Distributional impacts of climate change between and within EU regions

Extended Abstract

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Keywords: Climate Change, Regional Economy, Inequality, Agent-Based Models, Macroeconomic Dynamics
JEL: C63, Q52, R11

1. Motivation

Climate change and climate policies have profound socio-economic impacts, with significant heterogeneity in their propagation dynamics and spatial diffusion. A growing body of empirical evidence documents that poorer and warmer regions face disproportionately higher damages (Nordhaus and Moffat, 2017; Diffenbaugh and Burke, 2019; Méjean et al., 2024), while within countries, low-income groups are most affected, particularly in hot areas with large agricultural sectors (Palagi et al., 2022; Parsons et al., 2024; Coronese et al., 2025). Extreme weather events have been shown to exacerbate income inequality, especially in contexts of low adaptation capacity (Mumtaz and Theophilopoulou, 2024; Gilli et al., 2024). Trade, migration, and sectoral reallocation can partly mitigate these damages (Black et al., 2011; Dellink et al., 2017; World Trade Organization, 2022), yet constraints on household mobility and firms' ability to reconfigure trade networks may undermine these mechanisms, especially under uncertainty and bounded rationality (Taberna et al., 2023).

From a modeling perspective, several approaches have been developed to capture climate–inequality linkages. Regional integrated assessment models such as RICE (Nordhaus and Yang, 1996) capture inter-country inequality through aggregate damage functions, but lack micro-level mechanisms. Spatial IAMs introduce local heterogeneity and geographic resolution (Conte et al., 2021; Desmet and Rossi-Hansberg, 2024), yet typically rely on representative agents and cannot trace distributional effects among heterogeneous individuals. Agent-based IAMs offer the ability to model climate and policy impacts among heterogeneous agents with bounded rationality (Taberna et al., 2023; Ravaioli et al., 2025), but have so far not been deployed in a multi-regional setting with empirically validated micro-level climate shocks.

This study addresses this gap by extending the Multi-Agent model for Assessing Transition Risks (MATRIX) model, a stock-flow consistent, agent-based integrated-assessment model, to explicitly incorporate regional heterogeneity within the European Union. Our contribution is threefold. First, we develop a multi-regional agent-based IAM that links micro-level climate shocks to macro and distributional outcomes through endogenous trade and migration. Second, we provide a detailed empirical calibration of region- and sector-specific climate damage functions using JRC-PESETA IV data, allowing for heterogeneous exposure across agents. Third, we quantify the role of inter-regional economic integration, trade and labor mobility, as endogenous adaptation channels, through counterfactual analysis.

Specifically, we aim to answer three research questions: (i) What are the aggregate and distributional effects of climate shocks across EU regions? (ii) How do different damage channels shape regional inequality? (iii) How do endogenous adaptation mechanisms (like trade and migration) mitigate or amplify climate damages?

2. Methodology and simulation setup

2.1. The MATRIX model

This work extends the MATRIX model, a stock-flow consistent, agent-based IAM where agents make decisions under uncertainty (Ciola et al., 2023; Turco et al., 2023; Bazzana et al., 2024; Rizzati et al., 2025). The model includes interconnected sectors populated by households (workers, entrepreneurs, bankers), corporate (consumption goods, energy services, capital goods, fossil fuels), banking, and public sectors. Heterogeneous agents within the sectors interact through decentralized markets. Firms across industries

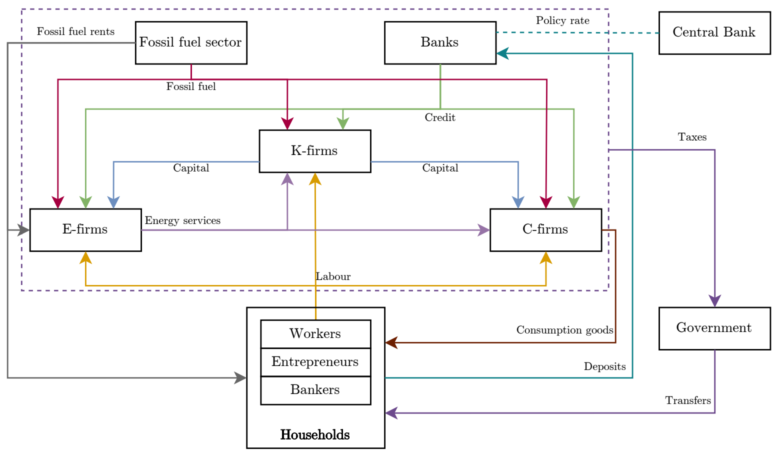

Figure 1: MATRIX model flowchart for a single regional economy.

are linked by empirically calibrated input-output relationships. The current version features two modules: an economic module implementing a multi-sector, multi-agent macro model of the Euro Area, and a climate module that integrates exogenous temperature scenarios with a regional agent-based damage function.

2.2. Multi-regional extension

The new version introduces three key extensions. First, endogenous growth is driven by human capital accumulation. Second, the EU is divided into four macro-regions grouped by climate similarity: North (DK, EE, FI, IE, LT, LV, SE, UK), South (CY, GR, ES, HR, IT, MT, PT, SI), East (BG, CZ, HU, PL, RO, SK), and Center (AT, BE, DE, FR, LU, NL). All regions share a common currency (extended Euro Area), and agents face iceberg trade costs ($\tau_{i,j,s}$) for cross-region economic activities.

Inter-regional trade and migration follow decentralized search-and-matching protocols that operate through separate but parallel mechanisms. On the goods market side, each buyer in every period decides whether to search for a supplier in another region. The probability of searching abroad is sector-specific and calibrated to reflect observed openness. When a firm searches abroad, it does not sample partners randomly but rather ranks foreign suppliers by their effective price, inclusive of corridor-specific iceberg trade costs that vary by sector and origin-destination pair, and contacts the most competitive ones first. The buyer then compares the best available foreign partner with its current supplier and switches if the new match offers a better price-quantity combination, generating a form of preferential attachment where the best partner becomes the new default.

On the labor market side, workers who are unemployed or underemployed search for new firms, with a probability of looking abroad that depends on their private wealth normalized so that the average search probability matches the calibrated baseline. When searching abroad, workers do not sample randomly but evaluate potential employers through a composite fitness score that combines the firm's human capital level (as an economic motive) with a regional attractiveness index based on the average human capital of firms in the destination region. Migration is tracked both as a flow (workers who changed region in the current period) and as a stock (workers currently employed outside their region of origin).

2.3. Climate shocks

Region- and sector-specific micro-level weather shocks are calibrated on the JRC-PESETA IV project. The damage function follows a two-step process. First, global temperature increases are mapped to region-specific event probabilities through probit functions estimated via weighted least squares on PESETA IV data:

$$\pi^{\text{exp}}_{r,s,k,t} = \Phi(\beta^{\text{exp}}_0 + \beta^{\text{exp}}_1 \Delta T_t) \tag{1}$$

for exposure and

$$\pi^{\text{fat}}_{r,s,k,t} = \Phi(\beta^{\text{fat}}_0 + \beta^{\text{fat}}_1 \Delta T_t) \tag{2}$$

for severity (fatality rate).

Second, these probabilities are translated into stochastic agent-level damages:

$$d^k_{j,r,s,t} = -\pi^{\text{fat}}_{r,s,k,t} \cdot X^k_{j,r,s,t}, \tag{3}$$

where $X^k_{j,r,s,t} \sim \text{Beta}(a_{r,s,k,t}, b_{r,s,k,t})$
and the shape parameters are

$$a_{r,s,k,t} = \frac{\pi^{\text{exp}}_{r,s,k,t}(1-\sigma)}{\sigma}, \qquad b_{r,s,k,t} = \frac{(1-\pi^{\text{exp}}_{r,s,k,t})(1-\sigma)}{\sigma}$$

The exposure probability π^{exp} governs the mean of the Beta distribution, determining the average share of agents affected, while the heterogeneity parameter σ controls the dispersion of damages across agents: $\sigma = 0$ yields homogeneous damages (all agents equally affected) and $\sigma = 1$ produces fully heterogeneous damages (a few agents severely hit while most are spared). The severity parameter π^{fat} then scales the overall magnitude of losses conditional on exposure.

The shocks affect agents through distinct transmission channels. Table 1 depicts the heterogeneity in terms of agents impacts and damages, as well as regional and seasonality patterns.

Agent	**Shock type**	**Impact**	**Damage**	**Season/Region**
House-holds	Heatwaves	Exposure/Fatality	H. capital loss	Su (All)
	Coldwaves	Exposure/Fatality	H. capital loss	W (All)
	Windstorms	Exposure/Fatality	H. capital loss	W (All)
Firms	Windstorms	Avg. Damage	Prod. disruption	W (All)
	Droughts	Avg. Damage	Prod. disruption	Su (N), Sp/Su (C,E), Sp/Su/F (S)
	Coastal floods	Exp./Avg. Dam.	P. capital loss	F/W (All)
	River floods	Exp./Avg. Dam.	P. capital loss	Sp (N,E), W/Su (C,S)

Su=Summer, W=Winter, Sp=Spring, F=Fall; N=North, C=Center, E=East, S=South

Table 1: Weather shocks by type, affected agents, and transmission channels (JRC-PESETA IV).

2.4. Calibration and simulation design

The model is initialized using the WIOD database (2016 Release) for the regional distribution of workers and firms, sectoral-regional factor shares, and initial differences in human capital. Central Europe accounts for the largest share of both workers (40%) and firms (41–47% depending on sector), followed by South (23–26%), North (21–23%), and East (6–16%). Search and trade cost parameters (κ_j, ζ_j, $\tau_{i,j,s}$) are calibrated to match empirical inter-regional trade and migration flows. Validation against observed trade flow matrices shows a good fit across all three firm sectors (energy, consumption, capital), with the model successfully replicating the dominant intra-regional concentration and the patterns of inter-regional exchange.

The baseline scenario (low temperature) produces realistic macroeconomic dynamics: regional GDP grows endogenously with Central and Northern Europe achieving higher levels, unemployment rates stabilize at plausible levels with regional variation, and the Gini index reflects within-region income inequality. Migration patterns in the baseline show net flows primarily from South and East toward North and Center, consistent with observed EU labor mobility.

We conduct three simulation experiments. First, we assess aggregate and regional GDP impacts under five IPCC AR6 climate scenarios: C1 (+1.6°C), C3 (+2.1°C), C6 (+2.9°C), C7 (+3.6°C), and C8 (+4.4°C). Second, comparing the low (C1) and high (C8) scenarios, we decompose GDP impacts by damage channel: human capital, output disruption, and physical capital. Third, we run counterfactual experiments decreasing by half (i) inter-regional trade and (ii) inter-regional migration to quantify the role of these adaptation channels in mitigating or amplifying climate damages.

3. Preliminary Results

3.1. Regional GDP impacts

Our simulations (100 Montecarlo simulations for each scenario) reveal highly heterogeneous climate impacts across EU regions, with damages increasing nonlinearly in temperature, summarized in Figure 2. Under the +4.4°C scenario (C8), Eastern Europe faces the largest GDP losses at −9.0%, followed by Northern Europe (−5.8%) and Southern Europe (−5.5%), while Central Europe proves most resilient (−3.6%). Notably, at moderate warming (+1.7°C), some regions, particularly the East and Center, still experience slight GDP gains, suggesting the presence of mild positive effects at low temperature increases that are subsequently overwhelmed by mounting damages. The regional inequality gap between the most and least affected regions (Eastern vs. Central Europe) widens from 0.5 percentage points at +1.7°C to 5.4 percentage points at +4.4°C.

3.2. Shock decomposition

The decomposition of GDP impacts by damage channel (Fig. 3) reveals markedly different transmission mechanisms across regions. In Eastern Europe, capital destruction from floods is the dominant channel, accounting for 5.9 of the 9.0 percentage points of GDP loss. In Northern Europe, output disruptions from droughts and storms represent the largest component (−2.2 pp), followed by substantial human capital losses (−3.4 pp). Southern Europe displays a more balanced damage profile, with human capital losses from

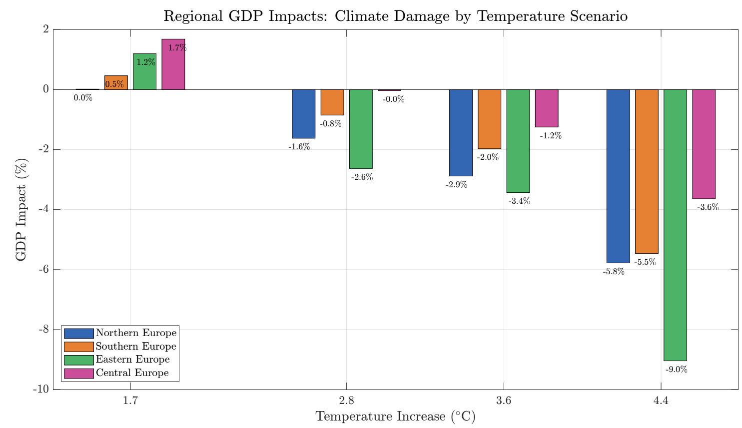

Figure 2: Regional GDP impacts by temperature scenario (IPCC AR6). Eastern Europe faces the largest damages (-9% at $+4.4$°C), while Central Europe is most resilient (-3.6%).

heatwaves (-2.0 pp), output disruptions (-1.9 pp), and capital losses (-1.7 pp) all contributing significantly. Central Europe experiences the smallest total damage, with output disruptions (-1.3 pp) partly offset by a positive capital shock effect ($+0.6$ pp).

A notable sectoral paradox emerges from the capital goods sector analysis. Capital destruction from floods generates substantial replacement demand, boosting capital goods sales by $+18.8\%$ in Eastern Europe, $+4.7\%$ in Southern Europe, and $+4.5\%$ in Northern Europe. This "broken window" effect illustrates how the capital goods sector can profit from disaster reconstruction even as aggregate GDP contracts, a perverse incentive structure with important policy implications for post-disaster resource allocation.

3.3. Role of trade and migration

Counterfactual experiments reveal that the two main inter-regional adaptation mechanisms, trade and migration, have contrasting effects on climate resilience. Shutting down inter-regional trade worsens GDP outcomes in most regions, confirming that trade acts as a mitigating factor: it reduces losses by approximately 0.6 percentage points in Northern Europe and 1.4 pp in Central Europe, as these regions can source goods and inputs from less-affected areas. Conversely, shutting down migration improves GDP outcomes in Southern and Eastern Europe. Migration amplifies damages in these regions, by approximately 2.2 pp in Southern Europe and 1.9 pp in Eastern Europe, as workers relocate toward less-damaged areas, draining human cap-

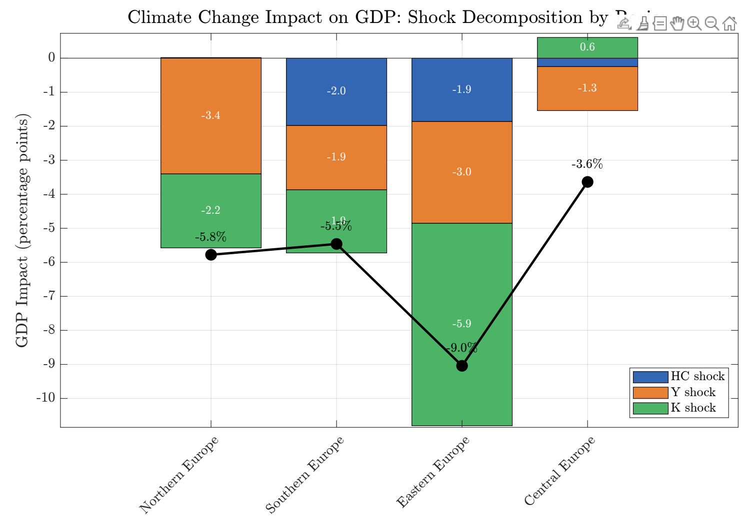

Figure 3: Climate shock decomposition by region (C8 vs. C1). Stacked bars show contributions of human capital (HC), output (Y), and physical capital (K) shocks to total GDP loss.

ital from the regions that need it most. Northern and Central Europe, as net recipients of migration, benefit from these flows, creating a tension between individual adaptation and regional welfare.

3.4. Conclusions

These findings carry several policy implications. First, the stark heterogeneity of climate impacts across EU regions underscores that one-size-fits-all climate policies are inadequate: regional targeting is essential to address the specific vulnerabilities of each area; flood prevention infrastructure in Eastern Europe, heat adaptation in the South, and drought resilience in the North. Second, facilitating inter-regional trade can enhance climate resilience by allowing supply chain adjustments, while migration flows require careful management to avoid exacerbating inequality between origin and destination regions. Policies that improve labor market conditions in vulnerable regions could reduce the push factors driving brain drain, while transfer mechanisms could compensate for the negative externalities of climate-induced migration. Third, the broken window effect in the capital sector highlights the need to monitor sectoral distortions during disaster reconstruction, ensuring that replacement investment does not crowd out productive allocation.

Future work will extend the analysis along two dimensions. First, we will

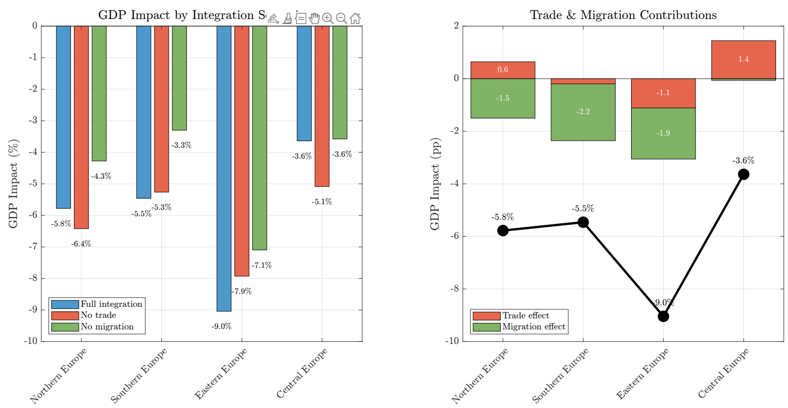

Figure 4: Role of trade and migration as adaptation mechanisms. Left: GDP impacts under full integration, no trade, and no migration. Right: decomposition of trade and migration contributions.

examine distributional impacts among heterogeneous agents within regions, exploiting the micro-level granularity of the agent-based framework to assess how climate damages affect income and wealth inequality within each macro-region. Second, we will compare the effects of homogeneous versus heterogeneous climate shocks, both random and agent-specific, to evaluate how the distributional structure of damages at the individual level shapes aggregate and inequality outcomes.

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