Climate Risk and Financial Stability in the Network of Banks and Investment Funds

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Acknowledgments

Current grants:

- **NGFS - Network for Greening the Financial System**: engaging stakeholders in framework for climate-related financial risk management under uncertainty
- **EU FET CLIMEX**: tool for practitioners to assess portfolio exposure to climate-related financial risk

Previous grants

- **SNF Professorship at Dpt. Banking and Finance, UZH**: Financial Networks and Systemic risk
- Other EU projects: **ISIGROWTH, SEIMETRICS, BIGDATAFINANCE**
Disclaimer: The views expressed are those of the authors and do not necessarily represent the views of the BdM, CEMLA.
Key messages

1. Growing concern for financial stability from climate inaction or late and sudden action

2. Stress-tests: primary tool to ensure orderly functioning and stability of financial markets

3. Challenges to go from stress-test to climate stress-tests: endogeneity of climate risk

4. First science-based Climate Stress-test of financial institutions: Battiston ea. 2017 (Nat Clim Change); applications at (ECB, EIOPA, and National Central Banks).

5. Roncoroni ea. 2019 (ssrn 3356459, RR on JFS): first climate stress-test combining: supervisory data (Banco de Mexico, as illustration for other LA countries), with network financial valuation (NEVA, Barucca ea. 2016) for banks and funds

6. Most parsimonious framework to conduct a science-based climate stress test
Stefano Battiston @zbattiz · Jan 17

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CALL FOR PAPERS: JFS Special Issue “Climate Risks and Financial Stability”

Guest Editors
Stefano Battiston, Univ. of Zurich
Yannis Dafermos, Univ. of West England
Irene Monasterolo, WU Wien

Deadline: Feb. 15th 2019

“We welcome original contributions investigating the sources and the impact of climate-related financial risks, possible financial policies and instruments to mitigate risks.”

ELSEVIER
Motivation

1. In the aftermath of the Paris Agreement, growing awareness of need for a combination of climate policies in order reach 2C target.

2. NGFS and other platforms have raised concerns about
   - unanticipated effect of introduction or implementation of climate policies
   - disorderly transition to a low-carbon economy

3. The assessment of climate-related financial risks is currently a major dossier for most policy makers in EU, Asia and Latin America.

4. There is growing demand for an established approach to conduct climate stress-tests.
Challenge

1. Climate risk is endogenous: our perception of the risk feedback on the risk itself
   1. Multiple economic scenarios with unknown probability.
   2. Historical market information not sufficient to assess climate transition risk.
   3. Backward-looking materiality of risk is misleading.

2. Standard finance approaches (expected value) to risk assessment and contracts valuation are inadequate.

3. How can financial supervisors and financial institutions manage climate-related financial risk?
Research questions

Q1 How do we build a science-based climate stress-test of the financial system?

Q2 How do we translate forward-looking knowledge from climate science and climate economics into metrics of financial risk at the level of individual institutions and at system level?

Q3 What are the policy insights that we can expect from a climate stress-test?
Methodology. Building on:

**Climate stress-test** (Battiston ea. 2017; Monasterolo ea. 2018):
- disorderly transition: temporary transition between equilibria of economic trajectories consistent with different climate policies
- shocks on financial assets: derived from shocks on GVA and revenues

**Network financial valuation** of claims (NEVA, Barucca ea. 2016) and (DebtRank, Battiston ea. 2012; 2016)
- standard finance valuation assumptions + fund contagion model

Data
- Economic trajectories from set of 6 climate economics models and 9 scenarios (IAM, LIMITS)
- **Supervisory data of Banco de Mexico** on bank and funds exposures to real economy
Contributions and Findings


**C2** **Analytical** and empirical relations on impact on financial stability from **interplay** btw 1) climate policy shocks and 2) financial market conditions including banks and funds.

**F1** Policy implication I: in the face of possible disorderly transition financial institutions have incentive to engage earlier, under the same market conditions

**F2** Policy implication II: possible to reach tighter climate policy target, at same level of risk if market conditions are strengthened enough.
THIS PRESENTATION

- Overview of climate risk issues that the framework addresses
- Visual illustration of components
- Appendix with formulas and more details
Framework

1. **Climate policy shocks**: Impact of a late and disorderly alignment to a climate policy scenario designed to meet a set of climate targets. Building on climate economics (e.g. LIMITS, CD-LINK)

2. **First round**: Losses suffered by banks and funds due to direct exposures to Climate Policy Relevant Sectors (CPRS) - supervisory data


4. **Third round**: Banks’ and funds’ reaction to shock to get to initial risk management level which add further pressure on prices.

5. **Fourth round**: Losses too large to be absorbed by banks’ capital and are transmitted to external creditors (Roncoroni ea. 2019 ECB WP).
Climate stress test framework
Climate stress test framework

Climate policy scenarios

Disorderly transition

Adjustment of gain/losses distr. → Value at Risk

FINANCIAL VALUATION NETWORK-BASED

CLIMATE ECONOMICS

Output sectors

Policy scenario change from "LIMITS-Base" to "LIMITS-450" at 2040

Probability

variation in assets (USD million)

Source: LIMITS Kriegler et al. 2013
Climate stress test framework

Disorderly transition

MODELLING DISORDERLY TRANSITION

Adjustment of gain/losses distr. → Value at Risk

FINANCIAL VALUATION MODEL + NETWORKS
Climate stress test framework

Climate policy scenarios

Output scenarios energy sectors

Disorderly transition

Adjustment of gain/losses distr. → Value at Risk

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Climate Risk and Financial Stability in Network of Banks and Funds
Climate stress test framework

Climate policy scenarios

Output scenarios energy sectors

Disorderly transition

Adjustment of gain/losses distr. → Value at Risk
Climate stress test framework

Disorderly transition: late-sudden alignment to climate targets
- shocks on revenue streams of securities issuers/borrowers
- adjustment of issuers’ default prob., bond spread, credit risk (CVA)
- shocks on value of financial instrument dependent on issuer firm

Output scenarios energy sectors

Disorderly transition

Adjustment of gain/losses distr. → Value at Risk

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Disorderly transition

Example trajectories for brown sector: negative shocks on market share wrt to business-as-usual

Policy Scenario Change from "LIMITS-Base" to "LIMITS-500" at 2020

Policy Scenario change from "LIMITS-Base" to "LIMITS-450" at 2030

Gain/losses probability distribution $\rightarrow$ Value at Risk

Method 1: longitudinal: along trajectories (Battiston ea. 2017 NCC)

Method 2: cross-sectional: across trajectories (Monasterolo ea. 2018 JCWE; Battiston&Monasterolo 2018)
Disorderly transition

A call for action
Climate change as a source of financial risk
April 2019

(*)Source: NGFS 2019
Results - how to read

**Figure 4:** Profile of losses suffered by the Mexican financial system conditional upon the policy scenario LIMITS-RefPol-500 (GCAM).

The x-axis represents time in years, along climate policy scenarios. The y-axis represents the magnitude of the losses in millions of Mexican pesos. Effect of a shock on the Mexican financial system triggered by a disorderly realignment from the policy scenario BAU to LIMITS-RefPol-500, estimated with the model GCAM. We set interbank recovery rate coefficient $R=0.5$, and market volatility $\sigma=1.0$, market liquidity $\alpha=\ln(4/3)$, and funds VaR=1%.

- **Black line:** initial loss
- **Red:** losses due to direct exposure
- **Orange:** losses due to interbank contagion
- **Blue:** losses due to common exposure contagion
- **Green:** losses suffered by external creditors of banks

Shock (in mln of Mex. pesos) under a mild policy scenario [RefPol-500, GCAM, $R=0.5$, $\sigma=1.0$, $\alpha=\ln(4/3)$, VaR=1%].

~40 bn of Mexican pesos
~360 bn of Mexican pesos

Roncoroni ea. 2019 - Climate risk and financial stability in the network of banks and investment funds.
Results - Policy implication I

Under the same market conditions (R, σ), a stricter climate policy scenario triggers larger shocks for the financial system.

Roncoroni et al. 2019 - Climate risk and financial stability in the network of banks and investment funds
Under the same market conditions, the disorderly transition to a stricter scenario may lead to the same level of losses if the alignment occurs earlier.

Roncoroni et al. 2019 - Climate risk and financial stability in the network of banks and investment funds
If market conditions ($R, \sigma$) are less risky, aligning to a more stringent climate policy scenario might lead to lower losses than aligning to a less stringent climate policy scenario.

Roncoroni et al. 2019 - Climate risk and financial stability in the network of banks and investment funds
Illustration of climate distress propagation

i invests in j’s obligation/security
Illustration of climate distress propagation

Transmission channel via banks
Illustration of climate distress propagation

Banks
- B1
- B2
- B3
- B4

External Creditors and Depositors
- Ext1
- Ext2

Deposits, short-term loans, banks’ bonds
Illustration of climate distress propagation

- Banks
  - B1
  - B2
  - B3
  - B4

- External Creditors and Depositors
  - Ext1
  - Ext2

Interbank liabilities (loans, bonds, other)
Illustration of climate distress propagation

- Climate policy relevant sectors
  - A1
  - A2
  - A3

- Loans and corporate bonds

- Banks
  - B1
  - B2
  - B3
  - B4

- External Creditors and Depositors
  - Ext1
  - Ext2

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Climate Risk and Financial Stability in Network of Banks and Funds
Illustration of climate distress propagation
Illustration of climate distress propagation

Climate policy relevant sectors
- A1
- A2
- A3

Banks
- B1
- B2
- B3
- B4

External Creditors and Depositors
- Ext1
- Ext2

DIRECT CONTAGION (interbank leverage + R<1)

Second Round Losses
Illustration of climate distress propagation

Climate policy relevant sectors

Banks

External Creditors and Depositors

Losses for Ext. Creditors

Loss on expected value of deposits, $R<1$
Illustration of climate distress propagation

Funds

F1

F2

F3

F4

External Investors

Ext1

Ext2

Shares in funds
Illustration of climate distress propagation

Transmission channel via funds
Illustration of climate distress propagation

Climate policy relevant sectors

A1

A2

A3

Loans and corporate bonds

Funds

F1

F2

F3

F4

External Investors

Ext1

Ext2

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Climate Risk and Financial Stability in Network of Banks and Funds
Illustration of climate distress propagation

Climate policy relevant sectors

A1

CLIMATE POLICY SHOCK

A2

A3

First Round Losses

Funds

F1

F2

F3

F4

External Investors

Ext1

Ext2

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Illustration of climate distress propagation

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Climate policy relevant sectors

A1

A2

A3

Funds

F1

F2

F3

F4

External Investors

Ext1

Loss on fund shares

Ext2

Losses for Ext. Investors
Illustration of climate distress propagation

Transmission channel via bank AND funds
Illustration of climate distress propagation

Climate policy relevant sectors
- A1
- A2
- A3

Banks + Funds
- B1
- B2
- B3
- F1
- F2
- F3

External Creditors and Investors
- Ext1
- Ext2

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Conclusions and key messages - I

1. Challenges to go from stress-test to climate stress-tests: endogeneity of climate risk

2. First science-based Climate Stress-test of financial institutions: Battiston ea. 2017 (Nat Clim Change); applications at (ECB, EIOPA, and National Central Banks).

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4. Most parsimonious framework to conduct a science-based climate stress test
Conclusions and key messages - II


**C2** Analytical and empirical relations on impact on financial stability from interplay btw 1) climate policy shocks and 2) financial market conditions including banks and funds.

**F1** Policy insight I: in the face of possible disorderly transition, incentive of financial institutions to engage earlier, under the same market conditions. Assess its magnitude in terms of Value at Risk reduction.

**F2** Policy implication II: possible to reach tighter climate policy target, at same level of risk if market conditions are strengthened enough.
APPENDIX
**First round**

**Losses due to direct exposure**

- Trajectories of market shares of economic (sub-)sectors under various climate policy scenarios (e.g. LIMITS, Kriegler ea. 2013).
- Relative difference in market share of sector $c$ at time $t$ btw scenario $S$ (model $m$, policy $p$) wrt Business-As-Usual (BAU).
- Shock on value of security $c$ (e.g. bond)
  
  \[
  \Delta A_c = f(\psi_c, F_c, r_c, YTM_c, T_c)
  \]

  where $\Delta A$ expected value, $F$ par value, $r_c$ recovery rate of bond, $YTM_c$ yield to maturity, $T_c$ maturity.

- Very simplified case: expected value $\Delta A_{ic} \approx F_{ic}(1 - r_c)\chi\psi_c$
  where $F$ face value, $\chi$ elasticity of profitability. [Monasterolo ea. 2018].

- Both for banks and funds, first round shock $\Xi_{i}^{1st}$ thus is
  
  \[
  \Xi_{i}^{1st} = \sum_c \min \{0, \Delta A_c\} \cdot A_{ic} = \sum_c \min \{0, \psi_c\} \cdot A_{ic}.
  \]
Network Valuation of Financial Assets (NEVA)

Ex-ante financial valuation [Barucca et al., 2016] of banks’ obligations carried out at $t$, consistent with:

1. network of contracts with maturity $T$
2. uncertainty on external assets $\sigma$
3. endogenous recovery rate, with recovery rate coefficient $R$

$$E_i(t, T) = A_i^e(t, T) + \sum_{j=1}^{N} A_{ij}^b \cdot V_{ij}(E_j(t, T), A_j^e(t, T), \sigma, R) - L_i$$

$A_i^e(t, T)$ is valuation at $t$ of bank $i$’s external assets at time $T$;
$V_{ii}(\ldots)$ is valuation at $t$ of $i$’s interbank assets towards $j$.
Network Valuation of Financial Assets (NEVA)

Endogenous recovery rate

- Under assumptions of limited liabilities, absolute priority and proportionality [Eisenberg and Noe, 2001]: interbank contract pays 1 if $E_j \geq 0$, and pays

$$R \cdot \left( \frac{E_j + \bar{p}_j}{\bar{p}_j} \right)^+$$

if $E_j < 0$, with $\bar{p}_j$ aggregate interbank debt of bank $j$.

Local information

- Valuation of financial contract $i,j$ carried out based on $j$’s equity, assets volatility $\sigma$:

$$V_{ij}(E_j) = 1 - p_j^D(E_j) + R \cdot \rho_j(E_j)$$

- with $p_j^D(E_j)$ endogenous default probability of $j$, $\rho_j(E_j)$ endogenous recovery rate of $j$. 
**Definition 1: Feasible valuation function**

Given an integer \( q \leq n \), a function \( V : \mathbb{R}^q \to [0, 1] \) is called feasible valuation function if and only if:

1. it is non-decreasing: \( E \leq E' \Rightarrow V(E) \leq V(E'), \forall E, E' \in \mathbb{R}^q \),
2. it is continuous from above.

**Theorem 1: Existence of solution**

The set of solutions is a complete lattice, i.e. it exists \( E^- \) and \( E^+ \).

**Theorem 2: Convergence to \( E^+ \)**

1. the sequence \( E^{(k)} \) is monotonic non-increasing:
   \[ \forall k \geq 0, \ E^{(k+1)} \leq E^{(k)}, \]
2. the sequence \( E^{(k)} \) is convergent: \( \lim_{k \to \infty} E^k = E^\infty \),
3. \( E^\infty \) is a solution and \( E^\infty = E^+ \).
Common Asset Contagion - Banks’ asset liquidation

**Banks’ target leverage strategy**

- If negative shock on asset is absorbed by equity $\rightarrow$ leverage ($\Lambda_i = \frac{A_i}{E_i}$) increases.

- After first ($\Xi_i^{1st}$) and second ($\Xi_i^{2nd}$) round shocks bank $i$ leverage is:

  $$\Lambda_i^{2nd} = \frac{A_i^{2nd}}{E_i^{2nd}} = \frac{A_i^0 + \Xi_i^{1st} + \Xi_i^{2nd}}{E_i^0 + \Xi_i^{1st} + \Xi_i^{2nd}} \geq \frac{A_i^0}{E_i^0} = \Lambda_i^0.$$

- Bank $i$ recovers initial level of leverage by liquidating a fraction $k_i$ of its assets, such that:

  $$\Lambda_i^{3rd} = \frac{(1 - k_i) \left( A_i^0 + \Xi_i^{1st} + \Xi_i^{2nd} \right)}{E_i^0 + \Xi_i^{1st} + \Xi_i^{2nd} + k_i \left( A_i^0 + \Xi_i^{1st} + \Xi_i^{2nd} \right)} = \Lambda_i^0 = \frac{A_i^0}{E_i^0}.$$
Common Asset Contagion - Funds’ asset liquidation

Funds’ target VaR strategy

- First ($\Xi_{1st}^i$) and second ($\Xi_{2nd}^i$) round shocks shift asset risk profile towards the left $\rightarrow$ VaR$_i$ increases.
- Initial relative VaR is $\overline{\text{VaR}}_i = \frac{\text{VaR}_i^0}{A_i^0}$.
- After first ($\Xi_{1st}^i$) and second ($\Xi_{2nd}^i$) round shocks fund $i$ VaR is:
  \[
  \text{VaR}_i^{2nd} = (A_i^0 + \Xi_{1st}^i + \Xi_{2nd}^i) \cdot \overline{\text{VaR}}_i - \Xi_{1st}^i - \Xi_{2nd}^i \geq A_i^0 \cdot \overline{\text{VaR}}_i = \text{VaR}_i^0
  \]
- Fund $i$ recovers initial level of VaR by liquidating a fraction $k_i$ of its assets, such that:
  \[
  \text{VaR}_i^{3rd} = (1 - k_i) \cdot (A_i^0 + \Xi_{1st}^i + \Xi_{2nd}^i) \cdot \overline{\text{VaR}}_i - \Xi_{1st}^i - \Xi_{2nd}^i = \text{VaR}_i^0.
  \]
Common Asset Contagion - negative pressure on asset price

- Banks’ and funds’ sudden liquidation adds further negative pressure on asset prices.
- We assume an exponential impact of liquidation on asset prices [Cifuentes ea. 2005]. The price of asset class $c$ thus is

$$p_c^{after} = p_c^{before} \cdot e^{-\alpha \frac{\sum_i A_{ic}^0 (1 - \psi_c) k_i}{\sum_i A_{ic}^0 (1 - \psi_c)}} = p_c^{before} \cdot e^{-\alpha K_c},$$

where $-\alpha$ is the market liquidity.
- The value of bank’s and fund’s assets decreases.
- Third round shock thus writes

$$\Xi^{3rd} = -\sum_c (1 - \psi_c) \cdot A_{ic}^0 \cdot (1 - k_i) \cdot \left(1 - \frac{p_c^{after}}{p_c^{before}}\right).$$
# Climate VaR and Climate Policy Shocks

## Definition. Portfolio Climate VaR conditional to shock $B \rightarrow P$

- **Portfolio Climate VaR** is defined as the Value-at-Risk of the portfolio of the investor, conditional to Climate Policy Shock Scenario $B \rightarrow P$, with $\pi$ portfolio return, $\psi_P(\pi)$ distribution of returns conditional to shock $B \rightarrow P$:

$$\text{ClimateVaR}(P) = \int_{\inf(\pi)} \text{ClimateVaR} \pi \psi_P(\pi) d\pi = C^{\text{VaR}}$$

- with *portfolio rate of return* $\pi_i$ at $T$, with $W_{ij}$ amount (numeraire) of j’s bond purchased by i, investor i’s *portfolio value* $z_i$, $z_i(T) = \sum_j W_{ij} v_j(T)$, $\pi_i = \frac{z_i(T) - z_i(t_0)}{z_i(t_0)}$.

## Proposition. Climate VaR and policy shock

- Conditional to policy shock scenario $B \rightarrow P$, the ClimateVaR$(P)$:
  - increases with magnitude of policy shock $|\xi_j(P)|$ if $\xi_j(P) < 0$
  - decreases with magnitude of policy shock if $\xi_j(P) > 0$
  - increases with marginal default probability adjustment $\Delta q_j(P)$ of bond $j$
Properties - direct contagion

- Second round losses non-decreasing for negative shock magnitude \((-\psi)\).
- Second round losses are non-decreasing in market volatility \((\sigma)\).
- Second round losses are non-increasing in recovery rate \((R)\).

Properties - common asset contagion

- Third round losses are non-decreasing for negative shock magnitude \((-\psi)\).
- Third round losses are non-decreasing in second round losses.
- Third round losses are non-increasing in market liquidity \((-\alpha)\).