Pricing climate financial risks under uncertainty: the CLIMAFIN framework

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Climate risks and financial stability: issues at stake

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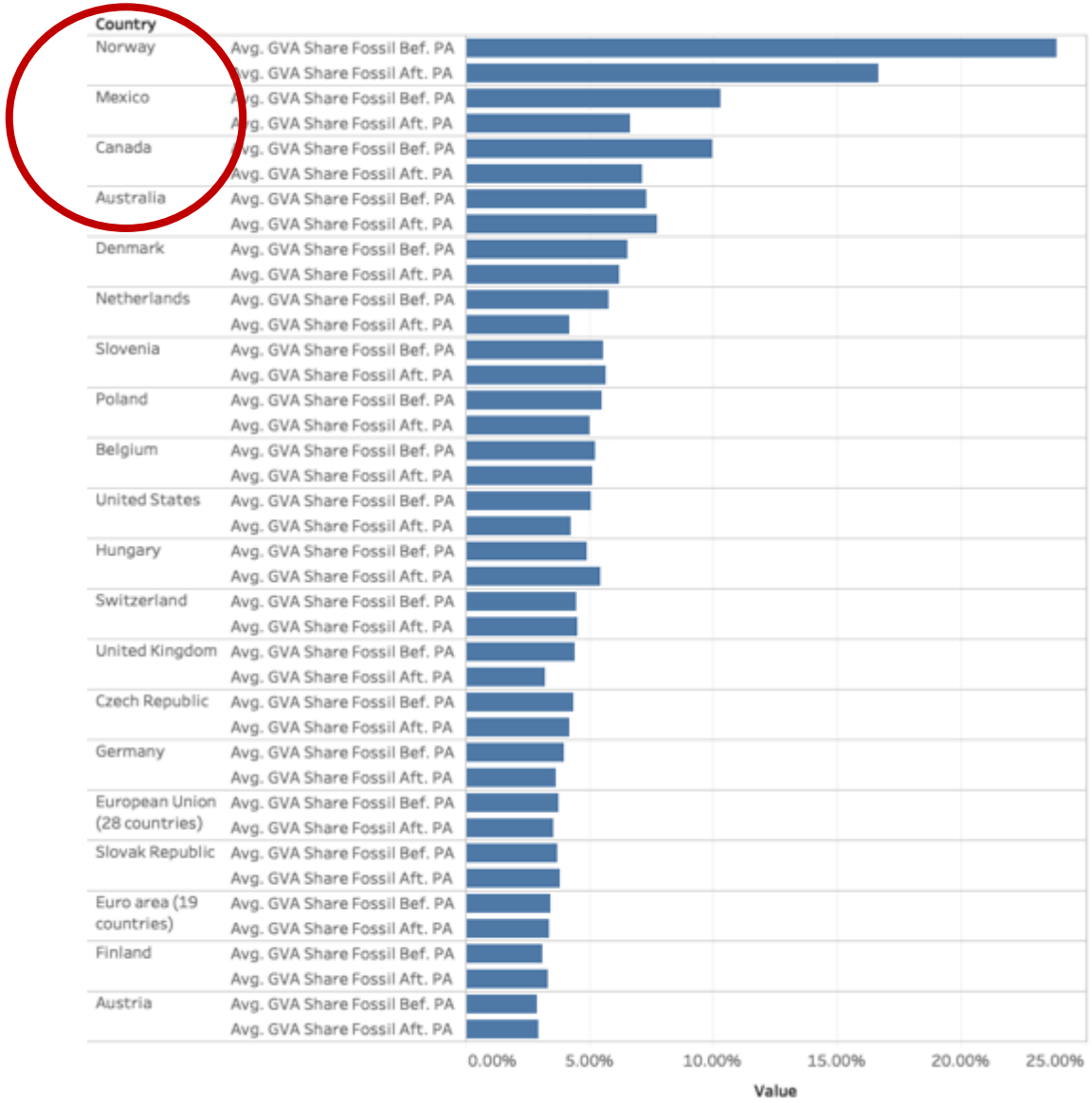
1. Growing awareness of the **materiality of climate financial risks** driven by a **disordered low-carbon transition** (late, unanticipated policies)

   - NGSF 2019: Climate **transition** risk can drive climate Minsky Moments

2. But **investors are not pricing** yet climate risks in their portfolios and risk management strategies

3. **Pricing climate financial risks** is crucial to inform portfolios' risk management (both greening and divesting) and measures to preserve financial stability

Why transition risk? Fossil fuels represent large share on Gross Value Added, even after Paris



- Average share of fossil fuels on Gross Value Added (GVA) by OECD country reaches even 18% after the Paris Agreement (OECD data).

Most countries' economies are misaligned to their climate targets

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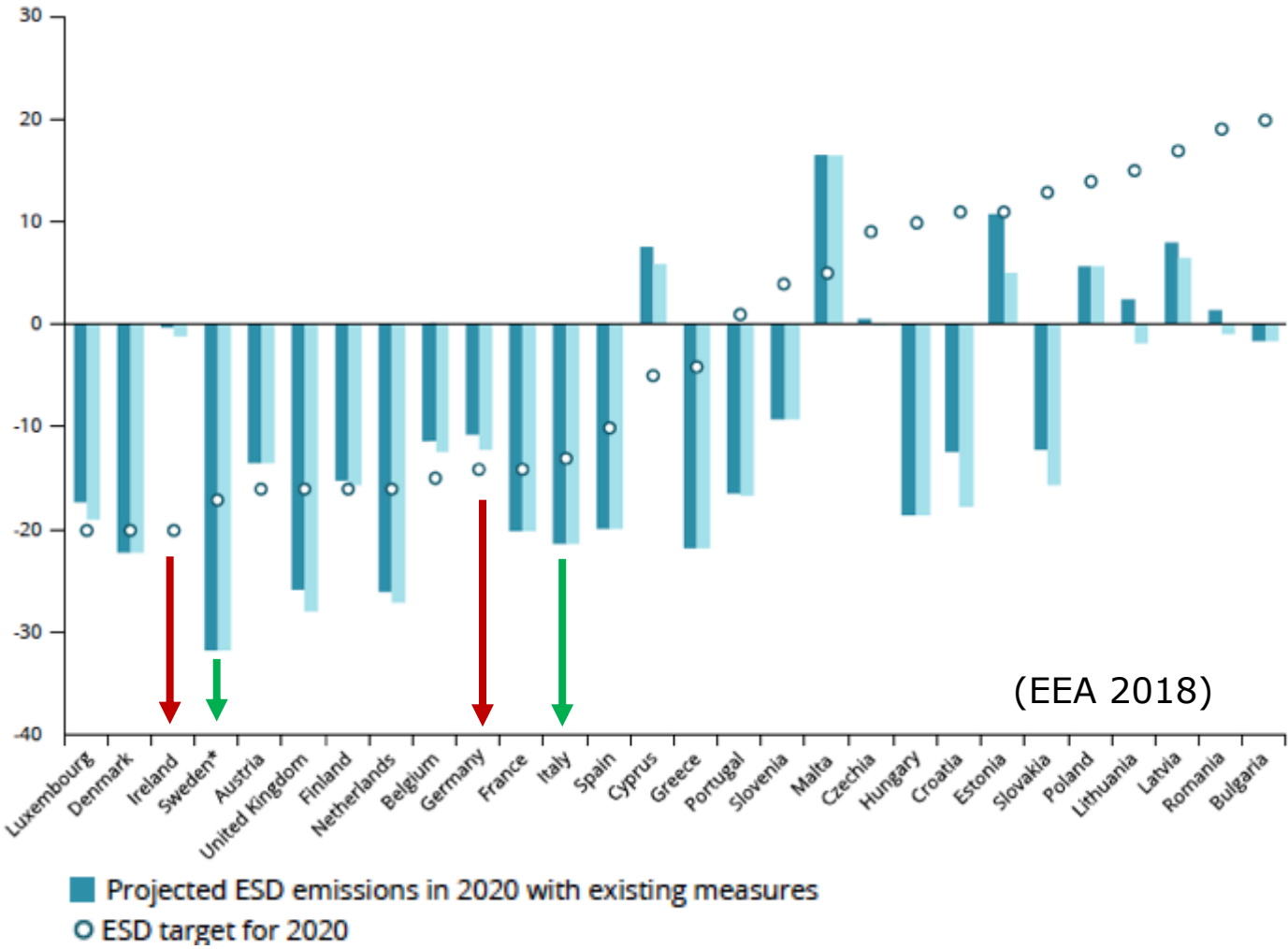
- *How IE misalignment (SW alignment) affects bond yields (**climate sovereign spread**)?*
- *Implications for risk management:*
  - *If I were a **pension fund,** should I keep my exposures or divest from Polish bonds?*
  - *What implications on country's refinancing conditions and solvability?*

Projected EU member states' progress towards (unambitious) 2020 targets



(EEA 2018)

In this context, a disordered transition can affect sovereign risk

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The Economist

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Countries most exposed to climate change face higher costs of capital

Poor countries find themselves trapped in a vicious cycle

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Aug 15th 2019

IIGCC @IIGCCnews · Aug 30

Nordea Asset Management suspends Brazilian government bond purchases due to Amazon fires! Its current exposure to Brazillian bonds - $111 million. @Nordea joins other big investors acting on #AmazonFires this week.

Thread 1/

Via @gfouche @reuters

YAHOO!

Nordea Asset Management suspends Brazilian gov...

The asset management arm of Nordea , one of the Nordics' biggest banks, said it is suspending ...

news.yahoo.com

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Implications on debt sustainability and surveillance duty

IMF Will Include Climate in Country Analysis, Georgieva Says
bloomberg.com

11:58 AM · Oct 17, 2019 · Twitter Web App

IMF Managing Director K. Georgieva: IMF gearing up to integrate climate risks in surveillance duty, including **climate stress-tests, climate risk pricing**

Need for pricing climate risk but markets are not there yet

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- We assessed the stock market's reaction to the Paris Agreement (PA):
  - If the market is pricing **risk of "staying brown"** (larger beta/smaller portfolio weights for carbon-intensive indices) and **opportunity of "going green"** (smaller beta/larger portfolio weights for low-carbon indices)
  - If the differences between low-carbon and carbon-intensive indices could be explained as reaction to the PA (structural break)
- **We found mispricing** of climate risks in EU, US, global stock markets:
  - Systematic risk of low-carbon assets significantly reduced after PA
  - Mild market reaction to PA for carbon intensive assets

Monasterolo, I., de Angelis, L. (2019). Blind to carbon risk? An Analysis of Stock Market's Reaction to the Paris Agreement. https://ssrn.com/abstract=3298298 (R&R *Ecological Economics*).

What does it mean for banking regulation and sustainability?

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- **EBA**: Art 98 CRD mandate *EBA to assess the potential inclusion…of environmental, social and governance risks (ESG risks):*
  - development of uniform definition of ESG risks, including physical and transition risks (depreciation of assets due to regulatory changes);
  - development of appropriate quali-quantitative criteria for the assessment of the impact of ESG risks on financial stability, including stress testing

➢ Transparent pricing of forward-looking climate risks in financial contracts and investors' creditworthiness is key to support greening of financial regulation

- **Mispricing** climate risk characteristics could introduce to new sources of financial instability

Three questions for you

1. **What do we need to know to price climate risks/opportunities in the value of financial contracts?**
   - How future climate policy shocks shift investors' default probability?
   - What is the price of climate risk (spread) for a country and investor?

2. **Do we have the models to do it?**

3. How could we use information from climate risk assessment to **inform risk management and prudential regulation**?

We developed CLIMAFIN

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- First approach to combine **forward-looking climate transition** risks based on **climate models** used by IPCC, with **climate financial risk metrics** now used by scholars and practitioners (Battiston et al., 2017)
- CLIMAFIN allows **a risk-averse investor** to **rationally** use climate finance information to manage financial risk in her portfolio:
  - Identify channels by which a disorderly transition (2030) affects issuer's **default probability and creditworthiness, and sovereign fiscal revenues**
  - **Price** forward-looking climate risks in financial contracts and portfolios
- *No need to reinvent the wheel but need to consider **climate risk nature***

Battiston S., Mandel A., Monasterolo I. (2019). CLIMAFIN Handbook: Pricing climate financial risk Part 1 https://papers.ssrn.com/sol3/papers.cfm?abstract_id=3476586

Methodology

Battiston, Mandel, Monasterolo 2019, CLIMAFIN Handbook: Pricing climate financial risk Part 1 https://papers.ssrn.com/sol3/papers.cfm?abstract_id=3476586

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Step 1. Rethinking financial risk (and value) under deep uncertainty and climate scenarios

Challenges for investors and supervisors to price climate risks

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1. **Climate deep uncertainty**: largest shocks expected to occur in mid-term but exact localization and magnitude unknown (Weitzman 2009)
2. **Non-linearity of impacts:** shocks probability distribution can't be inferred from historical data, nor proxied by *N* (Ackerman 2017)
   - But traditional pricing models neglect tail risk and incomplete markets
3. **Endogeneity:** climate policy decisions and financial actors' expectations of future policy leads to uncertainty and multiple equilibria
4. **Financial complexity**: interconnectedness could lead to mispricing with systemic effects (Battiston et al. 2016)

➢ *We need to go beyond green/brown factors and* ***embrace complexity***

Battiston, S. and Monasterolo, I. (2019). A climate risk assessment of sovereign bonds' portfolio. Working paper available at SSRN: https://ssrn.com/abstract=3376218.

ESG risk is different from climate risk

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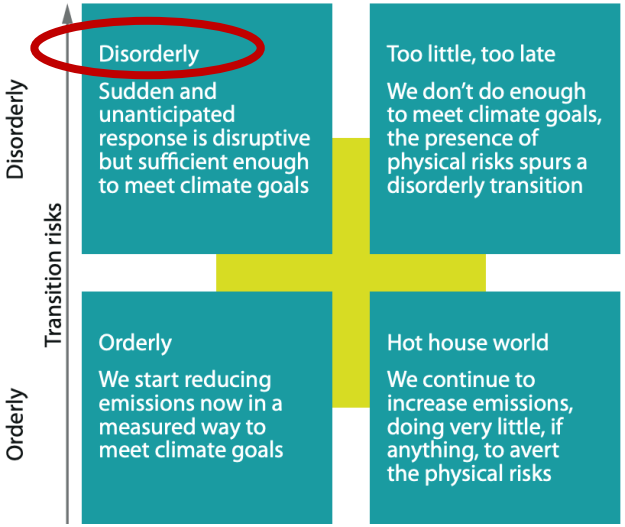
- **ESG** is not a good proxy of **climate risk:**
  - *Lot of S and G, little E*: lot of info but fragmented, not consolidated data (e.g. Scope 3, see Busch ea. 2018, Berg ea. 2019)
  - Proprietary methodologies, **not transparent -> accountability?** VW vs Tesla
  - **Backward-looking** assessment (vs forward looking climate risk)
  - No info on **technology risk** (current, future -> CAPEX)
  - Investment and **ownership chains** not considered in criteria

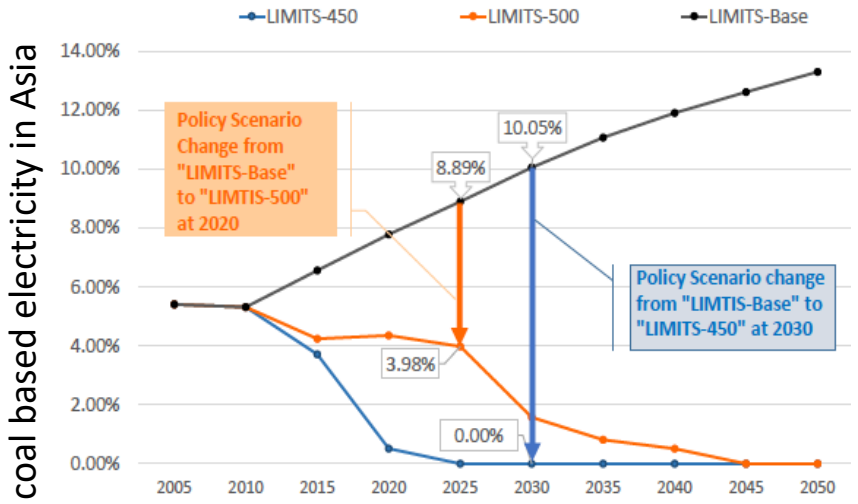
Step 2. Applying the CLIMAFIN approach to investors' portfolios

Climate transition scenarios



NGSF report 2019

Forward looking shocks on firm/plant market shares



Monasterolo ea (2018), G20 task Force report

Shock on firm cash flow, revenue stream

ENEL: 10TWh generation

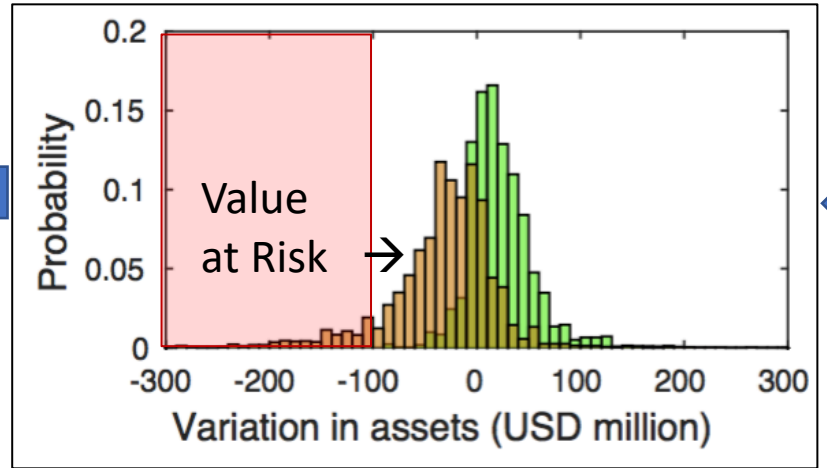
- 3 TWh from coal
- 7 TWh from renewables

Shock on price of financial contract (bond/loan/equity): climate spread

Country	WITCH: bond shock (%)	WITCH: yield shock (%)
Austria	1,3	-0,16
Australia	-17,36	2,45
Canada	-5,21	0,67
Norway	-14,82	2,05
Poland	-12,85	1,75

Battiston & Monasterolo 2019

Climate VaR conditioned to transition scenarios (Battiston ea 2017)



WE CLOSE THE LOOP: FEASIBILITY of CLIMATE SCENARIOS (finance: driver or barrier?)

CLIMAFIN tool

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What	**Portfolio breakdown** by instrument, classification in Climate Policy Relevant Sectors **CPRS**	Identification of relevant **climate scenarios** (physical, transition) by 2030/50	Climate **shocks** on firms' **market share,** cash flows profitability	**Forward-looking climate risk pricing** in individual contracts, e.g. climate spread	Climate-conditioned **probability of default** and **Climate VaR**	**Largest losses**/gains in portfolios, considering **network effects**
How	Financial macro-network analysis	Scientific reports (IPCC 2014, 2018)	Climate econ. models (IAMs, SFC-ABM)	CLIMAFIN climate-financial risk pricing model		CLIMAFIN Climate Stress-test
	Risk identification		**Risk assessment and management**			
Data & source	Financial, climate-relevant data (Scope, Capex,etc)	GHG emissions, temperature targets	Battiston ea. 2017	Battiston & Monasterolo 2019		Battiston ea. 2017

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How to move from forward-looking climate economic shocks to climate financial risk metrics

For calculating forward-looking shocks on activities NACE alone is not enough

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- **Emissions accounting** available at 2 digit level, underestimates indirect role of fossil fuels (B: Mining and quarrying) in the value chain
  - Indeed emissions from B circa 3% of total in the EU
- High **heterogeneity** within NACE: C – manufacturing includes both high
- No info by **technology** thus little relevance for climate policy and targets
- Activities of polluting companies classified as **financial** (e.g. FIAT, VW)
- No difference between recyclable/not recyclable i.e. **circular economy** relevance (steel is 100% recyclable)

We developed the Climate Policy Relevant Sectors (CPRS, Battiston et al 2017)

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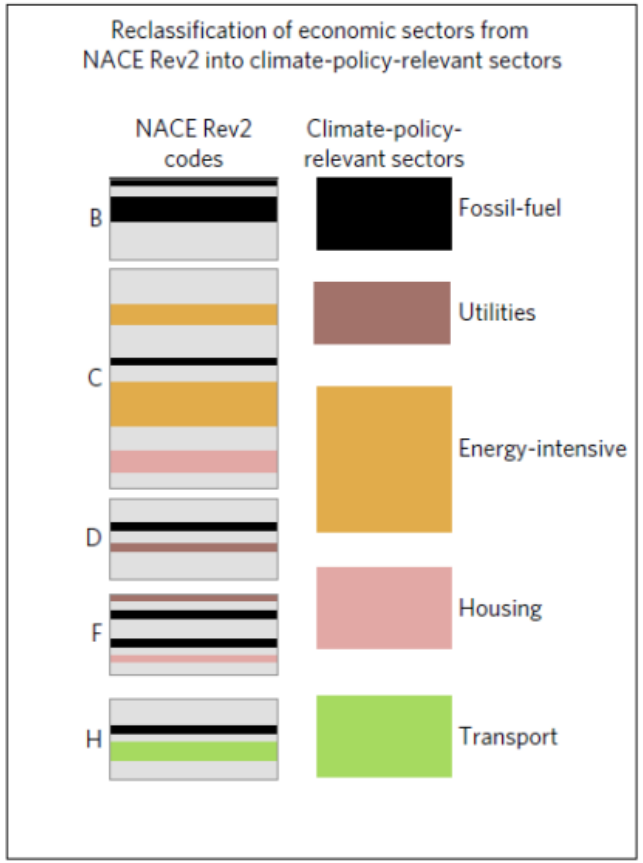
- CPRS classification is based on NACE economic sectors (4-digit) to assess investors' **exposure to climate risks and their relevance for climate change and policies** (PA, EU2030, etc.)

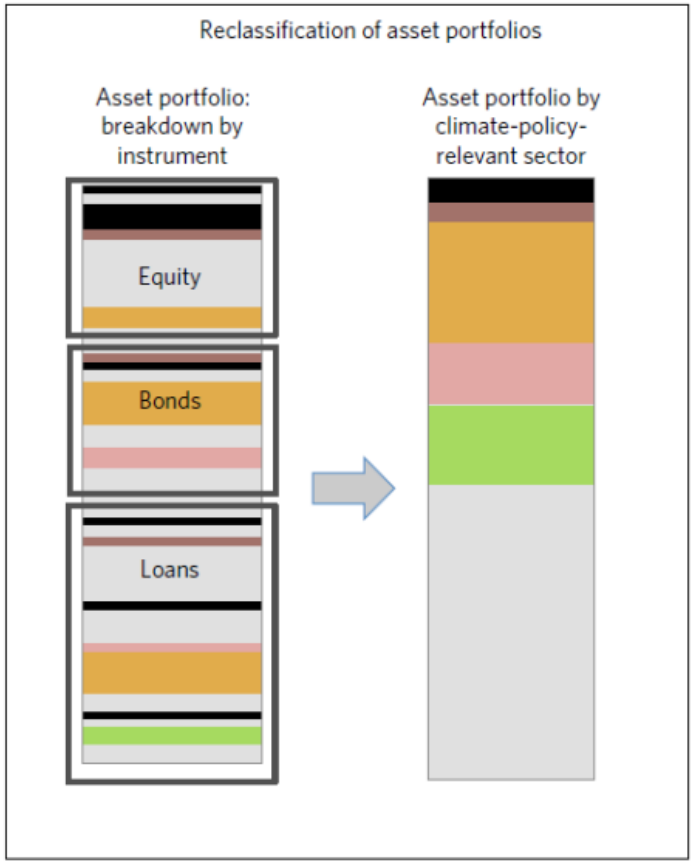
- Fossil fuels, utility, energy intensive, low/high carbon transport, housing,

- **3 dimensions considered by CPRS**:
  - Contribution to Greenhouse **emissions** (info on Scope1,2,3, climate relevant data)
  - Role of the firm and sector in the **energy value chain** (e.g. mining and quarrying sector (B) has low direct emissions (3%) but high indirect/induced emissions in the value chain)
  - **Relevance for climate policy** (carbon leakage classification) and traditional policy areas (e.g. energy, transport)

Source: Battiston ea. 2017

CPRS allows you to assess investments' exposure to climate risks (transition, Battiston ea 2017)





CPRS 1	CPRS Rev 2
1-fossil	1-fossil|coal
	1-fossil|oil
	1-fossil|gas
2-utility	2-utility|electricity|coal
	2-utility|electricity|gas
	2-utility|electricity|solar
	2-utility|electricity|wind
	2-utility|electricity|biomass
	2-utility|electricity|marine
	2-utility|electricity|nuclear
	2-utility|other
	2-utility|water&sewerage
	2-utility|waste

CPRS as a bridge from NACE to climate economic models to assess financial risk

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- Different CPRS Rev2 classification (e.g. fossil-fuel, energy intensive) for activities included in the same NACE (example: NACE B Mining and Quarrying)

NACE	NACE1	NACE2	NACE3	Description	climate relevance:	Relevance to Climate action	CPRS1	CPRS2	CarbLeak
05.1	B-MINING AND QUARRYING	05-Mining of coal and lignite	05.1-Mining of hard coal	Mining of hard coal	H	Extraction of fossil fuels is main cause of di e	1-fossil-fuel	1-fossil|coal	
05.10	B-MINING AND QUARRYING	05-Mining of coal and lignite	05.1-Mining of hard coal	Mining of hard coal	H	Extraction of fossil fuels is main cause of di e	1-fossil-fuel	1-fossil|coal	C
08.9	B-MINING AND QUARRYING	08-Other mining and quarryin	08.9-Mining and quarrying n.e.c.	Mining and quarrying n.e.c.	H	This sector does not share business model of	3-energy-intensiv	3-energy-intensive	
08.91	B-MINING AND QUARRYING	08-Other mining and quarryin	08.9-Mining and quarrying n.e.c.	Mining of chemical and fertiliser minerals	H	This sector does not share business model of	3-energy-intensiv	3-energy-intensive	C
08.92	B-MINING AND QUARRYING	08-Other mining and quarryin	08.9-Mining and quarrying n.e.c.	Extraction of peat	H	Extraction of fossil fuels is main cause of dire	1-fossil-fuel	1-fossil|coal	
08.93	B-MINING AND QUARRYING	08-Other mining and quarryin	08.9-Mining and quarrying n.e.c.	Extraction of salt	H	This sector does not share business model of	3-energy-intensiv	3-energy-intensive	A
08.99	B-MINING AND QUARRYING	08-Other mining and quarryin	08.9-Mining and quarrying n.e.c.	Other mining and quarrying n.e.c.	H	This sector does not share business model of	3-energy-intensiv	3-energy-intensive	A,C

- **Beyond NACE:** we consider exposure to climate risks and relevance for climate action (**questions to guide** the classification based on sectors' characteristics, Monasterolo & Battiston 2016: climate risk exposure of Caribbean Development Bank's portfolio)

Moving from NACE to CRPS

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- **Challenge**: assigning the right (business point of view) NACE 4-digit level for individual issuer requires sector-specific knowledge of the business model and emissions' role in the value chain
  - This challenge arises in particular for climate relevant sectors (e.g. mixed utility, car manufacturing,..)
  - NACE Classification Trust (from TR) see correspondence in NACEtoCPRS)

A	B	C	R	S	T	U	V	W	X	Y
ISIN	Issuer	LEI	NACEClassification	IssuerConsolida	Parent	NACEDescr	NACEC	SectorCPRS2		
XS158655551	VOLKSWAGEN INTERNATIONAL FINANCE NV	529900	Trusts, funds and similar financial entities (NACE) (64.30)	Volkswagen AG	FAMILIEN PORSCHE	Manufacture of motor vehicles	29.10	carbon-intensive transportation		
XS158655560	VOLKSWAGEN INTERNATIONAL FINANCE NV	529900	Trusts, funds and similar financial entities (NACE) (64.30)	Volkswagen AG	FAMILIEN PORSCHE	Manufacture of motor vehicles	29.10	carbon-intensive transportation		
XS158655586	VOLKSWAGEN INTERNATIONAL FINANCE NV	529900	Trusts, funds and similar financial entities (NACE) (64.30)	Volkswagen AG	FAMILIEN PORSCHE	Manufacture of motor vehicles	29.10	carbon-intensive transportation		
XS158655594	VOLKSWAGEN INTERNATIONAL FINANCE NV	529900	Trusts, funds and similar financial entities (NACE) (64.30)	Volkswagen AG	FAMILIEN PORSCHE	Manufacture of motor vehicles	29.10	carbon-intensive transportation		
XS158980690	HEIDELBERGCEMENT FINANCE LUXEMBOURG	529900	Trusts, funds and similar financial entities (NACE) (64.30)	HeidelbergCeme	HeidelbergCement A	Manufacture of cement	23.51	energy-intensive		
XS158988127	BMW FINANCE NV	529900	Trusts, funds and similar financial entities (NACE) (64.30)	BMW AG	BMW AG	Manufacture of motor vehicles	29.10	carbon-intensive transportation		
XS158988178	BMW FINANCE NV	529900	Trusts, funds and similar financial entities (NACE) (64.30)	BMW AG	BMW AG	Manufacture of motor vehicles	29.10	carbon-intensive transportation		
XS159056813	NATURGY CAPITAL MARKETS SA	959800	Trusts, funds and similar financial entities (NACE) (64.30)	Naturgy Energy	Naturgy Energy Gro	Manufacture of refined petrole	19.20	fossil-fuel		
XS159673936	MADRILENA RED DE GAS FINANCE BV	724500	Trusts, funds and similar financial entities (NACE) (64.30)	Madrilena Red I	ELISANDRA SPAIN I\	Distribution of gaseous fuels th	35.22	fossil-fuel		

Battiston, S. and Monasterolo, I. (2019). How could the ECB's monetary policy support the sustainable finance transition? FINEXUS working paper

Application to sovereign bonds' portfolio of OeNB

CLIMAFIN model objectives

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Model Objectives

- Identify economic transmission channels from:
  - forward-looking climate policy shock $\Rightarrow$ sovereign bond value
- Illustrate the methodology and results on the case of:
  - zero-coupon, defaultable bonds
  - static portfolio, constant interest rate
- Define Climate Value-at-Risk conditional to **forward-looking** climate policy scenarios
- Assess the impact of climate policy shock on individual sov. bond value and portfolio risk
- Consider a risk averse investor with portfolio management strategy based on the Value-at-Risk (VaR)
- Study the impact of Climate VaR on portfolio's greening

Investor information set

Definition. *Investor Information Set*: **InfSet**

- Set of *Climate Policy Scenarios* P_l corresponding to GHG emission reduction target across regions (B = Business-as-Usual):

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

- Set of economic output trajectories for each country j, sector k under each scenario P_l, estimated with each climate economic model M_m:

$$\textbf{EconScen} = \{Y_{1,1,1,1}, ..., Y_{j,k,P_l,M_m,...}\}$$

- Set of **forward-looking** *Climate Policy Shock Scenarios* (disorderly transition $B \rightarrow P_l$):

$$\textbf{TranScen} = \{B \rightarrow P_1, ..., B \rightarrow Pl, ..., B \rightarrow P_{n^{\text{Scen}}}\}$$

- Set of *Climate Policy Shocks* on economic output for j, k under transition scenario $B \rightarrow P_l$, estimated with model M_m

$$\textbf{EconShock} = \{..., \frac{Y_{j,k,P_l,M_m} - Y_{j,k,B,M_m}}{Y_{j,k,B,M_m}}, ...\}$$

Investor's risk management under uncertainty

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Investor risk management strategy

- The investor is risk averse and aims to minimize her Climate Value-at-Risk (*Climate VaR*) under the Investor Information Set *InfSet* (i.e. policy shocks, econ scenarios, climate models)
- The InfSet is compatible with hypothesis of incomplete information (Greenwald & Stiglitz 1986) and incomplete markets (not able to price forward-looking climate risk, Monasterolo & de Angelis 2019)
- Her **Climate VaR management strategy** aims to minimize the worst-case losses of the portfolio across the forward-looking Climate Policy Shock Scenarios:

$$\textbf{ClimVaRStr} = \min_{\text{Portfolios}} \{ \max_{\text{Shocks}} \{ \text{ClimateVaR}(\text{Portfolio} \mid \text{Shock}) \} \}$$

Defaultable sovereign bonds

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Portfolio of zero-coupon defaultable sovereign bonds

- Risky (defaultable) bond of country j issued at t_0 with maturity T
- Bond value at T:

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

  where $R < 1$ bond recovery rate, rLGD Loss-given-default (in %)
- Expected value of bond: $\mathbb{E}[v_j] = (1 - q_j) + q_j\, R_j = (1 - q_j(1 - R_j))$
- Discounted expected value of the bond, with: y_j bond j yield (under risk neutral measure) and y_f risk free rate

  $e^{-y_f\, T}\, \mathbb{E}[v_j] = e^{-y_f\, T}\, (1 - q_j(1 - R_j)) = e^{-y_j\, T}$
- Bond spread defined as: $s_j = y_j - y_f$, with $e^{-s_j\, T} = 1 - q_j(1 - R_j)$
- Useful fact about spread, with rLGD = relative LGD:
  $s_j \approx \frac{1}{T}\, q_j(1 - R_j) = \frac{1}{T}\, q_j\, \text{rLGD}_j$ (for small s_j)

Sovereign default conditions

Sovereign fiscal revenues: shocks and default condition

- Sovereign i balance sheet: $A_j(t_0)$, $A_j(T)$ **net fiscal asset** at t_0 and maturity; $L_j(T)$ liability.
  - Default condition (e.g. Gray-Merton-Bodie 2007)

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

  - $\eta_j(T) \in \mathbb{R}$: **idiosyncratic shock** (e.g. aggregate productivity), $\phi(\eta_1, ..., \eta_j, \eta_n)$ **joint probability distribution** (possibly correlated)
- We add climate policy shock ξ_j on j's fiscal assets ("jump" up/down), assuming idiosyncratic shock η_j and policy shock ξ_j are **independent**
- New sovereign default condition:

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

$$\iff \eta_j(T) \leq \theta_j(P) = L_j(T)/A_j(t_0) - 1 - \xi_j(T, P)$$

  - $\theta_j(P)$ default threshold under scenario P
  - $\xi_j(P)$ **climate policy shock** $B \to P$, positive/negative: $\xi_j(P) > -1$, possibly correlated across j

Change in sovereign default probability due to Climate policy shock

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Proposition. Δ default prob. with policy shock B$\rightarrow$P

- Assuming
  - idiosynchratic shocks are **independent** from policy shock
  - policy shock on fiscal asset is proportional to shock on GVA via elasticity $\xi_j = \chi_j \, u_j^{\mathrm{GVA}}(P)$
- The **change** $\Delta q_j(P)$ in default probability of sovereign j under Climate Policy Shock Scenario B$\rightarrow$P
  - increases with GVA shock magnitude $|u_j^{\mathrm{GVA}}(P)|$ if $u_j^{\mathrm{GVA}}(P) < 0$, and decreases viceversa (under mild condition on ϕ)
  - is proportional to the GVA shocks on climate relevant sectors (in the limit of small Climate Policy Shock):

$$\Delta q_j(P) \approx -\chi_j \left(u^{\mathrm{GVA}}_{j,\mathrm{PrFos}} \, w^{\mathrm{GVA}}_{j,\mathrm{PrFos}} + u^{\mathrm{GVA}}_{j,\mathrm{ElFos}} \, w^{\mathrm{GVA}}_{j,\mathrm{ElFos}} + u^{\mathrm{GVA}}_{j,\mathrm{ElRen}} \, w^{\mathrm{GVA}}_{j,\mathrm{ElRen}} \right).$$

Climate Sovereign Spread

Definition. Climate spread on sovereign bonds

- **Climate spread** Δs_j is defined as the change in the spread s_j, conditional to Climate Policy Shock Scenario $B \to P$

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

Proposition. Climate spread and policy shock

- Conditional to policy shock scenario $B \to P$, the climate spread $s_j(P)$:
  - increases with magnitude of policy shock $|\xi_j(P)|$ if $\xi_j(P) < 0$
  - decreases with magnitude of policy shock if $\xi_j(P) > 0$
- For small GVA shocks $u_j^{\text{GVA}}(P)$ it holds:

$$\Delta s_j \approx -\frac{1}{T} \chi_j \times$$

$$\times \left(u_{j,\text{PrFos}}^{\text{GVA}} \, w_{j,\text{PrFos}}^{\text{GVA}} + u_{j,\text{ElFos}}^{\text{GVA}} \, w_{j,\text{ElFos}}^{\text{GVA}} + u_{j,\text{ElRen}}^{\text{GVA}} \, w_{j,\text{ElRen}}^{\text{GVA}} \right)$$

Result 1: example of climate policy shock on OECD sovereign bonds

- Forward looking shock on yield of 10-years, zero coupon sovereign bonds
- Policy shock occurs at year **2030** (mild/tight 2C-aligned climate policy scenarios based on carbon pricing of LIMITS IAMs)
- Shocks on yield derive from net shock on GVA of CPRS

Geo region	Models' region	WITCH: bond shock (%)	WITCH: yield shock (%)	GCAM: bond shock (%)	GCAM: yield shock (%)
AUSTRIA	EUROPE	1,3	-0,16	0,13	-0,02
AUSTRALIA	REST_WORLD	**-17,36**	**2,45**	n.a.	n.a.
BELGIUM	EUROPE	0,84	-0,1	0,03	0
CANADA	PAC_OECD	-5,21	0,67	-18,29	2,61
POLAND	EUROPE	**-12,85**	**1,75**	-2,49	0,32

2,45=245 basis points
Source: Battiston & Monasterolo (2019).

- Under several climate policy scenarios, the financial solvability could be severely affected via **shocks on sovereign bonds value and spread** (E.g. -12,85%/ 1,75 for Poland).

Result 2: impact of climate policy shock on OeNB' portfolio

Model	Policy Scenario	Country	Region	Portfolio Shock
WITCH	LIMITS-RefPol-450	Country 1	REST_WORLD	-0.367%
WITCH	LIMITS-RefPol-450	Country 2	REST_WORLD	-0.350%
WITCH	LIMITS-RefPol-450	Country 3	PAC_OECD	-0.329%
WITCH	LIMITS-RefPol-450	Country 4	NORTH_AM	-0.110%
WITCH	LIMITS-RefPol-450	Country 5	EUROPE	-0.078%
WITCH	LIMITS-RefPol-450	Aggregate	Aggregate	-1.234%
WITCH	LIMITS-RefPol-450	Country 6	EUROPE	0.005%
WITCH	LIMITS-RefPol-450	Country 7	EUROPE	0.016%
WITCH	LIMITS-RefPol-450	Country 8	EUROPE	0.018%
WITCH	LIMITS-RefPol-450	Country 9	EUROPE	0.021%
WITCH	LIMITS-RefPol-450	Country 10	EUROPE	0.083%
WITCH	LIMITS-RefPol-450	Aggregate	Aggregate	0.143%

EUROPE includes different countries (disclosure issues).
Battiston & Monasterolo (2019)

- -0,367: negative shock (%) on the value of the OECD country's sovereign bond **weighted** for the role of the country issuing it on OeNB's portfolio.
- **Total negative shocks** = 1,234% of OeNB portfolio -> financial distress does not apply to a central bank (in monetary sovereignty), but what about a commercial bank experiencing such losses?
- Shocks can be also positive where

You think shocks are small?

- Consider that:
  - For leveraged institutions (leverage = 30), shock of 1% = 1/3 losses
  - Countries are not aligning to pledges thus tighter policy scenarios may be considered
  - IAMs' policy scenarios before the Paris Agreement (now SSPs)
  - Even few decimal points of GDP growth change could impact yields due to expectations (IT)

- ***Thus, our shocks results are conservative***

Take home messages

WU WIRTSCHAFTS UNIVERSITÄT WIEN VIENNA UNIVERSITY OF ECONOMICS AND BUSINESS

1. We develop the **CLIMAFIN** methodology to **price** forward-looking climate transition shocks in sov. bonds (**Climate Spread**) and **identify** drivers of largest losses in investors' portfolios (**Climate Value at Risk**)

2. We consider **climate financial risk characteristics** that cannot be analysed in traditional financial pricing models (ambiguity, interconnectedness)

3. Climate transition shock and country GVA composition create new risks and opportunities for financial stability via debt valuation (**Climate Spread**)

4. This information can help to:
   - Understand implications of sov. climate risk exposure on **economic competitiveness, cost of capital, financial solvability**
   - Design effective fiscal/financial measures to **mitigate climate risks**

Science-based method to support financial supervisors and investors

- **CLIMAFIN** is informing financial supervisors to mainstream climate risks in financial risk assessment and management:
  - **European Central Bank** (ECB) used it in its Climate Change and Financial Stability report (2019) "Euro area financial institutions' exposures to transition risk"

https://www.ecb.europa.eu/pub/financialstability/fsr/special/html/ecb.fsrart201905_1~47cf778cc1.en.html

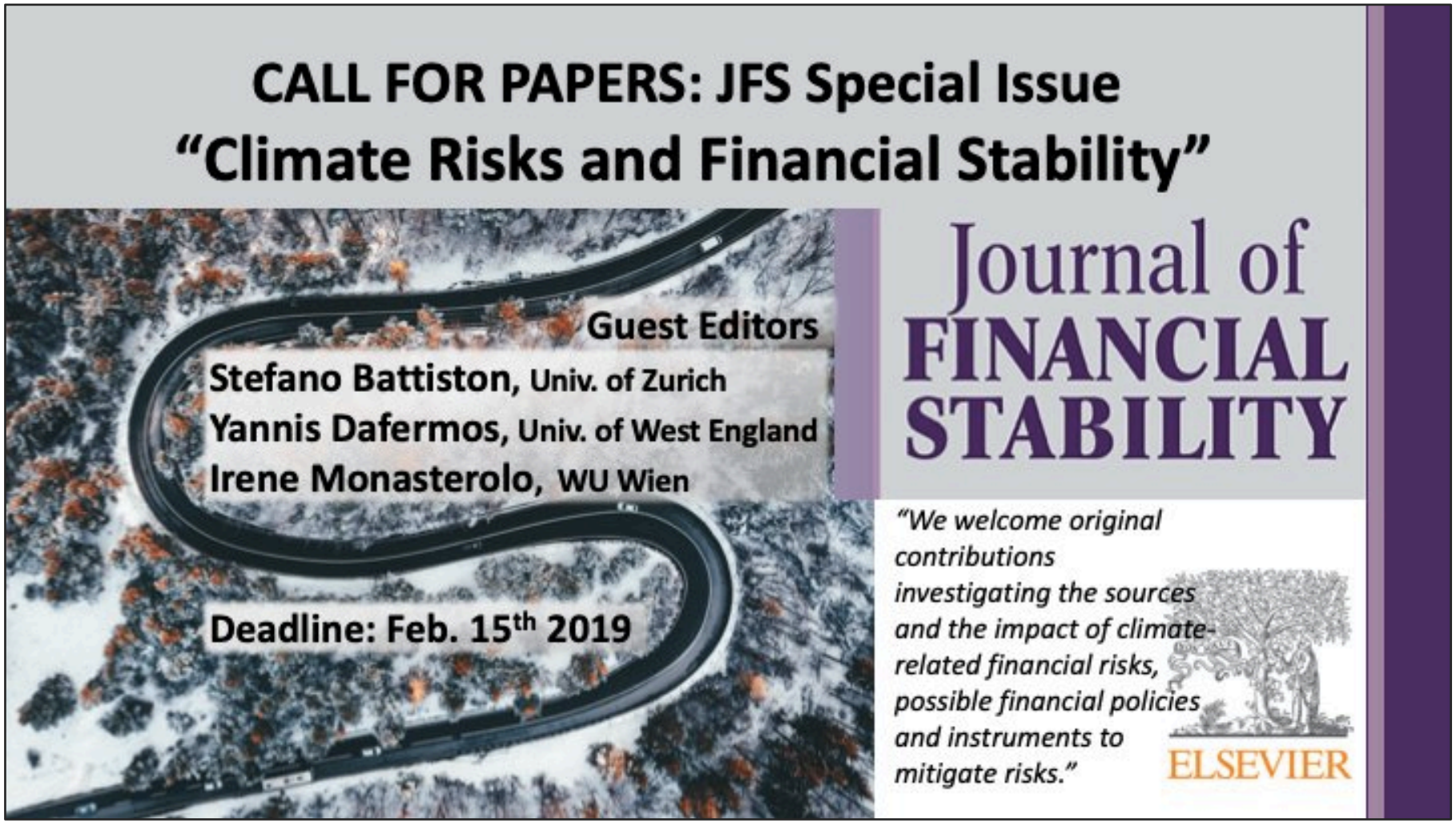
  - **European Insurance and Occupational Pension Authority** (EIOPA) used it in its Financial Stability Report (2018) "Climate related asset exposures of the European insurance sector"

https://eiopa.europa.eu/Pages/EIOPA--Financial-Stability-Report---December-2018.aspx

  - **French Prudential Supervision and Resolution Authority** used it in its analysis of transition risk in the insurance sector

https://acpr.banquefrance.fr/sites/default/files/medias/documents/20180628_as_placements_risque_climat_vf1.pdf

Climate Risks and Financial Stability: special issue on JFS



References

Battiston, S., Monasterolo, I. (2019). A climate risk assessment of sovereign bonds' portfolios. Forthcoming as OeNB working paper, see SSRN #3376218

Battiston, S., Mandel, A., Monasterolo, I., Schütze, F., & Visentin, G. (2017). A climate stress-test of the financial system. *Nature Climate Change*, *7*(4), 283–288.

Gray, D. F., Merton, R. C., Bodie, Z. (2007). New framework for measuring and managing macrofinancial risk and financial stability (No. w13607). National Bureau of Economic Research.

Greenwald, B. C., Stiglitz, J. E. (1986). Externalities in economies with imperfect information and incomplete markets. The quarterly journal of economics, 101(2), 229-264.

Kriegler et al . (2013) What does the 2 C target imply for a global climate agreement in 2020? The LIMITS study on Durban Platform scenarios. Clim. Change Econ. 4, 1340008.

Monasterolo, I., de Angelis, L. (2019). Blind to carbon risk? An Analysis of Stock Market's Reaction to the Paris Agreement. Available at SSRN: https://ssrn.com/abstract=3298298 (R&R at *Ecological Economics*).

References 2

Ramelli, S., Wagner, A. F., Zeckhauser, R. J., & Ziegler, A. (2018). *Stock price rewards to climate saints and sinners: Evidence from the Trump election* (No. w25310). National Bureau of Economic Research.

Sharpe, W. F. (1964). Capital Asset Prices: A Theory of Market Equilibrium Under Conditions of Risk. *Journal of Finance* 19(3), 425-442.

Singh, D. & Shrimali, G. (2018). Do Clean Energy Investments Add Value to a Portfolio? Climate Policy Initiative discussion paper.

Sterner, T. & Mukanjari, S. (2018). Do Markets Trump Politics? Evidence from Fossil Market Reactions to the Paris Agreement and the US Election. Working Paper.

Wagner, A. F., Zeckhauser, R. J. & A. l. Ziegler (2018). Company Stock Price Reactions to the 2016 Election Shock: Trump, Taxes, and Trade. *Journal of Financial Economics* 130: 428-451.