Climate Stress Testing

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The views expressed in this presentation are those of the authors and do not necessarily represent those of the Federal Reserve Bank of New York or the Federal Reserve System.
Climate Change and Financial Stability

How could climate-related shocks impose systemic risk on financial sector?

- If banks systemically suffer substantial losses following abrupt increases in:
  - Transition risks arising from changes in policies
  - Physical risks arising from damage to property

How can we estimate banks’ capital shortfall following a climate-related shock?

- We develop climate stress testing methodology to test the resilience of financial institutions to climate-related risks.
Climate Stress Testing Challenges

1. Analyses based on past climate events may not effectively capture the change in the perception of risk.
   - Our methodology is market-based, allowing us to fully incorporate changes in the market’s expectations.

2. Climate risk itself changes over time, and how firms, banks, and markets respond to the perceived risk also changes over time.
   - We estimate a dynamic model, allowing variations over time.

3. Data gaps and timeliness
   - Our methodology only requires publicly available information.
   - We estimate our model on a daily basis, allowing for a timely response to rapidly changing climate risk.
This Paper

- **Climate stress testing methodology** to test the resilience of financial institutions to climate-related risks.

- The methodology involves three steps:
  1. Measure the climate risk factor.
  2. Estimate time-varying climate beta of banks.
     - Dynamic Conditional Beta (DCB) model
  3. Compute systemic climate risk (CRISK).
     - CRISK: Expected capital shortfall of banks in a climate stress scenario

- Use the measure to study the climate-related risk exposure of large global banks
Key Findings

1. The climate beta and CRISK substantially increased during 2020.
   - Aggregate CRISK of top 4 US banks increased by $360 billion (40% relative to their market capitalization) during 2020.

2. The increase in CRISK during 2020 was primarily due to decrease in equity values of banks.
   - 75% due to equity deterioration
   - 23% due to debt deterioration
   - 2% due to increase in risk

3. CRISK is considerably higher than expected capital shortfall of banks under zero climate stress scenario.
   - Aggregate CRISK of top 4 US banks is higher than non-stressed CRISK by $245 billion.

4. Banks with higher exposure to gas & oil loans have higher climate beta and CRISK.
Step 1: Climate risk factor

- Litterman’s stranded asset portfolio: a measure of transition risk

$$0.3\textit{XLE} + 0.7\textit{KOL} - \textit{SPY}$$

Figure: Stranded Asset Portfolio Cumulative Return
Step 2: Time-varying climate beta

Estimate each bank $i$’s $\beta_{it}^{\text{Climate}}$

- Bank’s stock return sensitivity to the climate factor
- Dynamic Conditional Beta Model$^2$

$$r_{it} = \beta_{it}^{Mkt} MKT_t + \beta_{it}^{\text{Climate}} CF_t + \varepsilon_{it}$$

- Allows volatility and correlation to be time-varying.

- Expect:
  - $\beta_{\text{Climate}}^{\text{Climate}} > 0$ for banks with large exposure to gas and oil loans

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Time-varying climate beta of U.S. Banks

![Graph showing time-varying climate beta of U.S. Banks]

- Neg Beta
- Events
- ACWI
Time-varying climate beta of Canadian Banks

![Graph showing time-varying climate beta for Canadian banks]

- The x-axis represents the date from 01 Jan 2000 to 01 Jan 2020.
- The y-axis represents the cbeta (ma), acwi_stranded_spy values, ranging from -0.5 to 1.
- The graph plots the time series data for various banks:
  - BMO:CN
  - BNS:CN
  - CM:CN
  - NA:CN
  - RY:CN
  - TD:CN

The graph illustrates the fluctuation and trend of the climate beta over the specified period for each bank.
Time-varying climate beta of Japanese Banks

Date:
- 01jan2000
- 01jan2005
- 01jan2010
- 01jan2015
- 01jan2020

Lines:
- 8306:JP (red)
- 8316:JP (blue)
- 8411:JP (green)

Y-axis:
- cbeta (ma), acwi_stranded_spy

X-axis:
- 01jan2000 to 01jan2020

Legend:
- 8306:JP
- 8316:JP
- 8411:JP
Time-varying climate beta of French Banks

The graph shows the time-varying climate beta (cbeta) for different French banks from 2000 to 2020. The x-axis represents the date, ranging from 01 Jan 2000 to 01 Jan 2020. The y-axis represents the cbeta values, ranging from -0.5 to 1.

The graph includes data for the following banks:

- ACA:FP (red line)
- BNP:FP (blue line)
- GLE:FP (green line)

The graph indicates fluctuations in cbeta values over time for each bank, with notable peaks and troughs.
Step 3: CRISK

Follow the SRISK methodology

\[ CRISK_{it} = E_t[\text{Capital Shortfall}_i \mid \text{Climate Stress}] \]
\[ = E_t [k(D_{it} + W_{it}) - W_{it} \mid \text{Climate Stress}] \]
\[ = kD_{it} - (1 - k) \left(1 - LRMES_{it}\right) W_{it} \]
\[ = \exp(\beta_{it}^{\text{Climate}} \log(1 - \theta)) \]

- **D**: Book value of debt
- **W**: Market capitalization
- **LRMES**: Expected equity loss conditional on the climate stress
- **Prudential level of equity relative to assets** \( k = 0.08 \) (\( k = 0.055 \) for Europe)
- **Climate stress level** \( \theta = 0.5 \)
  - 1% quantile of 6 month return on the stranded asset portfolio

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CRISK of U.S. Banks

![Graph showing CRISK of U.S. Banks for various banks over time.]

- BAC:US
- BK:US
- C:US
- COF:US
- GS:US
- JPM:US
- MS:US
- PNC:US
- USB:US
- WFC:US
CRISK of U.K. Banks

The graph shows the CRISK (ma), acwi_stranded_spy for different dates and companies from 01 Jan 2000 to 01 Jan 2020.

The companies represented are:
- BARC:LN
- HSBA:LN
- LLOY:LN
- NWG:LN
- STAN:LN

The x-axis represents the dates from 01 Jan 2000 to 01 Jan 2020, and the y-axis represents the CRISK value.
CRISK of Canadian Banks

![Graph showing CRISK of Canadian Banks from 2000 to 2020. The x-axis represents dates from 01 Jan 2000 to 01 Jan 2020, while the y-axis represents CRISK values ranging from -40 to 40. Different banks are represented by distinct lines: BMO:CN in red, BNS:CN in blue, CM:CN in green, NA:CN in purple, RY:CN in orange, and TD:CN in magenta.]
CRISK of Japanese Banks

![Graph showing CRISK of Japanese Banks over time with different lines for 8306:JP, 8316:JP, 8411:JP and 8411:JP.](image)
CRISK of French Banks
CRISK of U.S. Banks in 2020

Loan Exposure to Gas & Oil Industry

<table>
<thead>
<tr>
<th>No</th>
<th>Name</th>
<th>Ticker</th>
<th>LoanAmt</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Wells Fargo</td>
<td>WFC</td>
<td>46,939</td>
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<tr>
<td>2</td>
<td>JP Morgan</td>
<td>JPM</td>
<td>38,792</td>
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<tr>
<td>3</td>
<td>BofA</td>
<td>BAC</td>
<td>29,720</td>
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<tr>
<td>4</td>
<td>Citi</td>
<td>C</td>
<td>28,072</td>
</tr>
<tr>
<td>5</td>
<td>US Bancorp</td>
<td>USB</td>
<td>12,091</td>
</tr>
<tr>
<td>6</td>
<td>PNC Bank</td>
<td>PNC</td>
<td>11,818</td>
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<tr>
<td>7</td>
<td>Goldman Sachs</td>
<td>GS</td>
<td>11,597</td>
</tr>
<tr>
<td>8</td>
<td>Morgan Stanley</td>
<td>MS</td>
<td>10,024</td>
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<tr>
<td>9</td>
<td>Capital One Financial Corp</td>
<td>COF</td>
<td>9,621</td>
</tr>
<tr>
<td>10</td>
<td>Bank of New York Mellon</td>
<td>BK</td>
<td>1,289</td>
</tr>
</tbody>
</table>
CRISK of U.K. Banks in 2020

Loan Exposure to Gas & Oil Industry

<table>
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<th>No</th>
<th>Name</th>
<th>Ticker</th>
<th>LoanAmt</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Barclays</td>
<td>BARC</td>
<td>19,893</td>
</tr>
<tr>
<td>2</td>
<td>HSBC Banking Group</td>
<td>HSBC</td>
<td>7,546</td>
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<tr>
<td>3</td>
<td>Standard Chartered Bank</td>
<td>STAN</td>
<td>3,945</td>
</tr>
<tr>
<td>4</td>
<td>Natwest</td>
<td>NWG</td>
<td>1,361</td>
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<tr>
<td>5</td>
<td>Lloyds Banking Group</td>
<td>LLOY</td>
<td>869</td>
</tr>
</tbody>
</table>
CRISK Decomposition

\[ d\text{CRISK} = k \cdot \Delta\text{DEBT} - (1 - k)(1 - \text{LRMES}) \cdot \Delta\text{EQUITY} + (1 - k) \cdot \text{EQUITY} \cdot \Delta\text{LRMES} \]

- \( d\text{DEBT} \): debt ↑ ⇒ CRISK ↑
- \( d\text{EQUITY} \): market cap ↓ ⇒ CRISK ↑
- \( d\text{RISK} \): effect of higher volatility or correlation
CRISK Decomposition: U.S. Banks in 2020

- CRISK(t-1): CRISK as of Dec 31, 2019
- CRISK(t): CRISK as of Dec 31, 2020

<table>
<thead>
<tr>
<th>Ticker</th>
<th>CRISK(t-1)</th>
<th>CRISK(t)</th>
<th>dCRISK</th>
<th>dDEBT</th>
<th>dEQUITY</th>
<th>dRISK</th>
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</thead>
<tbody>
<tr>
<td>WFC:US</td>
<td>-48.78</td>
<td>62.82</td>
<td>111.6</td>
<td>-0.84</td>
<td>106.57</td>
<td>5.03</td>
</tr>
<tr>
<td>JPM:US</td>
<td>-148.31</td>
<td>-47.99</td>
<td>100.32</td>
<td>38.42</td>
<td>74.39</td>
<td>-14.65</td>
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<tr>
<td>C:US</td>
<td>5.39</td>
<td>82.05</td>
<td>76.67</td>
<td>17.49</td>
<td>42.59</td>
<td>15.42</td>
</tr>
<tr>
<td>BAC:US</td>
<td>-60.61</td>
<td>15.19</td>
<td>75.79</td>
<td>24.63</td>
<td>55.2</td>
<td>-4.46</td>
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<tr>
<td>USB:US</td>
<td>-40.06</td>
<td>-10.86</td>
<td>29.2</td>
<td>4.13</td>
<td>23.41</td>
<td>1.3</td>
</tr>
<tr>
<td>PNC:US</td>
<td>-28.31</td>
<td>-12.57</td>
<td>15.74</td>
<td>3.8</td>
<td>13.75</td>
<td>-1.56</td>
</tr>
<tr>
<td>BK:US</td>
<td>-8.64</td>
<td>4.75</td>
<td>13.39</td>
<td>4.11</td>
<td>9.93</td>
<td>-0.83</td>
</tr>
<tr>
<td>GS:US</td>
<td>8.92</td>
<td>12.73</td>
<td>3.81</td>
<td>9.9</td>
<td>-1</td>
<td>-5.29</td>
</tr>
<tr>
<td>MS:US</td>
<td>2.05</td>
<td>-21.55</td>
<td>-23.6</td>
<td>3.65</td>
<td>-23.76</td>
<td>-3.85</td>
</tr>
</tbody>
</table>

**Top 4**  
364.38  79.7  278.75  1.35
CRISK Decomposition: U.K. Banks in 2020

- **CRISK(t-1):** CRISK as of Dec 31, 2019
- **CRISK(t):** CRISK as of Dec 31, 2020

<table>
<thead>
<tr>
<th>Ticker</th>
<th>CRISK(t-1)</th>
<th>CRISK(t)</th>
<th>dCRISK</th>
<th>dDEBT</th>
<th>dEQUITY</th>
<th>dRISK</th>
</tr>
</thead>
<tbody>
<tr>
<td>HSBA:LN</td>
<td>19.17</td>
<td>85.87</td>
<td>66.69</td>
<td>19.48</td>
<td>50.88</td>
<td>−2.85</td>
</tr>
<tr>
<td>LLOY:LN</td>
<td>19.27</td>
<td>41.8</td>
<td>22.53</td>
<td>3.14</td>
<td>21.2</td>
<td>−2.22</td>
</tr>
<tr>
<td>BARC:LN</td>
<td>60.59</td>
<td>79.61</td>
<td>19.02</td>
<td>11.08</td>
<td>11.71</td>
<td>−3.7</td>
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<tr>
<td>NWG:LN</td>
<td>27.64</td>
<td>42.7</td>
<td>15.05</td>
<td>3.12</td>
<td>13.15</td>
<td>−1.19</td>
</tr>
<tr>
<td>STAN:LN</td>
<td>18.94</td>
<td>29.86</td>
<td>10.92</td>
<td>4.17</td>
<td>8.77</td>
<td>−2.09</td>
</tr>
</tbody>
</table>

| Total    | 134.22     | 40.99    | 105.71 | −12.04 |
Marginal CRISK: U.S. Banks

Marginal CRISK: U.K. Banks

![Graph showing marginal CRISK (ma) bio USD for U.K. banks from 01 Jan 2000 to 01 Jan 2020. The graph compares five banks: BARC:LN, HSBA:LN, LLOY:LN, NWG:LN, and STAN:LN. The x-axis represents dates from 01 Jan 2000 to 01 Jan 2020, and the y-axis represents marginal CRISK (ma) bio USD on a scale from 0 to 100.]
Marginal CRISK vs. Marginal SRISK: U.S. Banks

BAC:US

C:US

JPM:US

WFC:US

Marginal CRISK vs. Marginal SRISK

Date

Marginal CRISK
Marginal SRISK

Marginal CRISK
Marginal SRISK

Marginal CRISK
Marginal SRISK

Marginal CRISK
Marginal SRISK
Marginal CRISK vs. Marginal SRISK: U.K. Banks

BARC:LN

HSBA:LN

LLOY:LN

NWG:LN

Marginal CRISK vs. Marginal SRISK
Banks with higher loan exposure to industries with high emissions have higher climate betas.

Based on Y-14 data, 21 listed U.S. banks, 2012 Q2 - 2021 Q4
Climate Beta and Brown Loan Exposure: U.S. Banks

<table>
<thead>
<tr>
<th></th>
<th>(1) Climate Beta</th>
<th>(2) Climate Beta</th>
<th>(3) Climate Beta</th>
<th>(4) Climate Beta</th>
</tr>
</thead>
<tbody>
<tr>
<td>Brown Loan Share (Emiss)</td>
<td>2.448**</td>
<td>1.862**</td>
<td>2.299*</td>
<td>0.869*</td>
</tr>
<tr>
<td></td>
<td>(3.16)</td>
<td>(2.89)</td>
<td>(2.45)</td>
<td>(2.58)</td>
</tr>
<tr>
<td>N</td>
<td>715</td>
<td>715</td>
<td>715</td>
<td>715</td>
</tr>
<tr>
<td>BankControl</td>
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<td>Y</td>
<td>Y</td>
<td>Y</td>
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<td>BankFE</td>
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<td>YearFE</td>
<td>N</td>
<td>N</td>
<td>N</td>
<td>Y</td>
</tr>
</tbody>
</table>

*t statistics in parentheses

* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

- $\beta_{Climate_{it}}$ is bank $i$’s time-averaged daily climate beta during quarter-end month $t$
- $Brown Loan Share_{it}$ is bank $i$’s loan exposure to industries with high emissions in quarter $t$
- Bank controls include log assets, leverage, ROA, loans/assets, deposits/assets, book/market, loan loss reserves/loans, non-interest income/net income, market beta
Average Probability of Default

Based on Y-14 loan level data, 21 listed U.S. banks, 2012 Q2 - 2021 Q4
Conclusion

- We introduce a measure called CRISK, systemic climate risk, which is the expected capital shortfall of a financial institution in a climate stress scenario.

- The climate beta and CRISK substantially increased during 2020.

- The increase in CRISK during 2020 was primarily due to decrease in equity values of banks.

- CRISK is considerably higher than expected capital shortfall of banks under zero climate stress scenario.

- Banks with higher exposure to brown loans have higher climate beta and CRISK.
Next Steps

1. Factor Model
   - Alternative measures of climate factor
   - Include common risk factors in bank stock returns

2. Verify and improve exposure measures
   - Granular data on bank holdings

3. Confidence Interval
   - Bootstrapping approach

4. Expand the sample of banks

Future directions:

5. Other financial sectors
6. Physical risk
Robustness to Climate Factor: CRISK

![Graph showing CRISK (C:US) trend from 01 Jan 2000 to 01 Jan 2020]

Key:
- ACWI / Stranded–SPY
- SPY / Stranded–SPY
- ACWI / Stranded
- ACWI / Emission
Appendix
Marginal CRISK: Canada

Date: 01 Jan 2000 to 01 Jan 2020

BMO:CN  BNS:CN  CM:CN  NA:CN  RY:CN  TD:CN

Marginal CRISK (ma) bio USD
Marginal CRISK: Japan

![Graph showing Marginal CRISK for Japan from 2000 to 2020 with different lines representing different categories.](image)

**Y-axis:** Marginal CRISK (ma) bio USD

**X-axis:** Date (01jan2000 to 01jan2020)

Lines:
- Red: 8306:JP
- Blue: 8316:JP
- Green: 8411:JP
Marginal CRISK: France

![Graph showing marginal CRISK over time for ACA:FP, BNP:FP, and GLE:FP]

- Marginal CRISK (ma) bio USD
- Date: 01jan2000 to 01jan2020
- AXA:FP, BNP:FP, GLE:FP
## Climate Beta and Brown Loan Exposure

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<th>(4) Climate Beta</th>
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<tr>
<td>Brown Loan Share (Intens)</td>
<td>2.122* (2.72)</td>
<td>1.756* (2.71)</td>
<td>2.382* (2.59)</td>
<td>1.019* (2.81)</td>
</tr>
<tr>
<td>N</td>
<td>726</td>
<td>726</td>
<td>726</td>
<td>726</td>
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<tr>
<td>BankControl</td>
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</tr>
<tr>
<td>YearFE</td>
<td>N</td>
<td>N</td>
<td>N</td>
<td>Y</td>
</tr>
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$^* \ p < 0.05, \ ^{**} \ p < 0.01, \ ^{***} \ p < 0.001$

- $\beta_{Climate}^{it}$ is bank $i$’s time-averaged daily climate beta during quarter-end month $t$
- *Brown Loan Share*$_{it}$ is bank $i$’s loan exposure to industries with high emission intensity in quarter $t$
- Bank controls include log assets, leverage, ROA, loans/assets, deposits/assets, book/market, loan loss reserves/loans, non-interest income/net income, market beta
Climate Beta and Brown Loan Exposure: U.S. Banks

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<td>1.862** (2.89)</td>
<td>2.299* (2.45)</td>
<td>0.869* (2.58)</td>
</tr>
<tr>
<td>Log Assets</td>
<td>0.0140 (0.89)</td>
<td>0.478*** (5.44)</td>
<td>0.0501 (0.67)</td>
<td></td>
</tr>
<tr>
<td>Leverage</td>
<td>3.612*** (4.26)</td>
<td>-1.314 (-0.83)</td>
<td>-2.274 (-2.00)</td>
<td></td>
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<tr>
<td>ROA</td>
<td>6.623** (3.12)</td>
<td>3.039 (1.87)</td>
<td>1.631 (1.52)</td>
<td></td>
</tr>
<tr>
<td>Loans/Assets</td>
<td>-0.0646 (-0.76)</td>
<td>-0.948* (-2.29)</td>
<td>-0.577* (-2.49)</td>
<td></td>
</tr>
<tr>
<td>Deposits/Assets</td>
<td>0.527** (3.83)</td>
<td>0.956* (2.39)</td>
<td>-0.182 (-0.75)</td>
<td></td>
</tr>
<tr>
<td>Book/Market</td>
<td>0.235*** (4.42)</td>
<td>0.237*** (5.95)</td>
<td>0.00956 (0.27)</td>
<td></td>
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<tr>
<td>Loan Loss Reserves/Loans</td>
<td>4.001 (1.93)</td>
<td>7.216*** (4.96)</td>
<td>3.151 (1.82)</td>
<td></td>
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<tr>
<td>Non-interest Income/Net Income</td>
<td>0.00134*** (3.93)</td>
<td>0.00123*** (5.90)</td>
<td>0.00109*** (5.68)</td>
<td></td>
</tr>
<tr>
<td>Market Beta</td>
<td>0.177*** (4.90)</td>
<td>0.0840** (3.22)</td>
<td>0.00808 (0.42)</td>
<td></td>
</tr>
</tbody>
</table>

N 715 715 715 715
BankFE N N Y Y
YearFE N N N Y

*t statistics in parentheses

* p < 0.05, ** p < 0.01, *** p < 0.001