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.
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

\[ 0.3XLE + 0.7KOL - SPY \]

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$^2$

$$r_{it} = \beta_{it}^{\text{Mkt}} \text{MKT}_t + \beta_{it}^{\text{Climate}} \text{CF}_t + \varepsilon_{it}$$

- Allows volatility and correlation to be time-varying.
- Expect:
  - $\beta^{\text{Climate}} > 0$ for banks with large exposure to gas and oil loans
  - $\beta^{\text{Climate}} < 0$ for banks with large exposure to renewable energy, for example

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Time-varying climate beta of U.S. Banks

![Graph showing climate beta for various U.S. banks over time, with a range from -0.6 to 0.8 on the y-axis and years from 2005 to 2020 on the x-axis. The graph includes lines for different banks such as BAC:US, JPM:US, MS:US, PNC:US, and WFC:US. The legend indicates different banks with specific colors and line styles.]

- Neg Beta
- Events
- CF Non-standardized
- ACWI
Step 3: CRISK

Follow the SRISK methodology\(^3\)

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

- \(D\): 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

CRISK of U.S. Banks

CRISK (US Banks)

- BAC:US
- BK:US
- C:US
- COF:US
- GS:US
- JPM:US
- MS:US
- PNC:US
- USB:US
- WFC:US

ACWI   CF Non-standardized
CRISK of U.K. Banks

CRISK (LN Banks)

- BARC:LN
- HSBA:LN
- LLOY:LN
- NWG:LN
- STAN:LN

Local
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>
</tr>
<tr>
<td>2</td>
<td>JP Morgan</td>
<td>JPM</td>
<td>38,792</td>
</tr>
<tr>
<td>3</td>
<td>BofA</td>
<td>BAC</td>
<td>29,720</td>
</tr>
<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>
</tr>
<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>
</tr>
<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

CRISK in 2020 (LN Banks)

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>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>
</tr>
<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>
</tr>
<tr>
<td>5</td>
<td>Lloyds Banking Group</td>
<td>LLOY</td>
<td>869</td>
</tr>
</tbody>
</table>
CRISK Decomposition

\[ dCRISK = k \cdot \Delta DEBT - (1 - k)(1 - LRMES) \cdot \Delta EQUITY \]

\[ + (1 - k) \cdot EQUITY \cdot \Delta LRMES \]

- **dDEBT**: debt ↑ ⇒ CRISK ↑
- **dEQUITY**: market cap ↓ ⇒ CRISK ↑
- **dRISK**: 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>
</tr>
</thead>
<tbody>
<tr>
<td>WFC:US</td>
<td>−48.78</td>
<td>62.82</td>
<td><strong>111.6</strong></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><strong>100.32</strong></td>
<td>38.42</td>
<td>74.39</td>
<td>−14.65</td>
</tr>
<tr>
<td>C:US</td>
<td>5.39</td>
<td>82.05</td>
<td><strong>76.67</strong></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><strong>75.79</strong></td>
<td>24.63</td>
<td>55.2</td>
<td>−4.46</td>
</tr>
<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>COF:US</td>
<td>−11.62</td>
<td>−3.38</td>
<td>8.24</td>
<td>3.25</td>
<td>6.36</td>
<td>−0.79</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**  

<table>
<thead>
<tr>
<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><strong>364.38</strong></td>
<td>79.7</td>
<td><strong>278.75</strong></td>
<td>1.35</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
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>
</tr>
<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>
<tr>
<td>Total</td>
<td>134.22</td>
<td>40.99</td>
<td>105.71</td>
<td>−12.04</td>
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<td></td>
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</tbody>
</table>
CRISK vs. Non-stressed CRISK: U.S. Banks

Stressed CRISK - Non-stressed CRISK (US Banks)

- BAC:US
- BK:US
- C:US
- COF:US
- GS:US
- JPM:US
- MS:US
- PNC:US
- USB:US
- WFC:US

CRISK ($bio)
CRISK vs. Non-stressed CRISK: U.K. Banks

Stressed CRISK - Non-stressed CRISK (LN Banks)

Canada

Japan

France
Marginal CRISK vs. Marginal SRISK: U.S. Banks

- **BAC:US**
- **C:US**
- **JPM:US**
- **WFC:US**
Marginal CRISK vs. Marginal SRISK: U.K. Banks

- **BARC:LN**
  - Marginal CRISK
  - Marginal SRISK

- **HSBA:LN**
  - Marginal CRISK
  - Marginal SRISK

- **LLOY:LN**
  - Marginal CRISK
  - Marginal SRISK

- **NWG:LN**
  - Marginal CRISK
  - Marginal SRISK
Banks with higher exposure to gas & oil loans have higher climate beta.
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 gas & oil loans have higher climate beta and CRISK.
Appendix
Time-varying climate beta of U.S. Banks

Bush withdraws from the Kyoto negotiations
Kyoto Protocol effective (not in the US or Australia)
4th IPCC assessment report
2009 Copenhagen UN Climate Change Conference
Black Monday 2011
WTI crude falls below $80 for 1st time since June 2012
Carney Speech
2015 Paris UN Climate Change Conference
Trump withdraws from the Paris Agreement
Big Banks Refuse Funds
Biden Elected POTUS

BAC:US
BK:US
C:US
COF:US
GS:US
JPM:US
MS:US
PNC:US
USB:US
WFC:US
Negative Climate Beta

Financial Sector SPDR ETF
Stranded Asset Portfolio
Time-varying climate beta of U.S. Banks

Climate factor \(0.3 \times \text{XLE} + 0.7 \times \text{KOL}\)

![Graph showing climate beta over time with key events marked: Bush withdraws from the Kyoto negotiations, Kyoto Protocol effective (not in the US or Australia), 4th IPCC assessment report, 2009 Copenhagen UN Climate Change Conference, Black Monday 2011, WTI crude falls below $80 for the first time since June 2012, Carney Speech, 2015 Paris UN Climate Change Conference, Trump withdraws from the Paris Agreement, Big Banks Refuse Funds for Some Fossil Fuel Projects, Biden Elected POTUS. Various banks are represented by different colors and lines, with the years 2005, 2010, 2015, and 2020 marked on the x-axis.]
### Climate Beta and Gas & Oil Loan Exposure

<table>
<thead>
<tr>
<th></th>
<th>(1) ( \Delta \beta^\text{Climate}_i )</th>
<th>(2) ( \Delta \beta^\text{Climate}_i )</th>
<th>(3) ( \Delta \beta^\text{Climate}_i )</th>
<th>(4) ( \Delta \beta^\text{Climate}_i )</th>
</tr>
</thead>
<tbody>
<tr>
<td>GO Loans</td>
<td>0.00607**</td>
<td>0.00622*</td>
<td>0.0111***</td>
<td>0.00904*</td>
</tr>
<tr>
<td></td>
<td>(2.91)</td>
<td>(2.26)</td>
<td>(3.61)</td>
<td>(2.08)</td>
</tr>
<tr>
<td>Constant</td>
<td>0.00102</td>
<td>0.00496</td>
<td>-0.00920**</td>
<td>-0.0281</td>
</tr>
<tr>
<td></td>
<td>(0.45)</td>
<td>(0.09)</td>
<td>(-2.48)</td>
<td>(-1.10)</td>
</tr>
<tr>
<td>Bank Controls</td>
<td>N</td>
<td>Y</td>
<td>N</td>
<td>N</td>
</tr>
<tr>
<td>Bank FE</td>
<td>N</td>
<td>N</td>
<td>Y</td>
<td>Y</td>
</tr>
<tr>
<td>Year FE</td>
<td>N</td>
<td>N</td>
<td>N</td>
<td>Y</td>
</tr>
<tr>
<td>N</td>
<td>462</td>
<td>462</td>
<td>462</td>
<td>462</td>
</tr>
<tr>
<td>RSqr</td>
<td>0.00611</td>
<td>0.00612</td>
<td>0.0140</td>
<td>0.176</td>
</tr>
</tbody>
</table>

\( t \) statistics in parentheses

* \( p < 0.1 \), ** \( p < 0.05 \), *** \( p < 0.01 \)

- \( \beta^\text{Climate}_i \) is bank \( i \)'s time-averaged daily climate beta during quarter \( t \)
- \( GOLoans^\text{it} \) is bank \( i \)'s new syndicated loans to the gas and oil industry (in log) in quarter \( t \)