Virtual Seminar on Climate Economics

Federal Reserve Bank of San Francisco

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On the dependence of investor's probability of default on climate transition scenarios

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Section 1

Background and motivation

Climate change: a new type of financial risk

- Central banks and financial regulators are increasingly concerned about **climate-related financial risks** (Carney 2015, FSB 2020):
  - **physical** risk: emissions concentration affects hazards and losses
  - **transition** risk: change in climate policy, regulation, technology affect firms' performance **based on energy technology**
- Financial supervisors worry about the impact of a **disorderly transition** on **financial stability** (NGFS 2019, FED 2020, etc)
  - Late/sudden introduction of climate policies whose impacts cannot be fully anticipated by investors
- Several central banks and financial regulators joined the Network for Greening the Financial System (NGFS):
  - Guidelines on **climate stress test** scenarios (NGFS 2020)
  - In action: some central banks developed climate stress tests (Dutch Central Bank 2019, Banque de France 2020).

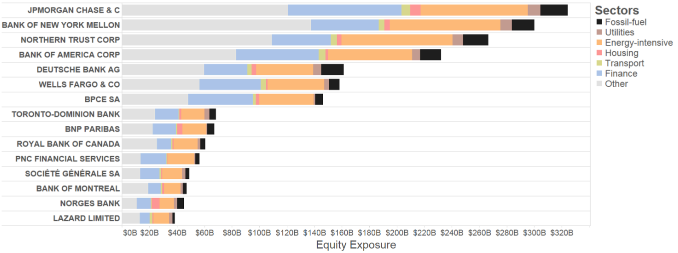
Should financial supervisors worry? YES

Their concerns are grounded in research results:

- Dietz ea (2016): climate value at risk (VaR) of global financial assets is 1.8 percent along a business-as-usual emissions path (USD2.5 trn), much of risk in the tail
- Battiston ea (2017)'s Climate stress test: investors are exposed to activities (**Climate Policy Relevant Sectors-CPRS)** that can face losses and become stranded assets in a disorderly transition:
    - 43-45 percent of equity holdings' portfolios of pension funds and investment funds; banks most exposed to fossil and utility via loans
    - Risk can be amplified by reverberation in the network of interconnected financial actors, creating conditions for systemic risk
- *Climate risks and financial stability* research at the core of forth. Special issue on *Journal of Financial Stability* (Battiston ea 2021)

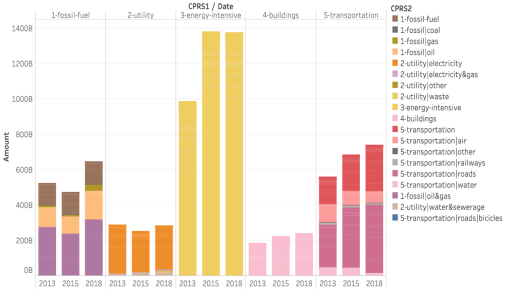
Why risk? Investors have large exposures to CPRS

- Classification of financial assets' transition risk is provided by **Climate Policy Relevant Sectors (CPRS)**, (Battiston ea. 2017): Fossil fuel, Utility, Energy intensive, Housing, Transport, Agriculture
- CPRS overcome key limitations of approaches based only on emissions by considering firms' energy technology mix and policy sensitivity, to operationalize the notion of **stranded assets**



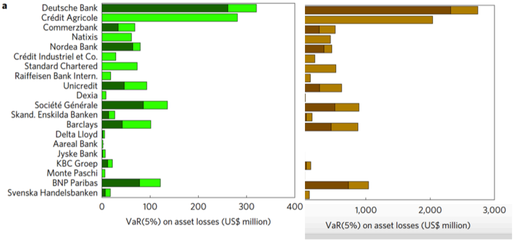
CPRS is applied by several financial supervisors

- **European Commission** JRC study of EU Taxonomy financial impact (EU equity and bonds market, this figure), 2019
- **EIOPA** Financial Stability Report 2019
- **European Central Bank** (2019)'s Climate change and financial stability (Financial Stability Review 2019)
- **EBA** Risk assessment of the EU banking system, Dec. 2020
- **National Bank of Austria**, Financial Stability Report 2020



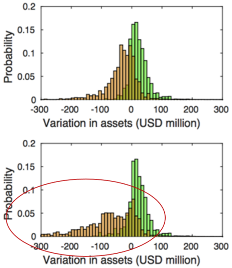
Source: Alessi et al. (2019) financial impact assessment of the EU Taxonomy

Large direct/indirect exposures may trigger systemic risk



***Value at Risk** (5% significance) on equity holdings of **20 most affected EU banks** under scenario of green (brown) investment strategy. Dark/light colors: first/second round losses. Source: Battiston ea (2017). A climate stress test of the financial system. Nature Climate Change*

1st round (top): brown bank incurs more losses.
Adding 2nd round (bottom) polarizes distribution of losses.



Knowledge gaps for supervisory activities

- Better understanding is needed of how climate transition risk affects financial assets and investors' financial stability
- In particular, we need to understand how sensitive are investor's risk metrics (Probability of default (PD) and Expected Shortfall (ES)) to the probability of occurrence of disorderly scenarios (the risky ones)
- **This is crucial for climate financial risk supervision and risk management strategies (incl. relevant scenarios for climate stress testing). But it is still missing in the literature**

Section 2

Contribution of the paper

Outline

- **Climate change** brings about **a new type** of financial risk that standard approaches to risk management are not adequate to handle
- With analytical and computational work, we study:
  - **Valuation adjustment of bonds** (corp.) based on available knowledge on climate transition scenarios (carbon pricing)
  - How PD of bonds depends on the interplay between energy technology profile of firm activities (high/low-carbon), climate transition scenarios, considering deep uncertainty on probabilities
  - Sensitivity of investor PD and ES to climate-adjusted bond PD and to the probability of occurrence of disorderly scenarios (including NGFS ones)
- We consider how PD varies across all spaces of portfolio configurations (high/low-carbon assets) that include also equilibrium portfolio

This paper is about climate transition risk

- Many economic papers consider climate risk only in terms of GHG emissions and/or disasters (i.e. backward- looking data on temperature, emissions, losses)
- However, **climate transition risk** is relevant for finance even before climate physical risk: time horizon (5-10y)
  - Relevant variables: energy technology profile of activity, policy design
- Assessing climate transition risk is more challenging:
  - **Forward-looking**: historical info. is not a good proxy of future risks
  - Many firms issuing green bonds have multiple activities (low/ high-carbon)
- Thus, we need to work with transition scenarios (e.g. those produced by Integrated Assessment Models (IAMs))

Economic intuition

- If markets price efficiently climate risk (high carbon firms are more risky) and anticipate policy impact, transition risk not financially relevant. However, no clear signals.
- **Friction**: deep uncertainty on climate transition scenarios, their probability of occurrence and their impact, means that agents are not able/willing to internalise information on transition risk
- Issuers can vary share of investments in low/high carbon activities, investors can vary portfolio composition across issuers. However, forward-looking risk make full hedging not possible

Main results

- The PD and ES of a leveraged investor increase non-linearly with the impact of the climate policy shock on revenues of corp. bond issuer (in low/high-carbon activities)
- The PD of a leveraged investor is sensitive to small changes in adjusted bond PD, to the probability of occurrence of disorderly climate transition scenarios
- Thus, assumptions on the sets of climate transition scenarios and their probability of occurrence play a main role for investors' risk management

Do they matter for climate risk supervision? YES

- Take home messages for financial supervisors involved in climate financial risk management (**NGFS, ECB's Climate Change center, NY FED's Supervision Climate Committee**):
  1. Investors' PD can be highly sensitive to choice and probability of occurrence of climate transition scenarios.
  2. Thus, in order to limit the underestimation of losses due to climate transition risk, **climate stress test** exercises should allow for wide enough sets of scenarios
  3. Our model provides **an operative framework** to assess the dependence of investors' PD on the choice of climate scenarios, applicable with several types of climate economic and macroeconomic models

Section 3

The model

Scenarios

Definitions

1. Set of *Climate Policy Scenarios* P corresponding to GHG emission reduction targets (e.g. 2degC) across regions (B = Base, no policy):

$$\textbf{ClimPolScen} = \{B, P_1, ..., P_l, ..., P_{n^{\text{Scen}}}\}$$

2. Set of economic output trajectories for each sector S, country C, scenario P, estimated with given climate economic model M:

$$\textbf{EconScen} = \{Y_{1,1,1,1}, ..., Y_{C,S,P,M,...}\}$$

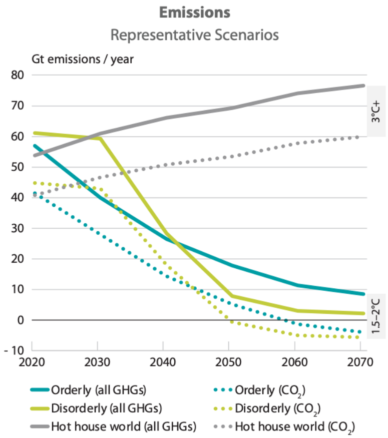
3. Set of **forward-looking** (disorderly) *Transition Scenarios*:

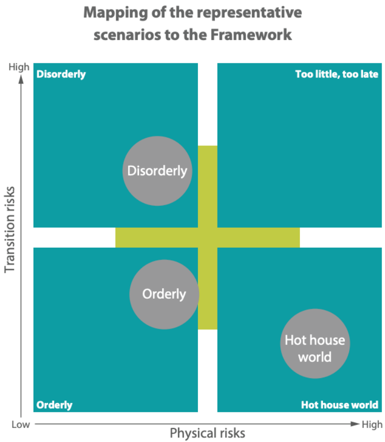
$$\textbf{TranScen} = \{BP_1, ..., BP, ..., BP_{n^{\text{Scen}}}\}$$

4. Set of *Climate Policy Shocks*: differences on economic output for S, C, from B to P, estimated with model M

$$\textbf{PolShock} = \{..., \frac{Y_{C,S,P,M} - Y_{C,S,B,M}}{Y_{C,S,B,M}}, ...\}$$

Example of orderly and disorderly scenarios





Source: IIASA NGFS Climate Scenarios Database, using marker models.

Impact of a disorderly transition on firm's revenues

- Decompose net shock on revenues of issuer j (with $u_{j,S}$: relative shock on S; $w_{j,S}$: share of j's revenues from S):

$$u_j(BP) = \frac{\text{rev}_j(P) - \text{rev}_j(B)}{\text{rev}_j(B)} = \sum_S \left(\frac{\text{rev}_{j,S}(P) - \text{rev}_{j,S}(B)}{\text{rev}_{j,S}(B)} \quad \frac{\text{rev}_{j,S}(B)}{\text{rev}_j(B)} \right)$$
$$= \sum_S (u_{j,S}(BP) \quad w_{j,S}(B)), \qquad (1)$$

- Focus on CPRS: Primary Energy Fossil (**PrFos**), Electricity Fossil (**ElFos**), Renewable (**ElRen**):

$$u_j(BP) = u_{j,\text{PrFos}}(BP)\, w_{j,\text{PrFos}}(B) + u_{j,\text{ElFos}}(BP)\, w_{j,\text{ElFos}}(B) + u_{j,\text{ElRen}}(BP)\, w_{j,\text{ElRen}}(B). \qquad (2)$$

- Impact of Transition Scenario BP on revenues u_j, result in shock $\xi_j(BP)$ on j's assets (χ_j^0 denotes elasticity):

$$\xi_j(BP) = \chi_j^0\, u_j(BP) \qquad (3)$$

Impact of a disorderly transition on firm's revenues

Remarks

- Firm is considered as a portfolio of (low/high carbon) activities
- In a disorderly transition, high-carbon (low-carbon) activities will incur losses (gains) from carbon-stranded assets
- Shock on j's revenues, $u_{j,S}(BP)$, can be approximated as a shock on output of the corresponding economic activities S (e.g. EIFos) in the economy provided by climate economic models (e.g. IAM)
- Which transition scenarios will occur is uncertain and endogenous because it depends on governments' climate policies and investors' expectations and reactions (climate sentiments, Dunz et al., 2020)

Securities: corporate bonds

Basic facts for zero-coupon defaultable bonds

- Risky (defaultable) bond of issuer j, issued at $t=0$ with maturity T
- Bond value at T, with R bond *Recovery Rate* (i.e. % of notional recovered upon default); LGD *Loss-Given-Default* (i.e. % loss)

$$v_j(T) = \begin{cases} R_j = (1 - \text{LGD}_j) & \text{if j defaults (with prob. } q_j) \\ 1 & \text{else (with prob. } 1 - q_j) \end{cases}$$

- Expected value of bond's payoff is given by:

$$\mathbb{E}[v_j] = (1 - q_j) + q_j\, R_j = 1 - q_j\,(1 - R_j) = 1 - q_j\, \text{LGD}_j$$

- Bond price v_j^*: bond discounted expected value, with y_f risk-free rate. Price defines implicitly bond yield y_j (risk neutral measure) as:

$$v_j^* = e^{-y_f\, T}\, \mathbb{E}[v_j] = e^{-y_f\, T}\, (1 - q_j \text{LGD}_j) = e^{-y_j\, T}$$

- Bond spread defined as: $s_j = y_j - y_f$, with $e^{-s_j\, T} = 1 - q_j\, \text{LGD}_j$
- Useful fact: for small s_j, spread = expected loss

$$s_j \approx \frac{1}{T}\, q_j(1 - R_j) = \frac{1}{T}\, q_j\, \text{LGD}_j$$

Corporate default

Shocks and default condition

- Issuer j balance sheet: $A_j(t_0)$, $A_j(T)$ **asset**, $t_0 = 0$ issue time, T maturity; $L_j(T)$ liability.
- Default condition: structural model, discrete time (Merton 1974)

$$A_j(T) = A_j(t_0)(1 + \eta_j(T)) < L_j(T)$$

  - $\eta_j(T) \in \mathbb{R}$: **idiosyncratic shock** (e.g. firm j productivity), $\phi(\eta_1, ..., \eta_j, \eta_n)$ **joint probability distribution of issuers** (defaults possibly correlated)

- We add climate policy shock $\xi_j(\text{BP})$ on j's assets ("jump" up/down)
- New default condition reads:

$$A_j(T) = A_j(0)(1 + \eta_j(T) + \xi_j(BP)) < L_j(T)$$

$$\iff \eta_j(T) \leq \theta_j(BP) = L_j(T)/A_j(0) - 1 - \xi_j(T, BP)$$

  - $\theta_j(BP)$ default threshold under scenario BP
  - $\xi_j(BP)$ positive/negative: $\xi_j(BP) > -1$, correlated across j

Section 4

Results

Adjustment of bond spread due climate transition

Definition and Proposition

- Climate Spread Δs_j is change in spread s_j, conditional to transition scenario BP:

$$\Delta s_j = s_j(q_j(P) - s_j(q_j(B)).$$

- Conditional to transition scenario:
  (i) Climate spread reads:

$$\Delta s_j(BP) = s_j(BP) - s_j(B) = \\ -(1/T)\left(log(v_j^*(BP)) - log(v_j^*(B)) - (y_f(BP) - y_f(B)\right)$$

  (ii) $\Delta s_j(BP)$ increases (decreases) with magnitude of policy shock on revenues $|u_j(BP)|$, if $u_j(BP) < 0$ ($u_j(BP) > 0$);
  (iv) For small shock $u_j(BP) << 1$:

$$\Delta s_j(BP) \approx -\frac{1}{T}\chi_j\left(u_{j,\mathrm{PrFos}}\, w_{j,\mathrm{PrFos}} + u_{j,\mathrm{ElFos}}\, w_{j,\mathrm{ElFos}} + u_{j,\mathrm{ElRen}}\, w_{j,\mathrm{ElRen}}\right)$$

Investor

Investor and Portfolio Value-at-Risk

- Leveraged investor: $(\Lambda = A/E)$
- Investor i's *portfolio value* z_i and *portfolio rate of return* π_i at T, with W_{ij} amount (numeraire) of j's bond purchased by i:

$$z_i(T) = \sum_j W_{ij} v_j(T), \qquad \pi_i = \frac{z_i(T) - z_i(t_0)}{z_i(t_0)}$$

- **Climate VaR** is the Value-at-Risk of the portfolio of investor i, conditional to Transition Scenario BP with: π portfolio return, $\psi_P(\pi)$ distribution of returns conditional to the Climate Policy Shock, and α is the confidence level:

$$\int_{-1}^{\text{ClimateVaR}_\alpha(BP)} \psi_{BP}(\pi)\, d\pi = \alpha \tag{4}$$

- **Climate ES** is the average of the losses above the Climate VaR:

$$\text{ES}(BP) = \frac{-1}{\alpha} \int_0^\alpha \text{ClimateVaR}_{\alpha'}(BP)\, d\alpha' \tag{5}$$

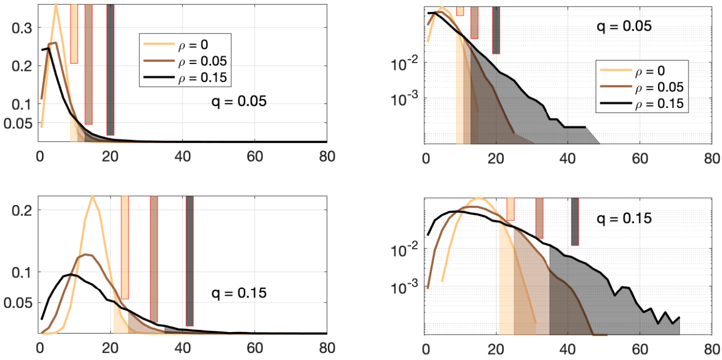
Adjustment in investor's ES and PD

Propositions

We prove several propositions on how investor's ES and PD are adjusted conditional to a transition scenario (Appendix). In short:

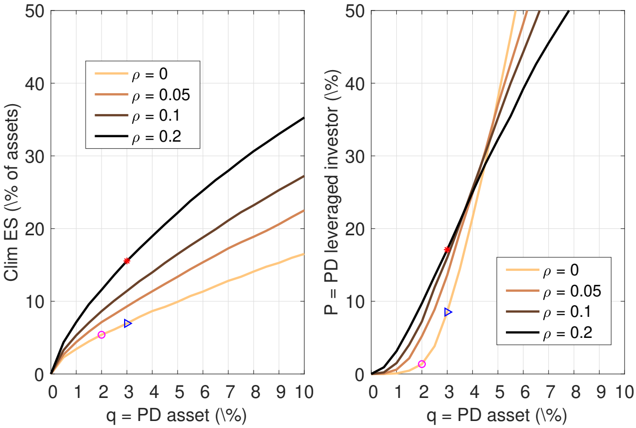
- ES(BP) increases with adjustment on bond default probability q(BP)
- Adjustment of PD of a leveraged investor can be derived analytically (numerically) in absence (presence) of correlation among bonds
- Under some assumptions of homogeneity, ES and PD decrease with share of climate-aligned revenues (i.e. renewable energy activities)

How losses on bond portfolio depend on q and ρ



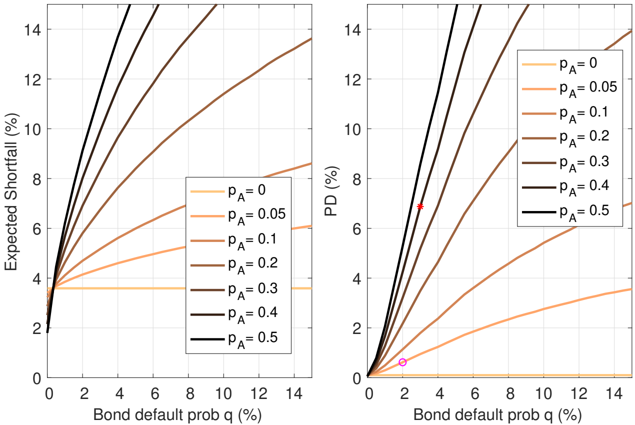
- Probability distribution (y-axis) of losses (x-axis, in %) on example portfolio of 100 bonds, equally weighted
- Climate ES (vertical bars) move right both with bond default probability q and with default correlation ρ

Climate ES and PD: sensitive to climate scenarios



- Consider a possible discrepancy between estimated (q, ρ) (magenta) and actual (blue, red)
- Large difference in Climate ES; even larger in PD

Considering adverse scenario mitigate impact of uncertainty on ES and PD



- Adverse scenario occurs with prob. p_A. Effect of discrepancy between estimated (q, p_A)(magenta) and actual (red) is smaller if investor consider multiple scenarios, but still large

Conclusion

- We develop a model to compute:
  - the valuation adjustment of a corporate bond, depending both on climate transition risk scenarios and on companies' shares of revenues across low/high-carbon activities, and
  - the corresponding adjustments in an investor's PD and ES
- Implications for climate financial risk management: **climate stress tests** should allow for a wide enough set of scenarios to limit the underestimation of losses
- The model provides an **operative framework** applicable with several types of climate and macroeconomic models
- Ongoing follow-up work: i) model calibration, ii) application to compound pandemic and **climate physical risk**.

Comments, suggestions, critiques:
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https://papers.ssrn.com/sol3/papers.cfm?abstract_id=3743647

Section 5

Appendix

A note on transition scenarios

- Climate economic models provide scenarios of emissions concentration to achieve 1.5/2 C world
- NGFS uses process-based IAM with granular representation of energy technologies (fossil, renewables)
- **Challenge**: IAM mitigation scenarios do not account for the role of finance in achieving the same scenarios, nor for financial complexity
- This has major implications on the design of **disorderly** scenarios:
  - Investments assumed to be available without frictions (no credit constraints)
  - Trajectories don't reflect the impact of mitigation scenarios on financial investment decisions
- Thus, considering more adverse scenarios on the IAM's range is important to avoid underestimate **financial risk associated** (Battiston ea. 2020)

Issuer's default probability: definition

Definition

- **Default probability** q_j of issuer j under Transition Scenario BP, with $\phi_{BP}(\eta_j)$ probability distribution of idiosyncratic shock η_j, η_{inf} lower bound of distribution support:
  $q_j(BP) = \mathcal{P}(\eta_j < \theta_j(BP)) = \int_{\eta_{\text{inf}}}^{\theta_j(BP)} \phi_{BP}(\eta_j)\, d\eta_j$

Definition. Default prob. adjustment $\Delta(BP)$

- Intuition. Frequent small productivity shocks across time and firms occur in a similar way with/without climate policy shock. Then, the policy shock shifts the probability distribution of productivity shocks and thus j default probability.
- Idiosyncratic shocks are **independent** from policy shock
- Result. Default probability **adjustment** under transition scenario:
  $\Delta q_j(BP) = q_j(P) - q_j(B) = \int_{\theta_j(B)}^{\theta_j(P)} \phi(\eta_j)\, d\eta_j$, with
  $\theta_j(P) = \theta_j(B) - \xi_j(P)$

Issuer's default probability: proposition

Proposition. Default prob. adjustment Δq_j(BP)

- Assuming
  - idiosynchratic shocks are **independent** from policy shock
  - policy shock on asset proportional to shock on revenues via elasticity $\xi_j = \chi_j^0 \, u_j(BP)$
- Then, the **adjustment** in default probability $\Delta q_j(BP)$
  - increases with shock magnitude $|u_j(BP)|$ if $u_j^{\mathrm{BP}} < 0$, and decreases viceversa
  - Under approximation of small policy shock, $\Delta q_j(BP)$ can be linearized to be proportional to shock on CPRS revenues:

$$\Delta q_j(BP) \approx -\chi_j \left(u_{j,\mathrm{PrFos(BP)}} \, w_{j,\mathrm{PrFos}} + u_{j,\mathrm{ElFos(BP)}} \, w_{j,\mathrm{ElFos}} + u_{j,\mathrm{ElRen(BP)}} \, w_{j,\mathrm{ElRen}} \right).$$

Adjustment in bond value

Definition and Proposition

- The adjustment in the value of the issuer's bond conditional to the Transition Scenario BP, $\Delta v_j^*(BP)$, is defined as the change in the discounted expected value of the bond, resulting from the Transition Scenario BP on issuer j's revenues $u_j(BP)$:

$$\Delta v_j^*(BP) = v_j^*(BP) - v_j^*(B) \tag{6}$$

- The following properties hold:
  (i) The expression of the adjustment of the value of the bond Δv_j^*, conditional to BP reads:

$$\Delta v_j^*(BP) = v_j^*(q_j(BP)) - v_j^*(q_j(B)) = -e^{-y_f\ T}\,\Delta q_j(BP)\mathrm{LGD}_j \tag{7}$$

Adjustment in investor's PD

Proposition

- Consider a leveraged investor with an equally weighted portfolio, of zero-coupon bonds, with issuers having independent defaults occurring with the same probability q and with the loss-given-default LGD. The following properties hold:
  (i) The investor's PD, $P(m, \Lambda, q)$ can be expressed in terms of the binomial distribution $\mathcal{B}(m_-^*, m, q)$:

$$P(m, \Lambda, q) = \mathcal{P}(X \geq m_-^*) = 1 - \mathcal{B}(m_-^*, m, q) \tag{8}$$

  (ii) The investor's PD is non decreasing in: a) the investor's leverage Λ; b) the loss-given-default LGD; c) the bond default probability q.

Adjustment in investor's PD

Proposition: Example effect of climate-aligned investment

Consider:

- an equally weighted portfolio of zero-coupon bonds with the same PD, q, and the same loss-given-default LGD
- all issuers j have the same shares of revenues across the three sectors Primary Energy Fossil, Electricity Fossil, Electricity Renewable, $w_{j,\mathrm{PrFos}}(B)$, $w_{j,\mathrm{ElFos}}(B)$, $w_{j,\mathrm{ElRen}}(B)$
- transition scenario BP such that $u_{j,\mathrm{PrFos}}(BP) < 0$, $u_{j,\mathrm{ElFos}}(BP) < 0$, $u_{j,\mathrm{ElRen}}(BP) > 0$ and the net shock on revenues $u_j(BP) < 0$ for all j

Then,

(i) Then, ES(BP) decreases with the share of revenues $w_{j,\mathrm{ElRen}}(B)$

(ii) Then, PD(BP) decreases with the share of revenues $w_{j,\mathrm{ElRen}}(B)$