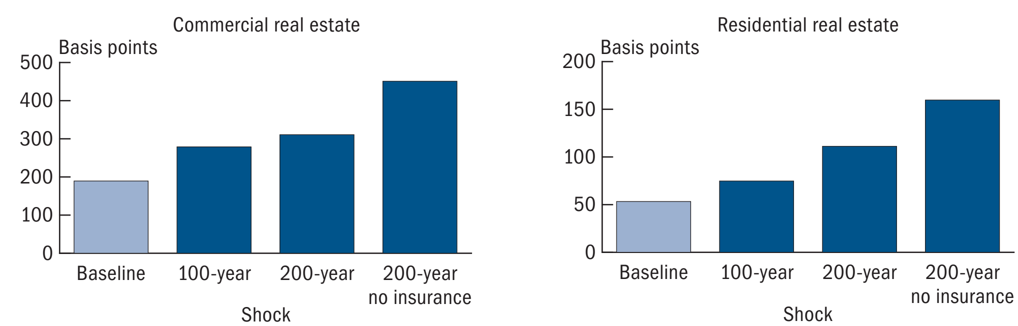
Figure 6. Average of participant estimates of probability of default in the physical risk module, common shock



Note: Bars show the average probability of default across five participants. See the appendix for more detail.

Source: Federal Reserve calculations based on CSA participant submissions.

Figure 7. Average of participant estimates of probability of default in the physical risk module, idiosyncratic shock



Note: Bars show the average probability of default across five participants. See the appendix for more detail.

Source: Federal Reserve calculations based on CSA participant submissions.

regions increased by about 260 bps for CRE and about 110 bps for RRE in the most severe iteration (200-year, no insurance) relative to the baseline (figure 7).

For most participants, the idiosyncratic shock was more impactful than the common shock. Participants generally found that the SSP/RCP pathway characteristic was less significant than the return periods in terms of severity because the SSP/RCP paths and related physical risks only start to meaningfully diverge after 2050.

Insurance mitigated participants' estimates of the impact of physical risk hazards on credit exposures. Assuming no insurance coverage generally increased PDs across RRE and CRE portfolios for most participants. In some cases, conservative assumptions about the level of insurance coverage in the 200-year shock limited the impact of insurance removal (i.e., where insurance coverage was assumed to be low, its removal did not result in significantly higher estimated PDs).

Assuming no insurance coverage had a more pronounced impact in the idiosyncratic shock relative to the common shock. In general, property damage estimates were lower in the common shock, as less severe hurricanes in the Northeast caused less damage to individual properties than hazards selected in the idiosyncratic shock. When property-level damages are low and do not exceed insurance deductibles, insurance provides minimal protection, and its removal does not have a significant impact on estimated PDs.

Table 8. Percent of loans impacted by physical risk shock

Shock	Commercial real estate		Residential real estate	
	Percent of aggregate loans in relevant NCA region with a change in PD	Percent of aggregate loans in relevant NCA region with > 500 bps change in PD	Percent of aggregate loans in relevant NCA region with a change in PD	Percent of aggregate loans in relevant NCA region with > 500 bps change in PD
Common				
100-year	21.7	1.3	45.0	0.1
200-year	18.7	1.2	46.5	0.1
200-year no insurance	19.9	1.4	50.7	0.3
Idiosyncratic				
100-year	73.6	3.8	46.2	0.8
200-year	74.7	4.8	49.7	2.4
200-year no insurance	76.2	9.2	54.6	4.3

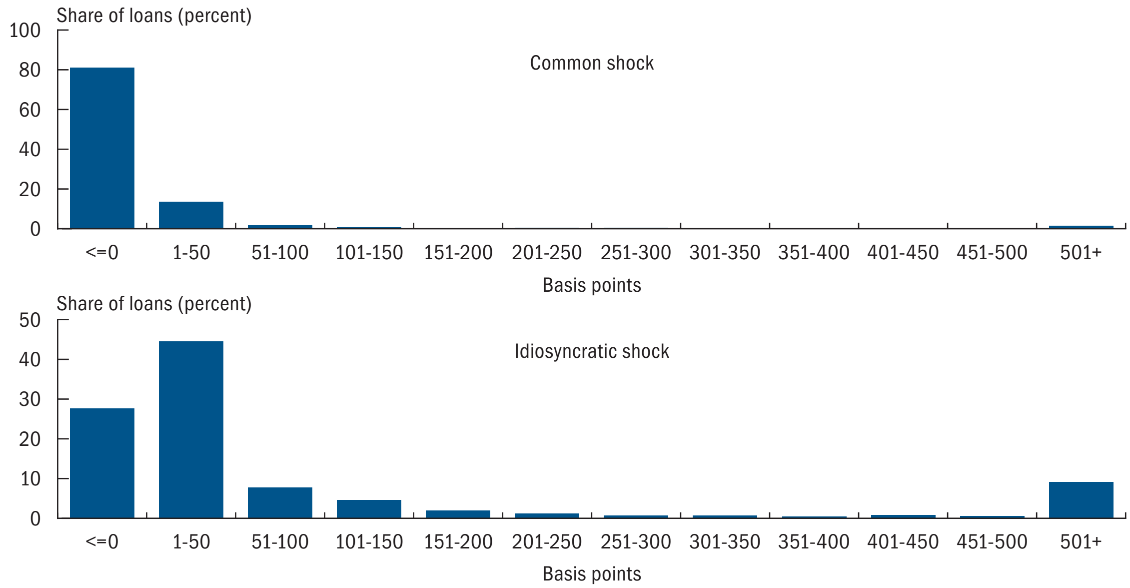
Note: There are 5,314 CRE loans and 471,157 RRE loans in the Northeast NCA region aggregated across five participants. There are 1,133 CRE loans and 368,918 RRE loans across five participants for idiosyncratic shocks. NCA regions for idiosyncratic shocks vary by participant. See the appendix for more detail.

Source: Federal Reserve calculations based on CSA participant submissions.

Participants reported that physical damages to property and related effects were the primary drivers of increased PDs. Credit risk was primarily concentrated in small pockets of loans with the highest expected damages in geographic areas directly in the paths of physical hazards. CRE damages were particularly sensitive to storm selection given the fewer number of properties and higher value of properties.

The underlying distributions of loan-level PDs in all scenarios were heavily concentrated in the 0-50 bps range with a small fraction of loans with PDs greater than 500 bps. As the severity of the shock increases, the distribution of loan-level PDs shifts to the right relative to the baseline, and the share of loans with PDs greater than 500 bps generally increases (see table 8). A larger percentage of CRE loans was impacted by the idiosyncratic shock.

Figure 8. Distribution of participant loan-level estimates of the change in probability of default in the physical risk module, 200-year, no insurance, common and idiosyncratic shocks, CRE



Note: Bars show the average change in probability of default between the baseline and 200-year, no insurance shock for all CRE loans across five participants for the common and idiosyncratic shocks. See the appendix for more detail.

Source: Federal Reserve calculations based on CSA participant submissions.

Figure 8 shows the distribution of changes in PD for CRE loans between the baseline scenario and the 200-year, no insurance scenarios for both the common and idiosyncratic shocks. The distribution shows that the majority of loans had a 50 bps or less change in PD for both the common and idiosyncratic shocks, and approximately 1 percent and 9 percent of loans had a change in PD of more than 500 bps in the common and idiosyncratic shocks, respectively.

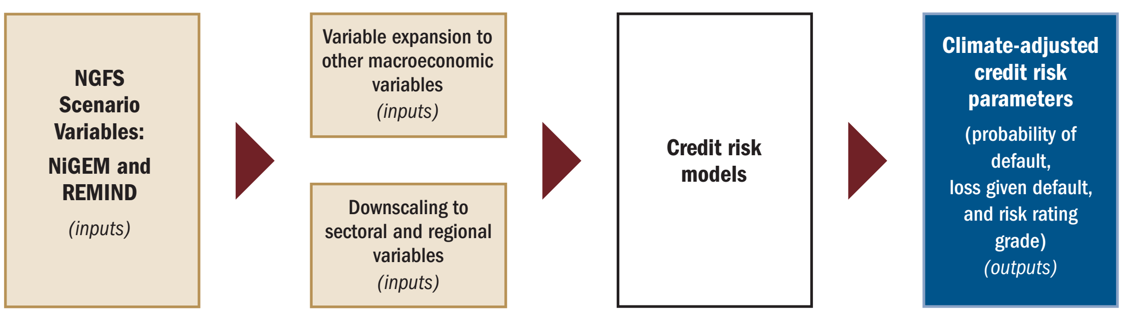
Transition Risk Module

The transition risk module required participants to estimate the credit risk impact of two macroeconomic pathways with different combinations of economic, technological, and policy assumptions and different estimates for economic and financial variables like GDP growth and carbon prices. Participants used the scenarios to estimate the credit impact on their corporate and CRE loan portfolios over a 10-year horizon.

Scenario Design

The transition risk module centered on two scenarios developed by the NGFS: Current Policies and Net Zero 2050. These scenarios include pathways for emissions, the energy system, and financial and macroeconomic conditions that participants were instructed to use for the pilot CSA exercise. Most participants identified a common set of key variables from the NGFS that they viewed as critical for determining the impact of the transition risk scenarios on their in-scope corporate and CRE exposures. Participants then used these variables to estimate climate-adjusted credit risk parameters. Figure 9 shows a stylized representation of this process.

Figure 9. Stylized modeling approach for transition risk estimation



Source: Federal Reserve summary of CSA participant submissions.

Key Variables

As shown in table 9, participants used GHG emissions, GDP, equity prices, carbon prices, and energy prices from the NGFS for the United States. Many participants also used additional MEVs from the NGFS scenarios similar to those used in traditional stress testing, such as unemployment, inflation, and interest rates, as detailed below.

Table 9. Common macroeconomic variables used by participants

Common NGFS variables types	Expanded by participants
Carbon prices	Corporate yields
Energy prices	CRE price index
Equity prices	Credit spreads
Greenhouse gas emissions	Emerging markets index
Gross domestic product	Gross value added
Inflation rate	LIBOR/SOFR/EURIBOR
Long term interest rate	Retail sales
Policy interest rate	Vehicle sales
Real disposable personal income	VIX index
Unemployment rate	

Note: Common variables are those used by three or more participants.

Source: Federal Reserve summary of CSA participant submissions.

Participants translated certain NGFS variables to observable variables and typical modeling frequencies. For example, internal credit risk models generally use specific variables (e.g., U.S. 10-year Treasury rate, S&P equity index), while the NGFS scenarios include some generalized variables that are not necessarily tied to a specific time series (e.g., long-term interest rates, equity prices). Thus, participants linked the NGFS variables to observable time series by converting NGFS variable trajectories from levels to growth rates and applying these to the observable time series. This approach also helped to smooth the discontinuities between the current macroeconomic environment and the initial scenario projection year.[11]

Participants noted challenges in interpreting the macroeconomic consistency of the transition risk scenarios. These included reconciling MEV relationships, understanding variable definitions, interpreting variable pathways, and estimating technological assumptions.

Variable Expansion

Most participants' modeling approaches incorporated additional variables not included in the NGFS Scenario Database, including additional macroeconomic, state- or MSA-level, and sector-level variables, like CRE indexes, credit spreads, and sector gross value added (GVA).[12] To fill these variable gaps, most participants expanded the NGFS scenarios in two ways: first to derive additional macroeconomic and regional variables that were inputs to internal stress testing models, and second to downscale macroeconomic and energy system variables to a more granular level to enable greater differentiation in impact across sectors.

In order to estimate the impact of transition risk across sectors, most participants needed to further downscale the NGFS scenarios to economic sectors that were not covered by the NGFS variables or to a greater level of granularity for economic sectors that were covered. These sectoral variables included production, prices, consumption, capital expenditure, and sector GVA. Partici-

[11] As noted in the *Participant Instructions*, variable pathways from the NiGEM model begin in 2022, and participants were instructed to view the year 2022 within the NGFS scenarios as projection "Year 1" for purposes of the pilot CSA exercise. While participants were able to overcome most discontinuities through the growth rate approach, most participants required bespoke approaches for interest rate variables, given the magnitude of the discontinuity and resulting uneconomic outcomes.

[12] Sector GVA shows the economic value of a sector's output less the value of that sector's input.

pants either developed these variables using internal models or used vendor models to estimate the direct impact of transition risk on certain sectors. Differences in approaches led to differences in estimates of sectoral variables (e.g., sector GVA), both across sectors and for a given sector across participants.

Measurement Methodologies

To estimate the impact of the NGFS scenarios on credit risk parameters, most participants largely relied on existing wholesale credit risk modeling frameworks used in stress testing and regulatory capital requirements. These frameworks generally first estimated the direct credit risk impact at the exposure level (i.e., obligor for corporate loans and property for CRE), then forecasted the impact of the scenario's macroeconomic conditions across the 10-year projection horizon.

Corporate Exposures Methodology

All participants applied transition risk effects at the obligor level to estimate the impacts of the transition on obligors' business models. Many participants segmented their corporate exposures by sector. For some sectors, participants developed granular methods to project the impact of transition risks on obligor financials, cash flows, and internal risk ratings. For other sectors, participants used more generalized approaches with less granularity to project transition risk impacts at the obligor level or used unadjusted obligor financial estimates or ratings. Several participants assumed some sectors were not impacted, and they did not estimate transition risk impacts on obligors within those sectors.

The granular methodologies for estimating transition risk impacts typically augmented traditional obligor risk rating systems. Some participants contracted vendor models, while others developed methodologies in-house. Most methodologies calculated the potential impact of the transition scenarios' carbon prices and resultant energy system effects on obligors' financial estimates (e.g., revenue, operating costs, capital expenditures, dividend payouts, debt, equity, cash flows) that are inputs to credit risk models. Others used statistical methods that related ratings to MEVs.

Once obligor risk parameters were adjusted for transition risk impacts, participants used a range of approaches to integrate these adjusted credit risk parameters into their PD rating transition modeling frameworks. Some participants condensed obligors' 10-year adjusted risk parameter impacts into a single adjustment to risk ratings at the beginning of the scenario. Others dynamically integrated the impact across the projection horizon either by using the adjusted risk ratings at each projection period or by using the adjusted ratings to update the quarterly transition matrices used by traditional stress testing models.

Nearly all participants applied the rating transition models from their existing stress testing modeling frameworks to migrate obligor ratings or PDs across the projection horizon using the MEV pathways from the NGFS scenarios. Some participants updated their existing ratings transition models to incorporate greater sectoral granularity, for example, by replacing macroeconomy-level variables with regional or sectoral variables. Other participants used their stress testing ratings transition models without alteration.

Emissions data were broadly used for credit risk modeling by all participants. Participants used similar emissions data sources for public companies, while using a greater range of proxies (either vendor or internally developed) for private or nonreporting public companies. Proxy methodologies for estimating missing emissions data included extrapolating emissions from regional industry averages or predicting emissions from regression or machine learning models.

In the pilot CSA exercise, participants had the option to incorporate information about an obligor's "transition capacity" into their estimation approaches. All participants considered obligors' plans to manage transition risks to some degree. In some cases, participants used this information in connection with an obligor's financial projections or risk assessment.

Commercial Real Estate Methodologies

Generally, participants adapted their existing CRE stress testing approaches to model transition risk. Several participants also applied new vendor or internally developed approaches to target property-level estimates of transition risk that were integrated with these existing stress testing models.

Most participants considered the impact of transition risk drivers through adjustments to property-level NOI pathways, cap rates, or loan and property valuation estimates. Participants used different methodologies that focused on estimating revenues based on estimated vacancy rates, rental rates, and lost revenue; operating costs based on higher utility prices; and capital improvements needed to retrofit properties for carbon abatement or increased energy efficiency. These transition risk-adjusted estimates were used to project DSCR and LTV values for each property across the projection horizon. These projected values were then input into the main risk parameter models used in participants' existing stress testing approaches for estimating PD and LGD parameters.

To obtain estimates of energy efficiency or capital expenditure needs, many participants required property-level information on emissions or energy usage that is not currently collected or systematically available. Emissions data facilitate estimates of potential carbon abatement costs or upper bounds of potential retrofitting capital expenditure, while energy usage and efficiency metrics facilitate estimates of the change in relative energy costs across properties. Participants acquired property-level information where available and used proxy estimates, sample methodologies, or client surveys to derive missing information. Examples of data needed and/or proxied include property characteristics (e.g., property location, square footage, number of floors, construction materials, renovation, age of building since construction), energy efficiency ratings (e.g., Energy Star score, LEED ratings), municipal regulatory data, and retrofitting costs.

Impact Estimates from Participants

This section summarizes estimates of average loan-level PDs across participants for the transition risk module. Similar to the physical risk impact estimates, the transition risk impact estimates were produced by participants using their own models and assumptions. Similar caveats as those described under "Impact Estimates from Participants" in the "Physical Risk Module" section apply.

Table 10. Transition risk summary

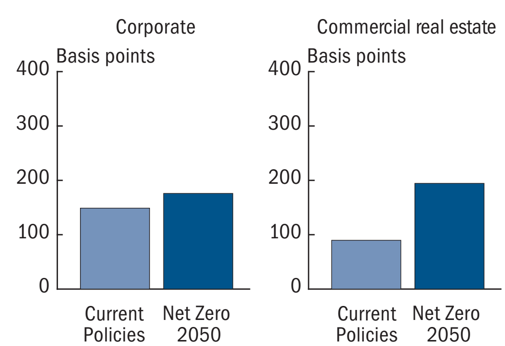
Corporate	Commercial real estate
Facilities	Loans
158,250	36,901

Note: A credit facility is a credit extension to a legal entity under a specific credit agreement, which may allow for multiple extensions of credit (i.e., loans). Number of facilities and loans are aggregated across the six participants.

Source: Federal Reserve calculations based on CSA participant submissions.

In the transition risk module, participants estimated the impact of two NGFS scenarios on their in-scope corporate and CRE exposures. As shown in table 10, in-scope corporate loans represent about 158,000 loans. In-scope CRE loans represent nearly 37,000 loans.

Figure 10. Average of participant estimates of probability of default in the transition risk module



Note: Bars show the average of the average probability of default over the 10-year horizon across six participants. See the appendix for more detail.

Source: Federal Reserve calculations based on CSA participant submissions.

Participants estimated that average PDs were higher in the Net Zero 2050 scenario for corporate and CRE loans relative to the Current Policies scenario. As shown in figure 10, the estimate of average PD for in-scope corporate loans was about 30 bps higher in the Net Zero 2050 scenario relative to the Current Policies scenario. The average PD for in-scope CRE loans was about 100 bps higher in the Net Zero 2050 scenario relative to the Current Policies scenario.[13]

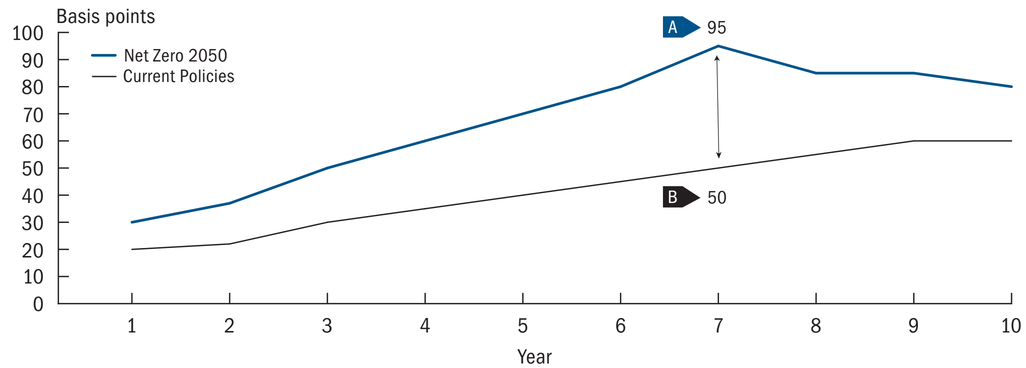
Similar to the physical risk module, the distributions of PDs in both scenarios were concentrated in the 0-50 bps range with a small fraction of loans with PDs greater than 500 bps. The underlying distribution of PDs for both corporate and CRE loans shifts to the right in the Net Zero 2050 sce-

[13] The estimated CRE credit risk parameters reported in figure 10 reflect different loan populations and measurement methodologies compared to the CRE credit risk parameters reported in figures 6 and 7.

Box 2. Transition Risk Impact Methodology

The transition risk impact for each loan is calculated as the largest annual difference in the PD between the Net Zero 2050 scenario and the Current Policies scenario. Figure A provides a stylized representation. In this example, the largest change in PD occurs in year 7, and the transition risk impact is estimated as 45 bps.

Figure A. Stylized representation of transition risk impact



Note: The transition risk impact is calculated as the largest annual difference in the probability of default between the Net Zero 2050 and the Current Policies scenarios.

Source: Federal Reserve.

nario relative to the Current Policies scenario, and there is an increase in the share of loans with PDs equal to or above 500 bps.

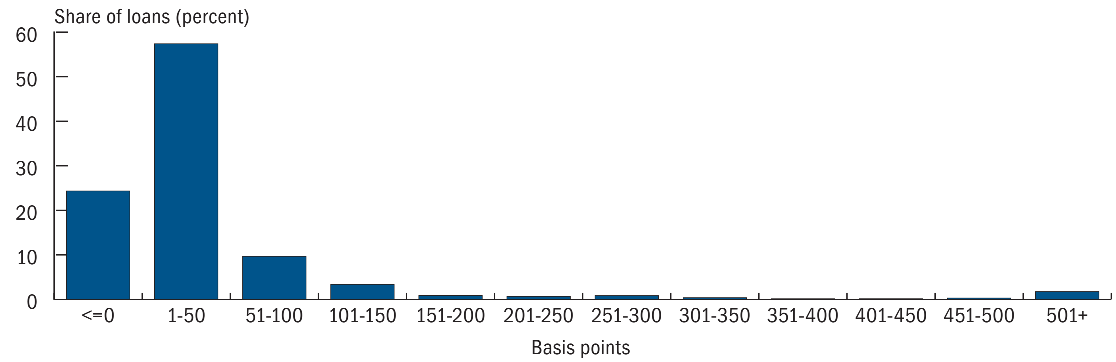
The transition risk impact can be estimated as the difference in the PD between the Net Zero 2050 scenario, which reflects higher carbon prices and related transition effects, and the Current Policy scenario, which doesn't. Box 2 describes the approach to define the transition risk impact for individual loans.

Corporate Estimates

Figure 11 shows the distribution of transition risk impact across all corporate loans. The distribution shows that the majority of loans had a 50 bps or less transition risk impact, while nearly 2 percent of loans had a transition risk impact of more than 500 bps. Participants' estimates also show significant heterogeneity across and within sectors.

One way to compare the impact of differences in methodologies and assumptions across participants is to look at the range of estimated transition risk impacts across participants for common obligors, that is, obligors that obtained credit from multiple participants (figure 12). Participants reported wide variation in estimates for some common obligors. For example, more than 20 per-

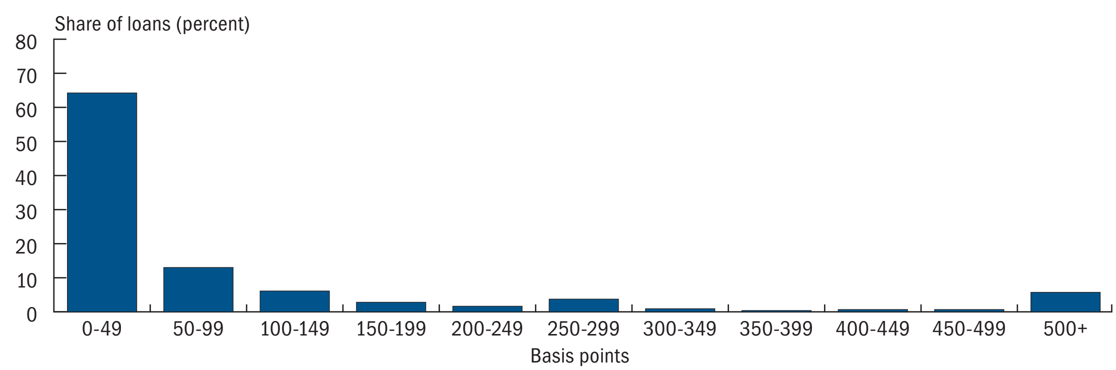
Figure 11. Distribution of transition risk impact across corporate loans



Note: Bars show the transition risk impact for all loans across six participants. See the appendix for more detail.

Source: Federal Reserve calculations based on CSA participant submissions.

Figure 12. Distribution of range in participant loan-level estimates of transition risk impact for common obligors



Note: Common obligor transition risk impact range is calculated as the maximum participant transition risk impact for an obligor less the minimum participant transition risk impact for that obligor. See the appendix for more detail.

Source: Federal Reserve calculations based on CSA participant submissions.

cent of loans to common obligors had differences in estimates of transition risk impact of more than 100 bps across participants. Almost 6 percent of loans to common obligors had differences in transition risk impact of more than 500 bps.

CRE Estimates

The average transition risk impact for CRE loans was about 100 bps across all property types. Participants saw meaningful heterogeneity in impact across CRE property types with property types with higher energy intensity showing the largest impact.

Governance and Risk Management

The pilot CSA exercise included a review of governance and risk-management practices used by participants for the exercise.

Governance

All participants used or adapted existing governance and risk-management practices for the pilot CSA exercise. Most participants created a working group or council reporting into an existing climate risk committee or a management-level risk committee. The working group was typically responsible for overseeing the conceptual design and execution of the pilot CSA exercise. In some cases, these working groups were supported by task forces focused specifically on the physical or transition risk modules of the exercise. Some of these bodies will be incorporated permanently in governance structures, while others will be decommissioned following the exercise.

Most participants used existing stress testing governance structures and practices in the execution of the pilot CSA exercise. Most participants described processes that included review and challenge of estimates with management and board level risk committees, lines of business, independent risk, and stress testing groups to varying degrees.

Internal Controls

Participants used existing internal controls where applicable and instituted a limited number of new controls for the exercise, which were primarily focused on compliance with the *Participant Instructions*. Other controls implemented during the pilot CSA exercise related to model inputs, processing, output and estimates, and submission verifications. Most participants noted that time constraints, data limitations, and the nature of the exercise precluded participants from applying a full control framework, which would typically include model validation.

Internal Audit

Internal audit coverage of the pilot CSA exercise varied across participants, with primarily limited scope monitoring engagements rather than discrete events. Practices ranged from conducting a pilot CSA-specific audit to incorporating testing of the pilot CSA exercise into a broader audit of climate risk methodologies to approaching internal audit through continuous monitoring of aspects of the pilot CSA exercise. Most participants reported that time constraints precluded full audits of the exercise.

Model Risk Management

All participants relied on existing model risk-management frameworks to develop the models used for the pilot CSA exercise, but participants faced several challenges in conducting reviews of modeling frameworks. These challenges included limited data, lack of back-testing capabilities, nonlinear risks, scenario horizon, heavy reliance on judgment, limited reliability of model output, and time constraints. Given the exploratory nature of the exercise, the *Participant Instructions* acknowledged and accepted the challenges with model validation.[14]

Participants focused on conceptual soundness, compensating controls, and overlays as applicable. Participants obtained appropriate waivers or exceptions in compliance with their internal policies and procedures.[15]

[14] "Unless participants also rely on a model used in this exercise for business-as-usual decisionmaking, or to assess risks on a regular basis, participants may use models that have not been fully integrated into their model risk-management framework, including those that have not yet been subject to comprehensive model validation. Examples of constraints include limited data or challenges in confirming model performance via outcomes analysis." *Pilot Climate Scenario Analysis Exercise: Participant Instructions*, 9, https://www.federalreserve.gov/publications/files/csa-instructions-20230117.pdf

[15] "The Board recognizes and accepts that these limitations may inhibit the application of certain principles for sound model risk management to models used in this pilot exercise." *Participant Instructions*, 9.

Appendix

Physical Risk Methodology

- The physical risk scenario analysis presented in this document is based on submissions from pilot CSA exercise participants of loan-level PD estimates for the scenarios prescribed in the *Participant Instructions*.
- Participants estimated loan-level PDs for all in-scope RRE and CRE loans to U.S. obligors in relevant NCA regions. The loan population included loans and/or credit facilities reportable in the FR Y-14M, Schedule A.1 – Domestic First Lien Closed-end 1-4 Family Residential Loan Schedule and Schedule B.1 – Domestic Home Equity and Home Equity Line Schedule that are directly held on the participant's portfolio as defined by the FR Y-14M Instructions, and in the FR Y-14Q, Schedule H.2 – Commercial Real Estate Loan Schedule.
- For the common shock, the relevant NCA region was the Northeast. For the idiosyncratic shock, the relevant NCA region was selected by each participant and may differ across participants.
- Unless otherwise noted, the analysis excludes one participant's estimates due to methodological differences that prevented aggregation across participants or comparison to baseline scenario estimates.
- The analysis excludes all loans with 100 percent PD in the baseline scenario.
- Baseline scenario figures reflect participants' estimates before the impact of the physical shock is incorporated. The baseline represents PDs reported by participants as of December 31, 2022, in their FR Y-14M Schedules A.1 and B.1 filings and FR Y-14Q Schedule H.2 filings. If a participant chose to estimate risk parameters using a different measurement approach from the one used to estimate the advanced approaches risk parameters reported in the corresponding FR Y-14 schedules as of December 31, 2022, risk parameter estimates as of December 31, 2022, were restated, using a consistent and comparable measurement approach to the one used in the pilot CSA exercise.
- The average of participant estimates of PD is calculated as the average of loan-level PDs for in-scope loans in the relevant NCA region.
- All averages are unweighted.

Transition Risk Methodology

- The transition risk scenario analysis presented in this document is based on submissions from pilot CSA exercise participants of facility-level and loan-level PD estimates for the scenarios prescribed in the *Participant Instructions*.

- Participants estimated loan-level PDs for in-scope Corporate and CRE loans. The loan population included active loans reportable in the FR Y-14Q, Schedule H.1 – Corporate Loan Data Schedule, and the FR Y-14Q, Schedule H.2 – Commercial Real Estate Schedule. Active facilities corresponded to Disposition Flag option 0 on FR Y-14Q, Schedule H.1, Field 98, or FR Y-14Q, Schedule H.2, Field 61.
- The analysis excludes loans with 100 percent PD as reported by participants as of December 31, 2022, in their FR Y-14Q H.1 and H.2. filings, or restated PDs if a participant chose to report risk parameter estimates using a different measurement approach from the one used to estimate the advanced approaches risk parameters reported in the corresponding FR Y-14 schedules as of December 31, 2022.
- Transition risk impact for an individual loan is defined as the largest annual difference in PD between the Net Zero 2050 and Current Policies scenarios over the 10-year projection horizon. See box 2 for more detail.
- The average of participant transition risk impacts is calculated as the average transition risk impact for all in-scope loans.
- All averages are unweighted.
- Common obligor is defined as an obligor that has a corporate facility at more than one participant (using the obligor's legal entity identifier).

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