Climate risks assessment in the economy and finance: insights from Stock-Flow Consistent Agent Based Models

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Overview

1. **Climate change, economic competitiveness and financial stability:**
   - Climate as a new type of risk: deep uncertainty, non-linearity, endogeneity
   - Financial institutions are highly exposed to climate risks (Battiston ea 2017, ECB 2019, EIOPA 2019), and losses potentially amplified by interconnectedness
   - Thus, financial supervisors' concern on financial instability (Green Swan)

2. **Compouding** COVID-19 and climate risks: losses amplification, implications for private/sovereign debt sustainability

3. **Macroeconomic modelling for climate stress-testing**
   - Assessing climate macrofinancial impacts requires to analyse how risk generates in agents' balance sheets, transmission channels and reinforcing feedbacks
   - Pros/cons of different macroeconomic models: no model fits all research questions
   - Added value of Stock-Flow Consistent behavioral models: EIRIN applications to research and policy (Monasterolo and Raberto 2018, 2019; Dunz ea 2020, Monasterolo ea 2020)

Central banks and financial supervisors started to worry and act about the climate

Mark Carney tells global banks they cannot ignore climate change dangers

Financial sector warned it risks losses from extreme weather and its stakes in polluting firms

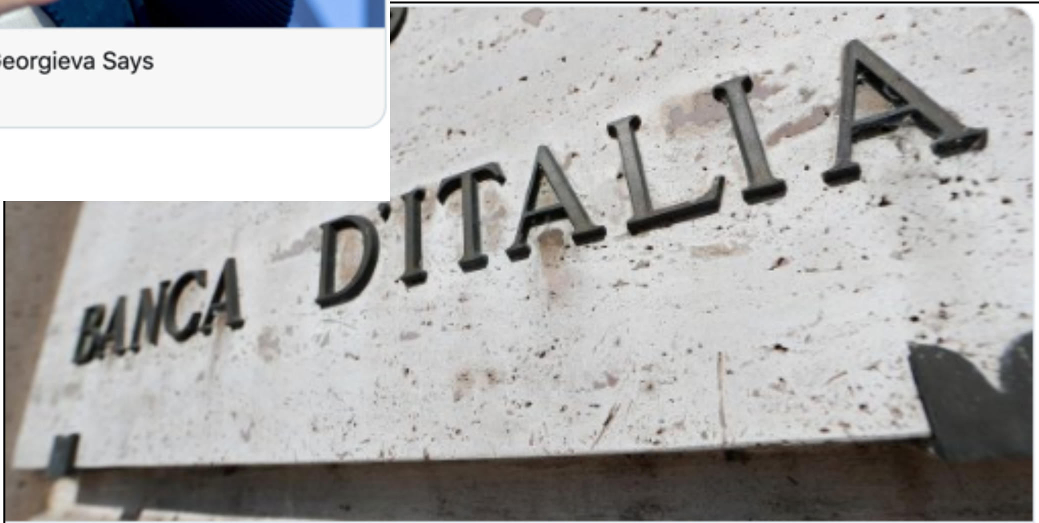
IMF Will Include Climate in Country Analysis, Georgieva Says
bloomberg.com

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

Network for Greening the Financial System
First comprehensive report

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

April 2019



Italy central bank to spurn firms that don't go green

The Bank of Italy plans to adopt investment criteria which reward companies that take action on climate change, joining other central bank...

reuters.com

Why? Climate change as a new type of risk for financial actors

- **Deep uncertainty:** climate forecasts and its impact contain irreducible uncertainties e.g. presence of tail events (Weitzman 2009) and tipping points (Solomon et al. 2009) that may trigger domino effects (Lenton et al. 2019)
- **Non-linearity:** distribution of extreme climate-related events (heat/cold waves) is highly non-linear (Ackerman 2017) and makes historical data poor proxy of future events
- **Forward-looking** nature of risk: climate impacts are expected in mid to long term while time horizon of finance is shorter (months for investors)
- **Endogeneity:** successful transition depends on governments and firms' investment decisions (policy, investments). But both decisions depend on perception of climate risk → occurrence of climate risk scenarios (above 2C) to realize depends on risk perception of decision makers.

Monasterolo, I., 2020. Climate change and the financial system. An. Rev. Envir. Res. Econ. (12) 1-22

Climate change and financial stability: where does risk come from?

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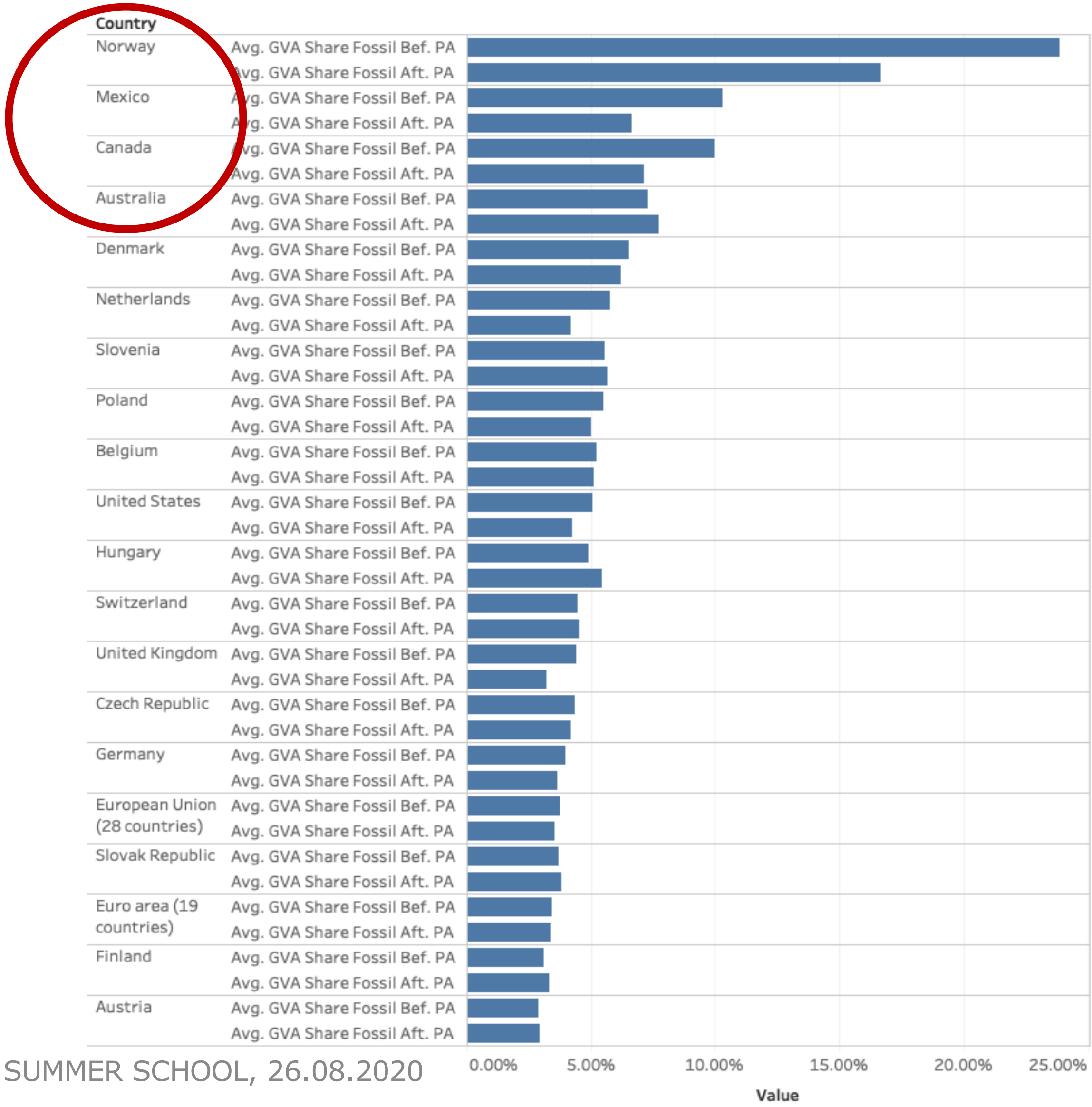
- **2** channels of climate risk transmission to finance (Carney 2015, Batten ea 2016):
  - **Physical**: impact of extreme weather events on eco. activities:
    - Insurance, banks: losses on value of financial contracts owned and traded
    - Government: lower GDP growth ->lower fiscal revenues -> impact on eco. competitiveness, budget balance, creditworthiness
  - **Transition**: policy, tech., regulatory shocks:
    - Losses on carbon-intensive assets -> investors' portfolios -> cascading effect on their investors in the financial network
- These channels are connected (but treated separately so far) and can lead to **stranded assets**
- **Climate transition risk to happen sooner and be more financially relevant** than physical risk (NGSF 2019). But in developing country the opposite holds true

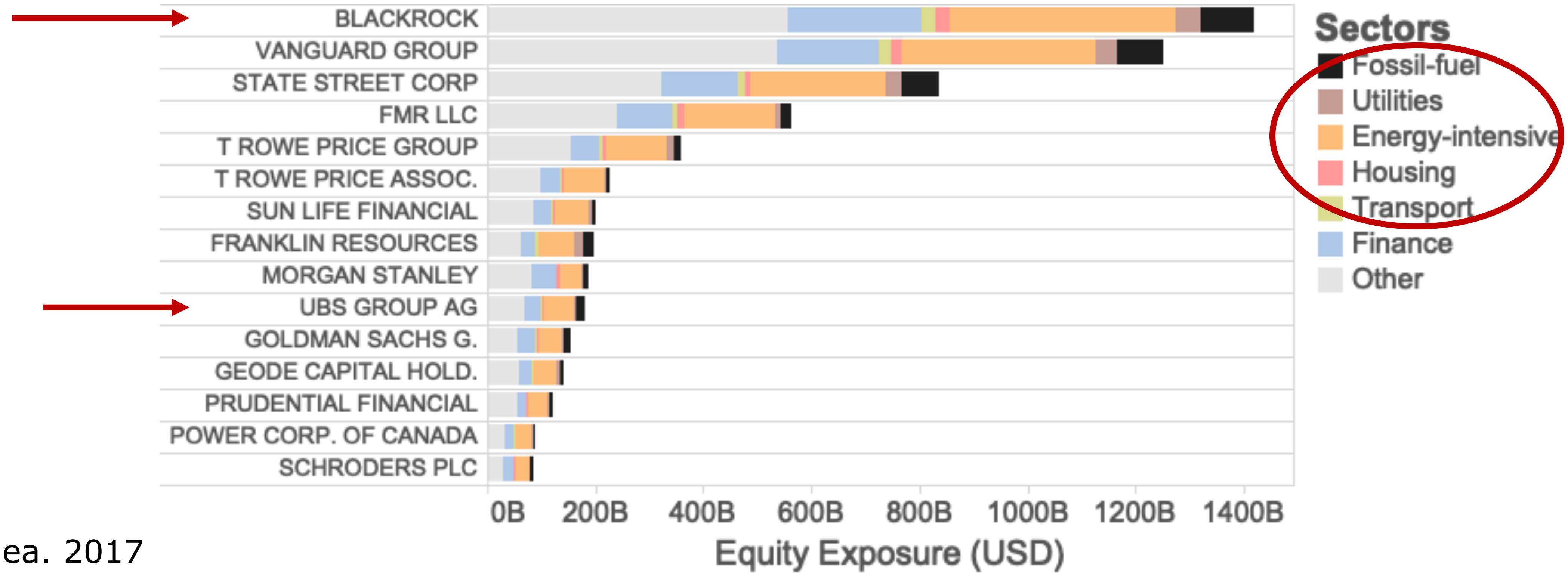
Indeed, fossil fuels still represent large share of Gross Value Added after Paris Agreement



Average share of fossil fuels on GVA by country, OECD data 2018.

And investors are highly exposed to economic sectors that are climate relevant

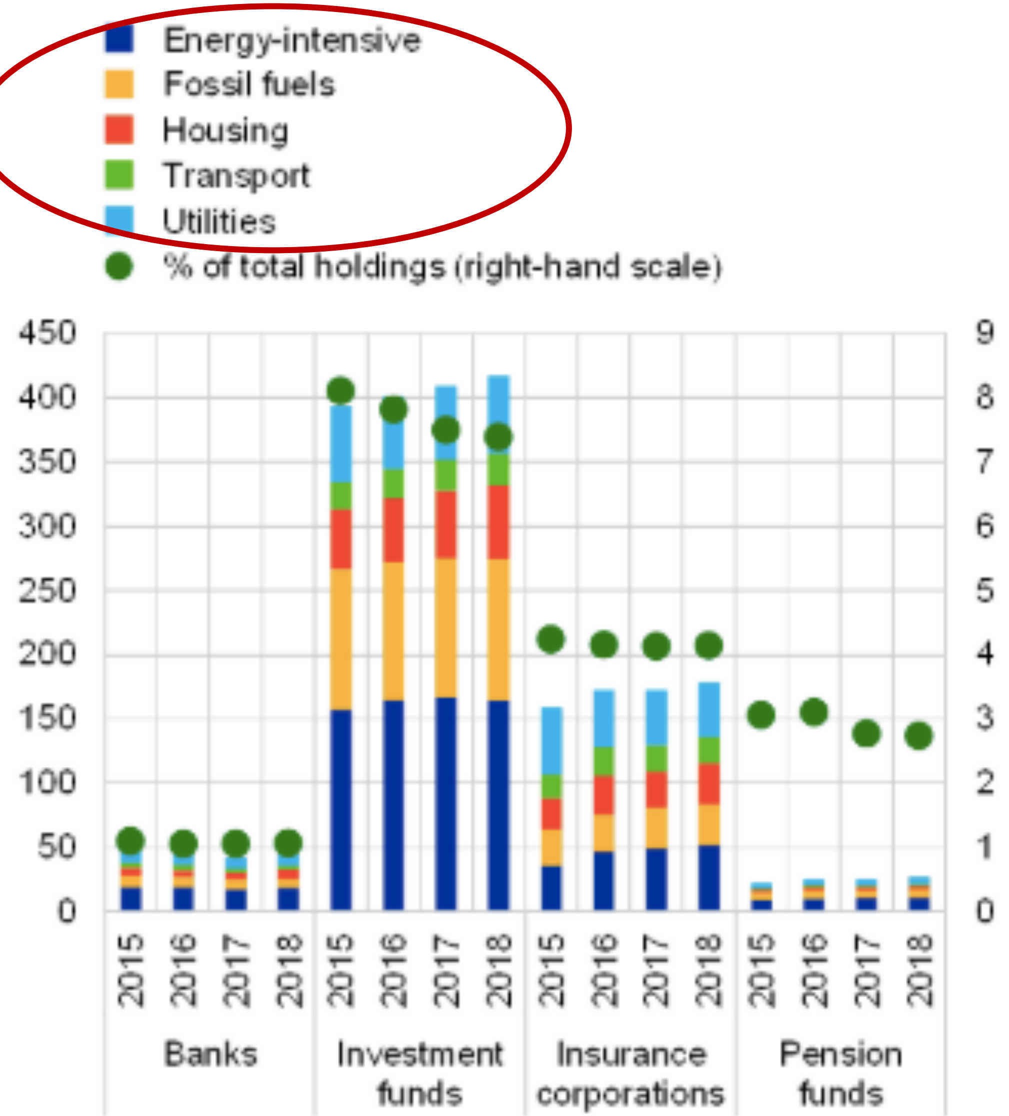
- Economic activities classifications (e.g. NACE) do not allow to consider energy technology, role in value chain and sector sensitivity (costs) to climate transition risk.
- We developed the Climate Policy Relevant Sectors (CPRS) classification. CPRS represent important value of investment funds' equity portfolios



Source: Battiston ea. 2017

Climate financial risk analysis at the ECB

- **European Central Bank** (2019)'s **"Climate change and financial stability"** (in Financial Stability Review (May 2019):
    - Euro area financial institutions' exposures to transition risk based on CPRS classification by Battiston et al. 2017
- Recent application to Austrian banking sector in collaboration with OeNB (Battiston ea 2020 forth FSR)



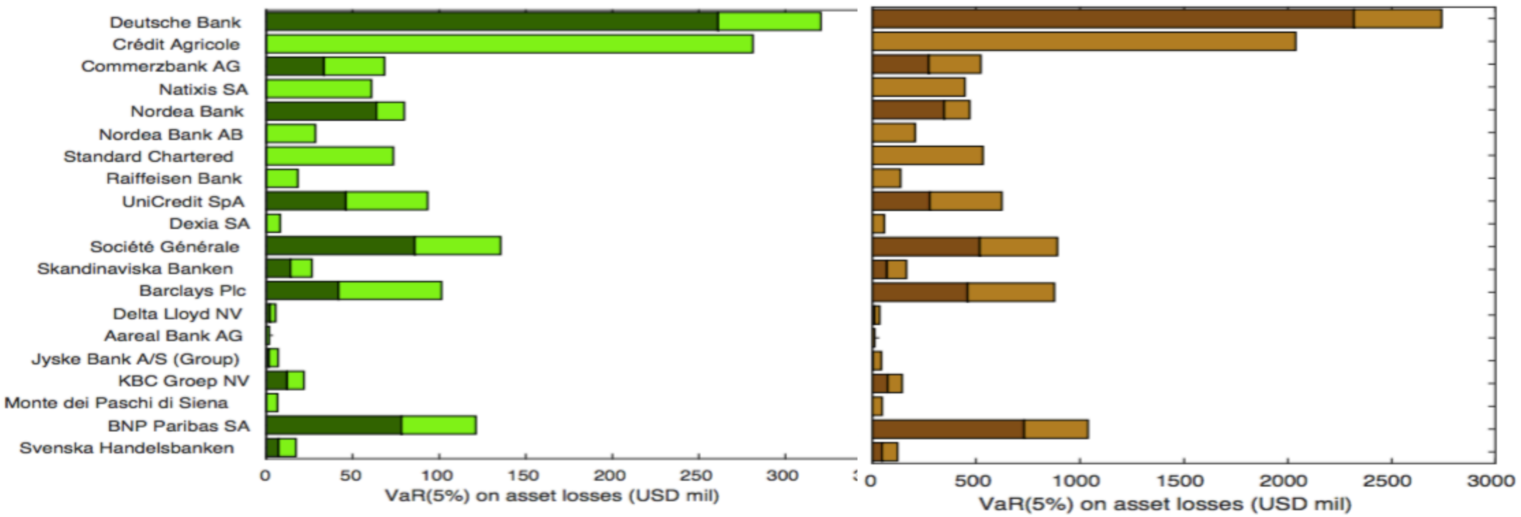
https://www.ecb.europa.eu/pub/financial-stability/fsr/special/html/ecb.fsrart201905_1~47cf778cc1.en.html

These exposures can trigger systemic risk in a disorderly low-carbon transition

nature climate change
ARTICLES
PUBLISHED ONLINE: 27 MARCH 2017 | DOI: 10.1038/NCLIMATE3255

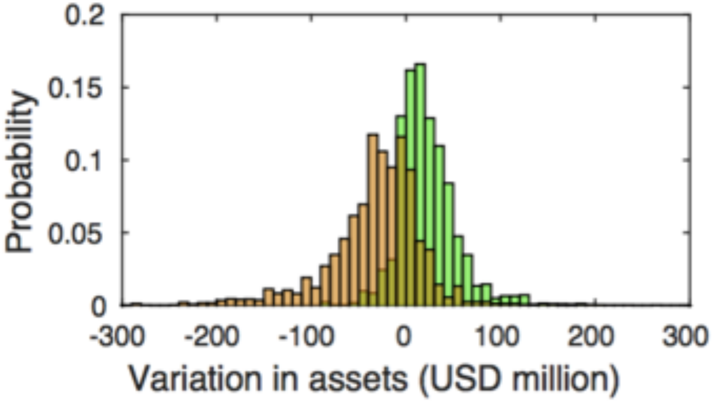
A climate stress-test of the financial system

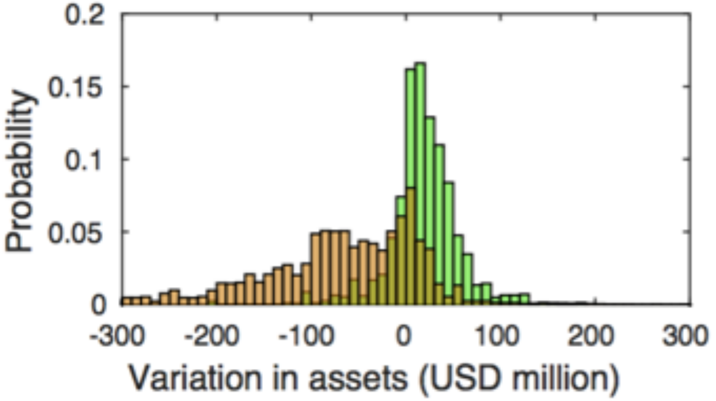
Stefano Battiston[1]*, Antoine Mandel[2], Irene Monasterolo[3], Franziska Schütze[4] and Gabriele Visentin[1]



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.*

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





But (stock) markets are still blind to carbon risk

Index	$\hat{\alpha}_i$	$\hat{\beta}_i$	$\hat{\gamma}_i$	SMB	HML	RMW	CMA
NASDAQ CLEAN EDGE GREEN ENERGY	−0.4597	1.4588***	**−0.8584*** **	0.5110***	−0.2490	−0.4978**	−0.8182***
WILDERHILL CLEAN ENERGY	−0.7697*	1.3463***	**−0.9114*** **	0.7814***	−0.1923	−0.7493***	−0.4516**
S&P GLOBAL CLEAN ENERGY	−0.8396*	1.5086***	**−1.0828*** **	0.0777	0.0222	−0.3676*	−1.2003***
WORLD RENEWABLE ENERGY (RENIXX)	−0.5156	1.3891***	**−1.2944*** **	0.6263***	−0.2177	−0.4793	−1.3047***
STOXX GLOBAL ESG ENV LEADERS	−0.1698	0.7782***	**−0.1570**	−0.1033	0.1641	−0.1374	−0.3437*
STOXX EUROPE 600 OIL & GAS	−0.5648*	1.0993***	**−0.4586*** **	−0.0285	0.0631	0.5802***	−0.0600
S&P 500 INTEGRATED OIL & GAS	−0.2239	0.8364***	**−0.0590**	−0.0700	0.0870	0.4056***	0.2337
FTSE USA OIL & GAS	−0.1717	0.8734***	**0.1542**	−0.0038	0.1842	0.3193**	0.1413
FTSE WORLD OIL & GAS	−0.3553	1.0304***	**−0.1891**	0.0900	0.1506	0.4975***	−0.0069

HAC robust standard errors
***, **, * denote significance at 1%, 5% and 10% levels, respectively

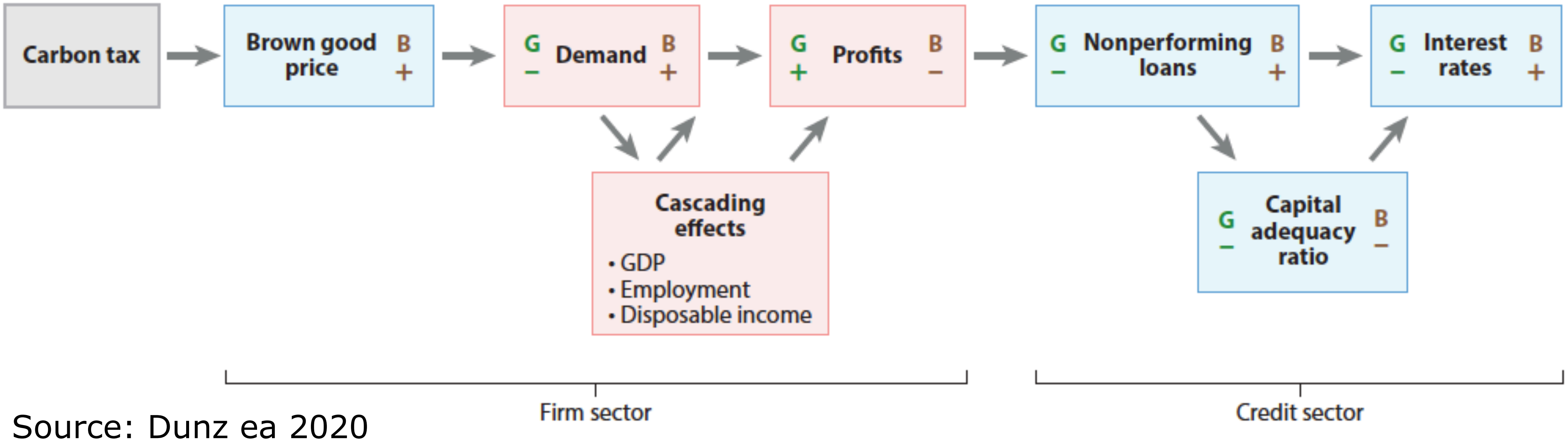
Source: Monasterolo & deAngelis 2020

- 5-factors Fama French model to test if low carbon/carbon-intensive indices **risk return profile after the Paris Agreement announcement** ($\boldsymbol{\gamma_i}$) is changed
- SMB: size factor, HML: value factor, RMW: profitability factor; CMA: investment factor
- **Systematic risk** $(\widehat{\beta_i + \hat{\gamma}_i})$ < 1 and close to zero for all low-carbon indices
- But **no significative results on carbon-intensive indices** (very mild reaction)

How material is the risk of stranded asset?

- Depends from the type of transition to low-carbon economy:
  - **Orderly:** introduction of credible and stable policies->investors *can* anticipate the policy and price it (e.g. increase (decrease) exposure to sustainable (unsustainable) assets-> smooth price adjustment and market signaling
  - **Disorderly:** delayed policy introduction (late and sudden wrt targets, e.g. EU2030)->investors *do not* fully anticipate the policy impact on the economy and finance-> no portfolio alignment to sustainability and carbon stranded assets
  - **Implications on asset price volatility** if large asset classes and systemic investors involved (Monasterolo et al. 2017)
    - Policies to mitigate it: carbon tax reinvestment for reconversion of some carbon intensive firms; bail out of fossil firms?
    - In reality, many fossil firms are buying renewable plants and buy insurance to hedge against risk (Exxon)

Climate transition risk transmission from economy to finance: carbon tax



Source: Dunz ea 2020

- Carbon tax (CT) can be transferred to households via mark-up pricing, affecting demand
- CT may induce a relative price effect in favor of green capital goods, lowering their demand
- Both channels contribute to decreasing the profitability of brown firms, lowering their ability to service loans
- Non-Performing Loans (NPL) risk transferred to the bank-> affects capital ratio, worsening lending conditions

What happens when risks compound?

Understanding compound risk: COVID-19, climate change and policy response

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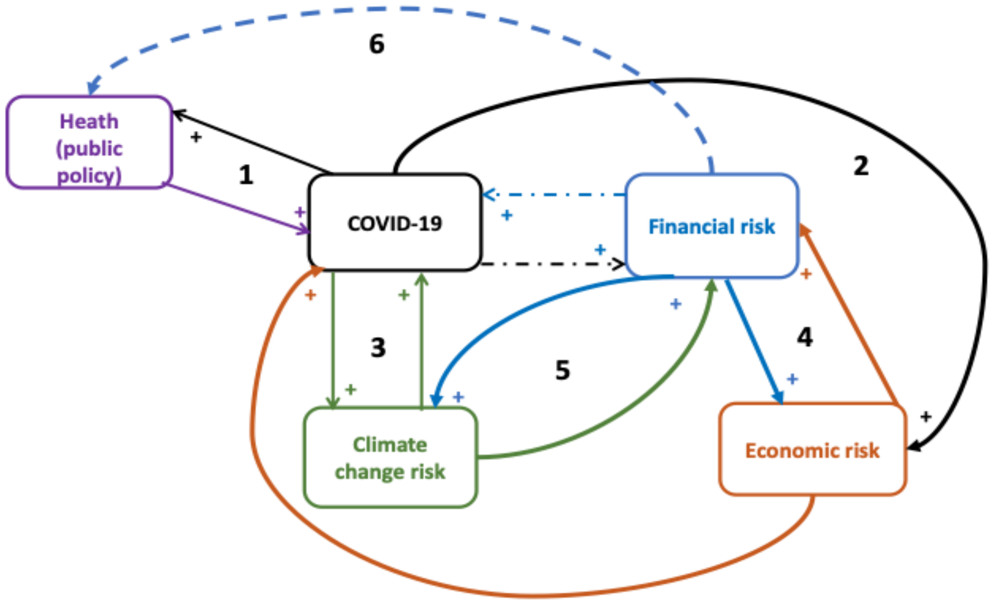
1. COVID-19 treated as public health issue with short-term economic and financial repercussions.
2. This prevents to look at how **pandemic risk interacts with climate and finance, and could lead to underestimate the policy response**
3. However, when COVID-19 compounds with climate and public finance risk, it amplifies losses. Neglecting this leads to underestimate losses
4. Understanding compounding is key to **design COVID-19 recovery policies that are aligned with climate agenda**, avoidining unnecessary trade-offs and building resilience to future pandemics
5. Methodological challenges and modelling opportunities: results from World Bank project, 1st time that Stock Flow Consistent Agent Based model informs international finance institutions

How COVID-19, climate and financial risks interact

- **Pandemic→economy→finance (we know):**
  - Restrictions to mobility negative impact transport, tourism, energy demand→global oil prices shock→impact on security issued by affected firms and held by investors
- **Climate change→pandemic risk (being analysed):**
  - increasing frequency of climate-related hazards damages socio-economic infrastructures (e.g. hospitals) critical to contain epidemic spread
  - Processes causing emissions cause also airborne pollutants (PM10) that make immune systems weaker
- **Finance → pandemic (new channel)**
  - Shocks on private finance (gov revenues) and gov. budget contribute to increase future pandemic risk by decreasing public spending on health infrastructures
  - feedback on ability of country to build resilience to future pandemic shocks



Source: Monasterolo ea 2020 (a).

Compound risk: direct and indirect effects

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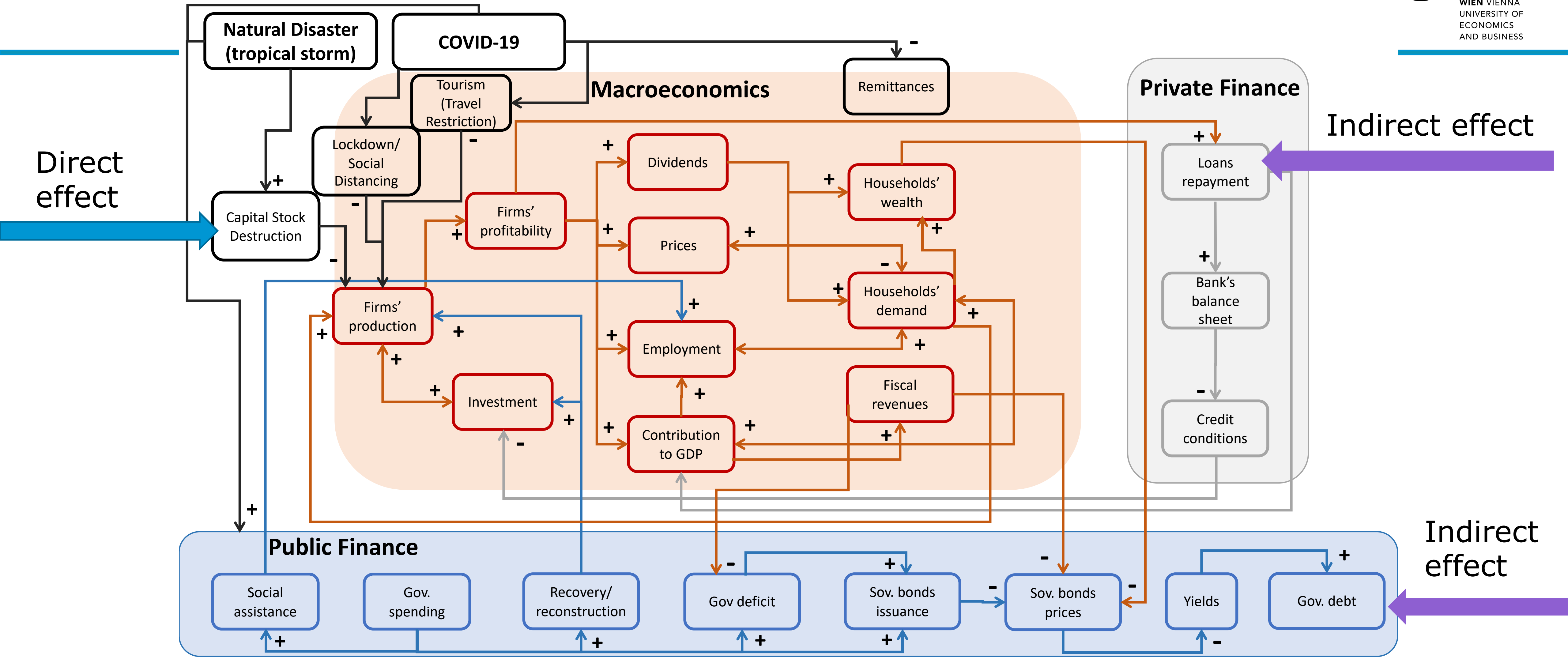

Arrows' directionality: Positive sign: variables comove in the same direction (either up or down). Negative sign: variables comove in opposite directions (an increase in A leads to a decrease in B). Monasterolo ea 2020

Modelling the macroeconomic and financial impacts of climate change

State of the art

- Macroeconomic impacts of climate change analysed in the literature:
  - **Macroeconometric models** (Burke ea. 2015, Hsiang ea. 2017, Noy ea. 2019, Mercure ea 2018)
  - **Integrated Assessment Models:**
    - Aggregated: long-term economic growth model; aggregated technology, mitigation cost curve and damage cost curve. Applied to cost-benefit analyses (DICE/RICE (Nordhaus), FUND (Tol), PAGE (Hope))
    - Process-based: cost minimization, disaggregated technologies (GCAM, IMAGE, MESSAGE, WITCH, etc. Kriegler et al. 2013, McCollum et al 2018)
  - **Dynamic Stochastic General Equilibrium (DSGE)**: Golosov ea. 2014, Annicchiarico ea 2020, etc.

Where modern macroeconomics went wrong

Joseph E Stiglitz

Oxford Review of Economic Policy, Volume 34, Issue 1-2, Spring-Summer 2018, Pages 70–106, https://doi.org/10.1093/oxrep/grx057

Published: 05 January 2018

- “At the heart of the failure were the wrong microfoundations, which failed to incorporate key aspects of economic behaviour, e.g. incorporating insights from information economics and behavioural economics.
- Inadequate modelling of the financial sector meant they were ill-suited for predicting or responding to a financial crisis;
- and a reliance on representative agent models meant they were ill-suited for analysing either the role of distribution in fluctuations and crises or the consequences of fluctuations on inequality”

Troubles with macroeconomics (wrt climate economics and finance)

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- Climate shocks: exogenous, averaged, no feedbacks, path-dependency
- Choice of damage function and discounting for policy (carbon price)

- Market clearing prices
- Unconstrained access to liquidity
- Perfect substitutability of production factors (Cobb Doglas)

Immediate shock reaction: reallocation brings back to equilibrium (no hysteresis)

- Finance: missing or stylized, conduit savings to investments
- Inequality: missing or by construction

Frictions: unstable or unequal by design

- Criticism: (Pindyck, 2013; Weitzman 2009, 2010; Stern 2013, 2016, Ackerman and Munitz, 2016)

State of the art (cont)

- Stock Flow Consistent (SFC), Agent Based (ABM), networks used to assess the macrofinancial impacts of climate change (Monasterolo ea. 2019 for a review)
- **SFC, ABM**: contribution to macroecological modelling and policy analysis
  - Green fiscal and monetary policies: Bovari ea. 2018, Dafermos ea. 2018, Monasterolo and Raberto 2018, Ponta ea. 2018, Lamperti ea 2020
  - Greening capital requirements and prudential regulation: Dafermos ea. 2019, Dunz ea. 2019, Raberto ea. 2019
  - Command and control policies: Lamperti ea. 2018
  - Unilateral climate policy introduction in North-South models: Carnevali ea. 2020, Dunz ea. 2020, Yilmaz and Godin 2020
- **Network models:** macro-financial impacts of forward-looking climate risks
  - Climate Stress-test: Battiston ea. 2017, Roncoroni ea. 2019, Regelink ea 2019

Dimension	CGE	DSGE	I-O	SFC	ABM
Production function	Cobb-Douglas/CES	Cobb-Douglas /CES	Leontief	Leontief	Cobb-Douglas /Leont.
Drivers of technical change (if any)	Macro (exogenous or endogenous, R&D or labor returns to scale >1)	Macro (exogenous or endogenous, R&D or labor returns to scale >1)	None	Macro (endogenous investment or R&D based)	Macro or Micro (evolutionary adaptive)
Saving (S)/investment (I)	S=I	S=I	S=I	I=S	I=S
Money creation	Exogenous (Central Bank)	Exogenous (Central Bank)	None	Endogenous (credit creation)	Endogenous (credit creation)
Interest rate	**2**, Optimal intertemporal consumption balancing	**2**, Optimal intertemporal consumption balancing, CB policy rate as benchmark	None	**Several**, set by CB as policy rate and commercial banks based on sector-specific risk considerations affecting investment decision (NPV in EIRIN)	**Several**, set by CB as policy rate and commercial banks based on sector-specific risk considerations affecting investment decision (NPV in EIRIN)
Monetary policy	CB policy rate	Taylor-rule CB policy rate	None	Taylor-rule CB policy rate	Taylor-rule CB policy rate
Driver of Output formation	Supply side	Supply side	Depending on applied I-O inverse	Demand side	Demand side
Equilibrium	Yes	Yes	Yes	Accounting principles	Out of equilibrium
Prices	Market clearing (sometimes with frictions)	Market clearing (sometimes with frictions)	No price changes	Non-market clearing	Non-market clearing
Agents	Representative	Representative	Representati ve	Limited heterogeneity	Heterogeneous
Decision making	Unbounded rationality	Unbounded rationality (some frictions)	Unbounded rationality	Bounded, heuristics	Bounded, heuristics
Expectations	Rational	Rational	Rational/no ne	Adaptive	Adaptive
Markets	Centralized	Centralized	Centralized	Decentralized	Decentralized
Behaviors	Optimizing based on relative price changes	Optimizing based on relative price changes	Fixed by technical coefficients	Limited by accounting identities and budget constraints	Emerging from agents' interactions
Finance (beyond intermediary bank)	No	No	No	Yes	Yes

Macro-models comparison: Computable General Equilibrium (CGE), Dynamic Stochastic General Equilibrium (DSGE) and Input-Output models (I-O), with SFC and ABM (Monasterolo ea. 2020b)

However, in the real economy

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- Climate shocks are endogenously generated (emissions-> production structures, decisions to postpone climate policy) and can have long term effects (hysteresis)
- Time delay in reaction (including policy): effect on investors’ expectations
- Agents’ reaction may depart from optimization and full rationality (e.g. when incomplete information, Greenwald and Stiglitz 1986)
- Interconnectedness of economic and financail actors can amplify shocks: price of complexity in banks’ networks (Battiston ea 2016 on 2008 crisis)
- Shocks can compound and disconnected sectoral interventions could amplify shock
- **Thus, when uncertainty about the future, the simulation of feasible “what if” scenarios first step, beforee punctual forecasting**

SFC ABM characteristics

- **Represent agents as a network of interconnected balance sheets**: allows to increase transparency with regards to to drivers of shocks transmissions and impacts for better policy evaluation
- **Depart from equilibrium conditions** and from strong assumptions on agents' rationality and representativeness, perfect markets
- **Provide a rigorous accounting framework**: equilibrium conditions substituted by accounting identities that hold irrespective of any behavioral assumption
- **Allow the study of the emergent aggregate statistical regularities** in the economy, which cannot be originated by the behavior of a “representative” or “average” individual, but is the result of heterogeneous agents’ behavior, interaction and coordination processes

SFC features: sectoral balance sheet matrix

- **Sectoral balance sheet** matrix is a key feature of SFC models. It describes all assets and liabilities for each sector i.e. it represents a snapshot of the economy at certain time
- **Each column** represents the balance sheet of an agent or sector and always sums to zero to highlight the definition of equity (or net worth)
- **Each row** show assets and/or claims of assets across sectors, thus generally adding up to 0 (exception: tangible capital accumulated by firms)
- Assets are reported with no sign while liabilities with a negative sign

EIRIN sectoral balance sheet matrix

	H_w	H_k	C_k	C_l	K	EN	BA	CB	G	ROW	$\sum$
Tangible capital			$p_K K_{C_k}$	$p_K K_{C_l}$		$p_K K_{EN}$					$p_K K$
Inventories			$p_{C_k} I_{C_k}$								$p_{C_k} I_{C_k}$
Gold in the vault								M_{CB}			M_{CB}
gov bonds		$p_B n_{H_k}$					$p_B n_{BA}$	$p_B n_{CB}$	$-p_B n_G$		0
Bank's loans			$-L_{C_k}$	$-L_{C_l}$		$-L_{EN}$	L_{BA}				0
CB's loan							$-L_{CB}$	L_{CB}			0
Bank's deposits	M_{H_w}	M_{H_k}	M_{C_k}	M_{C_l}	M_K	M_{EN}	$-D_{BA}$		M_G		0
CB's reserves							M_{BA}	$-M_{fiat}$		M_{ROW}	0
Equity (net worth)	$-E_{H_w}$	$-E_{H_k}$	$-E_{C_k}$	$-E_{C_l}$	$-E_K$	$-E_{EN}$	$-E_{BA}$	$-E_{CB}$	$-E_G$	$-E_{ROW}$	$-E_{EIRIN}$
$\sum$	0	0	0	0	0	0	0	0	0	0	0

Cash flow matrix

- The cash flow matrix reports changes between two points in time.
- **Sectors are reported in columns, monetary flows are reported in rows.** The result of agents’ sector transactions is the net cash flow (NCF) of each sector
- The top section refers to cash receipts or outlays of operating activities with an impact on net worth
- The bottom section refers to cash flows generated by variations in real, financial and monetary assets or liabilities

EIRIN Cash flow matrix

Cash flows from:	H_w	H_k	C_k	C_l	K	EN	BA	CB	G	ROW	Σ
Consumption of:											0
- goods	$-C_{H_w}$	$-C_{H_k}$	$p_{C_k} q_{C_k}$	$p_{C_l} q_{C_l}$					$-C_G$		0
- energy	$-p_{EN} q_{EN}^{H_w}$	$-p_{EN} q_{EN}^{H_k}$	$-p_{EN} q_{EN}^{C_k}$	$-p_{EN} q_{EN}^{C_l}$	$-p_{EN} q_{EN}^{K}$	$p_{EN} q_{EN}$					0
Imports	$-q_{H_w} p_{R_c}$	$-q_{H_k} p_{R_c}$	$-p_R q_R$							$p_R q_R + q_H p_{R_c}$	0
Exports			$p_{C_k} q_{C_k}$	$p_{C_l} q_{C_l}$		$p_{EN} q_{EN}$				$-p_{C_k} q_{C_k}$ $-p_{C_l} q_{C_l}$ $-p_{EN} q_{EN}$	0
Tourism				TU_{C_l}						$-TU_{ROW}$	0
Remittances	R_{H_w}	R_{H_k}								$-R_{ROW}$	0
Wages	Y_{H_w}		$-N_{C_k} w_{high}$	$-N_{C_l} w_{low}$	$-N_K w_{high}$				$-N_G w_{high}$		0
Interests:											
- bonds' coupons		$c_B n_{Hk}$					$c_B n_{BA}$	$c_B n_{CB}$	$-c_B n_G$		0
- bank's loans			$-r_D L_{C_k}$	$-r_D L_{C_l}$		$-r_D L_{EN}$	Y_{BA}				0
- CB's loan							$-r_{CB} L_{CB}$	$r_{CB} L_{CB}$			0
Income tax	$-T_{H_w}$	$-T_{H_k}$	$-T_{C_k}$	$-T_{C_l}$	$-T_K$	$-T_{EN}$			T_G		0
Dividend payout		$Y_{H_k}^d$	$-d_{Ck}$	$-d_{Cl}$	$-d_K$	$-d_{EN}$	$-d_{BA}$				0
Seignorage								S_{CB}	S_G		0
	=	=	=	=	=	=	=	=	=	=	
(Net Cash flow)	$+NCF_{H_w}$	$+NCF_{H_k}$	$+NCF_{C_k}$	$+NCF_{C_l}$	$+NCF_K$	$+NCF_{EN}$	$+NCF_{BA}$	$+NCF_{CB}$	$+NCF_G$	$+NCF_{ROW}$	0
	+	+	+	+	+	+	+	+	+	+	
Investment in:											
- capital			$-p_K q_K^{C_k}$	$-p_K q_K^{C_l}$	$p_K q_K$						0
Δ Loans			ΔL_{C_k}	ΔL_{C_l}		ΔL_{EN}	$-\Delta L_{BA} + \Delta L_{CB}$	$-\Delta L_{CB}$			0
brown bond issues		$-p_B \Delta n_{H_k}$					$-p_B \Delta n_{BA}$	$-p_B \Delta n_{CB}$	$p_B \Delta n_G$		0
Δ bank's deposits	$-\Delta M_{H_w}$	$-\Delta M_{H_k}$	$-\Delta M_{C_k}$	$-\Delta M_{C_l}$	$-\Delta M_K$	$-\Delta M_{EN}$	ΔD_{BA}		$-\Delta M_G$		0
Δ CB's reserves							$-\Delta M_{BA}$	ΔM_{fiat}		$-\Delta M_{ROW}$	0
Σ	0	0	0	0	0	0	0	0	0	0	

Net worth change matrix

- The net worth change matrix reports the variation of agents' net worth between two periods, due to:

1. Net cash flows
2. Stock changes in real asset
3. Price changes in assets and liabilities

EIRIN Net worth change matrix

	H_w	H_k	C_k	C_l	K	EN	BA	CB	G	ROW
(Net cash flows Table C	$+NCF_{H_w}$	$+NCF_{H_k}$	$+NCF_{C_k}$	$+NCF_{C_l}$	$+NCF_K$	$+NCF_{EN}$	$+NCF_{BA}$	$+NCF_{CB}$	$+NCF_G$	$+NCF_{ROW}$
Capital depreciation			$-\delta_k K_{C_k}$	$-\delta_k K_{C_l}$		$-\delta_K K_{EN}$				
Capital destruction (potentially)			$-\xi_k K_{C_k}$	$-\xi_k K_{C_l}$		$-\xi_K K_{EN}$				
Change of inventories			$p_C \Delta I_C$							
Price change of:										
- tangible capital			$\Delta p_K K_{C_k}$	$\Delta p_K K_{C_l}$		$\Delta p_K K_{EN}$				
- inventories			$\Delta p_C I_C$							
- bonds		$\Delta p_B n_{H_k}$					$\Delta p_B n_{BA}$	$\Delta p_B n_{CB}$	$-\Delta p_B n_G$	
	$-\Delta E_{H_w}$	$-\Delta E_{H_k}$	$-\Delta E_C$		$-\Delta E_K$	$-\Delta E_{EN}$	$-\Delta E_{BA}$	$-\Delta E_{CB}$	$-\Delta E_G$	$-\Delta E_{ROW}$
Σ	0	0	0	0	0	0	0	0	0	0

EIRIN model description

Research questions addressed so far

1. How could green fiscal, monetary policies and financial instruments could help fostering the low-carbon transition? **What role for policy complementarity?** (Monasterolo and Raberto 2017, 2018, 2019)?

2. Under which conditions **unintended effects** (financial instability, inequality) could emerge?

3. **How investors' expectations towards climate policy** affect the low-carbon transition (and success of climate policy implementation?) (Dunz ea 2020)

4. **What are the macrofinancial implications of compound risks** (i.e. COVID-19 and climate change (Monasterolo ea 2020)

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EIRIN: analysing the interplay of policies, economy and finance in the low-carbon transition

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- SFC-ABM with heterogeneous agents (parsimonious in complexity):
  - Households (capitalist/worker, Goodwin 1967): income source, wealth, access to finance, saving/consumption (Deaton's buffer-stock theory)
  - Leontief production function (Capital, Labor, Raw Material, Energy)
  - Capital goods, with possibility for firms to choose between green/brown capital
    - Green/brown capital defined based on emissions and resource intensity parameters (based on historical data)
    - No perfect substitution because different relative prices and cost of technology (green/brown) but possible, depending on NPV (thus, investment decisions not constrained by Leontief)

- Independent real and monetary flows represented

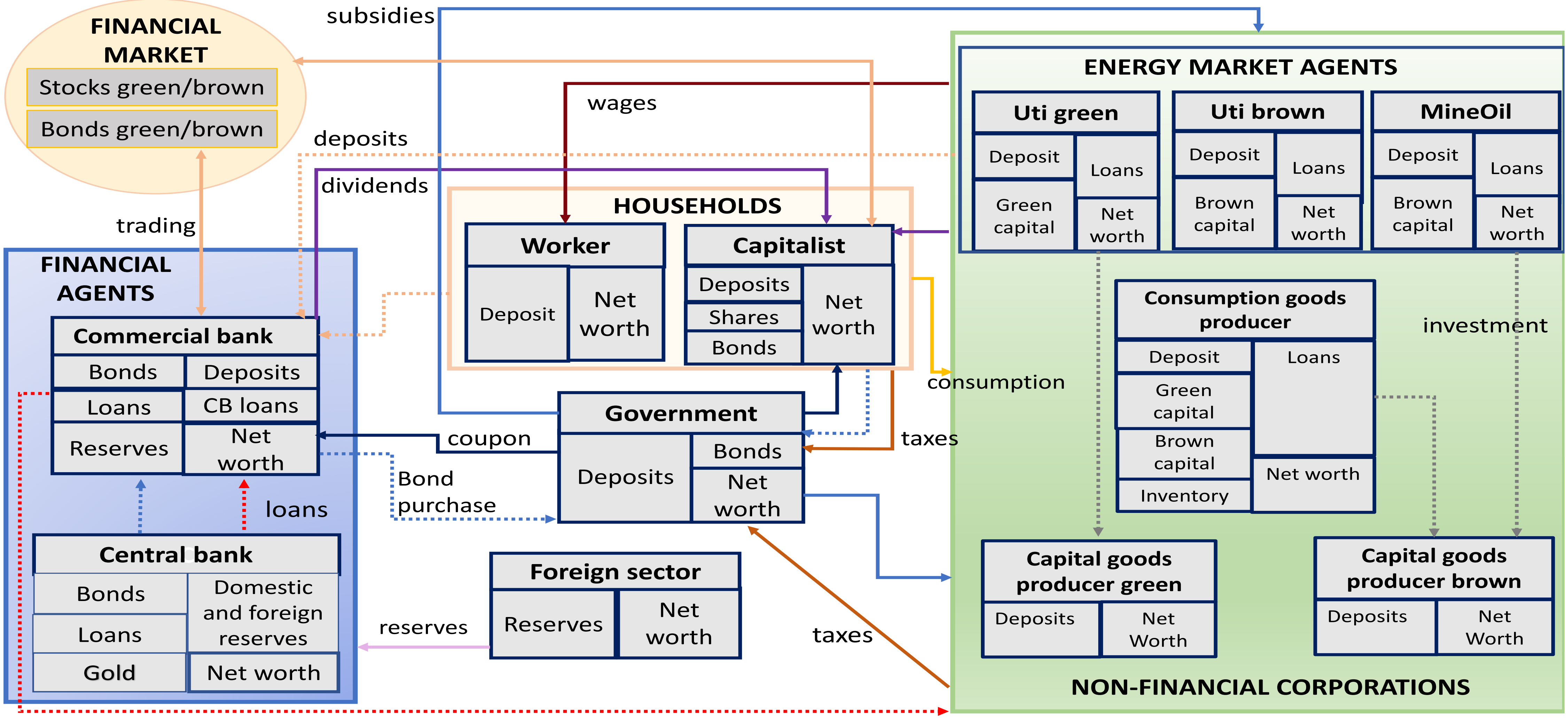
- Energy producers by fossil/renewable technology (utilities, energy)

- Behavioral rules based on experimental, evolutionary economics

Main features

- **Endogenous GDP growth** emerging from micro-macro interactions (Post-Keynesian, demand driven)
- **Endogenous money creation** to support investment decisions (McLeay ea 2014, Lavoie 2014)
- **Feedback loops** between sectors of the real economy and finance
- No market clearing and no perfect competition: mark up pricing on costs
- Deep uncertainty on the future translates in adaptive expectations of agents: **no optimal foresight**
- **Portfolio choices of firms**, households and investors drive distributive effects (differentiated access to gains on markets)
- Conditions for public policies to **crowd in** green investments

The EIRIN model framework



Dotted lines: capital account flows; solid lines: current account flows. Dunz ea 2019

Main behavioral equations

Monetary policy decision

$$r_{CB} = \omega_{\pi}(\pi - \bar{\pi}) + \omega_{\mu}(\bar{\mu} - \mu)$$

with:

π : inflation (endogenous)

μ : unemployment (endogenous)

ω_{π}: weight on inflation term

ω_{μ}: weight on unemployment term

$\bar{\pi}$: inflation target

$\bar{\mu}$: unemployment target

- A Central Bank sets the interest rate according to a Taylor-like rule.
- The interest rate depends on the inflation and output gap, measured as employment gap (i.e. the distance to a target level of unemployment)

Government’s bonds issuance

$$\Delta n_B = \frac{\bar{M} - M_G}{p_B}$$

with:

$\bar{M}$: given positive threshold

M_G: government’s deposits

p_B: bond price

- To cover its regular expenses (e.g. salary to public workers and subsidies) the government raises taxes and issues **sovereign bonds**, bought by Hk, bank and central bank. The government pays coupons on its outstanding bonds.
- In case of budget deficit, tax rate increases. In case of a budget surplus exceeding a given threshold, tax rate is decreased by the same fixed amount. Otherwise, tax rate is constant.
- If government's deposits are lower than a given positive threshold, i.e., $M_G < \bar{M}$, the government issues a new amount Δn_B of bonds to cover the gap. p_B is the endogenously determined government bond price

Households' consumption

$$C_m = Y_m^{net} + \rho\,(M_m - \phi Y_m^{net})$$

with:

$m = H_w, H_k$

Y_m^{net}: net disposable income

M_m : Liquid assets

ρ : parameter that determines the speed of adjustment of consumption

ϕ : parameter that sets the target level of liquid assets M_m to net income Y_m^{net}

- Households' consumption plans based on the buffer-stock theory of savings (Deaton, 1991; Carroll, 2001): balances impatience of households to consume all income and wealth with prudence about the future (econ. conditions) preventing them to draw down their assets too far

Consumption good firms' production

$$q_j^c = \min(\gamma_j^N N_j, \gamma_j^K K_j, \gamma_j^R Q_j^R)$$

with:

$j = C_l, C_k$

N_j : Labor force employed with productivity γ_j^N

K_j: total capital endowment with productivity γ_j^K

Q_j^R: raw material amount required with resource efficency γ_j^R

- Firms' production amount of consumption goods q_c is carried out according to a Leontief production technology, characterized by no substitutability among production factors in the short-term model horizon (5y)

Investment decision: Net Present Value

$$NPV_j = -p_k I_j + \underbrace{\frac{\widehat{\Delta q_j^C}\, p_j}{r_D^j - \pi_j^{C,e}}}_{\text{Capital goods}} - \underbrace{\frac{\Delta N_j\, w_j}{r_D^j + \varsigma_j}}_{\text{Labour m.}} - \underbrace{\frac{\Delta q_j^R p_R}{r_D^j - \pi_R^e}}_{\text{Nat. res.}} - \underbrace{\frac{\Delta q_j^E\, p_{EN}}{r_D^j - \pi_{EN}^e}}_{\text{Energy}}$$

with:

$j = C_l, C_k$

p_k : present price of capital goods

I_j : real investments in new capital goods

Δq_j^C : additional expected production

p_j : present consumption goods sale price

ΔN_j : additional amount of workers to match additional production capacity

w_j : salary paid to workers

Δq_j^R: additional amount of raw materials required to meet additional production capacity

p_R : present raw material price

Δq_j^E : additional amount of energy required to match additional production capacity

p_{EN} : present energy price

r_D^j : present sector dependent loan interest rate on debt

$\pi_j^{C,e}$: expected inflation in the j consumption goods market price

ς_j : **labour** productivity growth rate

π_R^e : expected inflation of raw materials prices

π_{EN}^e : expected inflation of energy price

Net Present Value (NPV)

$$NPV_j = -p_k I_j + \frac{\widehat{\Delta q_j^C}\, p_j}{r_D^j - \pi_j^{C,e}} - \frac{\Delta N_j\, w_j}{r_D^j + \varsigma_j} - \frac{\Delta q_j^R p_R}{r_D^j - \pi_R^e} - \frac{\Delta q_j^E\, p_{EN}}{r_D^j - \pi_{EN}^e}$$

- Endogenous investment decisions based on firms' **NPV->** 4 cash flows:
  - Positive cash flow given by the additional sales due to investment.
  - 3 negative cash flows: (i) additional labor costs required to match the need for increased production capacity; (ii) additional raw materials costs to produce the additional output; (iii) additional energy requirements for producing additional output.
- **This formulation allows us to understand agents' intertemporal behavior by comparing the short-term costs of investments with their long-term benefits.**
- The sign of the NPV determines whether the agent makes the decision to invest.

Credit supply

$$\Delta L_n = \max\left(\frac{E_{BA}}{CAR} - L_{n,t-1}, 0\right)$$

with:

E_{BA} : Bank's equity

CAR : Regulatory Capital Adeguacy Ratio

- Maximum credit supply of the bank is set by its equity level E_{BA} divided by the CAR parameter, in order to comply to banking regulator provisions (Basel III)
- Additional credit that the bank can provide at each time step is given by its maximum supply, minus the amount of loans already outstanding

Rational (fundamental) asset prices

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- $\hat{p}^s_{E_a}$ (**expected rational equity price**)

$$\hat{p}^s_{E_a} = \frac{\hat{d}^s_a}{r^s_{E_a} - \hat{g}^s_a} \qquad a \in \{C, K_b, K_g, mi, U_b, U_g, BA\},$$

  - $\hat{d}^s_a$: expected next step dividend (**adaptive expectations**)
  - $\hat{g}^s_a$: expected dividends's growth rate (**adaptive expectations**)
  - $\hat{r}^s_{E_a}$: CB's policy rate plus a given **risk premium** δ, **higher when investors react to the carbon tax** (climate sentiments).

- $\hat{p}^s_{B_a}$ (**expected rational bond price**) (infinitely-lived bonds)

$$\hat{p}^s_{B_a} = \frac{c}{r^s_a} \qquad a \in \{b, g\},$$

  - c: (known and fixed) coupon equal for brown and green
  - $\hat{r}^s_a$: discount rate set as CB's policy rate plus a premium

Asset pricing model

- End of period liquid assets (deposits) is a binding constraint that revise asset allocation plan to keep relative ratios:

$$\sum_s M^s = \sum_s M_0^s - \Delta M_{B_b}^G - \Delta M_{B_g}^G + \Delta M_{B_b}^{CB} + \Delta M_{B_g}^{CB}$$

- The new asset price is set as the ratio between the aggregate amount of financial wealth W invested in it and the number of outstanding shares/units:

$$p_{E_a} = \frac{\sum_s W_{E_a}^s}{n_{E_a}} \quad \text{new share price of asset } a \in \{C, K_b, K_g, mi, U_b, U_g, BA\}$$

$$p_{B_b} = \frac{\sum_s W_{B_b}^s - \Delta M_{B_b}^G + \Delta M_{B_b}^{CB}}{n_{B_b}} \quad \text{(new brown bond price)}$$

$$p_{B_g} = \frac{\sum_s W_{B_g}^s - \Delta M_{B_g}^G + \Delta M_{B_g}^{CB}}{n_{B_g}} \quad \text{(new green bond price)}$$

Applications:
How to finance the low-carbon transition?

- **3 research questions:**
  - How could a EU country foster a carbon free transition with public policy?
  - To what extent carbon tax and green sov. bonds financing could endogenously trigger the green investments needed?
  - Under which conditions could trade-offs and unintended effects on macroeconomic performance, financial stability, inequality emerge?

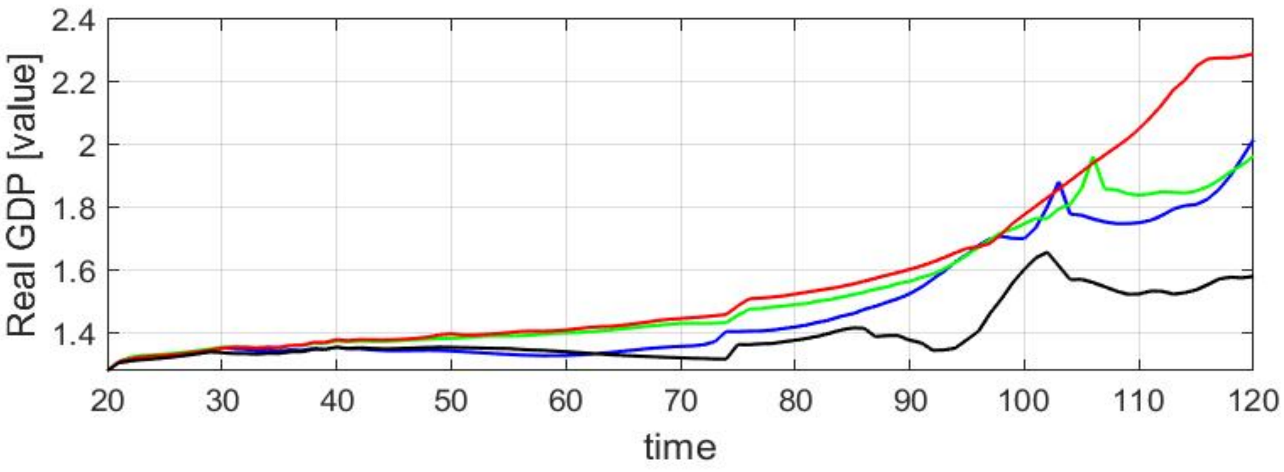
Example from: Dunz, N., Monasterolo, I., Raberto M (2019)

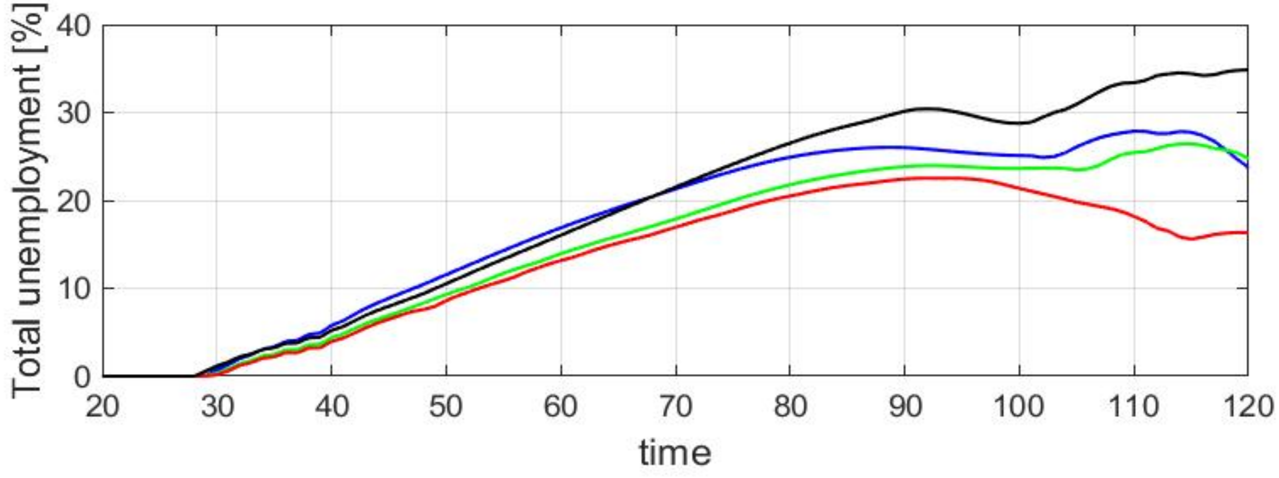
Scenarios

- We simulate 3 scenarios characterised by different financing of green subsidies to allow the country to achieve the emissions reduction targets, vis a vis the Business as Usual:

  - Carbon tax (with reinvestment of revenues in green subsidy) (value set according to the Stiglitz/Stern report 2017) (blue)
  - Green sovereign bonds conditioned to green energy investments (red)
  - Policy coordination: green sov. bonds and carbon tax (green)
  - Business as Usual (BAU): no policy (black)

GDP and unemployment



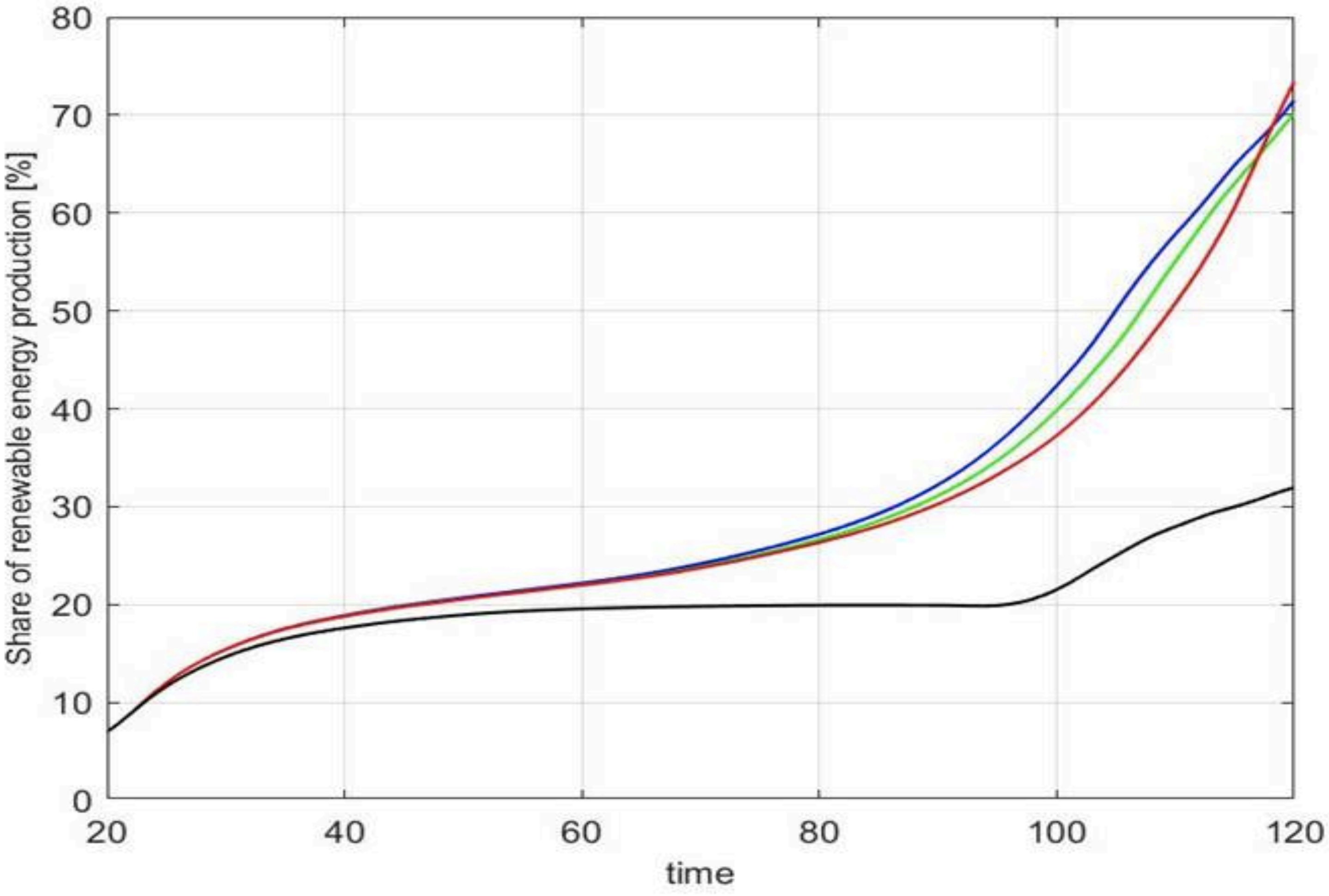


- Scenarios characterized by the introduction green bonds (Sc) and policy complementarity (Sc) experience higher real GDP (top panel) growth as a result of growing investments in the green real economy.

- Green bonds (Sc): best case for real GDP growth-> lower total unemployment (bottom panel), compared to the other scenarios.

 Dunz, Monasterolo & Raberto 2019

Renewable energy share

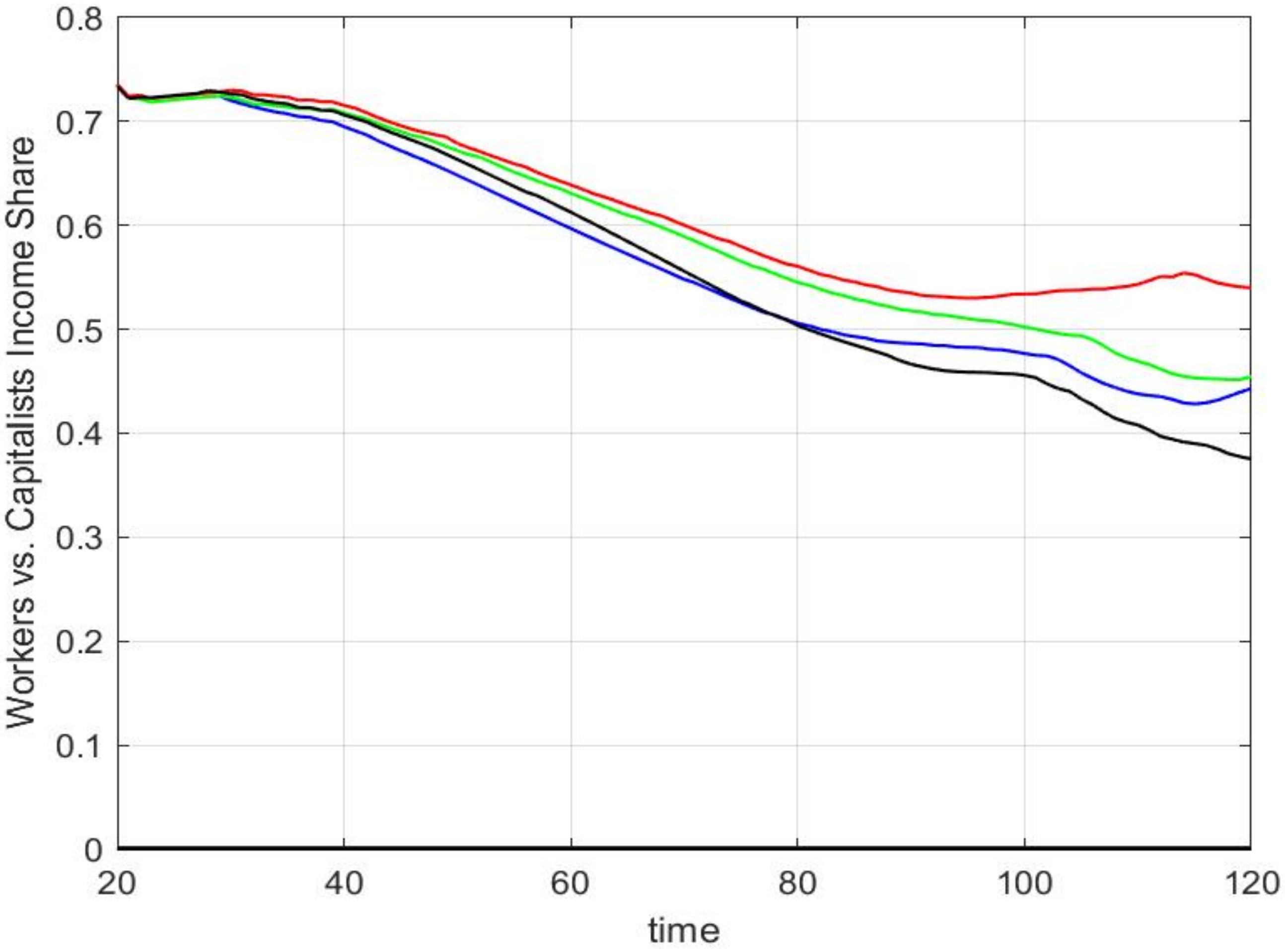


- Green subsidies foster the production of renewable energy and thus its share on total energy produced, and on green investments in the economy. Thus, greening of GDP growth, with small differences across the three green scenarios.

- All the scenarios characterized by government's initiatives perform largely better than the BAU.

 Dunz, Monasterolo & Raberto 2019

Distributive effects: wage share



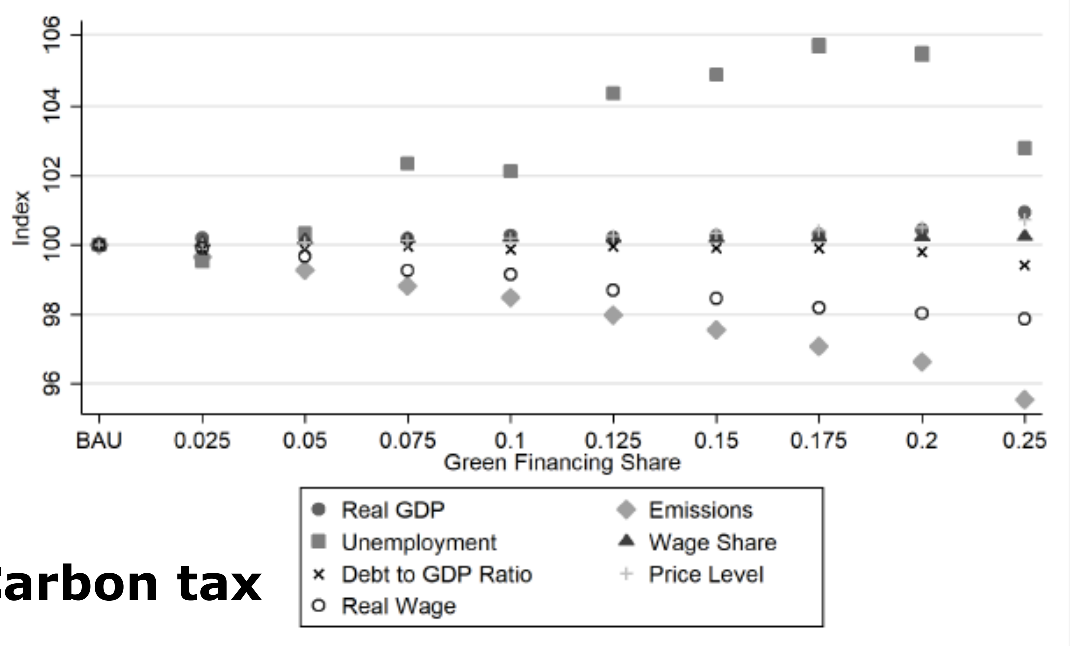
- Carbon tax scenario (Sc) has highest distributive effects on worker households due to higher energy prices decreasing consumption and thus GDP growth (inelastic energy demand)

- Distributive effects of carbon tax smoothed when policy complementarity (Sc)

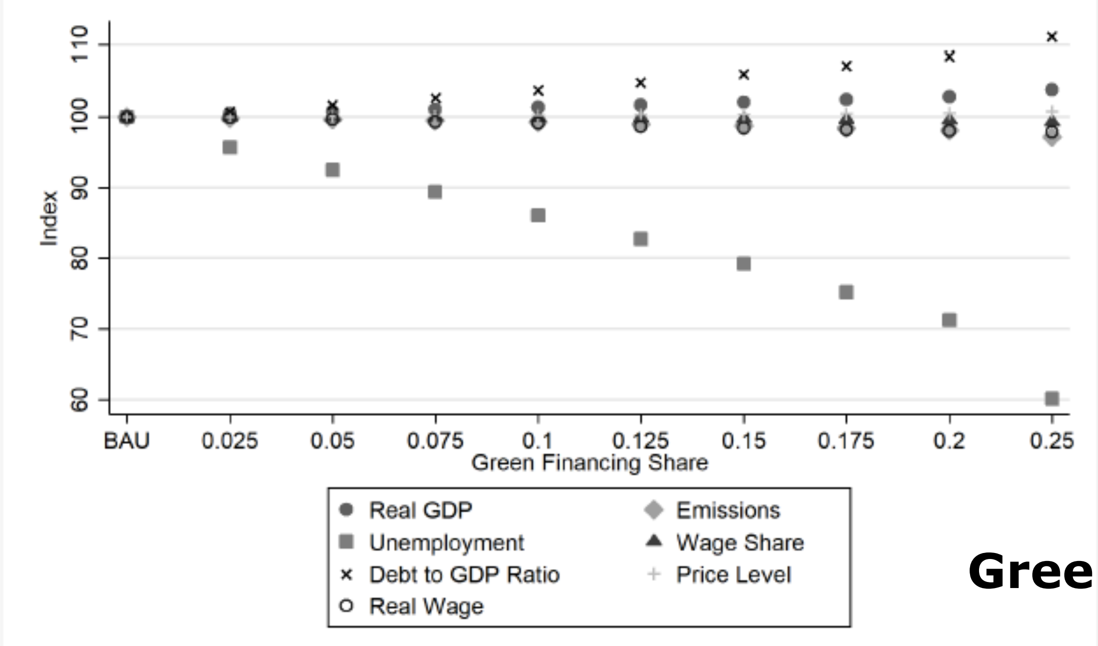
- Green sovereign bonds' scenario (Sc), shows lowest ones due to the performing (green) real economy, which fosters new green investments and jobs (i.e. potential green multiplier effect).

 Dunz, Monasterolo & Raberto 2019

Comparing carbon tax vs green bonds



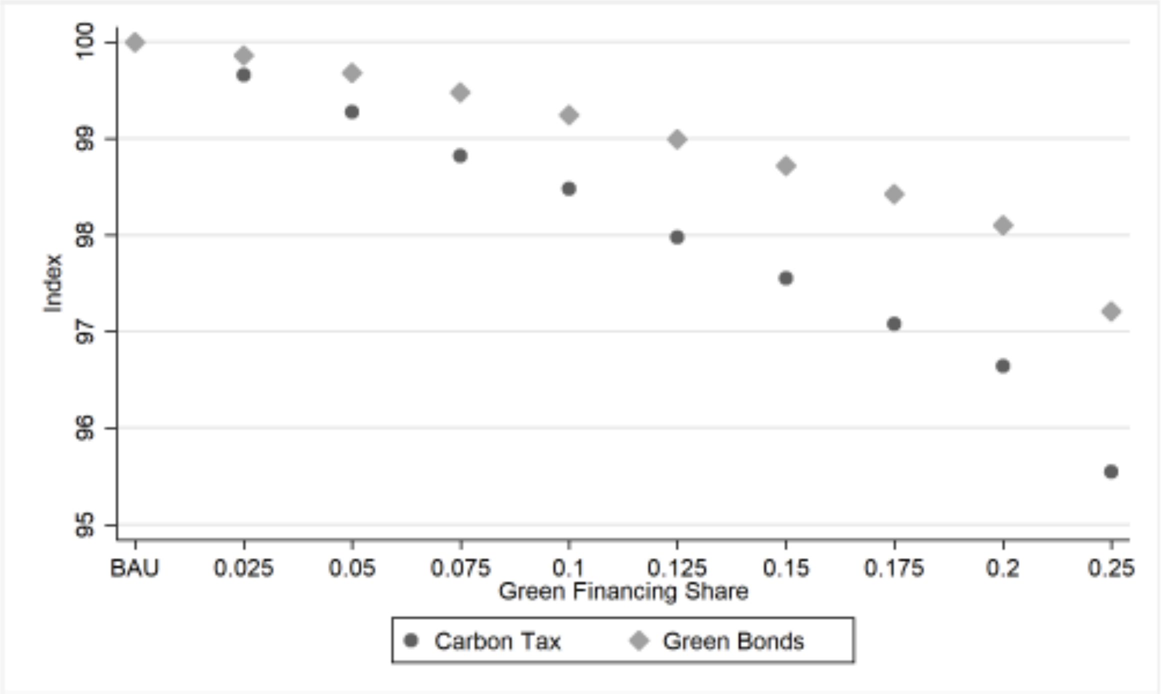
Carbon tax



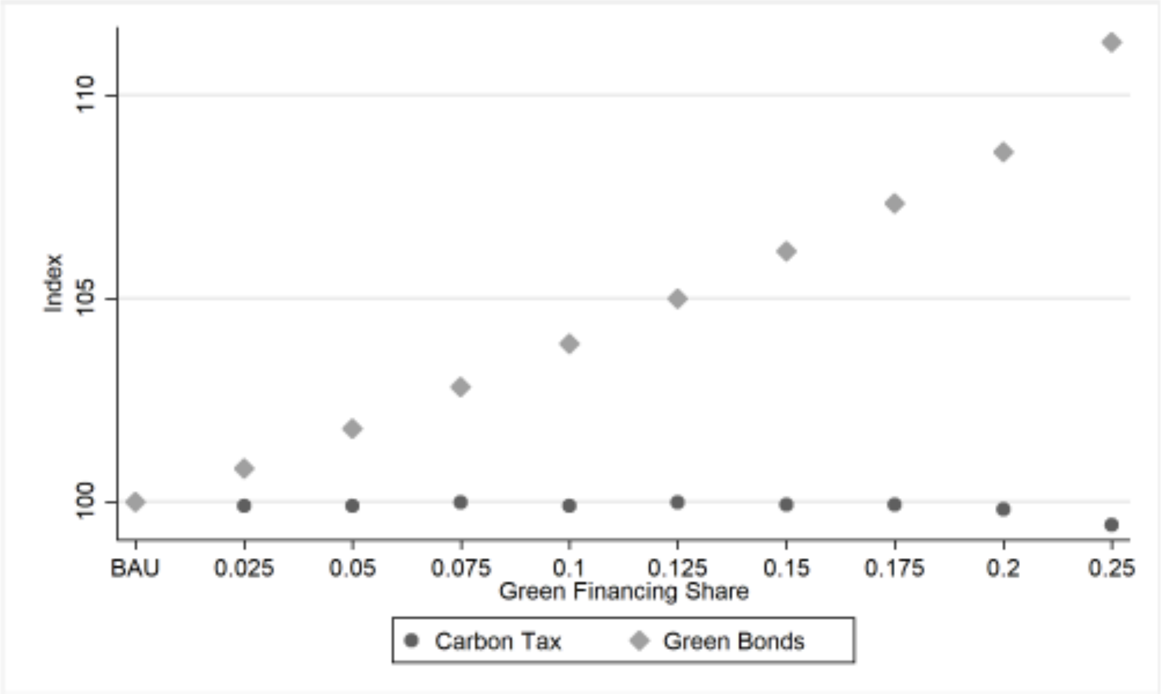
Green bonds

- **Carbon Tax** subject to trade-off: larger emissions decrease (because lower brown investments thus GDP) and budget neutral (debt to GDP). But higher unemployment and prices (mark-up).
- **Green Bonds**: higher increase in share of green investments on GDP and thus employment. Higher capitalist income from higher bond yields. But no budget neutral (higher debt/GDP ratio); emission reduction effect partly offset by GDP growth.

Emissions and debt/GDP ratio



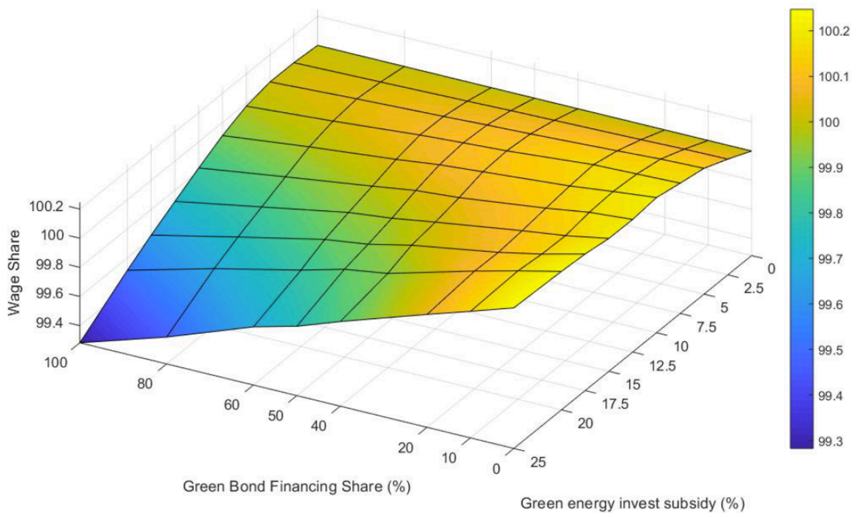
(i) Mean CO2 Emissions



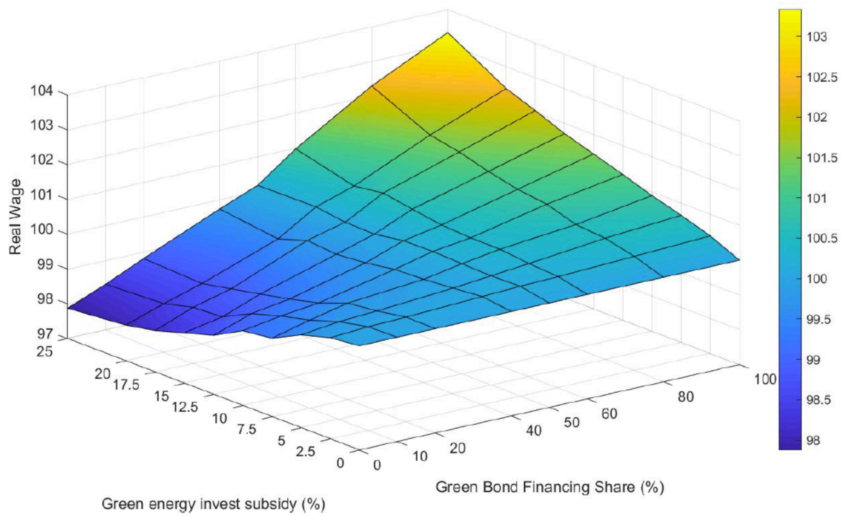
(j) Mean Debt to GDP

- Emissions in green bonds scenario decrease less than carbon tax because of GDP effect (positive impact of green bonds on green GDP growth

Policy mix: non-linear distributive effects



(k) Mean Wage Share



(l) Mean Real Wage

- Wage share increases with high carbon tax share: lower brown firms' profits and stock prices reduce capitalists income
- Wage share decreases with high green bonds share: positive effect on GDP and bond yields (issuance/price) drives capitalists' profits
- Wages increase w.high green bond share (better GDP, workers wage bargain)/decreases w.high carbon tax share (inflation, unemployment)

Conclusion: a role for policy complementarity?

- Governments does not have to choose between financing COVID-19 response, crucial long-term investments to promote climate and financial stability

- Important to align COVID-19 recovery with countries climate and energy strategy (in the EU, with the EU Green Deal program)

- **Need and opportunity for complementarities** across fiscal and monetary policies, programs and financial instruments (Monasterolo and Volz 2020):
  - Immediate COVID-19 response, resilience to future pandemics, and "build back better" coherently with climate objectives.
  - In low-income countries, development finance institutions should target recovery support (conditional lending, debt guarantees) to long term programming for climate alignment

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