Why Climate Disasters Don't Guarantee Climate Action?

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

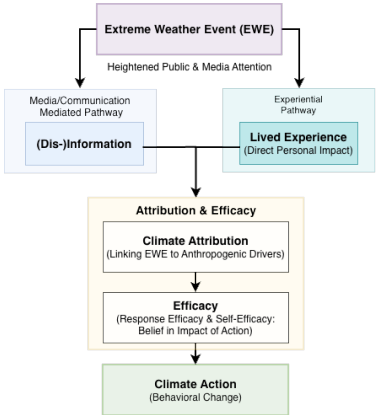
Anmol Soni[1]
Tina Comes[2] Giulia Piccillo[1] Tania Treibich[1]

[1]School of Business and Economics, Maastricht University
[2]Faculty of Technology Policy & Management, TU Delft

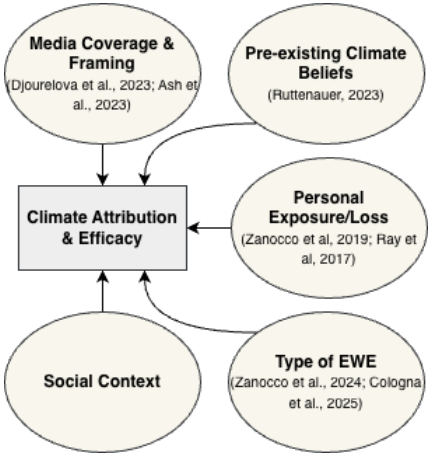
April 13, 2026

Introduction

- Extreme weather events (EWEs) are increasing in frequency, intensity and economic damages
  Intergovernmental Panel On Climate Change (2014); Coronese et al. (2019)
- Public and media attention are heightened during EWE
  Roxburgh et al. (2019); Friedman et al. (2019)
- EWEs can serve as catalysts for major societal and political shifts ("critical junction") Casali et al. (2024)
- Attribution of EWEs to climate change is key for converting experience into mitigation motivation Ogunbode et al. (2019)



What shapes climate attribution post EWE?



Regional heterogeneity in climate impacts & opinions

- Climate damages from EWEs are **uneven across regions**, creating long-run path dependencies in economic performance and climate policy support
  Ray et al. (2017); Giordono et al. (2020a)
- Regional EWE exposure differs in frequency as well as type
- National support for climate policy reflects interactions across regions, including:
  - **Opinion dynamics** among affected residents (e.g., climate attribution after shocks)
    Cologna et al. (2025)
  - **Economic & demographic weight** of impacted regions (core vs periphery)
    Bølstad (2015)
- Heterogeneous exposure & perceptions help explain **variation in local support for climate policies**
  Giordono et al. (2020b)

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

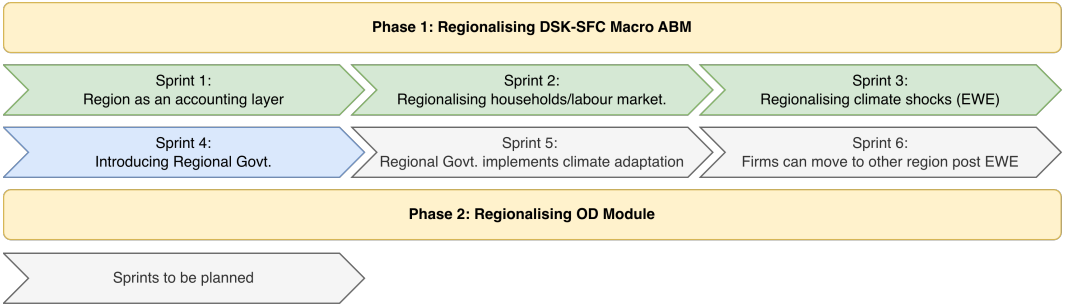
Phase 1: Regionalised Agents and Climate Shocks

- **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

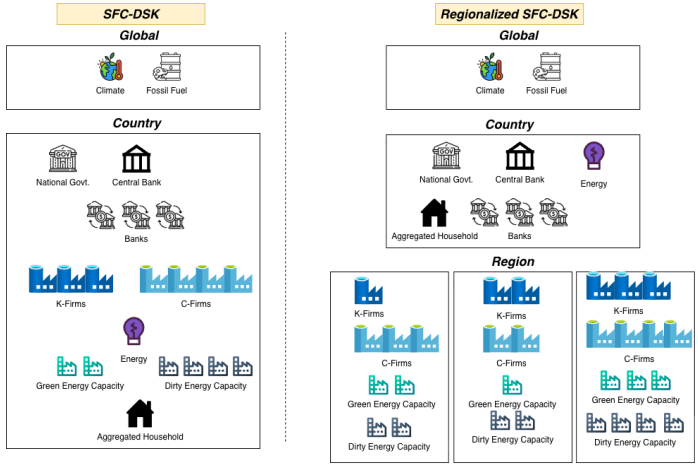
- **Objective:** Endogenize support for climate policies via opinion dynamics.
- **Modelling:**
  - Drivers: EWE exposure, attribution, beliefs, employment, (dis)information.
  - Outcomes: Differentiated support for mitigation (national) vs. adaptation (regional) policies.
- **Hypotheses:**
  - EWE exposure 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



Regional Firms

Sprint 1: Regionalising K & C Firms and Energy Capacity



Sprint 1: Regionalising K & C Firms and Energy Capacity

1. Region is conceptualized as an aggregator/accounting layer in the existing model. It is not an agent and does not influence model behaviour.
2. In this first sprint, K-Firms, C-Firms are tagged to a region.
3. Energy capacity, production, emissions, etc. are computed at regional level as derivatives based on regional capacity share.
4. `'AGGREGATE_REGIONS'` function is introduced which reports regional aggregates and also act as a verification to ensure regional aggregates sum to global aggregates.
5. Other variables and behavioural aspects are left untouched.

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!

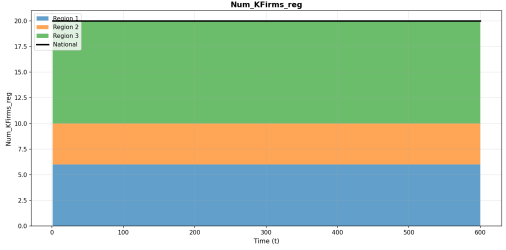


Figure: Number of K-Firms

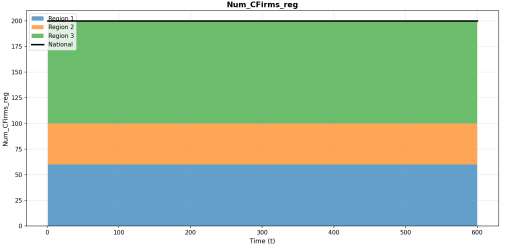


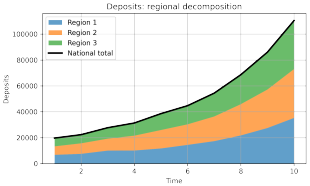
Figure: Number of C-Firms

Sprint 1: Regionalising Energy Capacity (Plants)

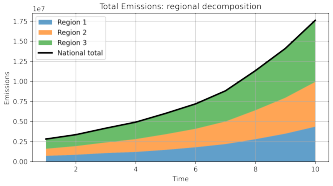
- Regional accounting layer computes following energy sector parameters (derived) at regional level using `dirty_capacity_share` and `green_capacity_share`.
- The energy market is also at national level analogous to a national electricity grid.
- The climate shock to energy capacity (plants) can be implemented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

Sprint 1: Verifying Regional Aggregates (Sanity Check)

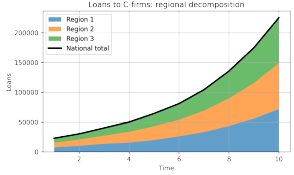
A 10-step simulation with three regions is executed to ensure that regional aggregates align with national-level aggregates.



Deposits



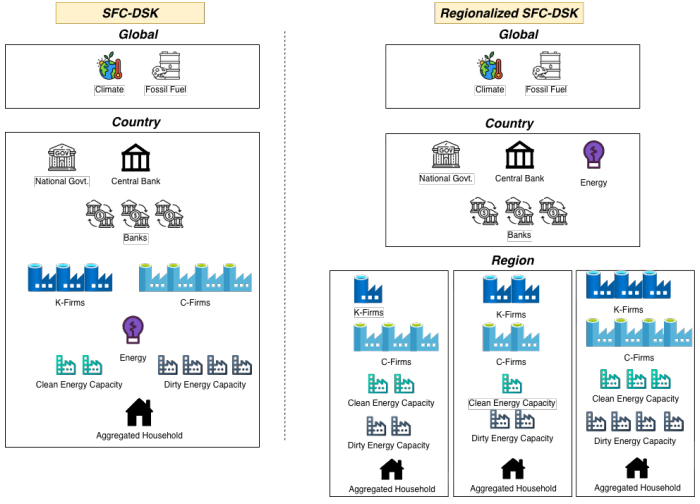
Emissions



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'`.

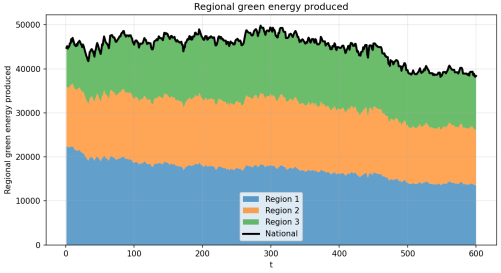


Figure: Green Energy Production

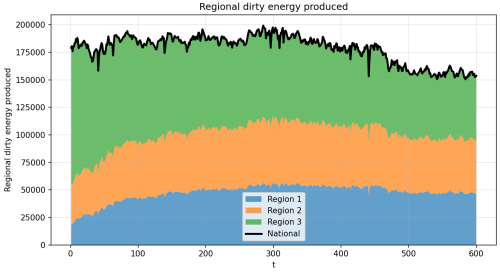


Figure: Dirty Energy Production

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 `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: Regionalising Households/Labour

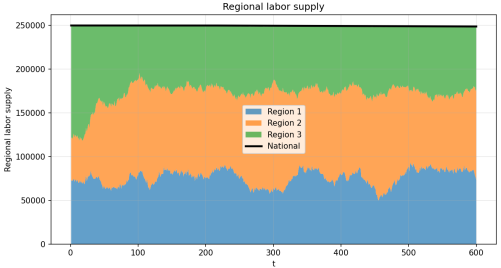


Figure: Labour Supply Pool LS0

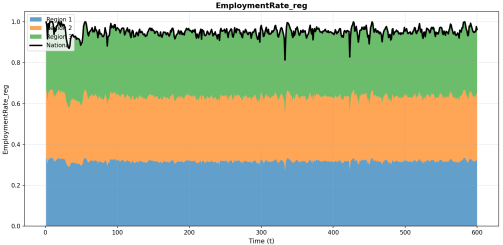


Figure: Employment Rate

Sprint 2: Regionalising Firm Emissions

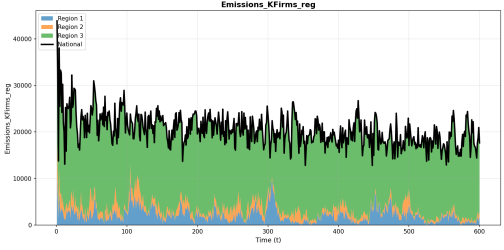


Figure: K firm Emissions

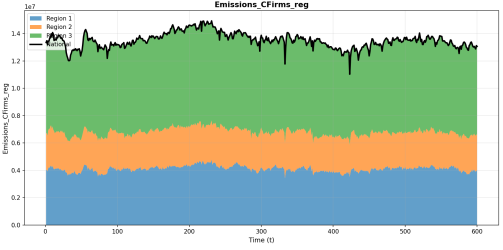


Figure: C firm Emissions

Sprint 2: Regionalising Emissions

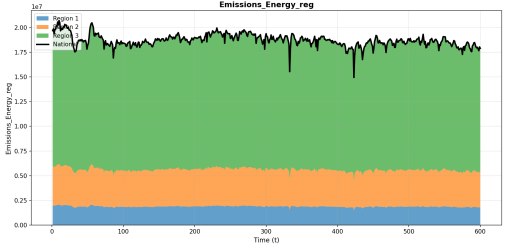


Figure: Energy Sector Emissions

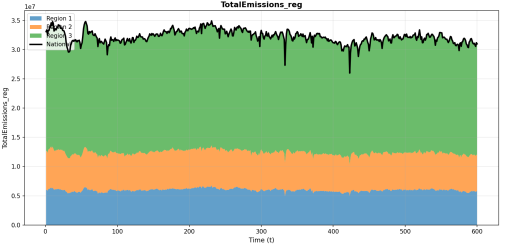


Figure: Total Emissions

Sprint 2: Regional Accounting of GDP

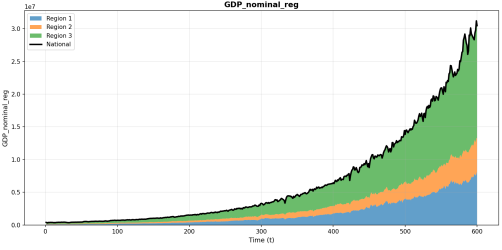


Figure: Nominal GDP

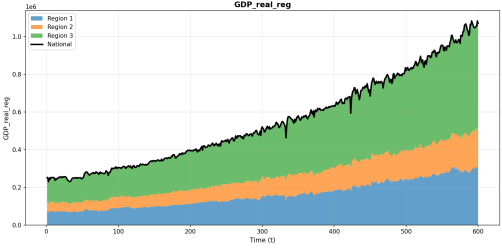


Figure: Real GDP

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 $s \in \{1, \ldots, S\}$ and period t:

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

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:

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

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 $s \in \{1, \ldots, S\}$, region r, and period t:

$$\varepsilon_{s,r,t} \sim \mathrm{Beta}\left(a_{s,r,t},\ b_{s,r,t}\right)$$

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

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

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

Sprint 3: Regionalisation of climate shock channels

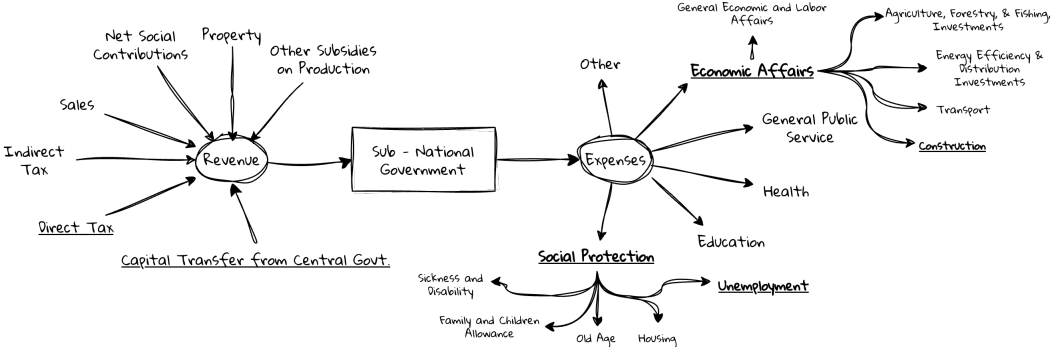
Regional Climate Shocks

- At each period, we draw one climate shock per region and per channel, driven by a common global temperature path and applied uniformly to all firms in the region.
- Regions differ in how strongly specific climate shock types hit (damages) and scale with warming, but all regions share the same global climate forcing.

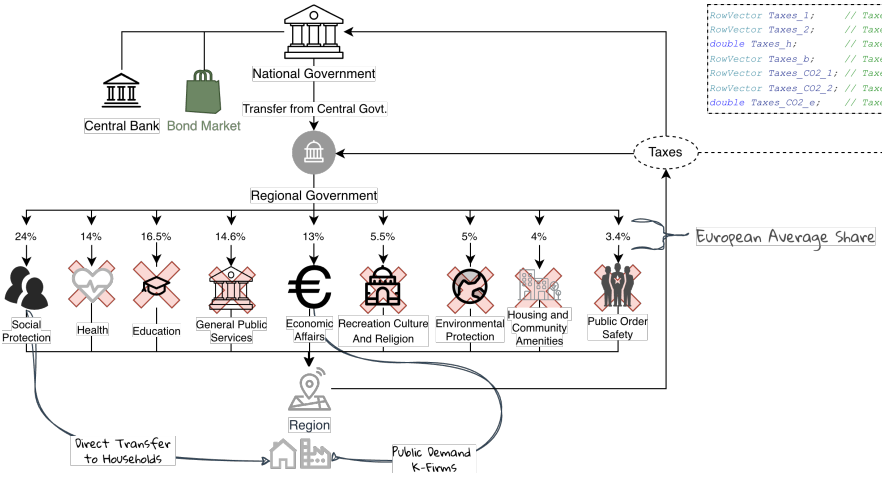
Regional Govt.

Conceptualising Sub-National Government in European Context

- Each country creates its own arrangement for dividing responsibilities between regional and local entities which can be collectively called as sub-national governments (Halaskova et al., 2021)
- Expenses and revenues of sub-national government can be calibrated using subnational government finances from ECB Olsson and Catz (2023)



Regional Govt. Revenue & Expenditure




```
RowVector Taxes_1;      // Taxes on profits paid by K-firms
RowVector Taxes_2;      // Taxes on profits  paid by C-firms
double Taxes_h;         // Taxes on income (wages) paid by households
RowVector Taxes_b;      // Taxes on profits paid by banks
RowVector Taxes_CO2_1; // Taxes on CO2 paid by K-firms
RowVector Taxes_CO2_2; // Taxes on CO2 paid by C-firms
double Taxes_CO2_e;     // Taxes on CO2 paid by energy sector
```

Regional Government Revenue Design

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

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

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

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

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

- $TaxShare_{r,t}$: 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

$$SocialProtection_{r,t} = LS_{r,t} \cdot U_{r,t} \cdot w_{t-1} \cdot \omega_{u,r}$$

- $LS_{r,t}$: Regional labour supply pool
- $U_{r,t}$: Regional unemployment rate
- w_{t-1}: Wages
- $\omega_{u,r}$: Regional wage replacement rate

Economic Affairs

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

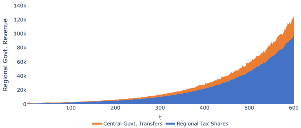
- Public investment expenditure for building public stock
- For each K-firm in region r:

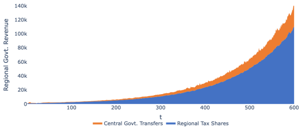
$$EconomicAffairs_{Kfirm,r,t} = \frac{EconomicAffairs_{r,t}}{N_{r,t}^{Kfirm}}$$

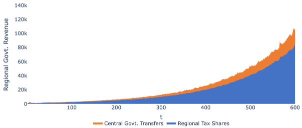
Regional Government Revenue and Expenditure Components

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

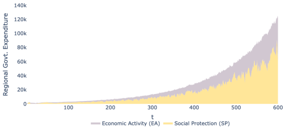
No Shock | CS | $LP + EF$

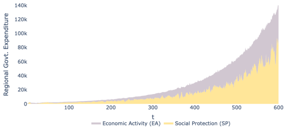


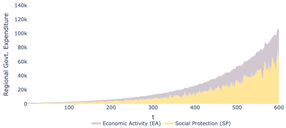




$$EXPENDITURE_{RegGovt,r,t} = SocialProtection_{r,t} + EconomicAffairs_{r,t}$$







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

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

Verification

Verification

To ensure model behaviours remains unchanged after introduction of regional government, we perform following simulation experiment. **Models** : (1) DSK (Reissl et al., 2025) (2) Regional - DSK

Setup

Scenarios

1. No Shock
2. Capital Shock
3. Labour Productivity + Energy Efficiency Shock

Unemployment Benefits routed through Regional Govt.

- DSK: $w_u = 0.4$
- Regional DSK: $w_u = 0$; $w_{u,r} = 0.4$

Regional Govt. Setup

- **Revenue**
  - $TaxShare_{r,t} = \tau_r^{share} \left(T_{r,t}^{Cfirms} + T_{r,t}^{Kfims} \right) = 0$
  - Central Govt. Transfers = Regional Unemployment Benefits
- **Expense**
  - Social Protection = Unemployment benefits
  - Economic Affairs: We set regional tax share zero so that regional govt. relies entirely on central govt. transfers. This mandates that regional govt. never goes in surplus and thus has zero EA expense.

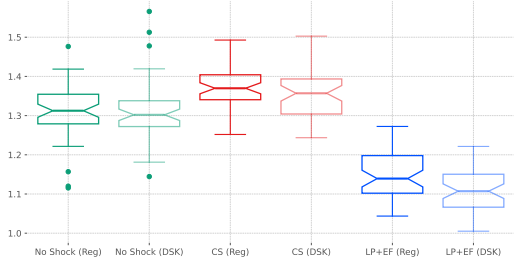
Verification | Macro Performance (R-DSK relative to DSK)

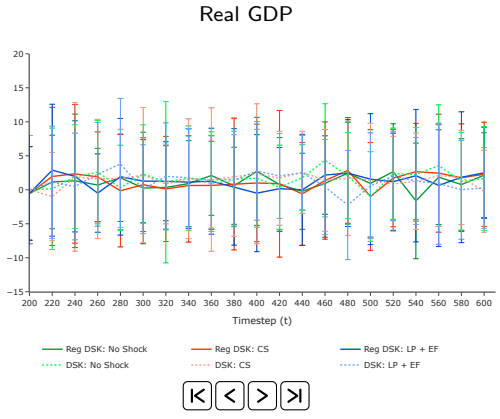
Metric	No Shock	CS	LP + EF
Unemployment	0.9980(0.21)	0.9934(0.79)	0.9961(0.38)
GDP Volatility	0.9932(0.45)	0.9976(0.16)	1.0094(− 0.65)
GDP Growth	0.9986(0.13)	1.0002(− 0.02)	1.0048(− 0.41)
Crisis Likelihood	0.9809(1.00)	0.9946(0.29)	1.0030(− 0.17)
Emissions	0.9906(0.42)	0.9672(1.56)	0.9866(0.62)

Entries report mean *Regional-DSK* / *DSK* for $n = 50$ monte-carlo simulations.
t-statistics for H_0: equal means are in parentheses.
$^{*}p < 0.10$, $^{**}p < 0.05$, $^{***}p < 0.01$.

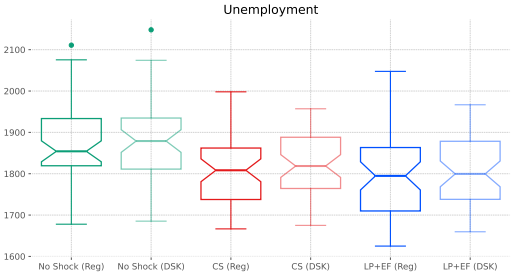
	No Shock
$\frac{\text{RegGov SocialProtection (R-DSK)}}{\text{UnemploymentBenefit (DSK)}}$	0.9975
t-statistic	0.2036

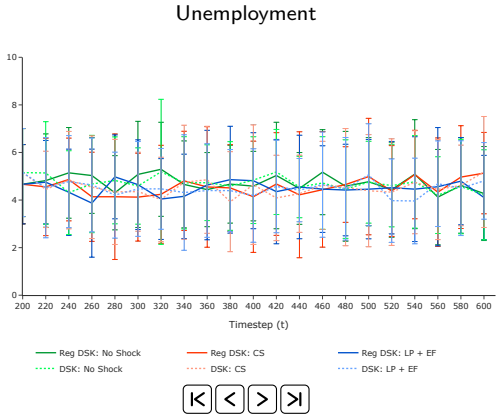
Verification | GDP Growth





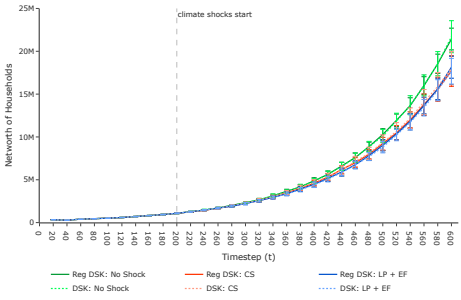
Verification | Unemployment





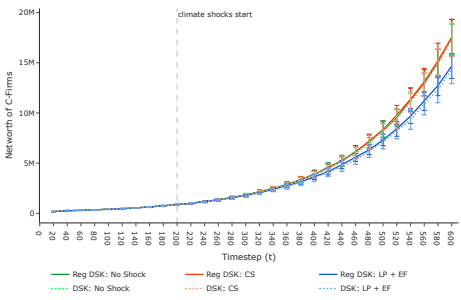
Verification | Net Worth Comparison I

Net worth of Households



Scenario	Ratio *R-DSK*/*DSK*
No Shock	1.0016(− 0.13)
CS	0.9878(0.90)
LP + EF	1.0133(− 1.10)

Net worth of C Firms

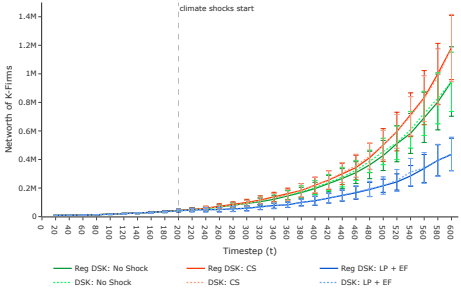


Scenario	Ratio *R-DSK*/*DSK*
No Shock	1.0112(− 0.76)
CS	1.0158(− 1.01)
LP + EF	1.0281(− 1.93)

Welch's t-test ($n = 50$). $^{***}p < 0.01$.

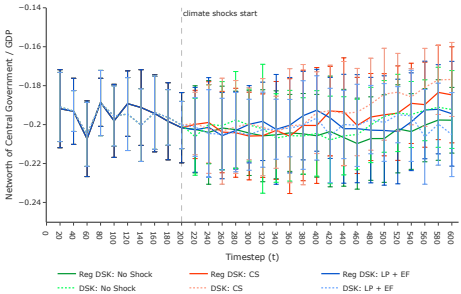
Verification | Net Worth Comparison II

Net worth of K Firms



Scenario	Ratio *R-DSK*/*DSK*
No Shock	0.9667(1.05)
CS	1.0074(− 0.22)
LP + EF	0.9808(0.59)

Net worth of *CentralGovt.*/*GDP*



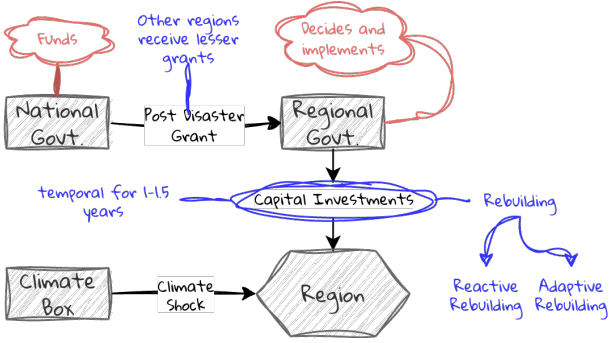
Scenario	Ratio *R-DSK*/*DSK*
No Shock	0.9909(− 0.66)
CS	0.9759(− 1.56)
LP + EF	0.9830(− 1.43)

Welch's t-test ($n = 50$). $^{***}p < 0.01$.

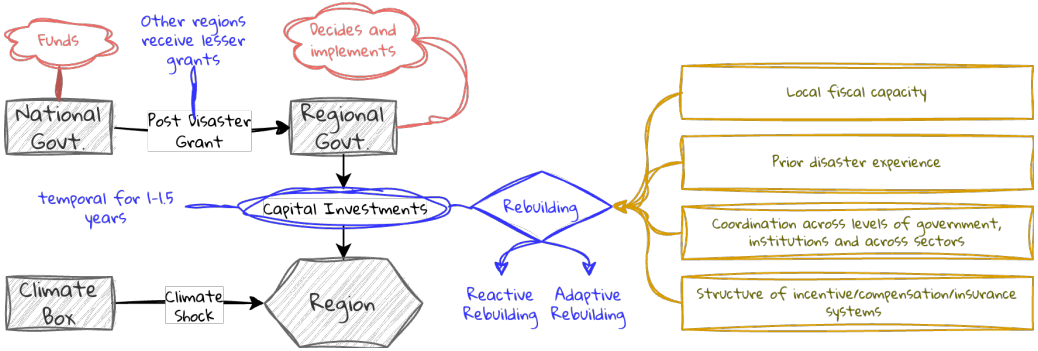
Adaptation

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)
- For instance, Italian municipalities react to floods by increasing capital investments. Less resilient and more vulnerable municipalities highly depend on transfers (Lodi et al., 2023)
- On the other hand, insurance is the primary financing source for private rebuilding. Insurance 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)

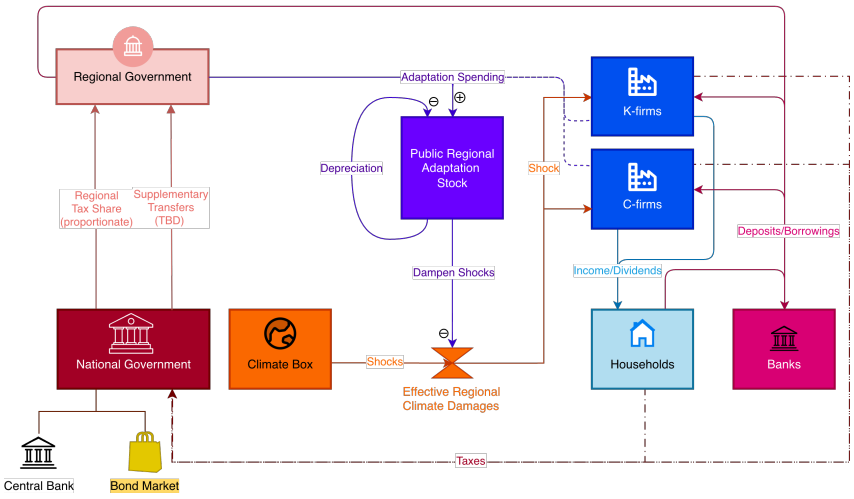


Reactive v/s Adaptive Rebuilding



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)

Regional Adaptation Conceptualisation



References

References I

Bølstad, J. (2015). Dynamics of european integration: Public opinion in the core and periphery. European Union Politics, 16(1):23–44.

Casali, Y., Aydin, N. Y., and Comes, T. (2024). A data-driven approach to analyse the co-evolution of urban systems through a resilience lens: A Helsinki case study. Environment and Planning B: Urban Analytics and City Science, 51(9):2074–2091.

Cologna, V., Meiler, S., Kropf, C. M., Lüthi, S., Mede, N. G., Bresch, D. N., Lecuona, O., Berger, S., Besley, J., Brick, C., Joubert, M., Maibach, E. W., Mihelj, S., Oreskes, N., Schäfer, M. S., and Linden, S. v. d. (2025). Extreme weather event attribution predicts climate policy support across the world. Nature Climate Change, 15(7):725–735.

Coronese, M., Lamperti, F., Keller, K., Chiaromonte, F., and Roventini, A. (2019). Evidence for sharp increase in the economic damages of extreme natural disasters. Proceedings of the National Academy of Sciences, 116(43):21450–21455.

Endendijk, T., Rodriguez Castro, D., Dillenardt, L., Guntu, R. K., Botzen, W. J., de Moel, H., Thieken, A. H., Kreibich, H., Dewals, B. J., and Aerts, J. C. (2025). Flood experience and access to insurance contribute to differences in homeowners' post-disaster adaptation in a cross-border region of Western Europe. Communications Earth and Environment, 6(1):1–9.

Farinós-Dasí, J., Pinazo-Dallenbach, P., Peiró Sánchez-Manjavacas, E., and Rodríguez-Bernal, D. C. (2025). Disaster risk management, climate change adaptation and the role of spatial and urban planning: evidence from European case studies. Natural Hazards, 121(19):23479–23512.

References II

Friedman, E., Breitzer, R., and Solecki, W. (2019). Communicating extreme event policy windows: Discourses on Hurricane Sandy and policy change in Boston and New York City. Environmental Science & Policy, 100:55–65.

Giordono, L., Boudet, H., and Gard-Murray, A. (2020a). Local adaptation policy responses to extreme weather events. Policy Sciences, 53(4):609–636.

Giordono, L., Boudet, H., and Gard-Murray, A. (2020b). Local adaptation policy responses to extreme weather events. Policy sciences, 53(4):609–636.

Halaskova, M., Halaskova, R., Gavurova, B., and Kubak, M. (2021). Fiscal Decentralisation of Services: The Case of the Local Public Sector in European Countries. Journal of Tourism and Services, 12(23):26–43.

Intergovernmental Panel On Climate Change, editor (2014). Climate Change 2013 – The Physical Science Basis: Working Group I Contribution to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press, 1 edition.

Lodi, C., Marin, G., and Modica, M. (2023). The public finance response to floods of local governments in Italy. Journal of Environmental Management, 332:117352.

References III

Mello, L. d. and Ter-Minassian, T. (2024). Subnational Investments in Mitigation and Adaptation to Climate Change: Some Financing and Governance Issues. Public Finance and Management, 23(3):113–131.

Ogunbode, C. A., Demski, C., Capstick, S. B., and Sposato, R. G. (2019). Attribution matters: Revisiting the link between extreme weather experience and climate change mitigation responses. Global Environmental Change, 54:31–39.

Olsson, H. and Catz, J. (2023). A closer look at subnational government finances.

Ray, A., Hughes, L., Konisky, D. M., and Kaylor, C. (2017). Extreme weather exposure and support for climate change adaptation. Global Environmental Change, 46:104–113.

Reissl, S., Fierro, L. E., Lamperti, F., and Roventini, A. (2025). The DSK stock-flow consistent agent-based integrated assessment model. Ecological Economics, 236:108641.

Roxburgh, N., Guan, D., Shin, K. J., Rand, W., Managi, S., Lovelace, R., and Meng, J. (2019). Characterising climate change discourse on social media during extreme weather events. Global Environmental Change, 54:50–60.

References IV

Sheehan, B., Mullins, M., Shannon, D., and McCullagh, O. (2023). On the benefits of insurance and disaster risk management integration for improved climate-related natural catastrophe resilience. Environment Systems and Decisions, 43(4):639–648.

Surminski, S., Aerts, J., Botzen, W., Hudson, P., Mysiak, J., and Perez-Blanco, D. (2015). Reflections on the current debate on how to link flood insurance and disaster risk reduction in the European Union. Natural Hazards, 79(3):1451–1479.

Suykens, C. B. R., Tarlock, D., Priest, S. J., Doorn-Hoekveld, W. J., and van Rijswick, H. F. M. W. (2019). Sticks and carrots for reducing property-level risks from floods: an EU–US comparative perspective. Water International, 44(5):622–639. _eprint: https://doi.org/10.1080/02508060.2019.1640957.