

Why Climate Disasters Don't Guarantee Climate Action?

Linking Regional Extreme Weather Events and Opinion Dynamics to Macroeconomic Outcomes in DSK+OD
ABM

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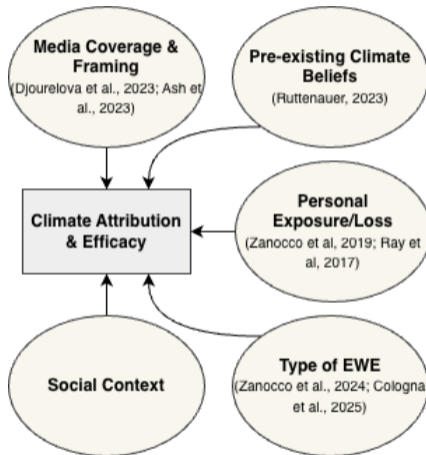
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Introduction

What shapes climate attribution post EWE?



Research Question

How do regionally heterogeneous extreme weather events shape macroeconomic dynamics and climate policy outcomes through opinion dynamics?

- 1 How does heterogeneous regional exposure to extreme weather events affect regional economic trajectories and aggregate national macroeconomic outcomes?

▶ Phase 1

- 2 How do localized experiences of extreme weather events influence regional and national climate policy preferences, including both the strengthening and erosion of support for mitigation and adaptation policies?

▶ Phase 2

Model Extension

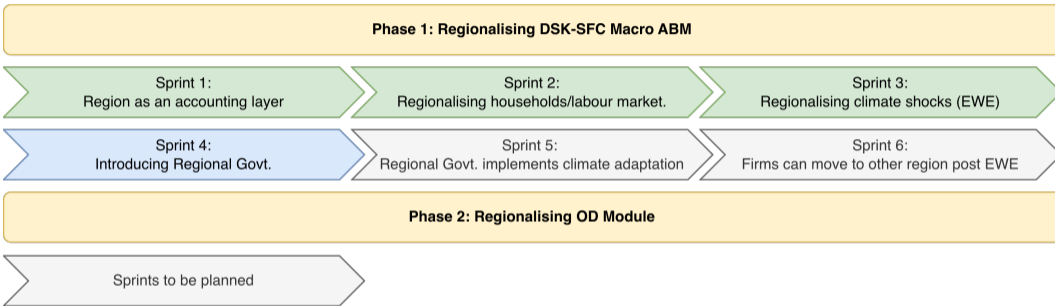
Phase 1: Regionalised Agents and Climate Shocks

- **Objective:** Explore how regional EWE exposures affect national and regional macro-economic outcomes.
- **Modelling:**
 - Regionalised agents: firms, labour (households), and energy plants
 - Capital Market, Goods Market and Energy Market remains at national level (unchanged).
 - Regional governments with budgets and policies.
- **Hypothesis:** Regional EWE damages create persistent economic path dependencies.
- **Policies:**
 - Baseline: no active regional governments.
 - Adaptation: regions offer relief subsidies or invest in damage reduction/rebuilding post EWE.
 - Policy mixes: test interactions of national mitigation and regional adaptation.

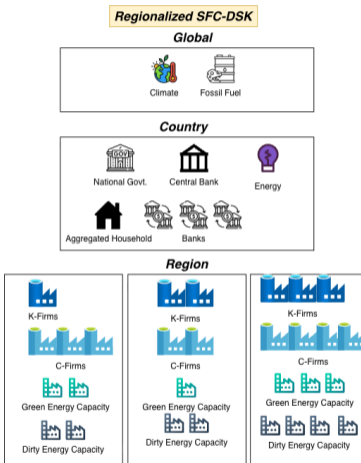
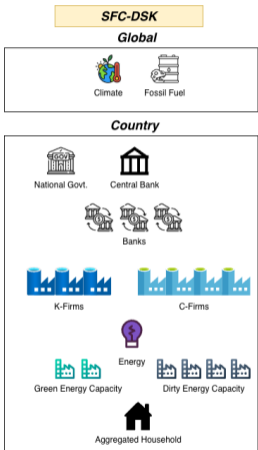
Phase 2: Opinion Dynamics and Regional Climate Shocks

- **Objective:** Endogenize support for climate policies via opinion dynamics.
- **Modelling:**
 - Drivers: EWE exposure, attribution, beliefs, employment, (dis)information.
 - Outcomes: Differentiated support for mitigation (national) vs. adaptation (regional) policies.
- **Hypotheses:**
 - EWE exposure increases adaptation support; mitigation support is conditional
[▶ see figure](#)
 - Repeated EWE can either exacerbate or alleviate political polarization and climate fatalism among residents.
- **Policies:**
 - Baseline: Households form opinions on national carbon policy.
 - Adaptation scenario: Opinions include regional adaptation support.
 - Election scenario: Opinion shifts only affect policies during election cycles.

Model Extension Roadmap: Sprint Planning



Sprint 1: Regionalising K & C Firms and Energy Capacity



Sprint 1: Regionalising K & C Firms

- If "regions" entry is present in the input file, firms are assigned a regional tag at initialization (sequential attribution).
- Upon exit and entry, firms inherit the regional tag associated with the slot they occupy.
- **Assumption** the proportion of K & C-firms does not evolve endogenously over the time.
- **Assumption** The market remains at national level. **No** regional dynamics here!

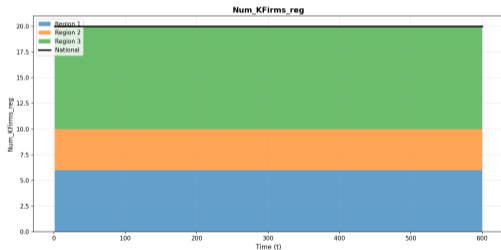


Figure: Number of K-Firms

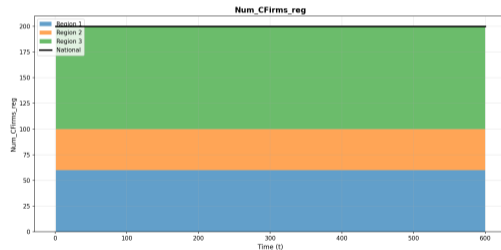


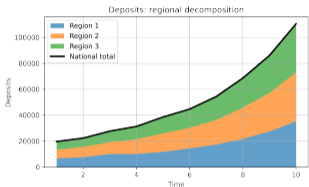
Figure: Number of C-Firms

Sprint 1: Regionalising Energy Capacity (Plants)

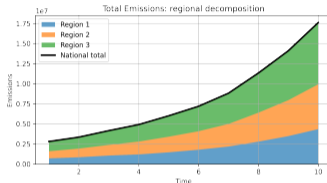
- Regional accounting layer computes following energy sector parameters (derived) at regional level using `dirty_capacity_share` and `green_capacity_share`.
- The energy market is also at national level analogous to a national electricity grid.
- The climate shock to energy capacity (plants) can be implemented using `dirty_capacity_share` and `green_capacity_share` when a region is hit by an EWE/Shock.

Sprint 1: Verifying Regional Aggregates (Sanity Check)

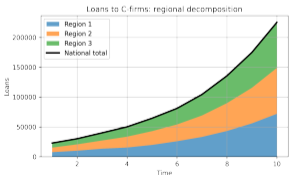
A 10-step simulation with three regions is executed to ensure that regional aggregates align with national-level aggregates.



Deposits



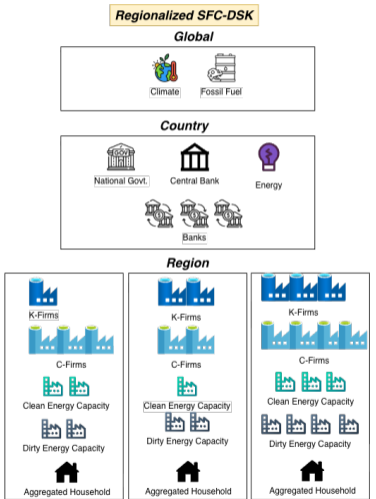
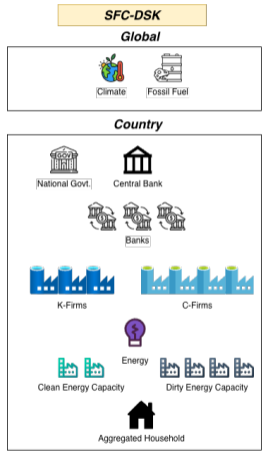
Emissions



loans

Regional Labour

Sprint 2: Regional Labour and Refining Regionalisation of Energy Capacity, K & C Firms



Sprint 2: Refining regional allocation of firms and energy capacity

- Introduced proportion-based regional allocation for:
 - 1 K-firms (static)
 - 2 C-firms (static)
 - 3 Dirty energy capacity & expansion
 - 4 Clean energy capacity & expansion
- Endogenous regional distribution of Labour 'LS0'
- Regional computation of Emissions from K-Firms, C-Firms & Energy sector

Excerpt from 'regions_input.json'

```

...
"regions":
{
  "NR": 3,
  "K_firm_shares": [0.3, 0.2, 0.5],
  "C_firm_shares": [0.3, 0.2, 0.5],

  "energy": {
    "dirty_capacity_shares": [0.1, 0.2, 0.7],
    "green_capacity_shares": [0.5, 0.3, 0.2]}},

  "de_growth_probability": [0.1, 0.2, 0.7],
  "ge_growth_probability": [0.5, 0.3, 0.2]
}
...

```

Sprint 2: Probability based regional allocation for new energy capacity

- Distribution of clean and dirty energy capacity is specified in the 'regions_input.json'
- New capacity expansion is determined based on regional growth probability specified in 'regions_input.json'.

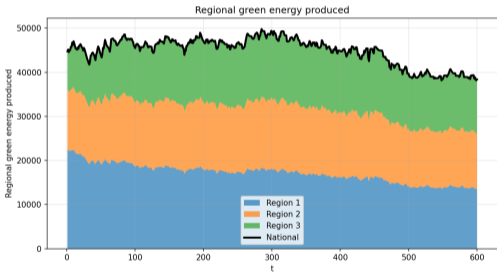


Figure: Green Energy Production

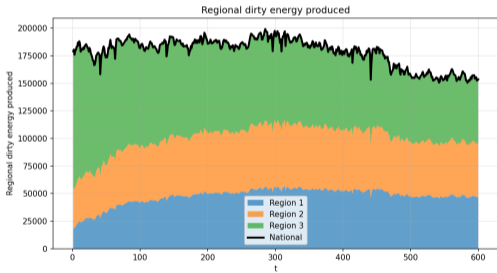


Figure: Dirty Energy Production

Sprint 2: Regionalising Households/Labour

- 1 Regional labour demand (C-Firms, K-Firms and Energy Sector) is computed during initialisation and Labour 'LS0' is distributed across regions in a way that all labour demands are met at $t = 1$.
- 2 Regional labour shares are distributed endogenously based on labour demand by K and C firms in that region. This keeps the existing SFC-DSK mechanisms intact.
- 3 **Assumption Free inter-region mobility** If a labour loses employment, it will move to another region with labour demand.
- 4 Labour stays unemployed in a region, until a new labour demand emerges in the same or different region.

Sprint 2: Regional Accounting of GDP

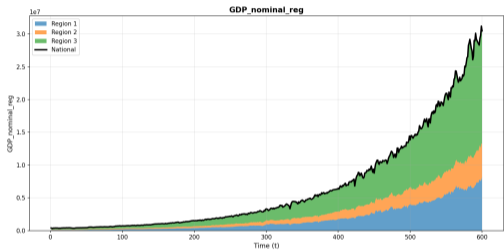


Figure: Nominal GDP

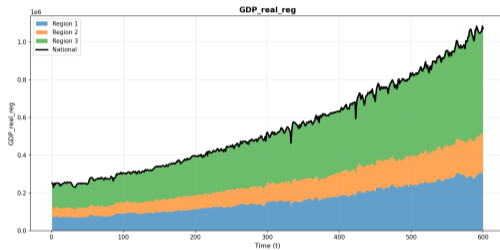


Figure: Real GDP

Regional Shocks

Sprint 3: Climate Shock Channels in Reissl et al. (2025)

- All firms in the region receive uniform shocks `flag_uniform_shock = 1`
 - 1 Shocks to productivity affecting the characteristics of capital vintages `flag_prodshocks1`
 - 2 Shocks to productivity (not affecting characteristics of capital vintages) `flag_prodshocks2`
 - 3 Energy Capacity both green and brown `flag_encapshocks`
 - 4 Shock to labour population `flag_popshocks`
 - 5 Shock to aggregate consumption demand `flag_demandshocks`
 - 6 Shock to C-Firms capital stock `flag_capshocks`
 - 7 Output shocks to C & K Firms `flag_outputshocks`
 - 8 Shock to C-Firms inventories `flag_inventshocks`
 - 9 Shock to R & D of K Firms `flag_RDshocks`

Sprint 3: Climate shocks in DSK

Climate shocks are modelled as stochastic shocks drawn from temperature-dependent Beta distributions in Reissl et al. (2025).

For each shock channel $s \in \{1, \dots, S\}$ and period t :

$$\varepsilon_{s,t} \sim \text{Beta}(a_{s,t}, b_{s,t}), \quad \varepsilon_{s,t} \in (0, 1)$$

The shape parameters evolve with global temperature T_t :

$$a_{s,t} = a_{0,s} \left[1 + \ln \left(\frac{T_{t-1}}{T_0} \right) \right]^{\theta_s^{(1)}}$$

$$b_{s,t} = b_{0,s} \left(\frac{T_0}{T_{t-1}} \right)^{\theta_s^{(2)}}$$

- $a_{0,s}, b_{0,s}$ are baseline shape parameters,
 - $a_{s,t}$ governs mean/median of damages,
 - $b_{s,t}$ governs right tail thickness (extreme events),
- $\theta_s^{(1)}$ controls increase in typical damages,
- $\theta_s^{(2)}$ controls amplification of extremes,
- T_t is global mean temperature, T_0 is reference level.
- Climate shocks affect real economic variables (e.g. X) multiplicatively:

$$X_{i,t} = X_{i,t-1} (1 - \varepsilon_{s,t})$$

Sprint 3: Parameters of Climate shock β distribution

- 1 **Global temperature** (T_t) is common to all regions
- 2 **Shock exponent** $\theta_s^{(1)}$ **and baseline severity parameters** $a_{0,s}$ have regional values but are kept same common across regions as they reflect physical damage sensitivities (how temperature translates into damage)
- 3 **Baseline exposure** ($b_{0,r}$): Region-specific right-tail thickness capturing structural exposure to extreme events (e.g. coastal vs inland regions).
- 4 **Extreme-event amplification** ($\theta_r^{(2)}$): Region-specific scaling of tail risk as temperature rises, allowing extreme damages to accelerate faster in some regions.

Sprint 3: Regionalisation of climate shock channels

- In the regional extension, climate shocks are generated **at the regional level** and propagated to all firms located in that region.
- For each shock channel $s \in \{1, \dots, S\}$, region r , and period t :

$$\varepsilon_{s,r,t} \sim \text{Beta}(a_{s,r,t}, b_{s,r,t})$$

- The realised regional shock $\varepsilon_{s,r,t}$ is then broadcast to all firms (or specified channel) i in region r :

$$X_{i,t} = X_{i,t-1}(1 - \varepsilon_{s,r,t}), \quad i \in r$$

- This mechanism is identical to Reissl et al. (2025).

Sprint 3: Verification

- Implementation of regional climate shock dynamics is verified by reproducing following climate-shock scenarios from Reissl et al. (2025).
 - 1 Baseline – No Shocks
`flag_shockexperiment = 0;`
 - 2 Capital Stock Shocks (CS)
`flag_shockexperiment = 1; flag_capshocks = 1`
 - 3 Labour Productivity Shocks (LP) + Energy Efficiency Shocks (EF)
`flag_shockexperiment = 1; flag_prodshocks1 = 6`
- These scenarios are simulated separately on following models
 - 1 Reissl et al. (2025) DSK
 - 2 Regionalised DSK
- This ensures consistency with established agent-based climate shock dynamics.

Sprint 3: Verification | Climate shock parameters

Reissl et al. (2025)

Regionalised SFC-DSK

```

1  ...
2  "climshockparams": [
3    {
4      "nshocks": 9,
5      ...
6      "a2_0": 1,
7      "b2_0": 100
8      ...
9      "a6_0": 1,
10     "b6_0": 100,
11     ...
12     "a8_0": 1,
13     "b8_0": 100,
14     ...
15     "shockexponent2_1": 3,
16     "shockexponent2_2": 8,
17     ...
18     "shockexponent6_1": 3,
19     "shockexponent6_2": 8,
20     ...
21     "shockexponent8_1": 3,
22     "shockexponent8_2": 8,
23     ...}
24  ]
25  ...

```

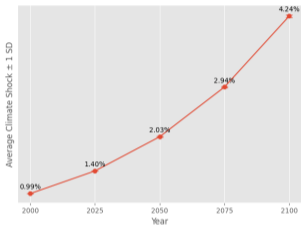
```

1  ...
2  "climshockparams": [
3    {
4      "nshocks": 9,
5      ...
6      "a2_0": [1, 1, 1],
7      "b2_0": [100, 100, 100],
8      ...
9      "a6_0": [1, 1, 1],
10     "b6_0": [100, 100, 100],
11     ...
12     "a8_0": [1, 1, 1],
13     "b8_0": [100, 100, 100],
14     ...
15     "shockexponent2_1": [3, 3, 3],
16     "shockexponent2_2": [8, 8, 8],
17     ...
18     "shockexponent6_1": [3, 3, 3],
19     "shockexponent6_2": [8, 8, 8],
20     ...
21     "shockexponent8_1": [3, 3, 3],
22     "shockexponent8_2": [8, 8, 8],
23     ...}
24  ]
25  ...

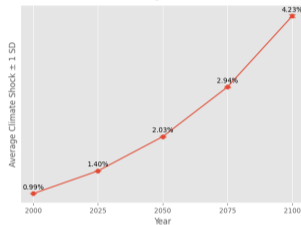
```

Sprint 3: Verification | Comparing Average Shock Values

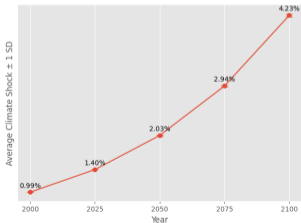
Capital Stock Shock
DSK



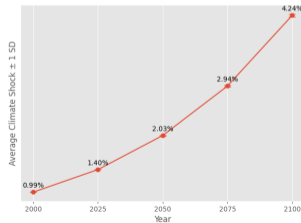
Labour Productivity & Energy Efficiency Shocks
DSK



REGIONAL DSK



REGIONAL DSK



Sprint 3: Verification | Comparing Average Shock Values

Scenario	Year	Mean (SFC-DSK)	Mean (Regional DSK)	$ \Delta $
<i>Labour Productivity (CS)</i>				
	2000	0.0072	0.0072	$< 10^{-4}$
	2025	0.0103	0.0103	$< 10^{-4}$
	2050	0.0149	0.0149	$< 10^{-4}$
	2075	0.0216	0.0216	$< 10^{-4}$
	2100	0.0307	0.0307	$< 10^{-4}$
<i>Energy Efficiency (LP+EF)</i>				
	2000	0.0072	0.0072	$< 10^{-4}$
	2025	0.0103	0.0103	$< 10^{-4}$
	2050	0.0149	0.0149	$< 10^{-4}$
	2075	0.0216	0.0216	$< 10^{-4}$
	2100	0.0308	0.0307	10^{-4}

Notes: Reported values correspond to the Monte Carlo average of the mean shock size at selected benchmark years. Absolute differences between the baseline model and the regional SFC-DSK model with homogeneous shocks are on the order of 10^{-4} or smaller. Shock distributions are therefore identical across model structures.

Verification | Comparing Climate Damages

Here we compare climate damages between Reissl et al. (2025) and Regional DSK model with homogenous regions i.e. $R1 : R2 : R3 : R4 = 0.25 : 0.25 : 0.25 : 0.25$

	No Shocks	CS Shock	LP+EF Shock
▶ Real GDP (ln)	0.9995 (0.9463)	0.9998 (0.3257)	1.0007 (-1.4043)
▶ Bad debt over nominal GDP	1.0000 (0.0000)	1.0133 (-0.6202)	1.0164 (-0.7721)
▶ Number of C-Firms failure	1.0000 (0.0000)	1.0043 (-0.7577)	1.0016 (-0.2554)
▶ Endogenous Emissions	1.0000 (0.0000)	0.9980 (0.0929)	1.0058 (-0.2738)

Entries report normalized macroeconomic performance of the regional model (homogenous regions) relative to Reissl et al. (2025). Values above (below) one indicate amplification (attenuation). All values refer to Monte Carlo simulation runs of size 50. T-statistics for H_0 : equal means are reported in parentheses.

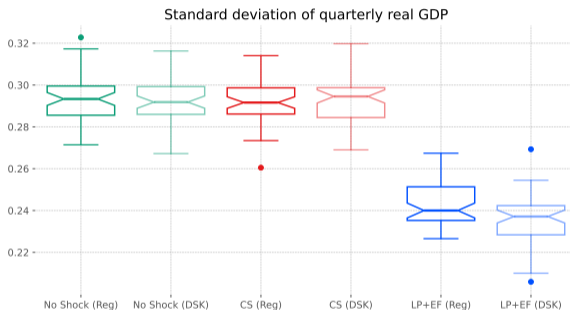
Verification | Comparing Sectoral Net-Worths

Change in sectoral net-worth under climate shocks between Reissl et al. (2025) and Regional DSK model with homogenous regions i.e. $R1 : R2 : R3 : R4 = 0.25 : 0.25 : 0.25 : 0.25$

▸ △ Sectoral Net Worth	CS Shock	LP+EF Shock
K-Firms	0.9905 (0.3036)	1.0875 (-2.4495)
C-Firms	1.0023 (-0.1451)	1.0308 (-1.8663)
Households	0.9978 (0.1529)	1.0149 (-1.2475)
Banks	0.9967 (0.2645)	0.9923 (0.5480)
Energy	1.0000 (-0.0352)	0.9902 (0.3462)
Government	0.9954 (-0.3377)	0.9846 (-1.2336)

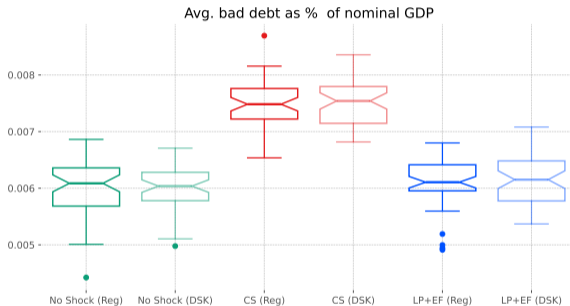
Entries report ratio of normalized net-worth of the sectors relative to baseline (no shock) for regional DSK and Reissl et al. (2025). Values above (below) one indicate amplification (attenuation). All values refer to Monte Carlo simulation runs of size 50. T-statistics for H_0 : equal means are reported in parentheses.

Verification | GDP



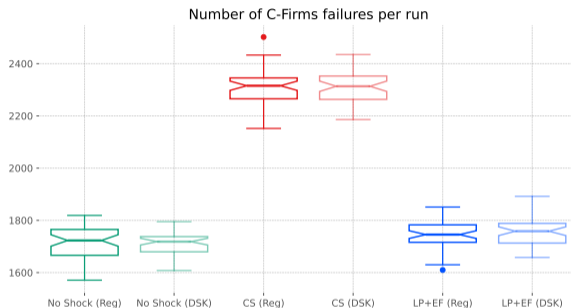
Entries report macroeconomic performance of the regional DSK model (homogenous regions) relative to Reissl et al. (2025). All values refer to Monte Carlo simulation runs of size 50.

Verification | Bad Debt / Nominal GDP



Entries report macroeconomic performance of the regional DSK model (homogenous regions) relative to Reissl et al. (2025). All values refer to Monte Carlo simulation runs of size 50.

Verification | Exiting C-Firms



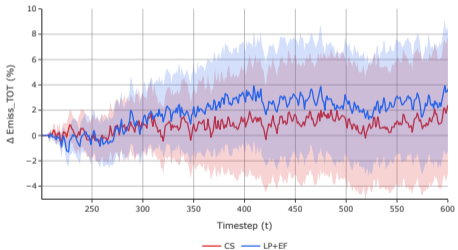
Entries report macroeconomic performance of the regional DSK model (homogenous regions) relative to Reissl et al. (2025). All values refer to Monte Carlo simulation runs of size 50.

Verification | Change in Sectoral Net-Worth Under Shocks

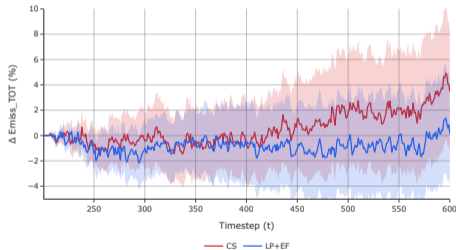
DSK Reissl et al. (2025) under CS and LP+EF

Regional DSK under CS and LP+EF

Emissions change vs baseline (%)



Emissions change vs baseline (%)



Verification | Change in Sectoral Net-Worth Under Shocks

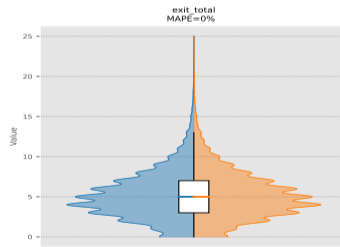
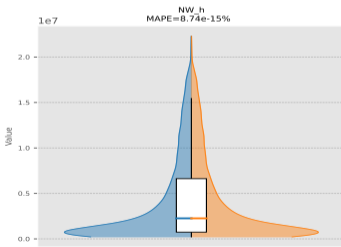
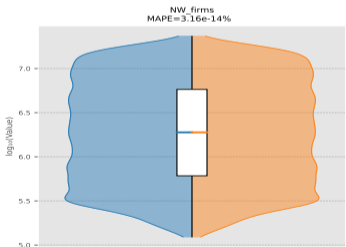
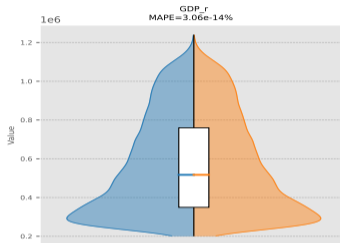
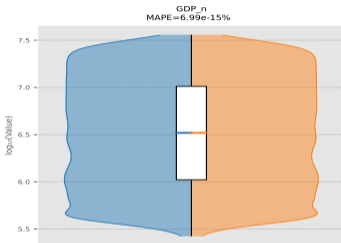
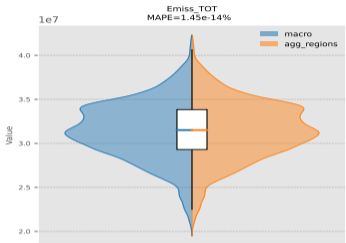
DSK Reissl et al. (2025) under CS

Regional DSK under CS

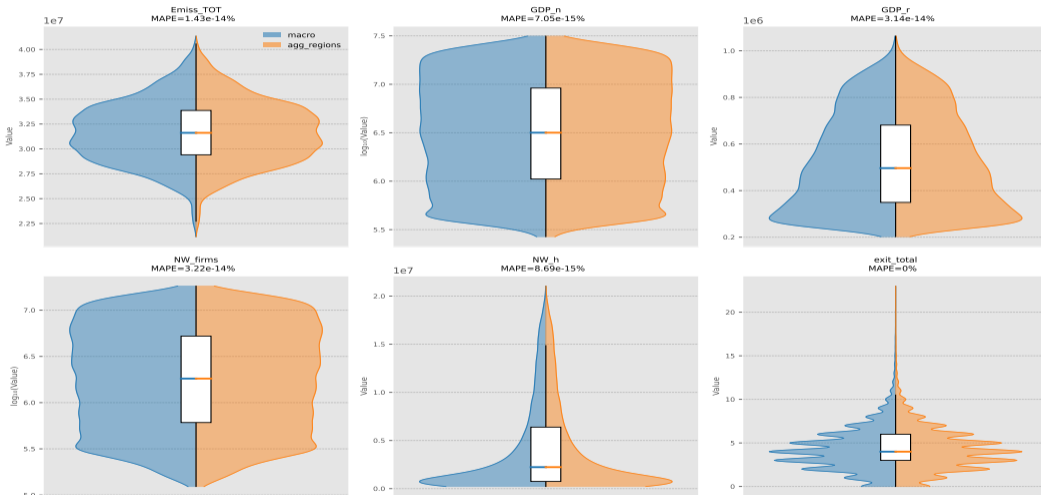
DSK Reissl et al. (2025) under LP+EF

Regional DSK under LP+EF

Verification | Regional Consistency Under Baseline (CS)

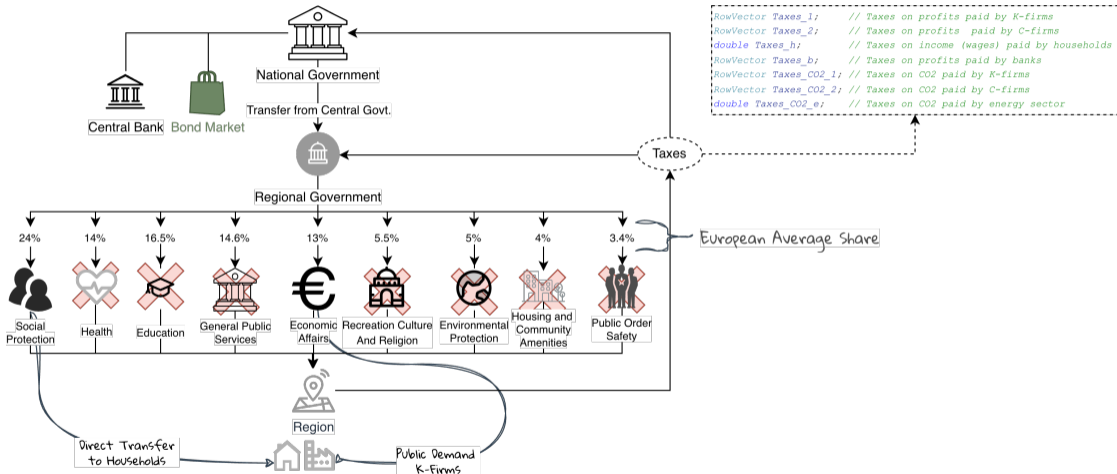


Verification | Regional Consistency Under Baseline (LP+EF)



Regional Govt.

Regional Govt. Revenue & Expenditure



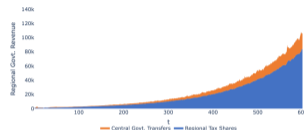
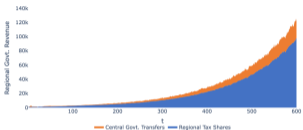
Regional Government Revenue and Expenditure Components

$$REVENUE_{RegGovt,r,t} = TaxShare_{r,t} + GovtTransfer_{r,t}$$

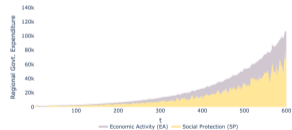
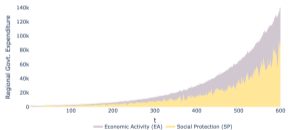
No Shock

CS

LP + EF



$$EXPENDITURE_{RegGovt,r,t} = SocialProtection_{r,t} + EconomicAffairs_{r,t}$$



$$REVENUE_{RegGovt,r,t} = EXPENDITURE_{RegGovt,r,t}$$

Above values refer to mean of Monte Carlo simulation runs of size 20.

Regional Government Revenue Design

$$TaxShare_{r,t} = \tau_r^{share} (T_{r,t}^{Cfirms} + T_{r,t}^{Kfirms})$$

$$GRANTPOOL_t = \bar{\gamma} \cdot REVENUE_{CentralGovt,t}$$

$$GovtTransfer_{r,t}^{base} = \omega_r \cdot GRANTPOOL_t$$

$$GovtTransfer_{r,t}^{topup} = \max \left\{ 0, SocialProtection_{r,t} - \left(TaxShare_{r,t} + GovtTransfer_{r,t}^{base} \right) \right\}$$

$$REVENUE_{RegGovt,r,t} = GovtTransfer_{r,t}^{base} + GovtTransfer_{r,t}^{topup} + TaxShare_{r,t}$$

- $TaxShare_{r,t}$: Region's share of centrally collected taxes
- $GovtTransfer_{r,t}^{base}$: Standard intergovernmental transfer from grant pool
- $GovtTransfer_{r,t}^{topup}$: Additional transfer ensuring minimum welfare provision
- $REVENUE_{RegGovt,r,t}$: Total regional government revenue
- National government collects all taxes and redistributes to regions
- Grant pool bounded: $\bar{\gamma} \in [0, 1]$
- Allocation weights: $\sum_r \omega_r = 1$
- Welfare guarantee: $REV_{rg,r,t} \geq SP_{r,t}^{plan}$

Regional Government Expenditure Design

$$EXPENDITURE_{RegGovt,r,t} = SocialProtection_{r,t} + EconomicAffairs_{r,t}$$

Social Protection

$$SocialProtection_{r,t} = \theta_r \cdot Wages_{r,t} \cdot U_{r,t-1}$$

- $\theta_r \in (0, 1)$: region-specific replacement rate
- $Wages_{r,t}$: total regional wage bill
- $U_{r,t-1}$: lagged unemployment rate
- Implemented as transfers to households (automatic stabiliser)

Economic Affairs

$$EconomicAffairs_{r,t} =$$

$$\max \{0, REVENUE_{r,t} - SocialProtection_{r,t}\}$$

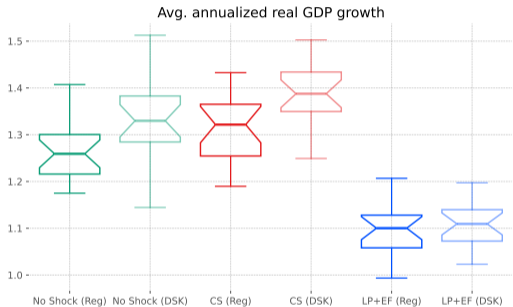
- Public investment expenditure
- For each K-firm in region r :

$$EconomicAffairs_{Kfirm,r,t} = \frac{EconomicAffairs_{r,t}}{N_{r,t}^{Kfirm}}$$

- Implemented as pre-payment; Production occurs with one-period lag.
- No public capital stock (pure demand channel)

Real GDP

Real GDP

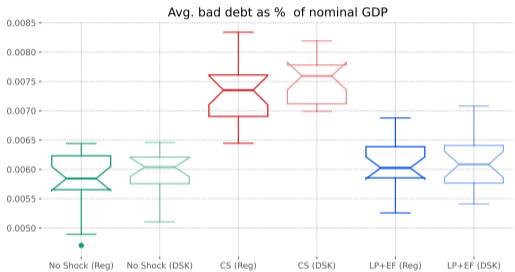


Scenario	DSK	REG-DSK	t	p
No Shock	13.401	13.413	-1.44	0.157
CS	13.408	13.411	-0.32	0.753
LP + EF	13.311	13.336	-3.01	0.0046***

Welch's t -test ($n = 20$). *** $p < 0.01$.

Bad Debt

Bad Debt as percentage of GDP

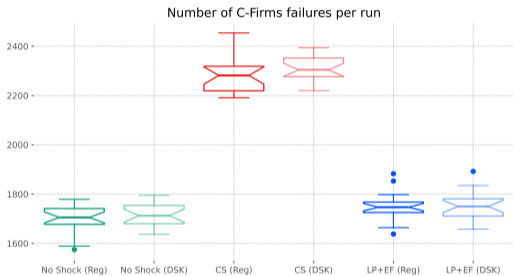


Scenario	DSK	REG-DSK	<i>t</i>	<i>p</i>
No Shock	0.0060	0.0058	1.14	0.263
CS	0.0075	0.0073	1.65	0.107
LP + EF	0.0061	0.0061	0.29	0.774

Welch's *t*-test ($n = 20$). *** $p < 0.01$.

Number of C Firms failure

Bad Debt as percentage of GDP



Scenario	DSK	HRHS	<i>t</i> -stat	<i>p</i> -value
No shock	4.285	4.248	0.88	0.386
CS	5.778	5.702	1.54	0.131
LP + EF	4.379	4.364	0.34	0.739

Welch's *t*-test ($n = 20$). *** $p < 0.01$.

Unemployment

Unemployment



Scenario	DSK	REG-DSK	t	p
No Shock	0.0060	0.0058	1.14	0.263
CS	0.0075	0.0073	1.65	0.107
LP + EF	0.0061	0.0061	0.29	0.774

Welch's t -test ($n = 20$). *** $p < 0.01$.

Net Worth Comparison I

Net worth of Households

Net worth of C Firms

Scenario	DSK	REG-DSK	t	p
No Shock	6.80e6	6.99e6	-1.71	0.096
CS	6.18e6	6.37e6	-1.38	0.176
LP + EF	5.96e6	6.30e6	-3.12	0.003***

DSK	REG-DSK	t	p
5.40e6	5.40e6	-0.02	0.981
5.49e6	5.42e6	0.50	0.622
4.79e6	4.98e6	-1.73	0.091

Welch's t -test ($n = 20$). *** $p < 0.01$.

Net Worth Comparison II

Net worth of K Firms

Net worth of *CentralGovt./GDP*

Scenario	DSK	REG-DSK	t	p
No Shock	3.05e5	6.21e5	-14.96	1.64e-17***
CS	3.36e5	8.51e5	-19.86	1.15e-21***
LP + EF	1.55e5	4.34e5	-20.44	4.23e-22***

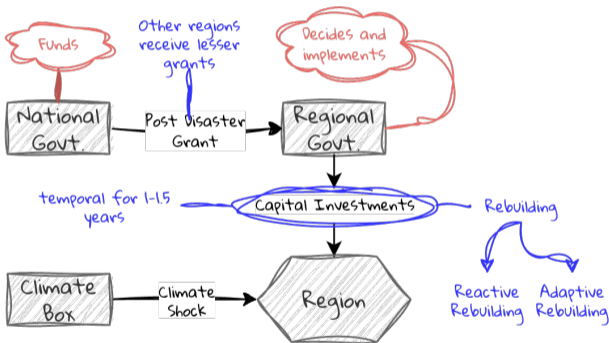
DSK	REG-DSK	t	p
-0.201	-0.204	0.84	0.406
-0.194	-0.197	0.73	0.471
-0.202	-0.200	-0.36	0.723

Welch's t -test ($n = 20$). *** $p < 0.01$.

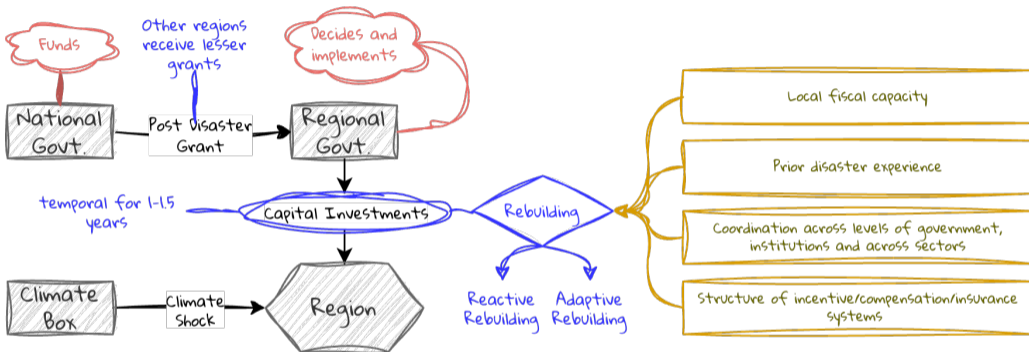
Adaptation

Recovery Post Climate Shock

- Adaptation and recovery responsibilities are distributed across sub-national governments, but primarily financed by national government and aided by EU (Mello and Ter-Minassian, 2024)
- Italian municipalities react to floods by increasing capital investments. Less resilient and more vulnerable municipalities highly depend on transfers (Lodi et al., 2023)
- Insurance is one of the main private financing, its regimes varies across countries; can speed recovery, but by itself it does not reliably prevent future risk (Surminski et al., 2015; Sheehan et al., 2023)



Reactive v/s Adaptive Rebuilding



- 1 Coordination across levels of government, institutions and across sectors (Farinós-Dasí et al., 2025)
- 2 Local fiscal capacity (Lodi et al., 2023)
- 3 Structure of incentive/compensation/insurance systems (Suykens et al., 2019; Surminski et al., 2015)
- 4 Prior disaster experience (among households for private adaptation) (Endendijk et al., 2025)

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