The double materiality of climate physical and transition risks in the euro area

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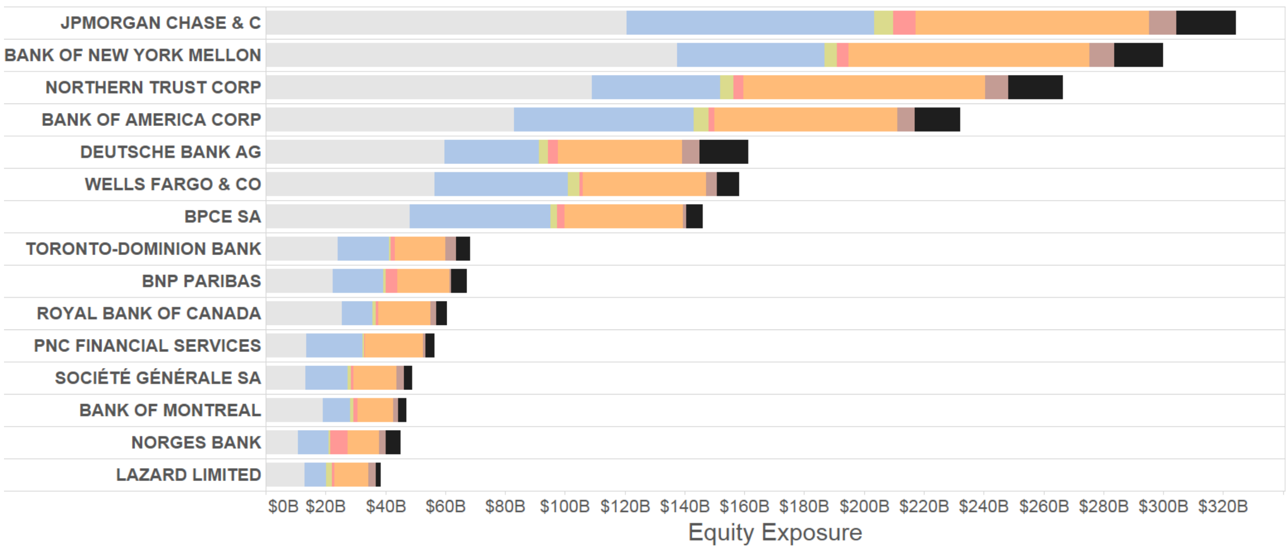
Motivation:
the role of climate financial risk assessment for an orderly transition

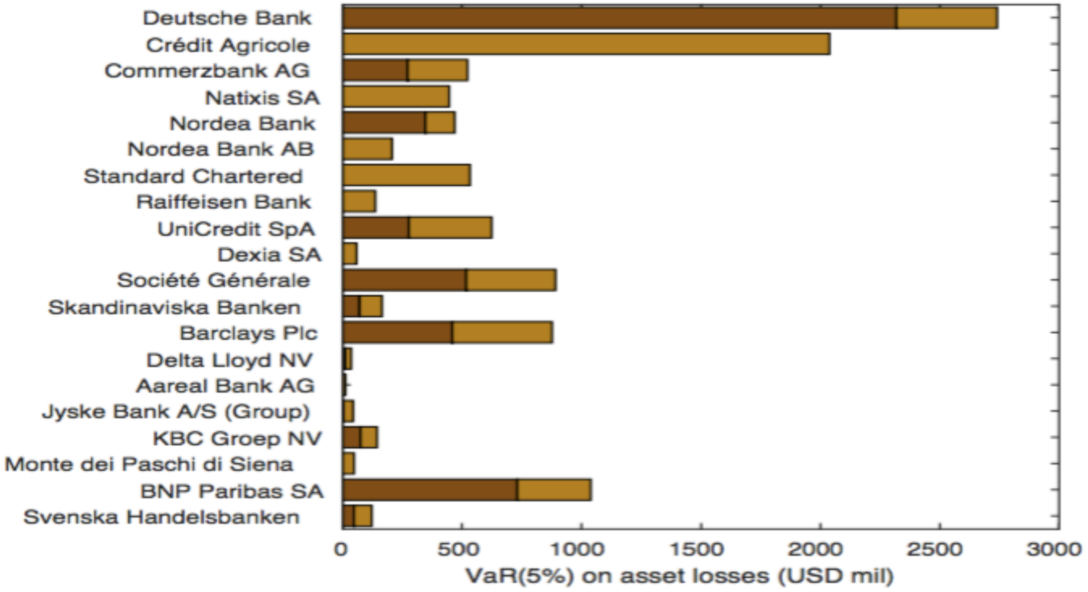
2017: a disorderly transition can trigger large financial losses

Battiston, S, ea (2017): A climate stress-test of the financial system. Nat Clim Chan

- investors' exposures to Climate Policy Relevant Sectors (CPRS, left) is high and could lead to financial risk (Value at Risk, VaR, right)



***Exposure** (USD billion) **of equity portfolio of largest banks to CPRS** including fossil (black), utilities (grey), energy-intensive (orange), housing (pink), transport (green). Battiston ea 2017*



***Value at Risk** (5% significance) on equity holdings of 20 most affected EU banks under scenario of CPRS investment strategy. Dark/light colors: first/second round losses. Battiston ea 2017*

Beyond exposure: climate financial risk assessment and climate stress test

- **Exposures** to carbon assets in the economy tell us what is at risk, but **don't give us the value of financial losses for individual institutions and the financial system**
- For this we need to consider **mispricing, leverage, interconnectedness**
- In Battiston ea 2017**,** we translated trajectories of Integrated Assessment Models across scenarios into adjustment of **financial valuation of contracts, individual and systemic risk in model of financial contagion (interbank network)**
- **Results:** direct losses (top figure): banks with high exposure to CPRS incur more losses than green ones
  - **Adding financial contagion effects** (bottom figure) further polarizes distribution of losses for the brown bank

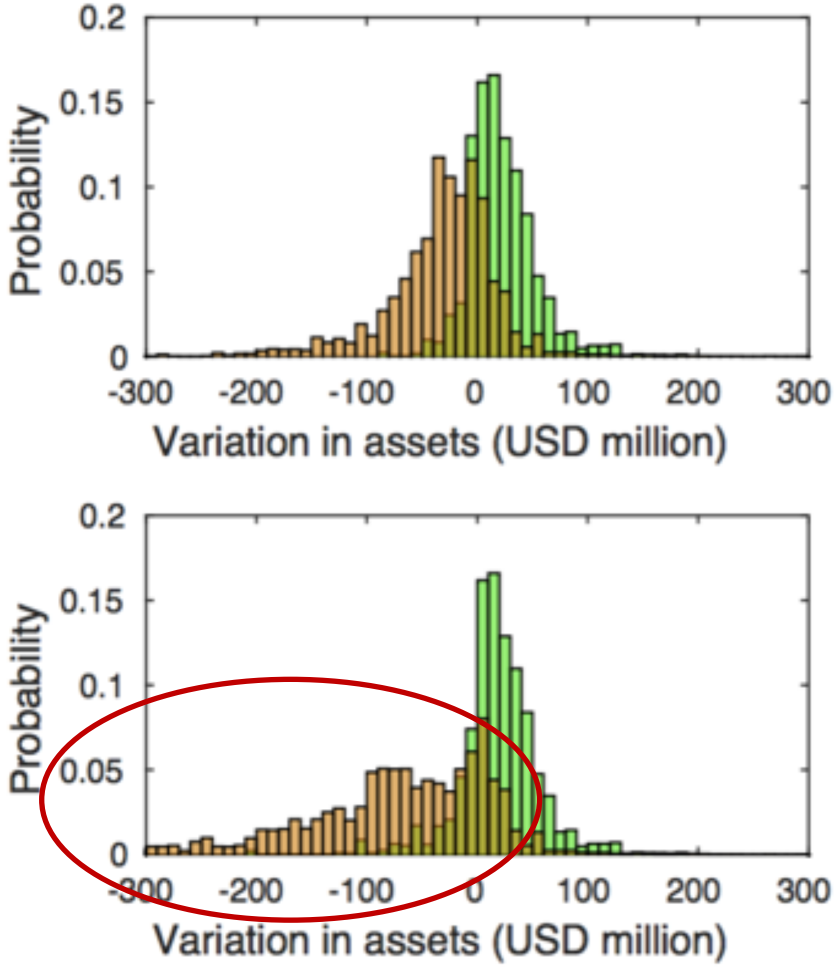
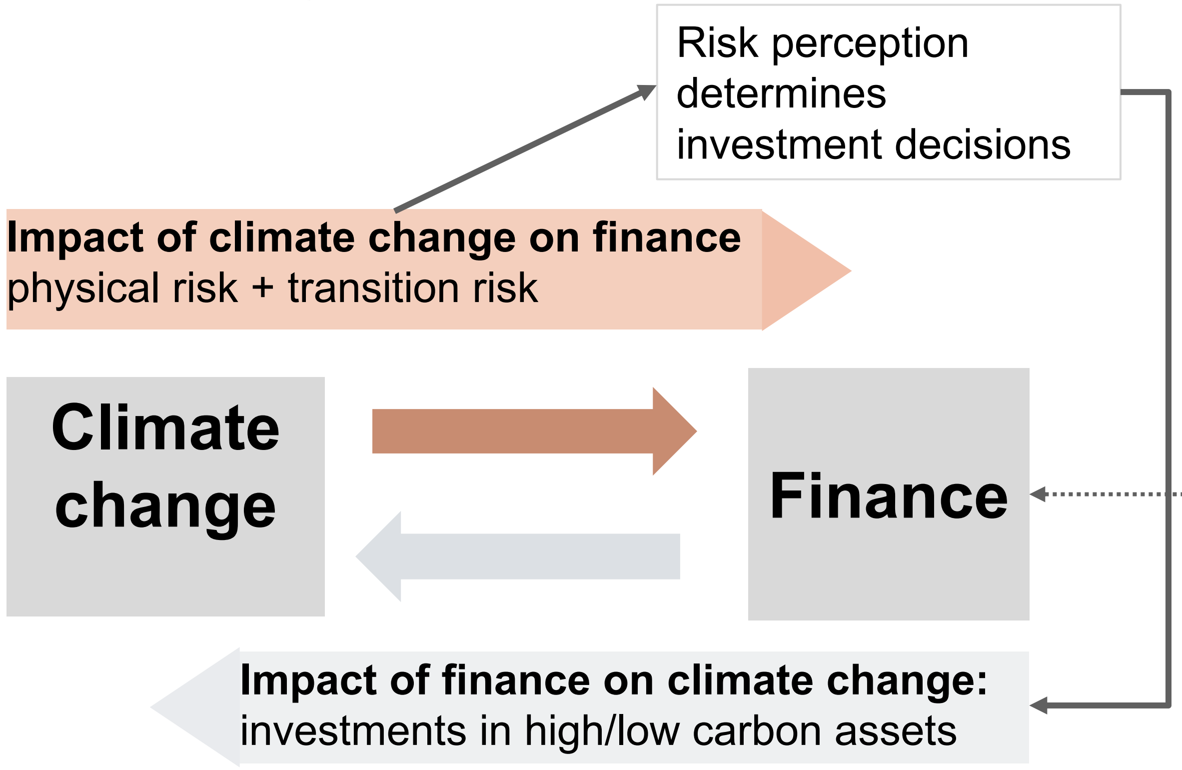


Fig.: 1st round (top). **2nd round** (bottom) polarizes distribution of losses.

2022, IPCC AR6 chapter 15:
poor climate risk assessment is main barrier to mitigation

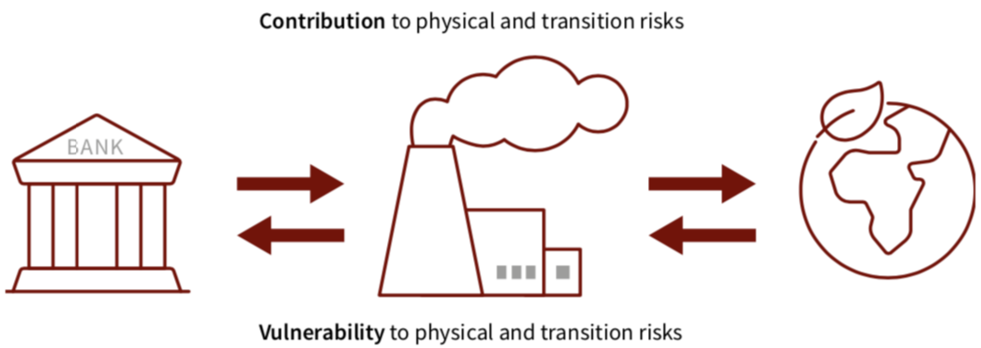


Source: courtesy of S. Battiston, IPCC lead author

- Firms make investment decisions (CAPEX) in high/low carbon equipment (e.g. wind vs coal power plants)
  - These decisions give rise to sectors' output trajectories of IAM in NGFS scenarios
- **Financial actors influence these decisions** by making capital more/less expensive for firms (e.g. interest rate)
- **The feedback btw climate financial risk assessment – investment decisions is not considered by NGFS scenarios**

The double materiality of climate physical and transition risks

- **EC (2019): double feedback between climate change, the economy and finance**
- So far, research and financial supervision analysed the impact of climate change on the economy and finance
- But the opposite feedback, i.e. **how investors (via financial risk assessment) influence firms' investments** and the realization of climate scenarios, is still largely unexplored.
- To do so, we need macrofinancial models that embed the interplay between finance and economic agents: **dynamic balance sheet assessment**



Source: EC (2019), Oman and Svartzman (2021)

Double materiality of climate risks: a dynamic balance sheet assessment

- We tailor the **EIRIN macrofinancial model endogenizing Network for Greening the Financial System (NGFS) scenarios** (e.g. carbon price trajectories)
- **EIRIN is a Stock-Flow Consistent (SFC) behavioral model** with heterogeneous agents and sectors of the econ. and finance, interconnected in a balance sheet network
- **Advantages** for climate financial risk assessment:
  - **Analyse shock entry point and transmission channels** to econ and finance, including **indirect and cascading impacts** that can amplify losses
  - **Embed finance** and its financial risk assessment, and connect it to firms’ low/high-carbon investment decisions, decarbonization, financial risk
  - Consider agents’ adaptive expectations to analyze **investors’ sentiments.**
- ***First time of a supervisory (ECB collaboration) application of a SFC model***

Modelling the double materiality in EIRIN

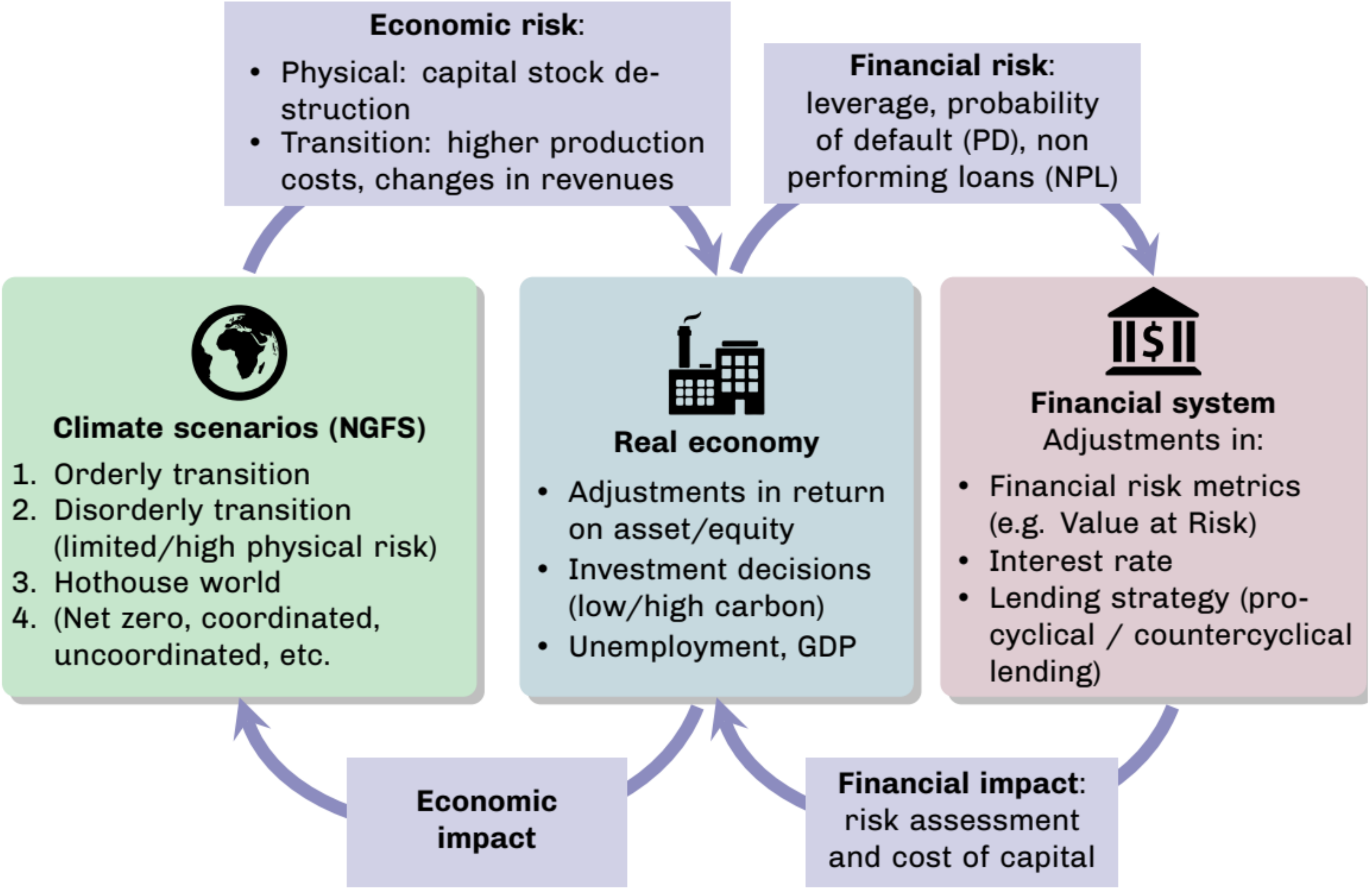
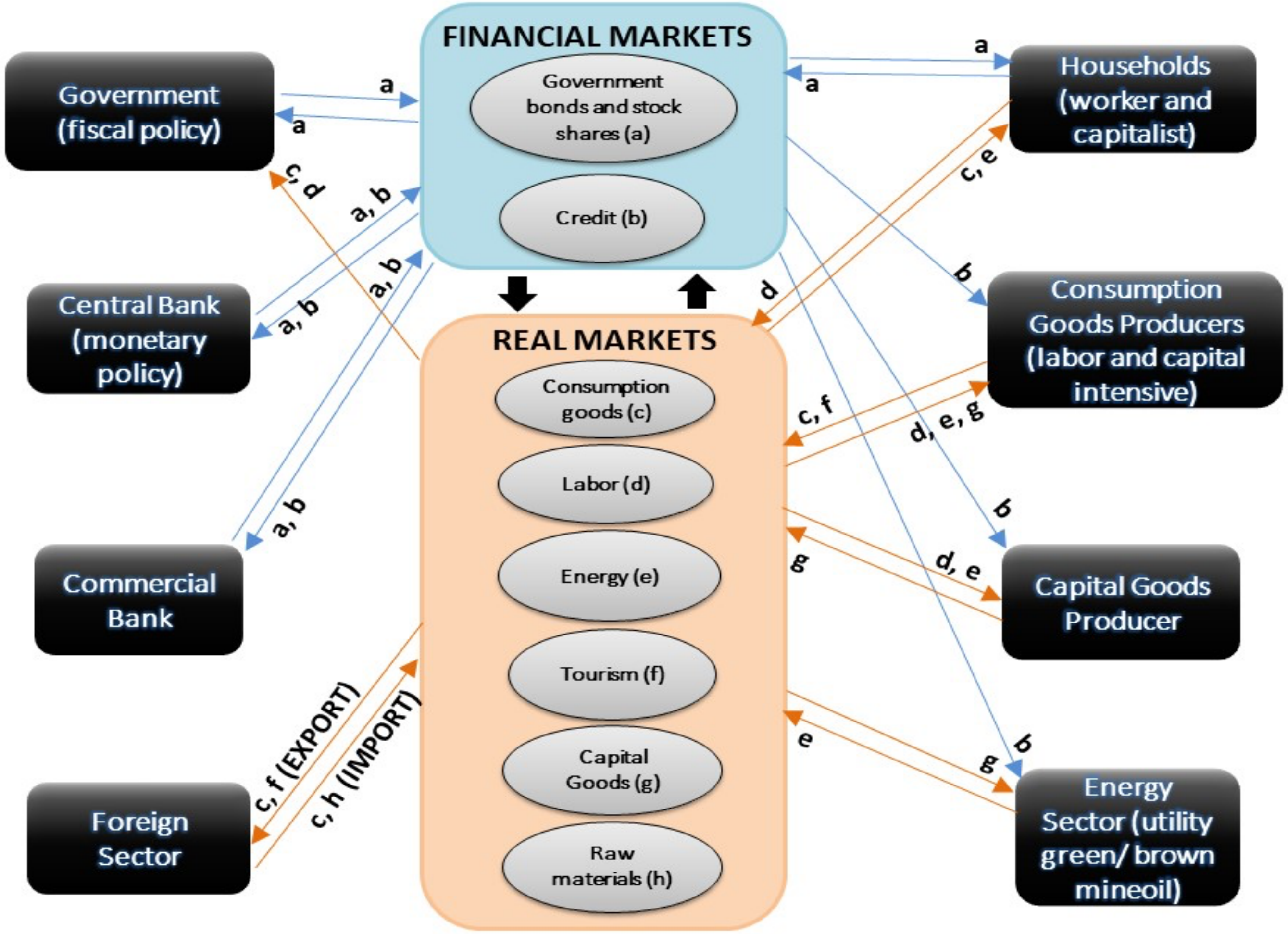


Fig 1: how the concept of double materiality of climate risks is implemented in the EIRIN model, and the respective macro-financial feedbacks. Source: Gourdel ea (2022).

The EIRIN macro-financial model



Legend:

a) *Government bonds and stock shares' market*

b) *Credit market*

c) *Consumption goods market*

d) *Labor market*

e) *Energy market*

f) *Tourism market*

g) *Capital goods market*

h) *Raw materials' market*

→ *supply*

← *demand*

Black boxes*: heterogenous agents and sectors*

Blue box*: financial markets*

Orange box*: real markets.*

Agents and sectors interact through real and financial markets.

Outgoing arrows: supply. Incoming arrows: demand

EIRIN framework

- Each agent and sector represented by balance sheet entries.
- Equilibrium conditions substituted by accounting identities that hold irrespective of behavioural assumptions

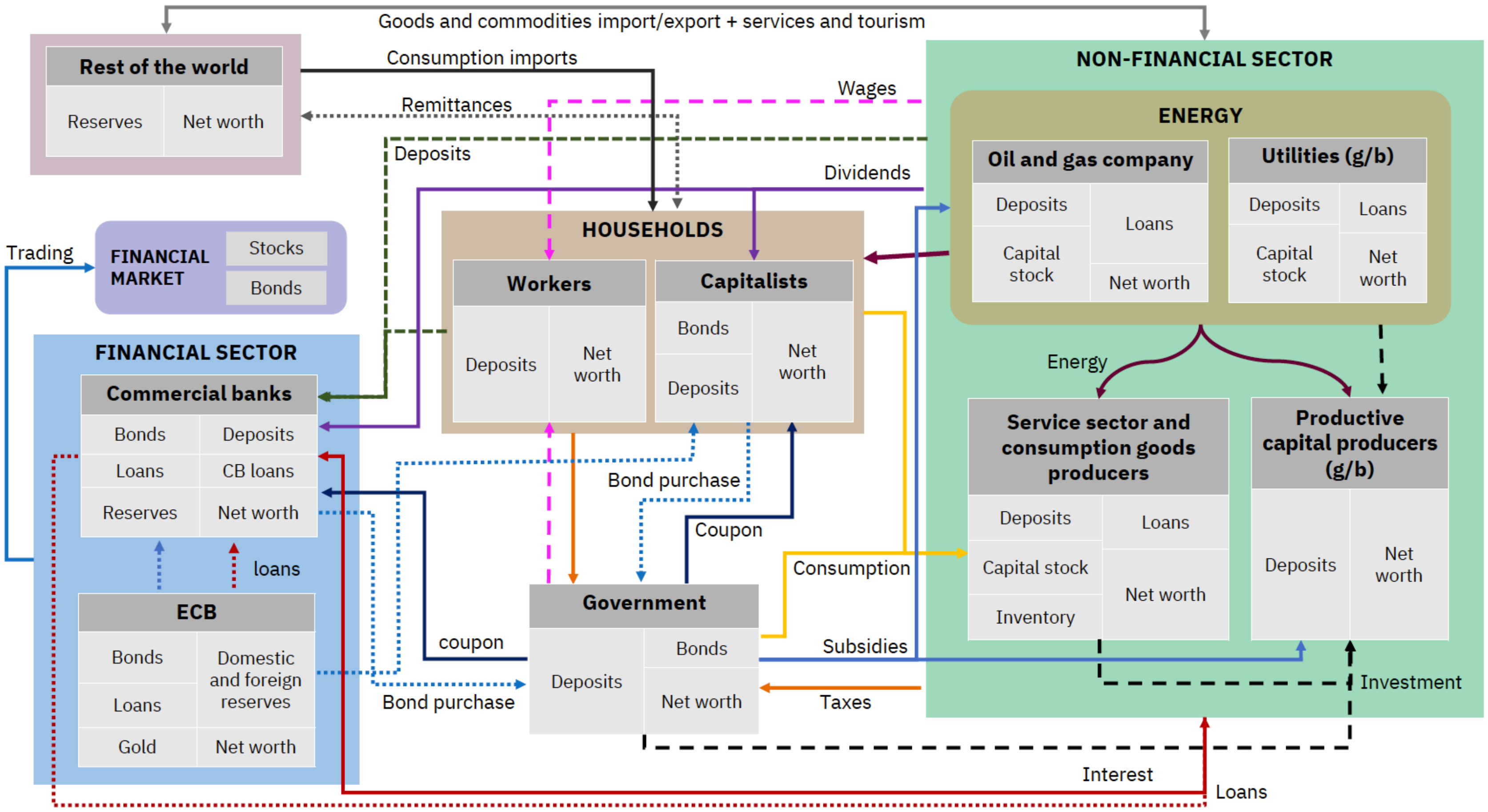


Figure: EIRIN framework: **capital** (dotted) and **current** (solid) account flows. Source: Gourdel ea (2022)

Endogenous investments decisions: Net Present Value (NPV)

NPV to compare expected discounted cash flows (sector-specific) with investment cost. NPV sign determines whether the agent makes the investment decision.

$$NPV_j(\iota, t) = -p_{capital}(t) \cdot \iota + \sum_{s=t+1}^{+\infty} \frac{CF_j(\iota, t, s)}{\left(1+\kappa_j\right)^{s-t}}$$

$$CF_j = \frac{\hat{p}_j \times \Delta\hat{q}_j}{1+\tau_{VAT}(t)} - \widehat{w_j} \times \Delta N_j - p_R \times \Delta\hat{q}_{R,j} - \hat{p}_{EN} \times \Delta\hat{q}_{EN,j} - \Delta\widehat{Em_j} \times \tau_{\mathrm{Em}}$$

5 cash flows to compare costs and long-term benefits of investment:

- 1 Positive cash flow given by the additional sales due to investment.
- 4 negative:
  - i. additional labour costs for increased production capacity,
  - ii. additional raw materials costs to produce the additional output,
  - iii. additional energy consumption for producing additional output,
  - iv. additional taxes on GHG emissions from the use of capital and energy consumption.

Credit market

1. **Level of credit**: Economic sectors partially rely on credit to finance investments (incl. disaster reconstruction). Maximum bank credit supply set by its equity level E_{BA} divided by the parameter $\widetilde{CAR}$.

- Demand for new credit $\boldsymbol{D}_{BA}(t)$ and previous credit level $\mathbf{L}(t-1)$: additional credit that the bank can provide at each time step is given by its maximum supply, minus the amount of loans outstanding :

$$\Delta^{+}\mathbf{L} = \min\left\{\mathbf{D}_{\mathsf{BA}}(t), \frac{E_{\mathsf{BA}}(t-1)}{\widetilde{\mathrm{CAR}}} - \mathbf{L}(t-1)\right\}$$

2. **Cost of credit**: Banks set sector-specific interest rates depending on PD determined by sectors' leverage, ROA, sector-specific coefficients.

Let $v(t)$ be the risk free interest rate, which is the sum of policy rate and banks' net interest margin. Given the annualized $PD_i(t)$ of sector i, we determine the objective loan interest rate $\hat{k}_i$:

$$\underbrace{\hat{k}_i(t) - \mathrm{v}(t)}_{\text{Credit spread}} = PD_i(t) \times (1 - \mathcal{R}_i)$$

where $\mathcal{R}_i$ is the (constant) expected recovery rate of i

13

Sectoral default probabilities (PD)

PDs are computed based on Alogoskoufis et al. (2021):.

$$\mathrm{PD}_i = \alpha + \beta_1 \Delta^{\%}\mathrm{ROA}_i + \beta_2 \mathrm{Leverage}_i + \beta_3 \ln(\mathrm{GDP}) + \beta_4 \ln(\mathrm{GDP})^2 + \mathrm{GICS}_i + \varepsilon_i$$

where $\Delta^{\%}$ denotes the growth operator, ROA, GICSi is a sector specific constant and ε_i is the error term.

PDs are determined by:

- Macroeconomic variables (GDP)
- Sectoral variables (Leverage and ROA)

*NB: GDP, Leverage and ROA are **endogenous** variables in EIRIN. Thus, the evolution of sectoral PDs is also endogenous and affected by the direct and indirect impacts related to the climate scenarios and to the banks and firms' sentiments.*

Firms’ climate sentiments

- Investments by consumption goods and service sector in low/high carbon capital are function of expected returns (NPV)
- We model firms’ climate sentiment as foresight of carbon price anticipation, which affects NPV and thus investment in low/high carbon capital.
- **By internalizing future carbon prices across NGFS trajectories earlier in their NPV, firms carry out their investment decisions based on longer time span (e.g., 10, 20 or 30 years): firms can prepare and smooth the low-carbon transition.**
- This is achieved by adjusting the value of the carbon tax in the NPV according to NGFS trajectories, projecting *u* periods in advance:

$$\Delta\widehat{Emi}(s)\times\tau_{GHG}(t) \rightarrow \Delta\widehat{Emi}(s)\times\tau_{GHG}(t+u)$$

Calibration

	Simulation values		Real values	
	Mean observation	Standard deviation	Mean observation	Standard deviation
Real GDP growth (in percentage points)	1.57	0.01	1.88	0.41
Exports of goods and commodities (% of GDP)	33.11	0.01	33.80	0.66
Exports of services (% of GDP)	11.94	0.00	12.75	0.86
Revenues from tourism (% of GDP)	2.56	0.00	2.38	0.20
Total imports (% of GDP)	44.86	0.04	42.50	1.63
Inflation (in percentage points)	1.41	0.01	0.88	0.71
Lending rate from the commercial bank (in percentage points)	2.14	0.01	2.32	0.43
Main refinancing operations rate (in percentage points)	-0.26	0.01	0.02	0.03
Total government expenditures (% of GDP)	50.44	0.18	47.72	0.97
Total government revenues (% of GDP)	50.53	0.10	46.40	0.21
Level of the public debt (% of GDP)	53.78	2.15	88.35	3.44
Net remittances received (% of GDP)	-0.04	0.00	-0.03	0.00
Value added of the energy sector (% of GDP)	8.10	0.13	2.36	0.03
Value added of the consumption goods sector (% of GDP)	34.88	0.04	17.24	0.11
Value added of the service sector (% of GDP)	61.44	0.23	70.58	0.18
Value added of the intermediary goods producers (% of GDP)	7.37	0.11	9.53	0.10
Value added of the oil and mining sector (% of GDP)	0.92	0.01	0.29	0.00
Share of employees in the consumption goods sector (% of total employees)	12.76	0.02	13.98	0.13
Share of employees in the service sector (% of total employees)	64.57	0.19	55.67	0.20
Share of employees in the intermediary goods production sector (% of total employees)	6.47	0.15	5.39	0.05
Share of employees in the oil and mining sector (% of total employees)	0.67	0.01	0.10	0.00
Share of unemployment (% of total workforce)	3.42	0.15	9.58	1.56
Share of labour in the total income of labour and capital (in percentage points)	73.90	0.29	88.88	0.24
Social benefits (transferred to households, % of GDP)	13.76	0.05	18.89	0.31
Disposable incomes of households (% of GDP)	78.02	0.23	56.89	0.58
Firms' total credit (% of GDP)	49.17	1.56	82.18	1.84
Total investments (% of GDP)	16.15	0.23	21.08	0.88
Energy consumption share of the consumption goods sector (% of total energy demand)	0.05	0.00	0.10	0.00
Energy consumption share of the service sector (% of total energy demand)	0.37	0.01	0.48	0.00
Energy consumption share of households (% of total energy demand)	0.45	0.01	0.26	0.00
Energy consumption share of the capital producers (% of total energy demand)	0.11	0.00	0.16	0.00
Share of renewable energy (% of total energy consumption)	19.48	0.01	17.14	0.93
Energy bill of households (% of GDP)	4.00	0.00	2.10	0.13
Share of households' expenses in energy (% of disposable income)	5.12	0.01	3.97	0.15
Share of GHG emissions of the energy sector (% of total emissions)	0.24	0.00	0.22	0.01
Share of GHG emissions of the consumptio goods sector (% of total emissions)	0.04	0.00	0.05	0.00
Share of GHG emissions of the service sector (% of total emissions)	0.37	0.00	0.32	0.01
Share of GHG emissions of households (% of total emissions)	0.21	0.00	0.22	0.00
Share of GHG emissions of capital producers (% of total emissions)	0.13	0.00	0.18	0.00
Share of GHG emissions of the mining sector (% of total emissions)	0.01	0.00	0.01	0.00
Revenues generated from the carbon tax (% of GDP)	0.08	0.00	0.08	0.00

Table: Calibration of the EIRIN model. Comparison of simulated variables compared to the target real values, displayed as the mean of observed data over a time span of 10 years.

- We initialize, calibrate and empirically validate EIRIN to euro area data to ensure that the shocks' dimensions are quantitatively meaningful (Eurostat, ECB data warehouse, OECD data)
- First, we considers parameters that appear explicitly in the model dynamics and are also observable from data (e.g. tax rates)
- Second, we set "free" parameters that cannot be observed directly, to allow other endogenously produced values to match observed data (e.g. GDP growth rate). **This allows us to ensure that the modelled economy replicates indicators observed in the reality.**

NGFS scenarios

EIRIN-NGFS scenarios

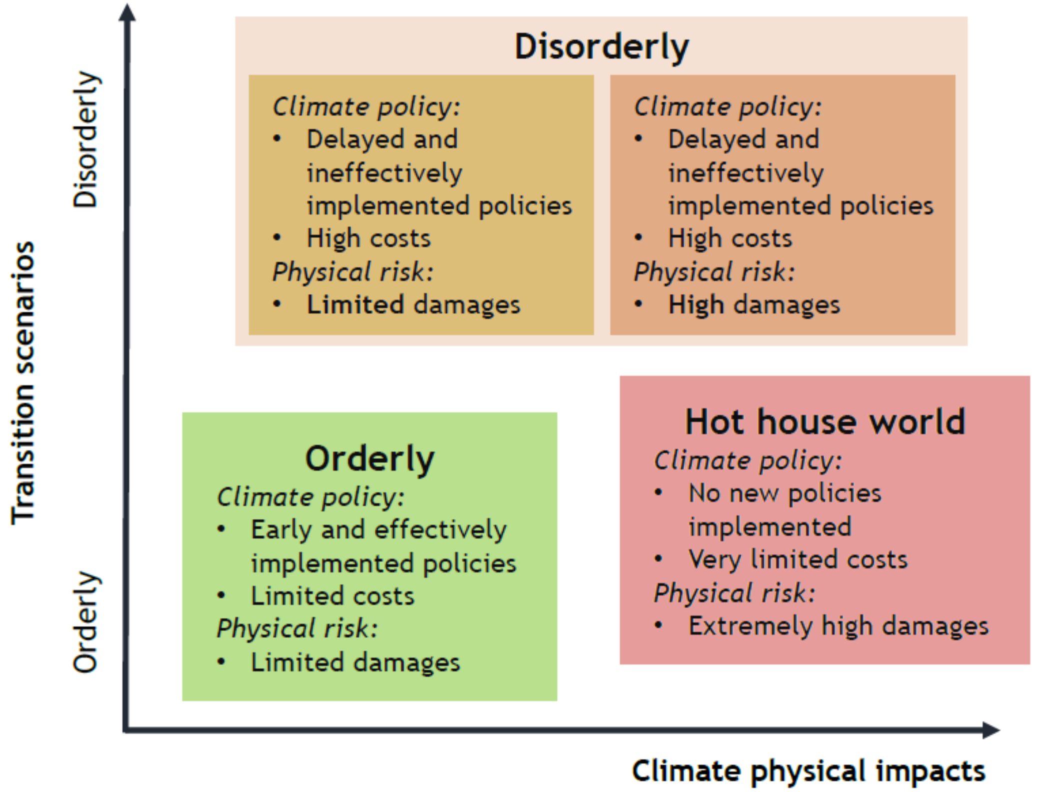


Figure: EIRIN-NGFS scenarios. The x-axis indicates the strength of physical risk, and the y-axis gives the steepness of the climate policies. Source: Gourdel ea (2022).

- Following Alogoskoufis et al. (2021), we design 4 scenarios characterized by different climate policy targets and design and climate physical impacts.
- All scenarios are run until 2050.
- Physical impacts differ after 2025 across scenarios, given inertia and a delayed response to emission reductions in the climate system.

Carbon price from NGFS scenarios

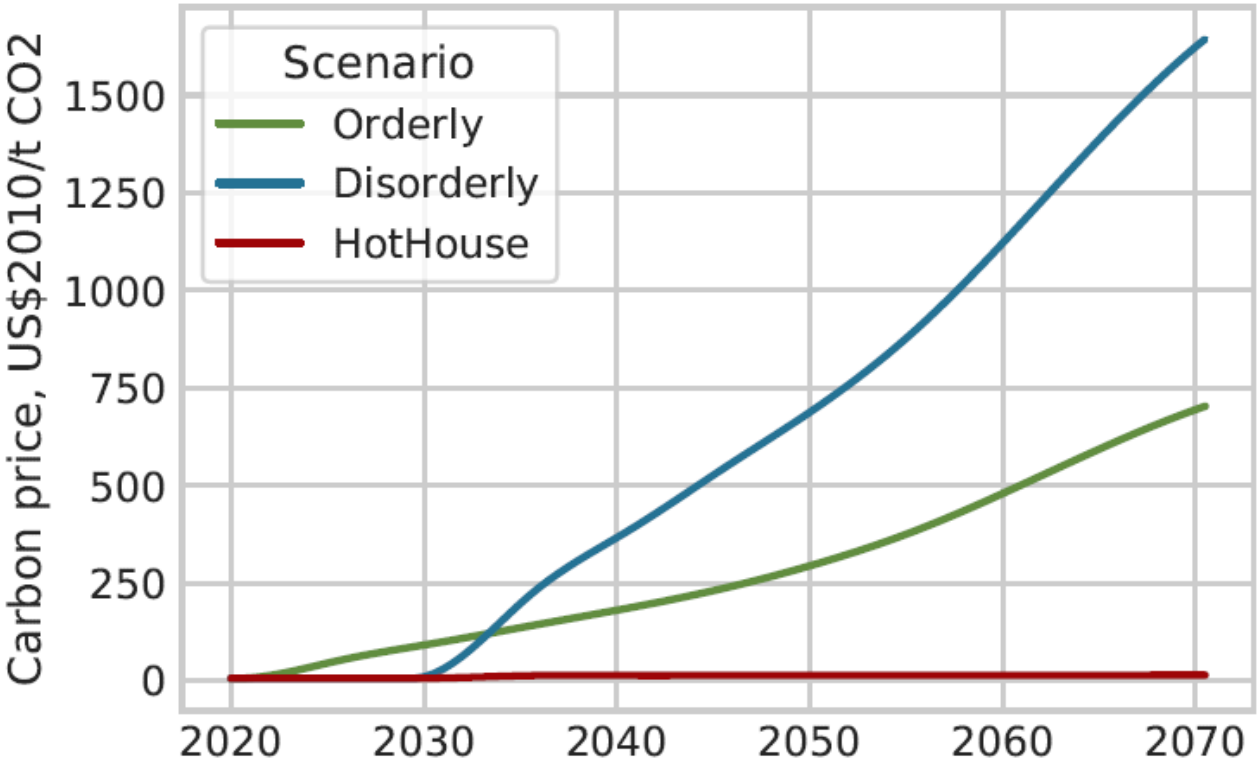
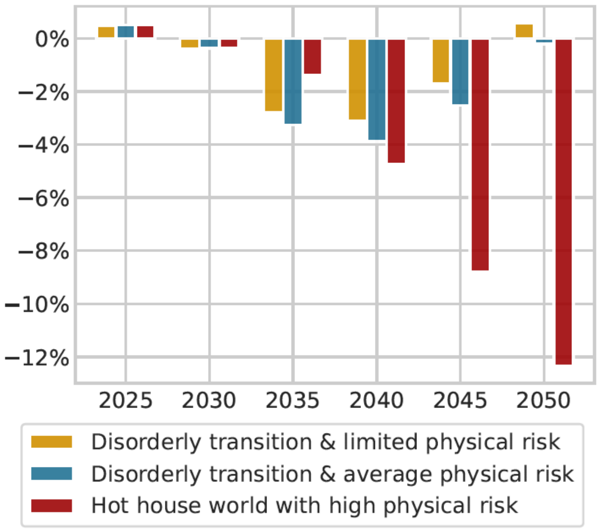


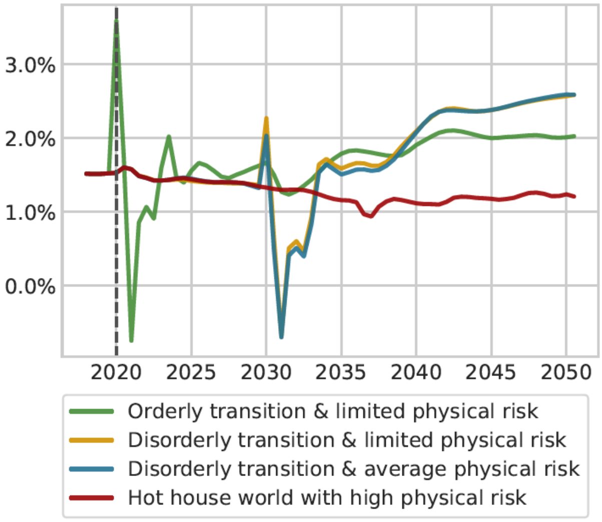
Figure: Carbon price trajectories from NGFS scenarios. Scenarios generated by REMIND-MAgPIE 1.7-3.0, where orderly corresponds to "Immediate 1.5° C with CDR", disorderly to "Delayed 2° C with limited CDR" and hot house to "Current policies". Values are interpolated from a 5 years to a 6 months period. Source: Gourdel ea (2022).

Results

Results: Real GDP



(A) Real GDP comparison to the orderly transition scenario



(B) Yearly growth of GDP

***Figures: Real GDP**. The x-axis displays the simulation time. The y-axis shows (i) the real GDP, compared to the orderly transition scenario and (ii) the yearly growth rate of real GDP in percentage points.*

- **Orderly**: short-term costs to economic growth, but significant co-benefits in mid to long term periods.
- **Disorderly**: Lower economic output than orderly but larger trade-off for growth.
- ***Hothouse world:*** *limited economic impact*. Impacts from physical risks increase over time. Capital has to be replaced frequently, driving up investment, financing needs, firms' leverage.
- **But risky scenarios still missing in NGFS framework, and so are large economic and financial impacts.**

GHG emissions

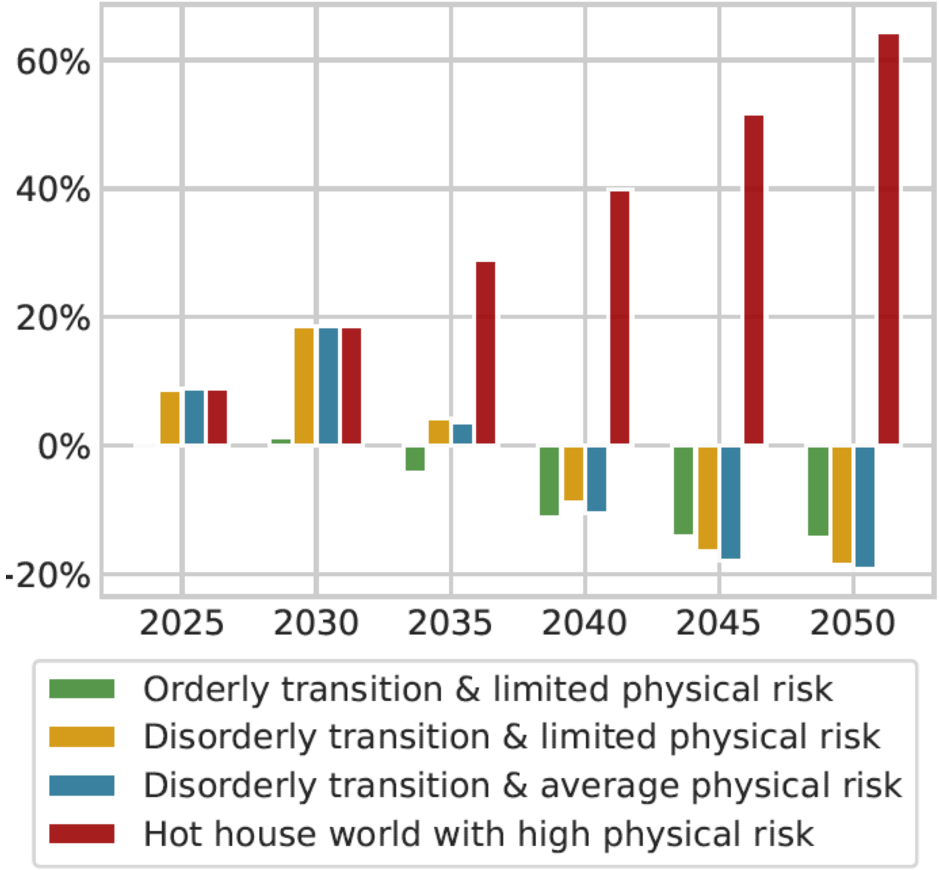


Figure: Additional GHG emissions compared to the initial value*. The x-axis displays simulation time. The y-axis shows the total GHG emissions at each semester, indexed at 100 in 2020.*

- **Orderly**: The large share of the emissions reduction is due to the change in energy production, showing the earliest GHG emission decrease. Decoupling of emissions from GDP growth takes place, as GDP grows but GHG emissions are contained.
- **Disorderly**: emissions start decreasing after 2030 and the reduction is more abrupt with respect to the orderly scenario; GHG emissions smoothed due to early and gradual transition to renewable energy.
- **Hothouse world**: constant share of renewable energies under the HHW scenario leads to increase of emissions over the whole simulation time span, as no climate-policies are implemented.

Share of renewable energy

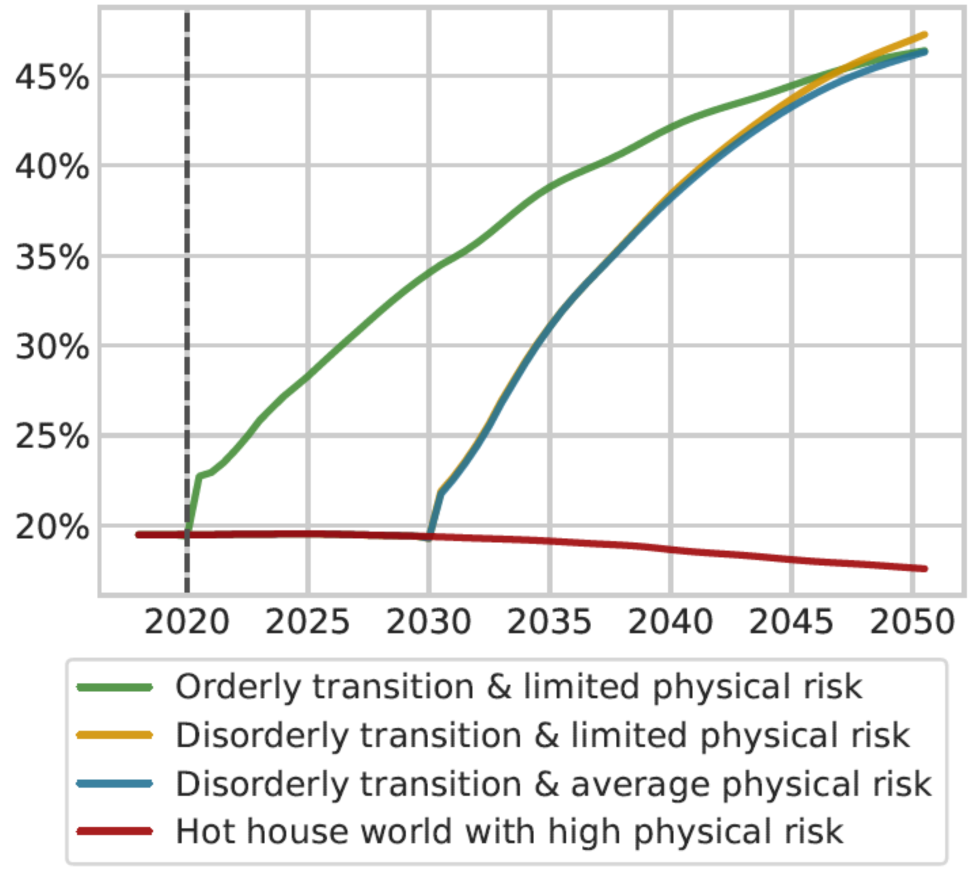
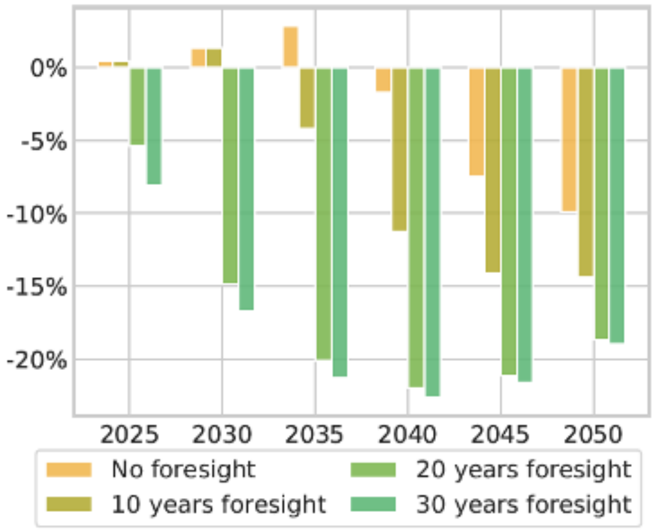


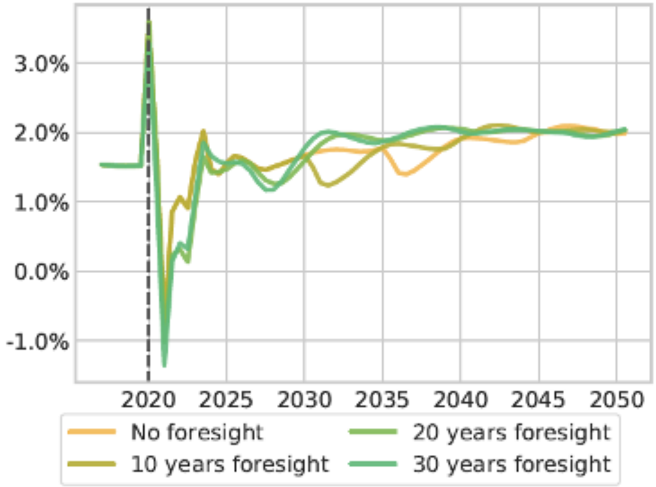
Figure: Ratio of renewable energy in the energy mix. *The x-axis displays the simulation time. The y-axis shows the share of renewable energy, as a percentage of supply from renewable energy over the total energy mix at each period. Source: Gourdel ea (2022)*

- **Orderly**: Transition starts in 2020 and increase of ratio of renewable energy over total energy mix is gradual, leading to lower financial spillovers.
- **Disorderly**: the increase in renewable energy is sudden and materializes later, leading to abrupt adjustments in other sectors (yet tamed by model's endogenous constraints to energy sector adjustment).
- **Hothouse world:** constant share of renewable energies under the scenario.

Firms’ sentiments: anticipation of carbon pricing



(A) Emissions added to initial level



(B) Yearly GDP growth

Figure: Simulation results of the orderly transition scenarios conditioned to firms’ foresight.*The x-axis displays the simulation time. The y-axis shows (i) the emissions through time, calculated as the quantity added to that of the 2020 level (left panel) and (ii) the GDP growth.*

- We study four variations of orderly scenario where consumption goods producer and service sector have a **different degree of foresight**, i.e. 10 years, 20 years, and 30 years of carbon price anticipation.
- When firms internalize future carbon prices earlier in their NPV, they smooth transition to green capital, with no negative impact on growth or unemployment.
- **The higher firms’ anticipation, the faster the larger the fall in total GHG emissions and the smoother the energy transition**

Conclusion

- We assess the double materiality of climate risks in the euro area economy and banking sector:
  - **Orderly** transition has co-benefits (GDP, emissions, financial stability) early.
  - **Disoderly** transition can lead to constrains on firms’ investments with potential implications on firms and banks’ financial stability.
  - **Hothouse world**: cost of inaction (GDP, emissions, banks’ financial stablity).

- Message 1: Neglecting the finance-economy feedback can lead to miss endogenous dynamics that could determine the success of the transition (firms’ sentiments) and financial stability
- **Message 2: where are large shocks from HHW? Lost in scenarios:** need to strengthen NGFS scenarios’ representation of physical risks by adding acute shocks and their compounding (Ranger ea 2022)

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Appendix

Risk transmission channels

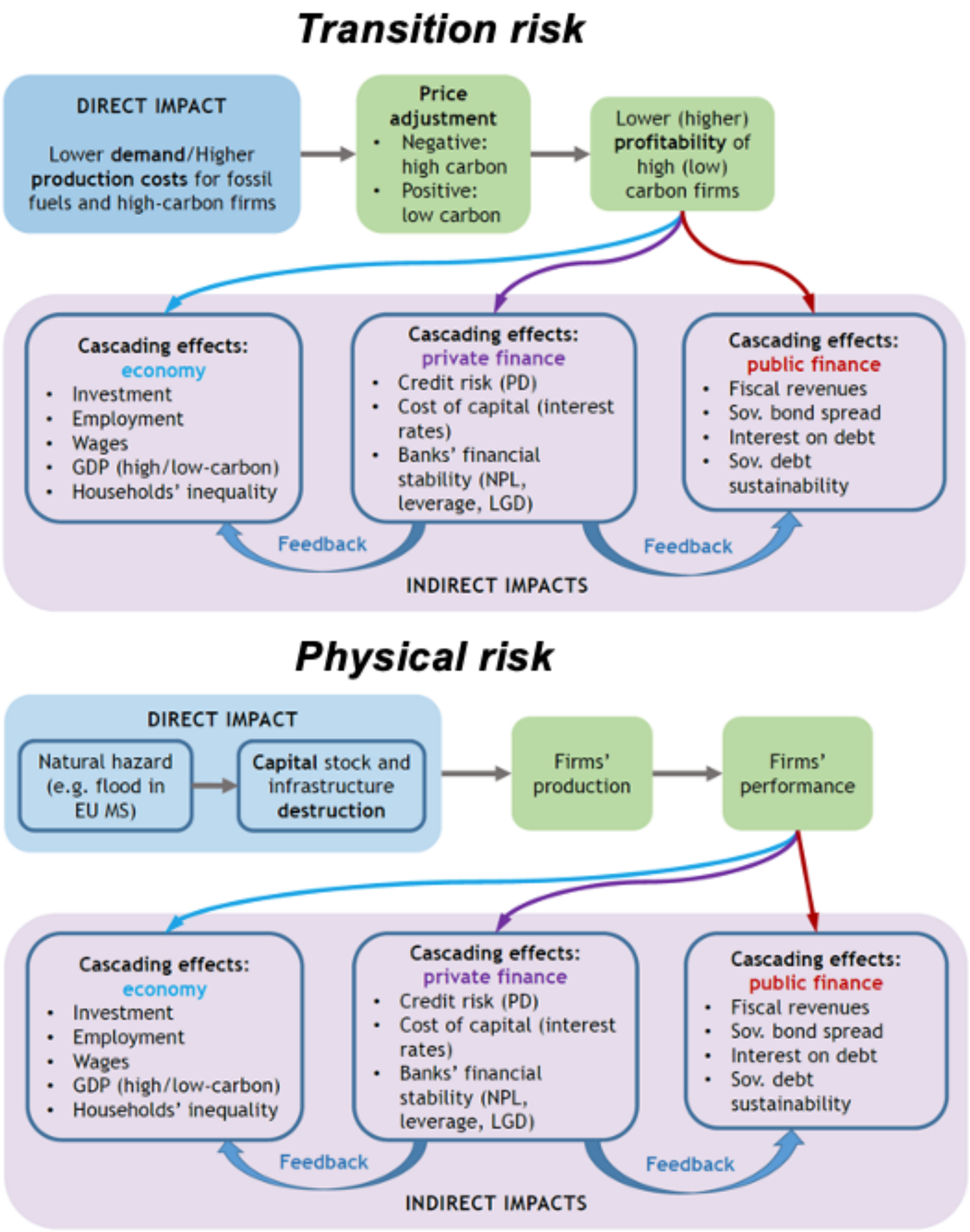


Figure: Channels of transmission of climate transition risks to the economy and finance. The figure shows the entry point, the direct and indirect impacts of climate transition risk (top) and physical risk (bottom) in the EIRIN economy. Source: Gourdel ea (2022)

EIRIN: main characteristics

- **Agents' heterogeneity**: capitalist/worker households (Goodwin 1967), dirty/green sectors
- **Real and monetary flows** (endog. money)
  - Central Bank sets the interest rate according to a Taylor-like rule
  - Banks subject to Regulatory Capital Adequacy Ratio (CAR) (Basel III)
- **Leontief** production function (Capital, Labor, Raw Material, Energy)
- **Firms' portfolio choice** (labour/capital intensive, debt financing):
  - No perfect substitution: different relative prices and technology cost
- *Focus on credit and bonds' markets, banks, ECB as financial actors.*

- **Agents' adaptive expectations** in the context of deep uncertainty
- **Behavioural rules**:
  - Households' saving/consumption (**Deaton's Buffer-Stock Theory): *maximize their ability to consume in the future***
  - Firms' investment decision are endogenous, based on **Net Present Value (NPV): *optimize their expected return***

- *EIRIN translates financial actors' expectations towards climate and policy scenarios into revision of their risk assessment and thus of cost of capital for firms, which in turn affects the feasibility of transition scenarios*

Revenues and expenditures of climate policies

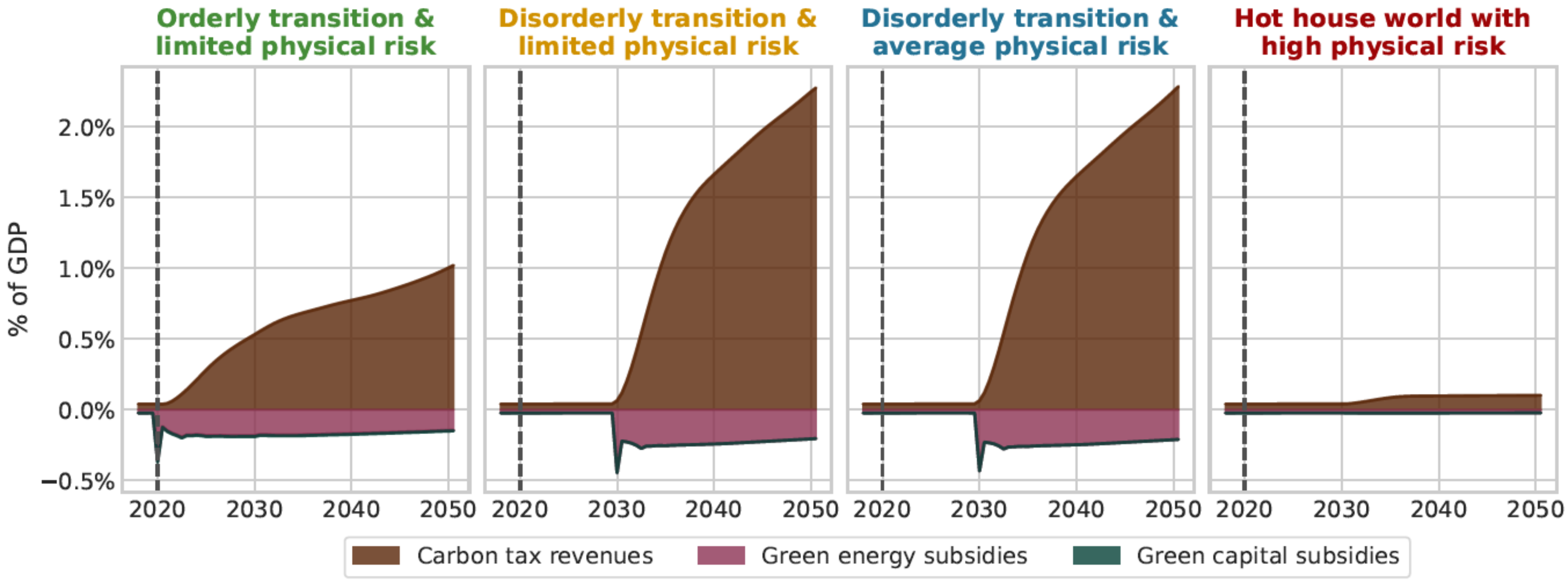


Figure: Nominal revenues and expenditures from climate policies, as a share to GDP. *The x-axis displays the simulation timeline and the y-axis displays the climate policies budgets as ratios to GDP. Policies include the carbon tax, the subsidies to renewable energy, and the subsidies to green capital. Note that the GDP differs across scenarios..*

Physical damage

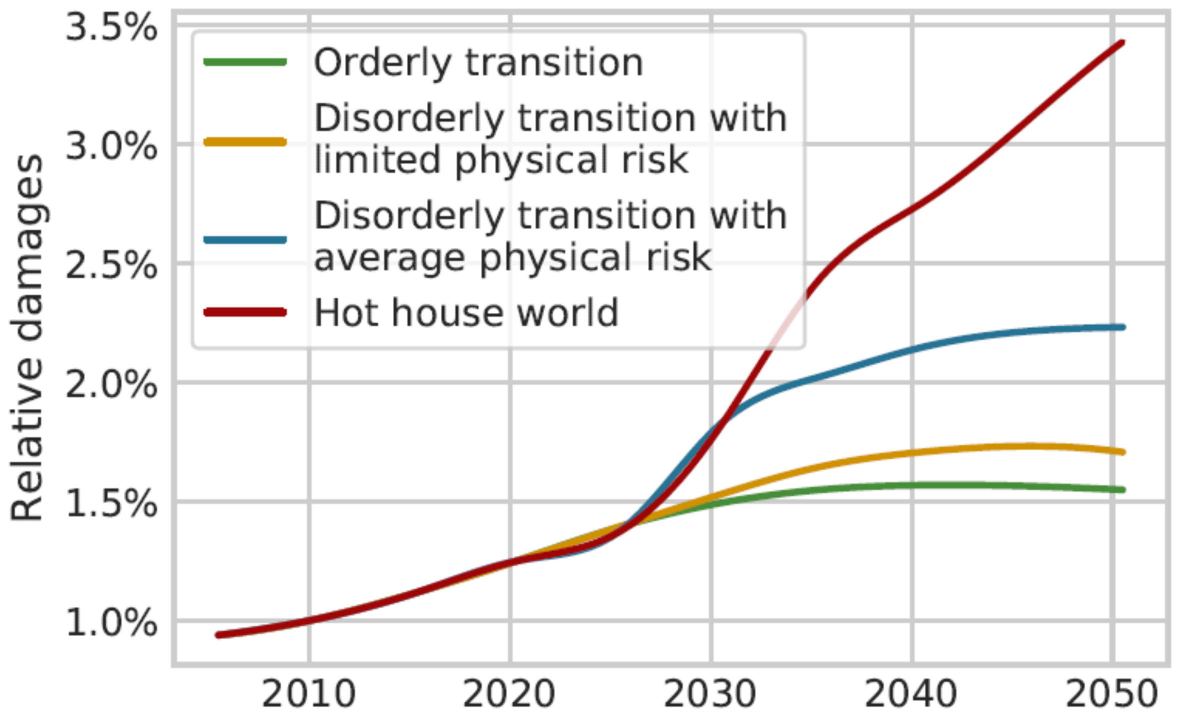


Figure: Physical risk trajectories across scenarios*. The x-axis displays the simulation time, while the y-axis shows the share of capital affected by physical damages at each period and that is used as an input in the model.*

Banking sector and credit cost

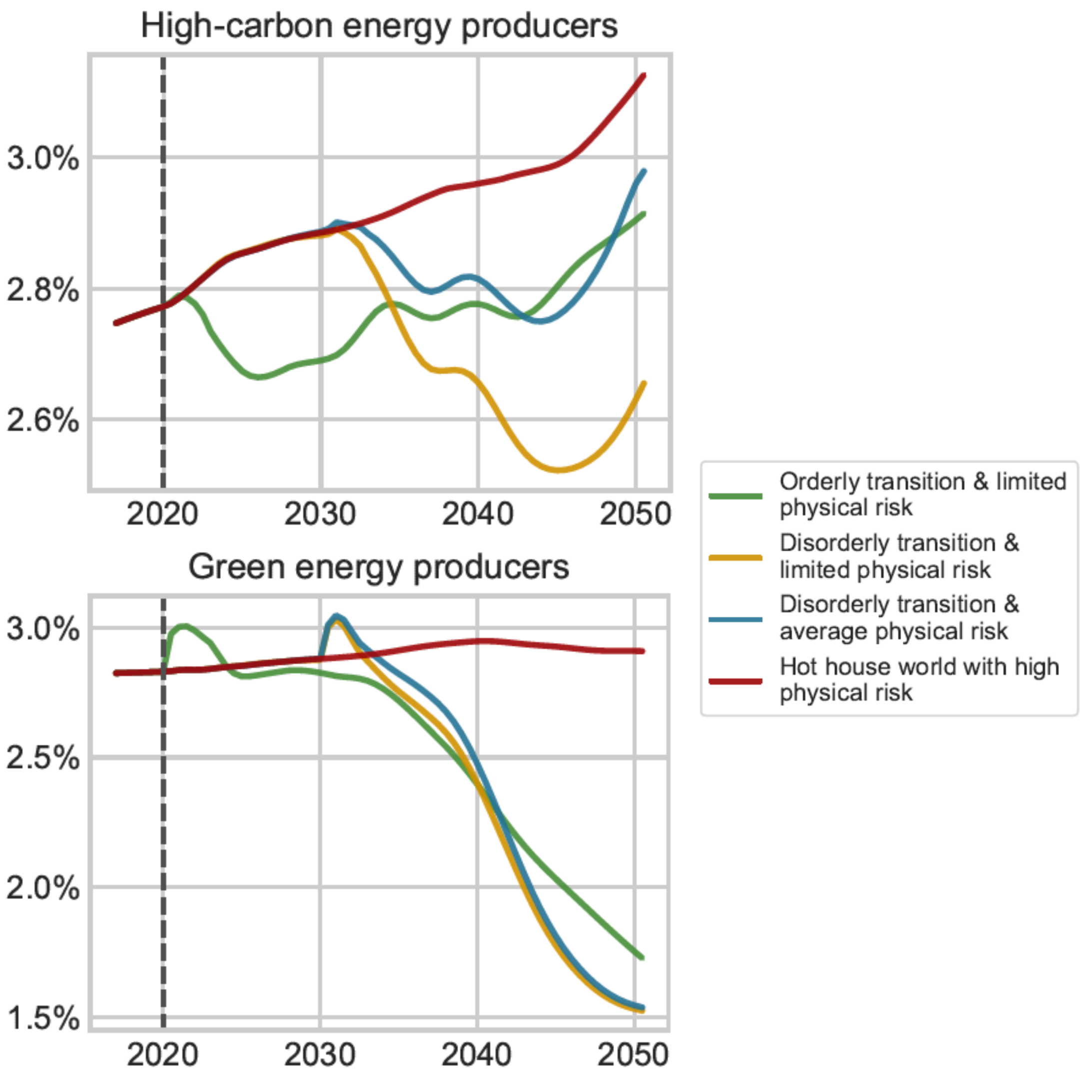


***Figure: Sectoral interest rates on loans**. The x-axis displays the simulation time. The y-axis shows interest rate of the fossil energy producer (top panel) and of the green energy producer (bottom panel).*

- **Orderly**: Cost of credit decreases for *fossil energy producer* due to deleveraging (low capital replacement, low demand), which couteracts a reduced profitability. Interest rate of *green energy producer* increases when transition starts (2020) due to the higher leverage driven by investment in green capital but drop a few years after the introduction of climate policies.

- **Disorderly**: Interest rate dynamics are similar to the orderly scenarios, but more volatile (abrupt).

- **Hothouse world:** Cost of credit increases both for the fossil energy producer and green energy producer, due to the higher leverage driven by higher credit demand to replace destroyed capital, which increases the probability of default, and, thus, the cost of credit.

Sectoral interest rates increase

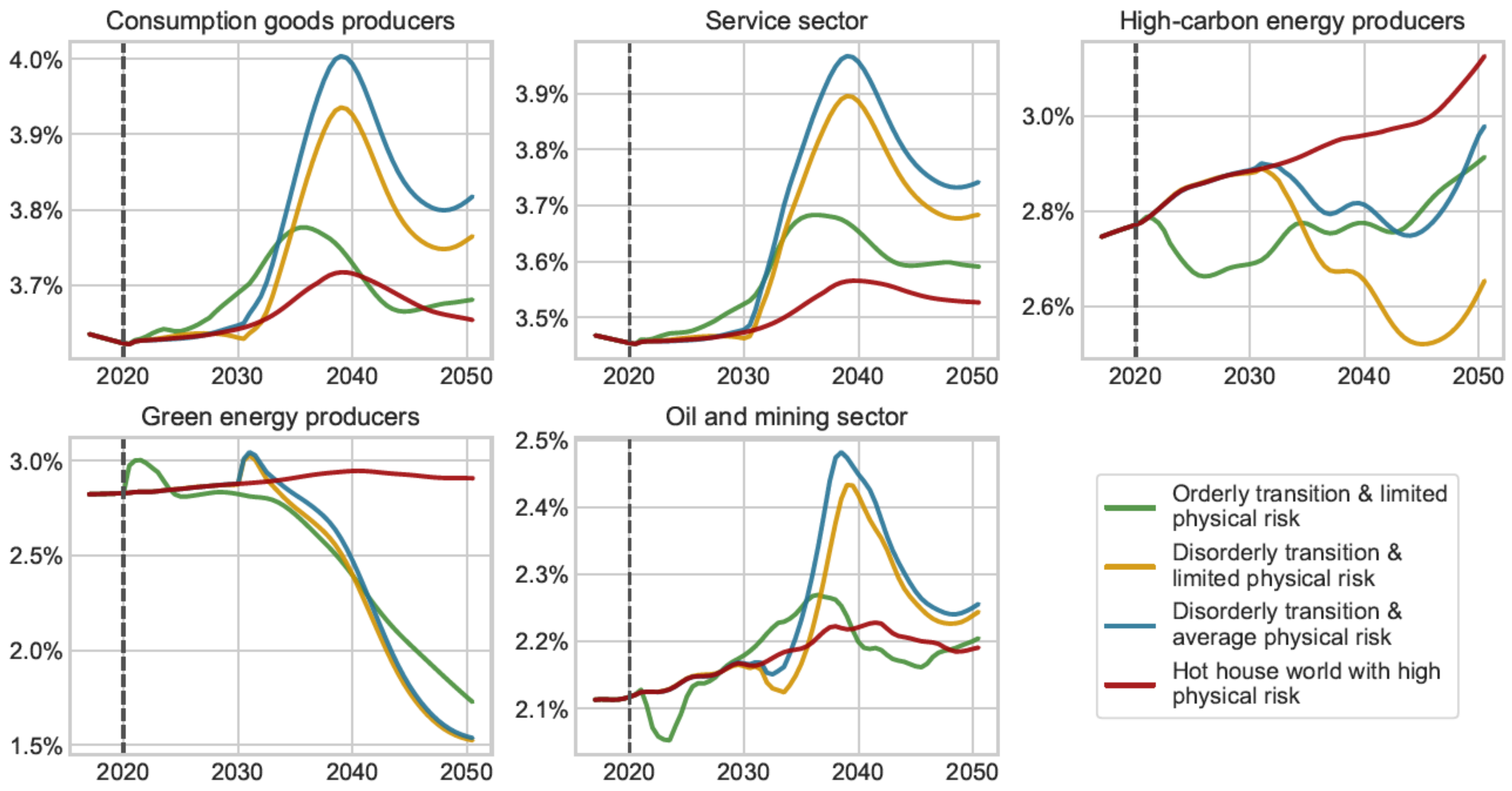
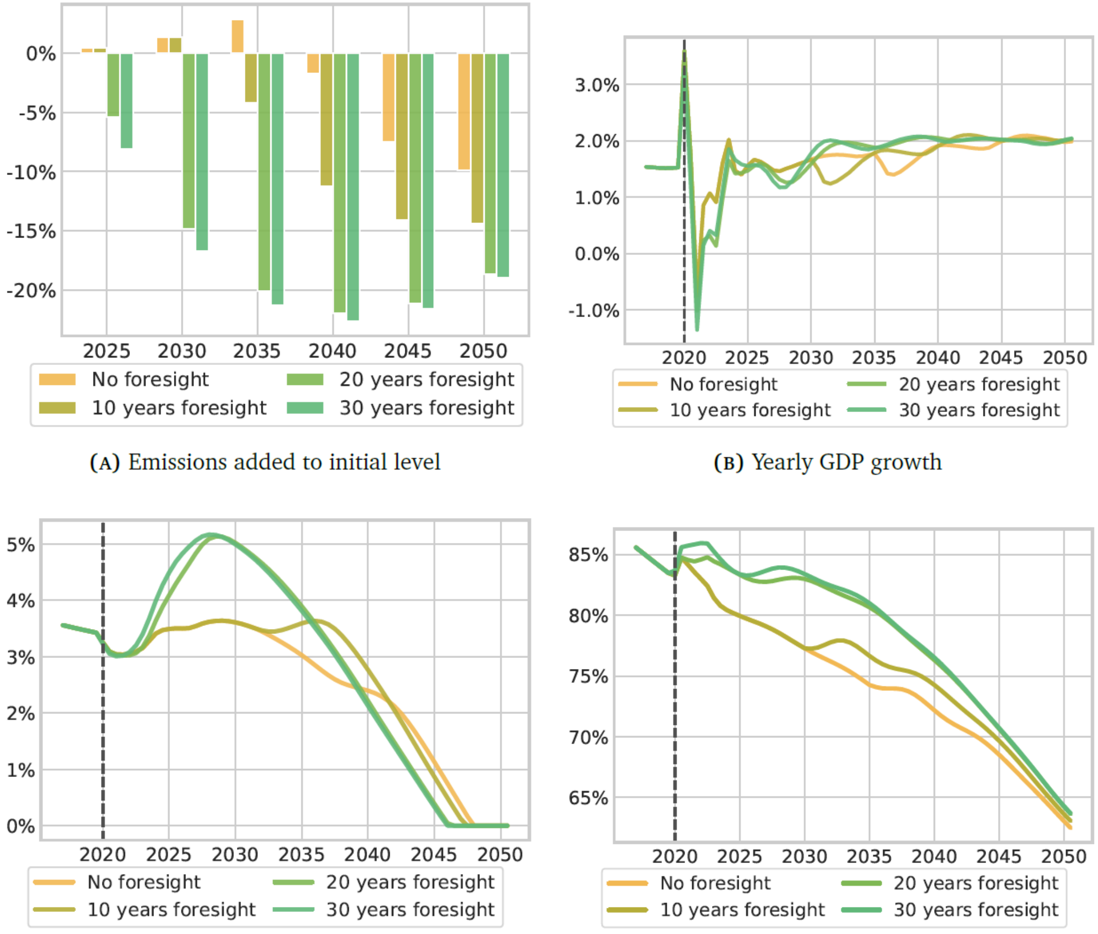


***Figure: Interest rates for real economy firms**. In each panel, the x-axis displays the simulation time, and the y-axis displays the interest rates (in percentage points) that firms pay on their loans in each period.*

Firms’ climate sentiments



(A) Emissions added to initial level

(B) Yearly GDP growth

(C) Unemployment

(D) Credit to GDP

Figure: Simulations results of the orderly transition scenarios conditioned to firms’ foresight. *The x-axis displays the simulation time. In the top left panel, the y-axis displays emissions through time, calculated as the quantity added to that of the 2020 level. In the top right panel, the y-axis represents the GDP growth of the EA economy. In the bottom left panel, the y-axis displays unemployment as a percentage of the total active workforce. In the bottom right panel, values on the y-axis are given as ratios in percentage points of the overall credit granted to GDP.*