The cost and opportunity of climate change: policies for the green transition

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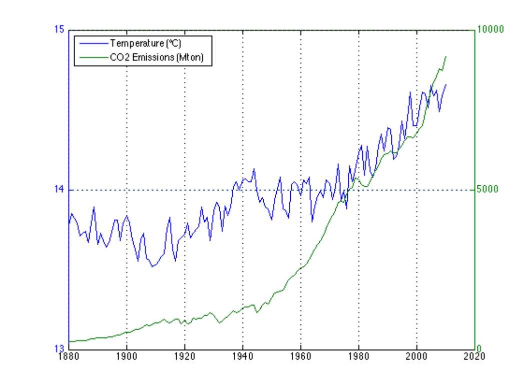
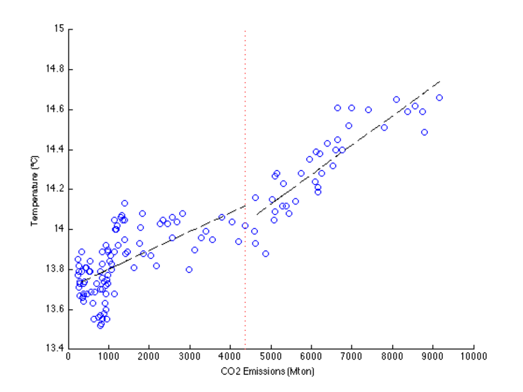
The climate emergency

Emissions and global temperature are on the rise ...



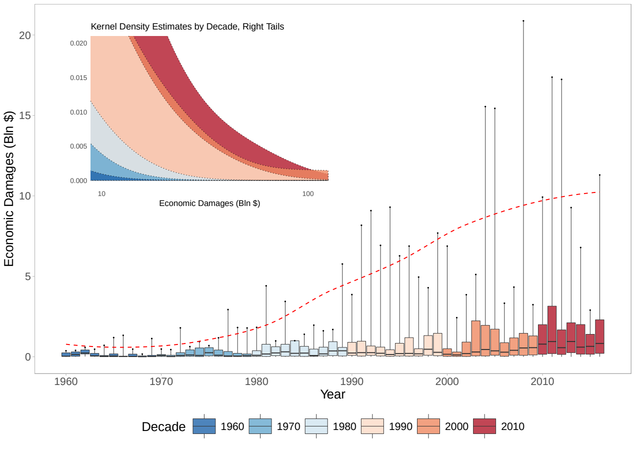
(a) Coevolution of temperature and emissions



(b) Temperature against emissions

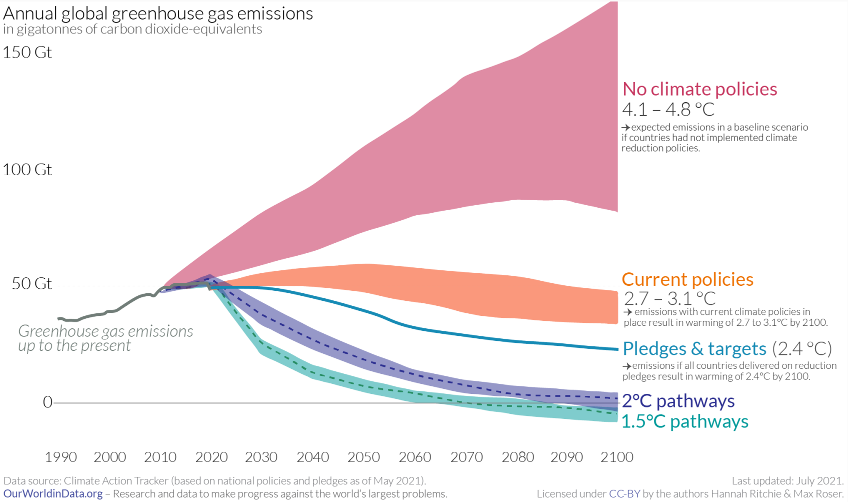
Note: Source: `http://cdiac.ornl.gov`.

… and economic damages of natural disasters are sharply increasing

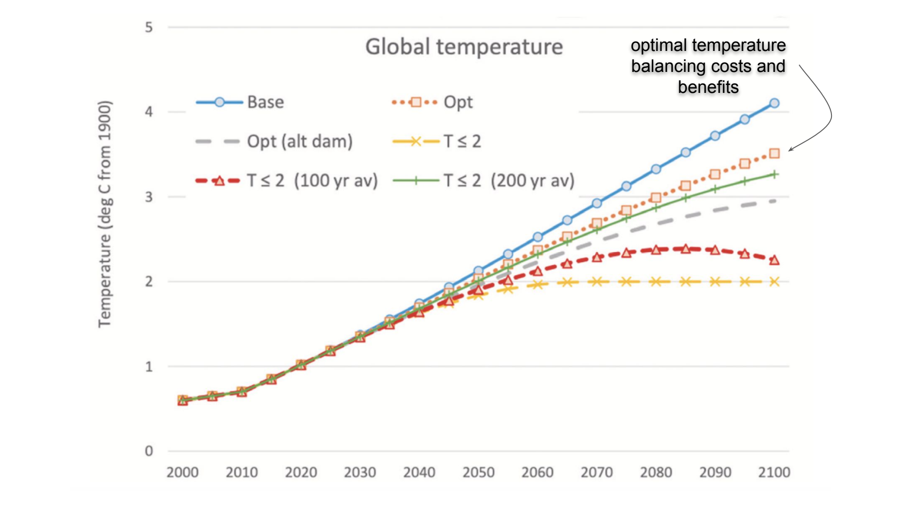


Coronese, M., Lamperti, F., Chiaromonte, F., Keller, K., Roventini, A. (2019). Evidence of sharp increase in the economic damages of naural disasters, PNAS.

The problem with current greenhouse gas emission scenarios...



… and the problem with CGE-based IAMs



Source: Norhaus (2019) - Nobel lecture

Climate change and evolutionary economics

- Climate change poses formidable challenges to mainstream economic modeling
- CGE-based IAMs underestimate the cost of climate-change impacts and the benefits from technical change
- New generations of models grounded on evolutionary and complex-system approaches can jointly account for the salient features of climate change (Balint et al. 2017)
    - deep Knightnian uncertainty
    - learning and innovation
    - structural change
    - path-dependency and lock-in
    - heterogeneity and agents' interactions

Agent Based Models (ABM) seek to provide more-realistic representations of socio-economics by simulating the economy through the interactions of a large number of different agents, on the basis of specific rules. ABMs are widely used in finance, but have yet to be seriously applied to climate change. These are promising developments (Stern, 2016)

The Dystopian Schumpeter Meeting Keynes Model (DSK)

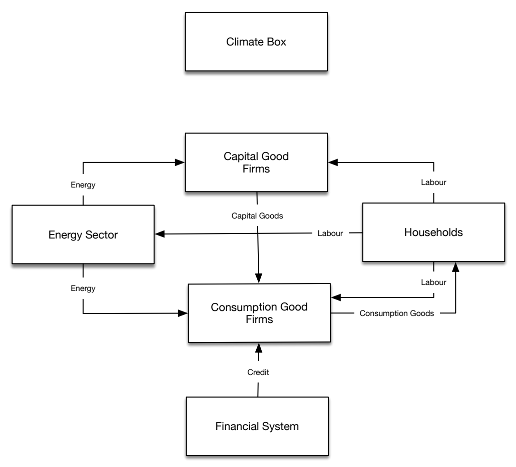
- First attempt to build an integrated assessment **agent-based model**
- **Endogenous** innovation and **technical change**
- **Climate box** with feedback loops and non-linear dynamics
- **Stochastic damage generating function**
- A model for studying coupled **climate/macroeconomic dynamics**
- A laboratory for studying the short- and long-run impact of **different ensembles of policies to achieve temperature targets with sustainable growth**

A Sneak Preview of the Results

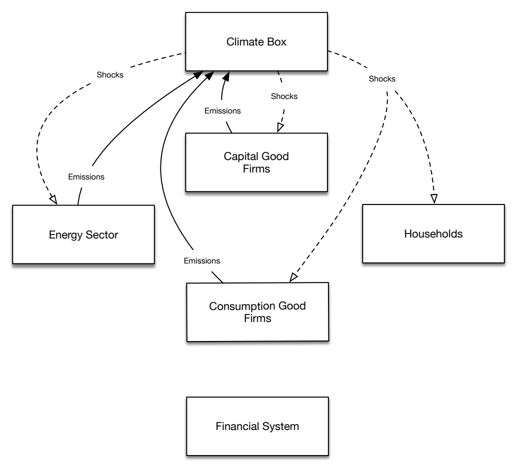
- **Validation**
  - The DSK model can reproduce a large ensemble of macro and micro statistical regularities concerning coupled economic and climate dynamics
- **Economic impacts**
  - After some emergent tipping point, the cost of climate change is catastrophic
  - Heterogenous climate change shocks have a diverse impact on the economy through different propagation channels
  - The financial system magnifies the cost of climate change
- **Policy analysis**
  - Timely and large-scale policies interventions are needed to foster the transition towards a green economy
  - Command-and-control and innovation policies are better than carbon tax in triggering the green transition; financial policies matter
  - In line with the Green New Deal, such policies lead to win-win pathways with higher long-run GDP growth and lower unemployment

The Dystopian Schumpeter Meeting Keynes Model

The Dystopian Schumpeter meeting Keynes model



(a) Economic flows.



(b) Climate-related flows.

Capital and consumption good Sectors

- Machines (and production techniques) are characterized by 3 elements
  - labour productivity (L), Energy Efficiency (EE), Environmental Friendliness (EF)
  - technical change occurs along all the three dimensions
- Innovation and imitation as two steps stochastic procedure
  1. R&D investment and search capabilities determine the success
  2. technological opportunities affect the new vintage
- Costs of production depends on labour, energy and (eventually) carbon taxes:

$$c_i(t) = \frac{w(t)}{A^L_{i,\tau}} + \frac{c^{en}(t)}{A^{EE}_{i,\tau}} + t_{CO2} Em_i$$

- Investment of consumption-good firms
  - expansionary investment driven by adaptive expectations (animal spiritis)
  - replacement investment driven by payback rule

$$\frac{p^{new}}{\left[\frac{w(t)}{A^L_{i,\tau}} + \frac{c^{en}(t)}{A^{EE}_{i,\tau}}\right] - c_j^{new}} \leq b$$

The energy sector

- Heterogeneous plants compete in a regulated market
- Unit production cost of energy
  - *green*: $c_{ge}(t) = 0$
  - *dirty*: $c_{de}(t) = \frac{p_f(t)}{A^{TE}_{de,\tau}}$ where $p_f(t)$ is the price of fossil fuels (exogenous)
- Total energy production cost depends on the mix of active plants
- Energy price is fixed adding a mark-up on the inframarginal unit' cost
- Investments expand power generation capacity
  - *green*: $IC_{ge,\tau} > 0$
  - *dirty*: $IC_{de,\tau} = 0$
- Innovation as a two steps procedure (akin to capital good sector)
  - reducing the fixed cost of green plant investment
  - increasing the thermal efficiency of dirty plants OR reducing their emissions

The banking sector

- Credit demand:
  - consumption-good firms' desired production and investment
  - maximum credit demand is constrained by loan-to-value ratio
- Credit supply:
  - Basel capital adequacy, banks' maximum credit supply is a multiple of their equity
  - endogenous capital buffer, credit supply is reduced if the bank is fragile
- Credit allocation:
  - credit is allocated to firms on a pecking-order base
  - credit rationing endogenously arises
- Emergent banking crises:
  - firm bankruptcies affect banks' balance sheet
  - banks fails whenever their net worth become negative
  - the Government steps in and bails the failing bank out with a negative impact on the public budget and possible sovereign debt crises

The climate module

- It links carbon emissions to the dynamics of Earth's mean surface temperature through a core carbon cycle characterized by non-linear feedbacks loops (as in Sterman et al., 2013)
  - one equation climate model based on the approximately linear relationship between cumulative emissions and global temperature
  - emulator obtained from ensembles of large scale global circulation models

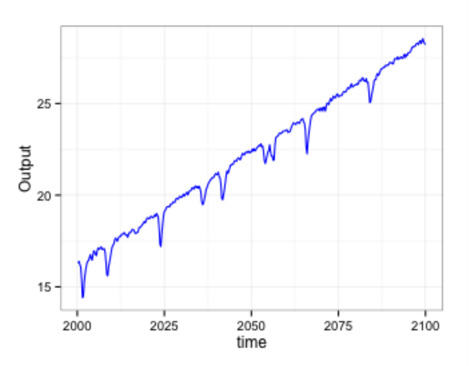
- Climate damages
  - micro-level shocks hitting firms in different ways (e.g. labour productivity and capital stocks)

$$A_{it} = A_{it}^{noshock}(1 - D_{it})$$

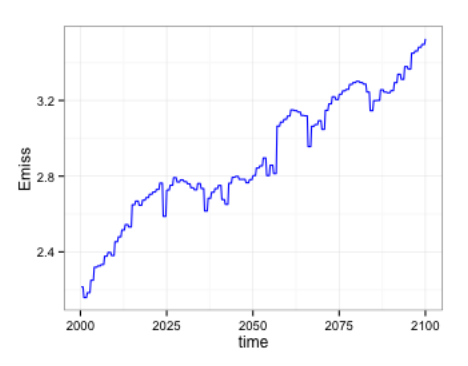
  - damages D_{it} are drawn from a Beta distributions whose parameters depend on the evolution of temperature
  - D_{it} are also defined as in Nordhaus (2017) but consistent with recent firm-level and lab evidence (e.g. Somanhatan et al. 2021)

Empirical validation of the DSK model

Model dynamics with no climate damages

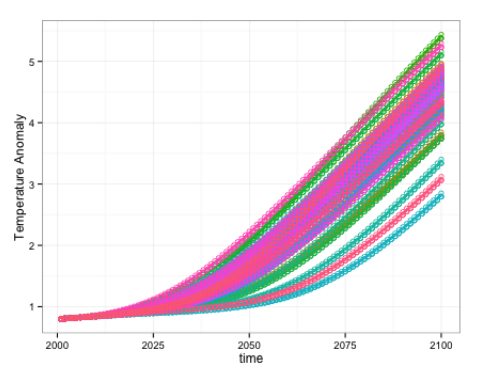


(a) Output

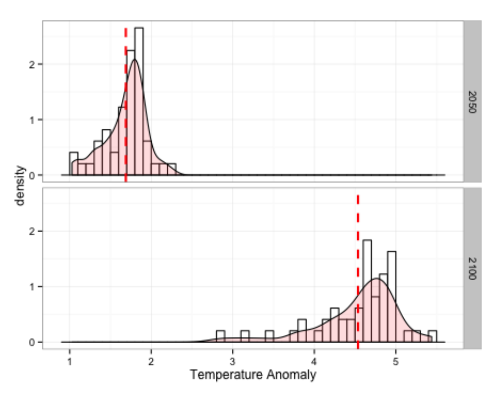


(b) Emissions.

Model dynamics with no climate damages



(a) Temperature projections.



(b) Distribution of temperature.

Model dynamics with no climate damages

	MC average	MC median	MC st. dev.
Output growth	3.19%	3.19%	0.001
Likelihood of crises	12.1%	11.9%	0.076
Unemployment	12.0%	12.1%	0.022
Energy demand growth	2.15%	2.14%	0.002
Emissions growth	1.19%	1.17%	0.003
Volatility of output	0.268	0.270	0.022
Volatility of consumption	0.197	0.199	0.019
Volatility of investments	0.308	0.309	0.024
Volatility of total debt	0.677	0.683	0.085
Volatility of energy demand	0.215	0.215	0.034
Share of emissions from energy sector	61.4%	61.0%	0.201
Share of green energy	29.9%	24.5%	0.285
Periods green beyond 20%	33.0%	34.3%	0.103
Emissions at 2100	26.9	25.5	9.236
Temperature at 2100	4.54	4.65	0.509

Notes: All values refer to a Monte Carlo of size 50. Emissions are expressed in GtC, which can be converted in $GtCO_2$ using the following conversion factor: 1 GtC = 3.67 $GtCO_2$. Temperature is expressed in Celsius degrees above the preindustrial level, which is assumed to be 14 Celsius degrees. Volatilities are computed as square roots of longitudinal variances of Bandpass-filtered (6,32,12) series.

Replicated micro and macro regularities: a recap

Macroeconomic stylized facts	Empirical studies (among others)
SF1 Endogenous self-sustained growth with persistent fluctuations	Burns and Mitchell (1946); Kuznets and Murphy (1966) Zarnowitz (1985); Stock and Watson (1999)
SF2 Fat-tailed GDP growth-rate distribution	Fagiolo et al. (2008); Castaldi and Dosi (2009)
SF3 Recession duration exponentially distributed	Ausloos et al. (2004); Wright (2005)
SF4 Relative volatility of GDP, consumption, investments and debt	Stock and Watson (1999); Napoletano et al. (2006)
SF5 Cross-correlations of macro variables	Stock and Watson (1999); Napoletano et al. (2006)
SF6 Pro-cyclical aggregate R&D investment	Wälde and Woitek (2004)
SF7 Cross-correlations of credit-related variables	Lown and Morgan (2006); Leary (2009)
SF8 Cross-correlation between firm debt and loan losses	Foos et al. (2010); Mendoza and Terrones (2012)
SF9 Pro-cyclical energy demand	Moosa (2000)
SF10 Syncronization of emissions dynamics and business cycles	Peters et al. (2012); Doda (2014)
SF11 Co-integration of output, energy demand and emissions	Triacca (2001); Ozturk (2010); Attanasio et al. (2012)
SF12 Banking crises duration is right skewed	Reinhart and Rogoff (2009)
SF13 Fiscal costs from recessions is fat tailed	Laeven and Valencia (2012)
Microeconomic stylized facts	**Empirical studies (among others)**
SF14 Firm (log) size distribution is right-skewed	Dosi (2007)
SF15 Fat-tailed firm growth-rate distribution	Bottazzi and Secchi (2003,0)
SF16 Productivity heterogeneity across firms	Bartelsman and Doms (2000); Dosi (2007)
SF17 Persistent productivity differential across firms	Bartelsman and Doms (2000); Dosi (2007)
SF18 Lumpy investment rates at firm-level	Doms and Dunne (1998)
SF19 Persistent energy and carbon efficiency heterogeneity across firms	DeCanio and Watkins (1998); Petrick et al. (2013)
SF20 Firm bankruptcies are counter-cyclical	Jaimovich and Floetotto (2008)
SF21 Firm bad-debt distribution fits a power-law	Di Guilmi et al. (2004)

The macroeconomic effects of climate change

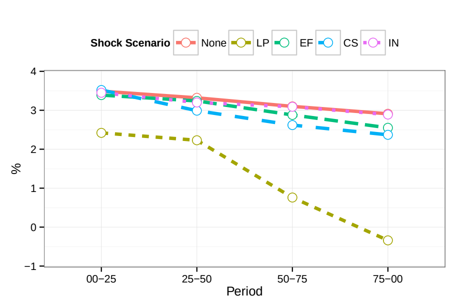
Heterogenous impact of climate shocks

		Output growth	Likelihood of crises	Unemployment
Baseline (no Shocks)	MC average	3.19%	12.1%	12.0%
	MC median	3.19%	11.9%	12.1%
	MC st. dev.	0.001	0.076	0.022
Productivity Shocks	MC average	1.17%	25.6%	22.2%
	MC median	1.16%	27.2%	19.51%
	MC st. dev.	0.003	0.051	0.022
Energy Efficiency Shocks	MC average	3.02%	17.7%	13.8%
	MC median	3.04%	17.3%	13.7%
	MC st. dev.	0.001	0.034	0.015
Both	MC average	0.92%	26.8%	23.4%
	MC median	0.94%	29.4%	23.3%
	MC st. dev.	0.003	0.034	0.016

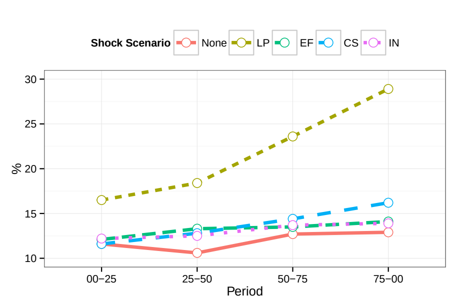
Lamperti F., G. Dosi, M. Napoletano, A. Roventini, A. Sapio (2018). "Faraway, so Close: Coupled Climate and Economic Dynamics in an Agent-Based Integrated Assessment Model", Ecological Economics 150, pp. 315-339

Emerging tipping points and climate-change shocks

- Cumulative exposition to unmitigated climate can induce a stagnating pathway
- Non-linear effects of climate change are much larger than in CGE model



(a) Output growth.

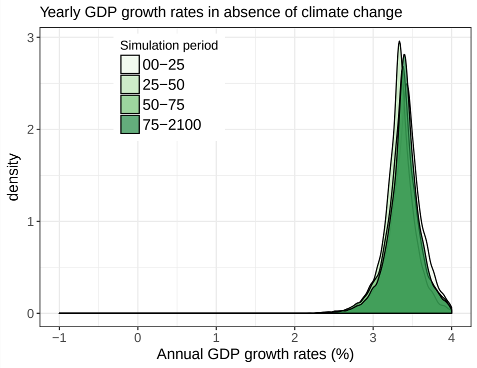


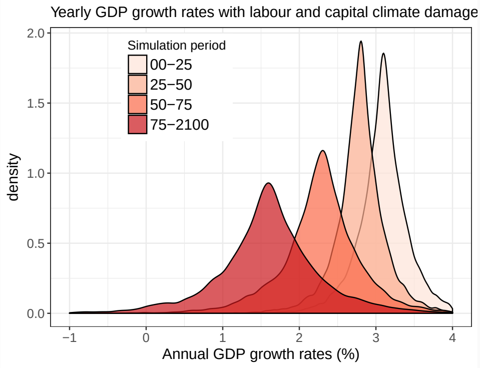
(b) Unemployment.

Lamperti F., G. Dosi, M. Napoletano, A. Roventini, A. Sapio (2018). "Faraway, so Close: Coupled Climate and Economic Dynamics in an Agent-Based Integrated Assessment Model", Ecological Economics 150, pp. 315-339

Tipping points and climate-change shocks

- Unstable and high volatile growth trajectories (growth-at-risk results in Kiley, 2021)
- Emergent super hysteresis

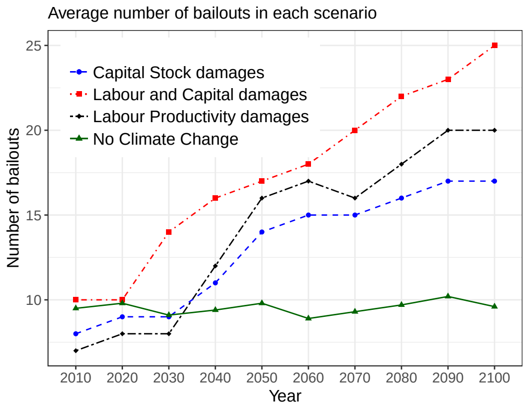


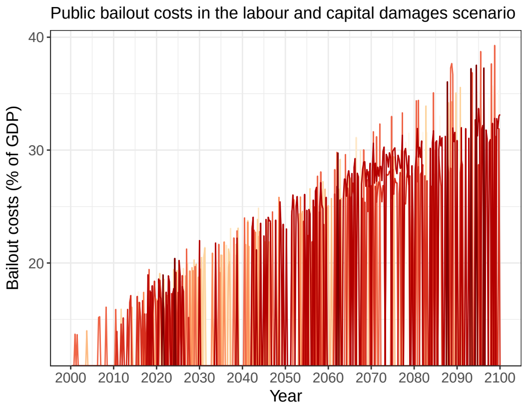


Lamperti F., Bosetti V., Roventini A., Tavoni M. (2019). The public costs of climate-induced financial instability, Nature Climate Change.

The finance sector magnifies the impact of climate change

- Climate impacts increase subtantially the fragility of the banking system
- Bailouts sharply increases after 2060, when temperature anomaly reaches about 3 degrees

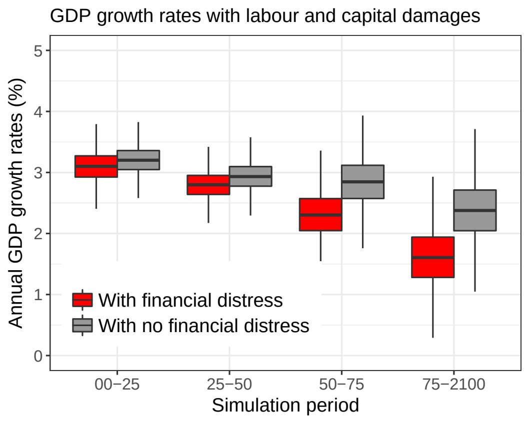




Lamperti F., Bosetti V., Roventini A., Tavoni M. (2019). The public costs of climate-induced financial instability, Nature Climate Change.

Finance-economy feedback loop

- Counterfactual experiment shows that around 20% of lost growth is attributable climate-induced worsening of banks' balance-sheet



Lamperti F., Bosetti V., Roventini A., Tavoni M. (2019). The public costs of climate-induced financial instability, Nature Climate Change.

Green transition, path dependency and lock-in

Endogenous transitions: path dependency and lock-in

	Carbon intensive lock in		Transition to green	
Likelihood	77%		23%	
	before 2025	after 2025	before 2075	after 2075
Likelihood	90%	10%	91%	9%
Output growth	3.16%	3.14%	3.27%	3.18%
	0.001	0.002	0.001	0.008
Unemployment	11.4%	12.1%	9.12%	10.0%
	0.016	0.020	0.019	0.012

Lamperti F., Dosi, G., Napoletano, M., Roventini A., Sapio, A. (2020). Climate change and green transitions in an agent-based integrated assessment model, Technological Forecasting and Social Change.

Green transition and climate shocks

- Climate shocks can increase or decrease the likelihood of a transition, depending on the impact channel
- Energy efficiency shocks do not cause large aggregate damage, but foster carbon lock-ins

Shock scenario:	Transition likelihood	GDP growth	Energy growth	Emissions at 2100
Aggregate output	18%	3.18%	3.09%	28.33
	(of which 83% before 2025)	(0.001)	(0.003)	(6.431)
Labour productivity	20%	1.30%	1.16%	25.70
	(of which 69% before 2025)	(0.002)	(0.003)	(4.921)
Energy efficiency	7%	3.12%	3.37%	40.64
	(of which 43% before 2025)	(0.001)	(0.003)	(3.872)

Lamperti F., Dosi, G., Napoletano, M., Roventini A., Sapio, A. (2020). Climate change and green transitions in an agent-based integrated assessment model, Technological Forecasting and Social Change.

Climate-change policies for sustainable growth

Climate policies

- **So far our results show that**
    1. the impact of climate damages on macroeconomic dynamics in a "hot world" (RCP 8.5) is catastrophic
    2. the financial systems can amplify damages if climate risks are not accounted for

- **The DSK model is a laboratory to study which combinations of climate policy can**
    1. contain temperature anomaly below $+2$ degrees at 2100
    2. guarantee a "smooth" transition with negligible transition costs

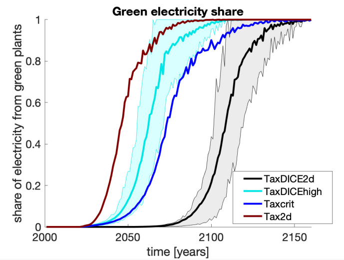
Policies for the green transition

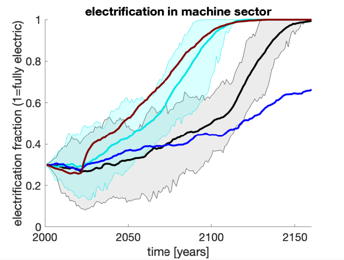
- **Carbon taxes**
  - constant, sufficiently high for the transition by 2100 (Tc)
  - constant, sufficiently high to reach the +2 degree target (T2)
  - increasing as the tax implied by DICE 2019 to meet the +2 target (TD)
  - as above, including full rebates to households (h) or firms (f)
- **Subsidies**
  - subsidies to green energy plants construction (C)
  - subsidies for green R&D (R)
- **Command and control**
  - mandatory electrification of production with 20 years grace period (E)
  - ban on construction of brown plants with 20 years grace period (B)
- **We consider different policy combinations**

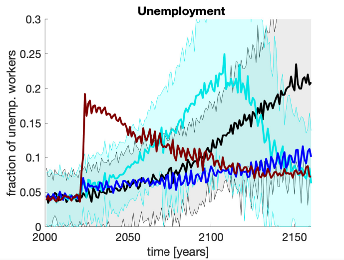
Carbon taxes are not the best policy instrument for the green transition

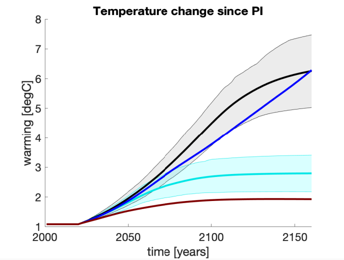
- Carbon taxes successfully trigger the transition only when they are sufficiently high to redirect investments towards green technologies
- However, high carbon taxes (Tax2d; TaxDICE2d; TaxDICEhigh) trigger unemployment crises caused by a surge in energy prices, large drop in investments and a rise in bankruptcy rates (see also Kanzig 2021)
- Gradually increasing tax schemes (TaxDICE2d; TaxDICEhigh) are almost ineffective until they reach a threshold, but they increase the transition costs

Carbon taxes and economic dynamics





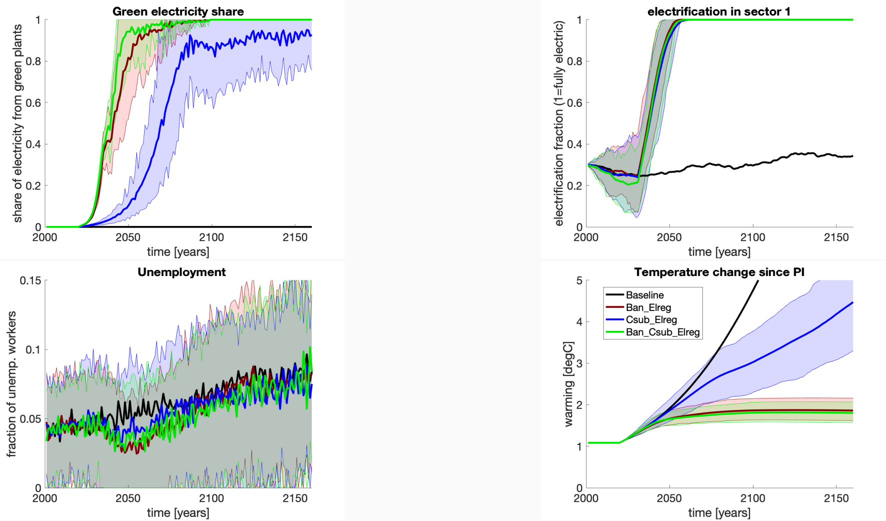




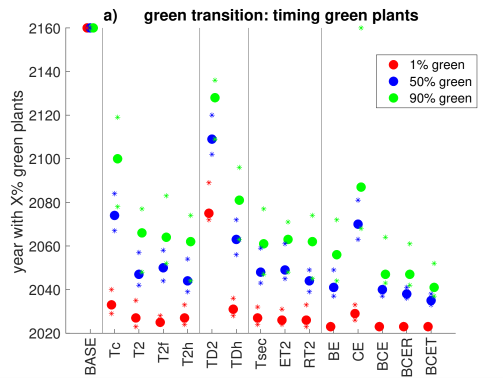
An ensemble of (non-tax) policies to achieve the sustainable transition

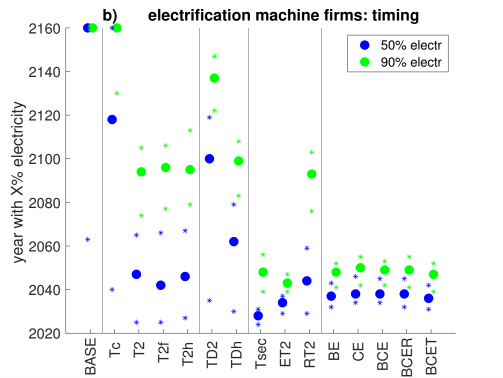
- Command-and-control policies (Ban-Elreg) are effective in stimulating a rapid transition in both the energy sector and manufacturing
- Adding subsidies for green plants construction (Csub) and green R&D (BCER) can further accelerate the transition in the energy sector
- The transition temporarily reduces unemployment and bankruptcies as a consequence of higher investments in energy and manufacturing sectors and relatively low energy prices
- Overall budget costs induced by non-tax based policies is low (between 1-2% of GDP per year)
- A small carbon tax (BCET) can be added to command-and-control cum subsidy policies to pay for the fiscal costs of the transition

An enseble of (non-tax) policies

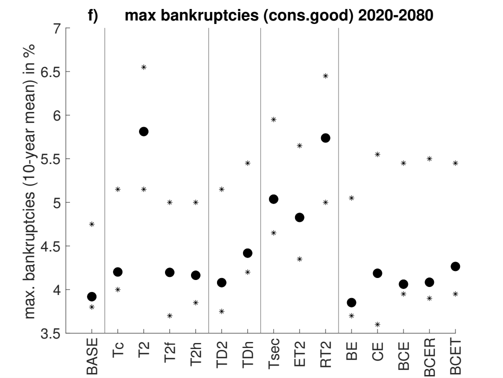


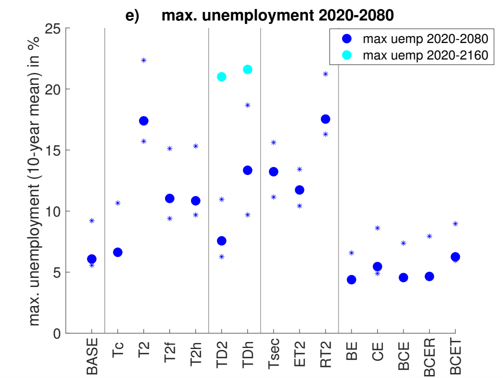
Overall comparison - timing of the transition



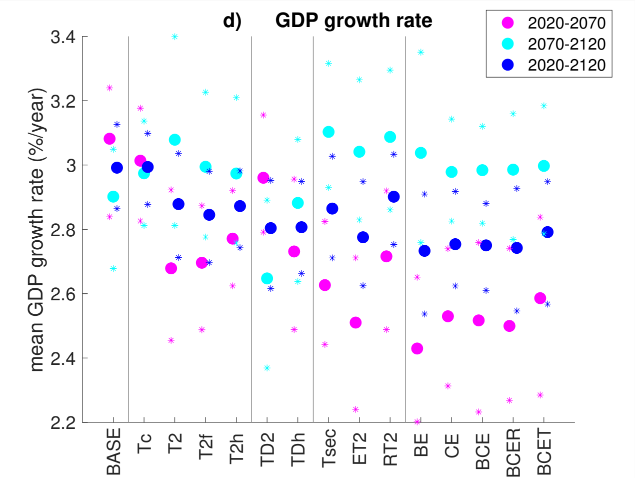


Overall comparison - transition risks

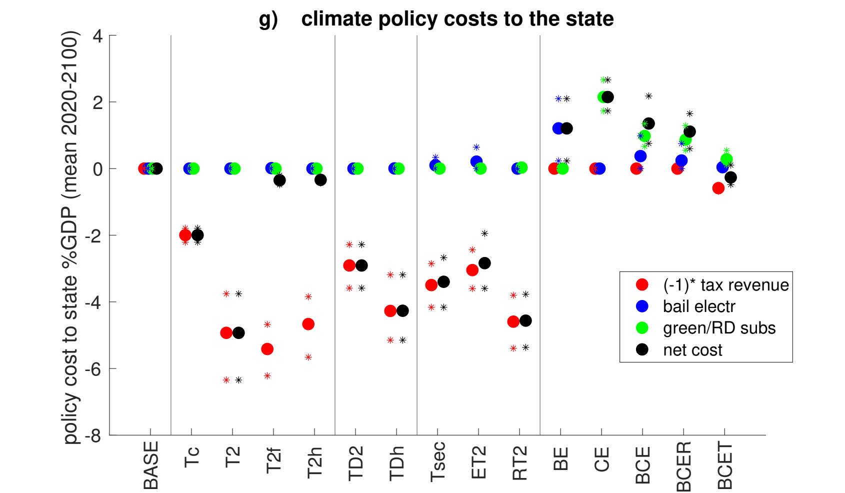




Overall comparison - growth



Overall comparison - public finances



Financial policies for the green transition

- Financial markets can greatly amplify the cost of climate impacts
- Can financial policies help the transition to sustainable growth?
- We focus on three stylized regulatory schemes affecting credit provision
    1. carbon risk-adjustment: inclusion of carbon footprint in solvency risk assessment
    2. green credit easing: the government "backs" loans to green firms
    3. green Basel II: loans to green firms excluded from CAR

The macro effects of green financial policies

- Each policy alone is self- defeating
- Combining all policies allows to achieve a win-win dynamics
- However, green climate policies are not enough and require mitigation policies

Climate impacts to capital and labour

	GDP growth	# Bank bailouts	Debt to GDP	Emissions growth
Baseline (BAU)	1 [0.024]	1 [0.035]	1 [2.09]	1 [0.014]
Risk adjustment	0.90**†	1.09*	1.04	0.95*
	(2.53)	(1.82)	(1.49)	(1.88)
Green credit easing	1.15*†	0.85**†	1.11*†	0.92**†
	(2.58)	(2.77)	(1.84)	(2.70)
Green Basel II	1.11*†	0.94	0.95*	0.93*†
	(1.80)	(1.87)	(1.70)	(1.88)
Policy mix	1.24**†	0.71**†	0.97*	0.76**†
	(3.50)	(6.04)	(1.78)	(4.02)

Lamperti F., Bosetti V., Roventini A., Tavoni M. (2021). Three green financial policies to address climate risks, Journal of Financial Stability.

Conclusions

Discussion and conclusions

- The DSK agent-based IAM accounts for coupled climate-economic dynamics and a rich list of macro and micro stylized facts
- The impact of unmitigated climate impacts is catastrophic after emerging tipping points
- The financial sector amplifies the impact of climate shocks
- Timely policy interventions are needed to trigger the green transition ad avoid lock-in
- Carbon taxes are not the best policy instrument to trigger the sustainable transition
- A combination of command-and-control policies and green subsidies allows to achieve the transition with small cost and good macroeconomic performance
- Green financial policies can be added to mitigation policies to accelerate the transition
- **Such policy combination leads to a win-win pathway characterized by sustainable growth**

Background papers

- Dosi G., G. Fagiolo, and A. Roventini (2010), "Schumpeter Meeting Keynes: A Policy-Friendly Model of Endogenous Growth and Business Cycle", Journal of Economic Dynamics and Control, 34: 1748-1767
- Balint, T., F. Lamperti, A. Mandel, M. Napoletano, A. Roventini, A. Sapio (2017). "Complexity and the Economics of Climate Change: a Survey and a Look Forward", Ecological Economics, 138: 252-265
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- Coronese M., F. Lamperti, K. Keller, F. Chiaromonte, and A. Roventini (2019). "Evidence for Sharp Increase in the Economic Damages of Extreme Natural Disasters", PNAS 116, pp. 21450-5
- Lamperti F., V. Bosetti, A. Roventini, M. Tavoni. (2019). "The Public Costs of Climate-Induced Financial Instability", Nature Climate Change 9, pp. 829-833
- Lamperti F., G. Dosi, M. Napoletano, A. Roventini, A. Sapio (2020). "Climate Change and Green Transitions in an Agent-Based Integrated Assessment Model", Technological Forecasting and Social Change Economics, 153, pp. 1-22
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Model details

Technical Change I

- **Capital-good firms search for better machines and for more efficient production techniques**
  - $A_{i,k}(t)$: feature of machine manufactured by firm i
  - $B_{i,k}(t)$: feature of production technique of firm i
  - $A_{i,k}(t)$ and $B_{i,k}(t)$ determine the technology of firm i at time t

- **R&D:**
  - R&D investment (RD) is a fraction of firm sales (S):

$$RD_i(t) = \upsilon S_i(t-1) \qquad \upsilon > 0$$

  - capital-good firms allocate R&D funds between innovation (IN) and imitation (IM):

$$IN_i(t) = \xi RD_i(t) \qquad IM_i(t) = (1-\xi) RD_i(t) \qquad \xi \epsilon [0, 1]$$

Technical Change II

- **Innovation and imitation: two steps procedure**
- **Innovation:**
  1) firm successfully innovates or not through a draw from a Bernoulli($\theta_1(t)$), where $\theta_1(t)$ depends on $IN_i(t)$:
  $$\theta_1(t) = 1 - e^{-o_1 IN_i(t)} \qquad o_1 > 0$$
  2) search space: the new technology is obtained multiplying the current technology by $(1 + x_i(t))$, where
  $x_i(t) \sim Beta$ over the support (x_0, x_1) with $x_0 < 0, x_1 > 0$
- **Imitation**
  1) firm successfully imitates or not through a draw from a Bernoulli($\theta_2(t)$), where $\theta_2(t)$ depends on $IM_i(t)$:
  $$\theta_2(t) = 1 - e^{-o_2 IM_i(t)} \qquad o_2 > 0$$
  2) firms are more likely to imitate competitors with similar technologies (Euclidean distance)

Capital-Good Market

- **Capital-good firms:**
  - if they successfully innovate and/or imitate, they choose to manufacture the machine with the lowest $p_i + c_i^1 b$
    - p_i: machine price;
    - c_i^1: unit labor cost of production entailed by machine in consumption-good sector;
    - b: payback period parameter
  - fix prices applying a mark-up on unit cost of production
  - send a "brochure" with the price and the productivity of their machines to both their historical and some potential new customers

- **Consumption-good firms:**
  - choose as supplier the capital-good firm producing the machine with the lowest $p_i + c_i^1 b$ according to the information contained in the "brochures"
  - send their orders to their supplier according to their investment decisions

Investment

- **Expansion investment**
  - demand expectations (D^e) determine the desired level of production (Q^d) and the desired capital stock (K^d)
  - firm invests (EI) if the desired capital stock is higher than the current capital stock (K):

$$EI = K^d - K$$

- **Replacement investment**
  - payback period routine:
    - an incumbent machine is scrapped if

$$\frac{p^*}{c(\tau)-c^*} \leqslant b, \qquad b > 0$$

    - $c(\tau)$ unit labor cost of an incumbent machine;
    - p^*, c^* price and unit labor cost of new machines
  - also machine older than Λ periods are replaced

Financial Structure

- **Production and investment decisions of consumption-good firms may be constrained by their financial balances**
  - consumption-good firms first rely on their stock of liquid assets and then on more expensive external funds provided by the banking sector
  - credit ceiling: the stock of debt (Deb) of consumption-good firms is limited by their gross cash flows ($=$ sales S):

$$Deb_j(t) \leqslant \kappa S_j(t-1), \quad \kappa \geqslant 1$$

Banks credit provision

Banks are different in terms of their fundamentals, as well as their supply of credit, which is a function of their equity (NW_b). In that, Basel-type capital adequacy requirements constrain credit supply but, on the other hand, banks maintain a buffer over the mandatory level of capital, whose magnitude is strategically altered over the business cycle according to their financial fragility (BIS, 1999; Bikker and Metzemakers, 2005). In particular, following Adrian and Shin (2010), we proxy banks fragility with the accumulated bad debt to assets ratio. Therefore, given the parameter $\tau_b \in [0,1]$ fixed by the regulatory authority (the central bank in our case), the higher the bad-debt-to-asset ratio, the lower the credit the bank provides to its clients:

$$TC_b(t) = \frac{NW_b(t-1)}{\tau\left(1 + \beta \frac{BD_b(t-1)}{TA_b(t-1)}\right)},$$

where TC_b indicates total credit supplied, BD_b the stock of bad-debt and TA_b the amount of total assets. $\beta > 0$ is a parameter which measures the sensitivity of banks to their financial fragility.

Consumption-Good Markets

- **Supply:**
  - imperfect competition: prices (p_j) $\Rightarrow$ variable mark-up (mi_j) on unit cost of production (c_j)

$$p_j(t) = (1 + mi_j(t))c_j(t);$$

$$mi_j(t) = mi_j(t-1)\left(1 + \alpha \frac{f_j(t-1) - f_j(t-2)}{f_j(t-2)}\right);$$

    $\alpha > 0$; f_j: market share of firm j
  - firms first produce and then try to sell their production (inventories)

Consumption-Good Markets

- **Market dynamics:**
  - market shares evolve according to a "quasi" replicator dynamics:

$$f_j(t) = f_j(t-1)\left(1 + \chi \frac{E_j(t) - \overline{E}(t)}{\overline{E}(t)}\right); \quad \chi \geqslant 0$$

    E_j: competitiveness of firm j; $\overline{E}$: avg. competitiveness of consumption-good industry;
  - firm competitiveness depends on price and unfilled demand (l_j):

$$E_j(t) = -\omega_1 p_j(t) - \omega_2 l_j(t), \quad \omega_{1,2} > 0$$

Firm Bankruptcies and Banking Crisis

- **Firm failure:**
  - zero market share or negative stock of liquid assets
  - in that case, firm exits and defaults on its loans

- **Bank failure:**
  - firm's default (BD) has a negative effect on banks' profits:

$$\Pi^{b}_{k,t} = \sum_{cl=1}^{Cl_k} r_{deb,cl,t} L_{cl,t} + r_{res,t} Cash_{k,t} + r_{B,t} Bonds_{k,t} - r_D Dep_{k,t} - BD_{k,t}$$

  - banks fail whenever their net worth becomes negative

- **Full bail-out rule**
  - the Government always steps in and save the failing bank
  - bank bail-out has a negative impact on public budget

Energy Sector

Profits of the energy monopolist at the end of period t are equal to

$$\Pi_e(t) = S_e(t) - PC_e(t) - EI_e(t) - RD_e(t)$$

where

- $S_e(t)$ are revenues
- $PC_e(t) = \sum_{\tau \in IM} g_{de}(\tau, t) c_{de}(\tau, t) A^{\tau}_{de}$ are production costs
- $EI_e(t) = K^d_e(t) - K_e(t)$ are expansion investments
- $RD_e(t)$ are R&D expenditures

To obtain **revenues**, the energy producer adds a fixed mark-up $\mu_e \geq 0$ on the average cost of the more expensive infra-marginal plant. Hence the selling price reads

$$p_e(t) = \mu_e$$

if $D_e(t) \leq K_{ge}(t)$, and

$$p_e(t) = \overline{c}_{de}(\tau, t) + \mu_e$$

if $D_e(t) > K_{ge}(t)$, where $\overline{c}_{de}(\tau, t) = \max_{\tau \in IM} c_{de}(\tau, t)$.

The **expansion investment** is made up of new green capacity is added whenever the cheapest vintage of green plants must be below the discounted production cost of the cheapest dirty plant:

$$\underline{IC}_{ge} \leq b\underline{c}_{de}$$

where b is a discount factor, $\underline{IC}_{ge} = \min_\tau IC^\tau_{ge}$, and $\underline{c}_{de} = \min_\tau c^\tau_{de}$.

The micro effects of green financial policies

The micro effects of green financial policies

- **All three policies** reduce the productivity enhancing effect of credit provision, while exacerbating the fragility- enhancing effect on firms receiving credit
- **Green Basel II** enlarges the supply of credit, stimulating on average productivity growth in the economy
- **Credit easing guarantees** absorb losses on banks balance-sheet

Firms

Policy	**Variable**	**Quartile of firms ranked on creditworthiness**				**Average firm**
		top	**middle-top**	**middle-bottom**	**bottom**	
Baseline (BAU)	productivity 1y ahead	1	1	1	1	1
Risk adjustment		0.92**†	0.88**†	0.84**†	0.8**†	0.89**†
Credit easing		0.75**†	0.77**†	0.81**†	0.85**†	0.85**†
Green Basel II		1.01	0.98	0.97	0.96*	1.26**†
Baseline (BAU)	creditworthiness 1y ahead	1	1	1	1	1
Risk adjustment		0.86**†	0.72**†	0.64**†	0.41**†	0.76**†
Credit easing		0.66**†	0.69**†	0.78**†	0.82**†	0.73**†
Green Basel II		0.96	0.95*†	0.92**†	0.90**†	1.15**†

Banks

Policy	**Losses on loans**	**Frequency of periods with negative profits**	**Total credit supply**
Baseline (BAU)	1	1	1
Risk adjustment	1.31**†	1.11**†	0.92*†
Credit easing	0.91**†	0.93*†	1.08*†
Green Basel II	1.10**†	1.05	1.26**†

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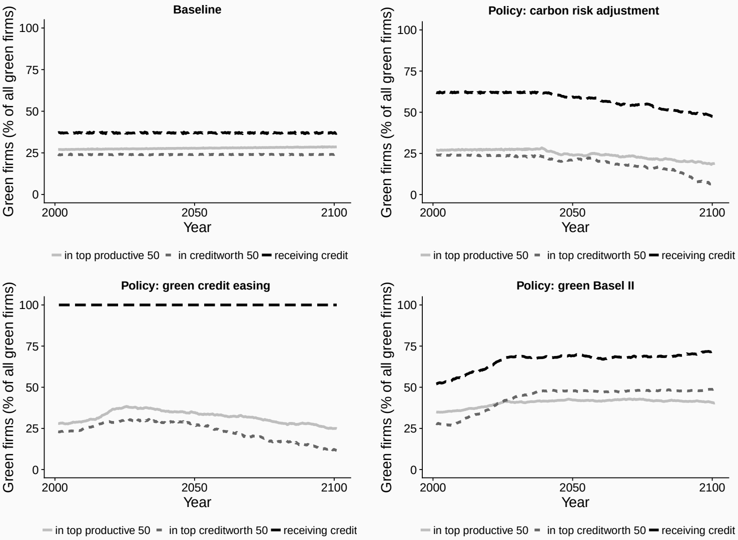
The micro effects of green financial policies

- **Short-vs-long run tradeoff of carbon risk adjustment & green credit easing**: they channel credit to green firms (fragility-enhancing effect dominate)
- **Green Basel II improves performance of green firms in the short run, then looses efficacy**: increases the share of green firms receiving credit yet maintaining the creditworthiness-based allocation



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