

Climate Risk across Europe

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Abstract

Who bears climate damage in Europe when workers and capital can adjust, and how much of that cost is risk? I answer in a dynamic spatial model of EU regions with migration, local capital and sectoral trade, in which heat, extreme precipitation and drought strike at frequencies that depend on local temperature and damage productivity, amenities and buildings. Solved by the Master Equation to second order, the model prices climate uncertainties at three scales: how much the planet warms, how much of that warming each part of Europe receives, and which hazards strike each region. The final climate under SSP2-4.5 costs the average worker -6.38% of consumption, -9.00% in the Mediterranean against -5.07% in the north; the migration friction keeps the cost where the damage falls and, lifted, would spread it without reducing it. The expected cost falls on workers and the risk mostly on capital. The uncertainty is worth a small gain to workers, because a milder climate than expected helps them more than a harsher one hurts, once capital, people and prices have moved; it is a risk to the owners of exposed buildings, who lose most and cannot leave. At most 21% of that risk can be pooled within Europe; the rest is global warming itself, which no reallocation of labour insures.

1 Introduction

How much will climate change cost a region of Europe, and how much of that cost is risk? The two questions are usually answered by different models. Integrated assessment models produce an expected damage and, when they are stochastic, a risk premium (Cai and Lontzek, 2019; Van den Bremer and Van der Ploeg, 2021), but for a country or the world taken as one unit, with no room for the economy to move away from the damage: nobody migrates, no capital is reallocated, no place changes what it produces. Spatial models with adaptation let the economy move, through migration, trade and the reallocation of capital, and they produce a geography of damages (Cruz and Rossi-Hansberg, 2024; Bilal and Rossi-Hansberg, 2023), but along a single deterministic path, so they put no price on risk. The first family prices risk without adaptation; the second models adaptation without risk. This paper answers both questions in one model, at the resolution of the NUTS2 regions of the European Union.

A worker in Andalusia and a worker in Mecklenburg face the same global warming and different climates. Along a given global emission path, the uncertainty they face has three layers, and only a spatial model keeps them apart. The first is how much the planet warms for a given path of emissions: if the climate’s sensitivity turns out high, every region of Europe is warmer, and the Andalusian and the Mecklenburger draw the same bad number. The second is how each region warms per degree of global warming: the climate models agree that the Mediterranean warms faster and disagree by how much, so that two regions can face opposite surprises. The third is which hazards actually strike: whether a given summer brings a heat wave to Andalusia or a flood to Saxony is a draw of its own, every year, and correlated across neighbours. The first two layers are drawn once, on where the climate will settle; the third is drawn again every year, and what it prices is the cost of living with a variable climate once it has settled. The distinction matters for policy. The second and the third layers can be pooled within Europe (one region’s bad year against another’s) so that a European fund, or migration, can carry part of them. The first cannot: when every region is hit alike there is nowhere better to go, and there is no region in the pool whose draw is independent.

In a spatial economy, exposure is partly a choice: the economy responds to the risk through where people live and where capital accumulates, and what the paper measures is what remains once it has responded. That residual is now a political object. On October 2026 the Commission proposed the first European law on climate resilience, asked Member States to plan on common warming levels, and undertook to identify the Union’s most climate-vulnerable territories (European Commission, 2026). This paper is a map of those territories, drawn before the economy has finished moving and after it has, and it says which part of what they face Europe can share among its regions and which part it cannot.

The economy is the spatial dynamic economy of Bilal and Rossi-Hansberg (2023), written on the regions of the European Union and extended in three directions. Two sectors, agriculture and the rest, are linked by trade between regions. Capital is local, and its owner is risk-averse and cannot insure: this is the agent for whom climate risk has a price. And the climate enters through a closed list of hazards — heat, extreme precipitation, drought — whose frequencies are functions of local temperature, estimated by event studies on regional panels and extrapolated to the final climate. Climate uncertainty is carried by a small vector of factors in the three layers just described: the global level of warming and the regional pattern per degree are draws on where the climate will be, made once; the realisations of hazards are a process with innovations every year

and a spatial covariance measured on the co-occurrence of events across regions.

The model is solved by the Master Equation of Bilal (2023): a second-order expansion around today's economy gives the expected path of every location and, in its curvature terms, a first reading of the premium. An expansion is a local object, however, and its curvatures are those of the economy at the point where it is taken. The premium of the paper is therefore measured exactly. Two of the climate factors are drawn once and for all, the level of warming and the regional pattern per degree. Their distribution is replaced by a finite list of possible climates, each with its probability; the economy is solved in full under each of them; and the premium is the difference between welfare averaged over these climates with their probabilities and welfare under the single expected climate. The second-order expansion overstates that premium by a factor of 23.1: today's economy, with its capital stock intact, is far more curved in the direction of the final climate than the economy that will bear it. All welfare changes are consumption equivalents per agent and per location, and they compare the final climate with the one Europeans live in today, for an agent who lives now and bears the transition.

Six results follow. First, the final climate has a cost, and it has a geography. The expected cost to the average European worker is -6.38% of steady-state consumption; it runs from Malta (-13.89%) to Poland and Latvia (-5.00%) and concentrates where heat makes life and work harder and extreme precipitation destroys the buildings. The expected cost sits where the spatial literature would put it, once the objects are matched. Bilal and Rossi-Hansberg (2023) find, on United States counties and with the same welfare convention, a loss of 2.8% of consumption for the average worker in 2025 and 4.2% by 2100, of which the depreciation of capital by climate accounts for more than half, and migration offsets 25–40%. Cruz and Rossi-Hansberg (2024) find welfare losses of up to 20% in the hottest parts of Africa and Latin America. The PESETA studies of the Joint Research Centre measure a different object, the additional annual welfare loss of the European Union and the United Kingdom from a list of sectoral impacts, and find 1.38% of GDP at three degrees of warming and with southern losses several times the northern ones (Feyen et al., 2020); the geography agrees, and the magnitudes are not comparable: PESETA prices an annual flow of sectoral impacts, mortality from heat included, where this paper prices a consumption equivalent between two steady states of an economy without mortality.

Second, who bears that cost is a property of the migration friction. At the estimated friction, workers of the Mediterranean group stand at -9.00% , those of western and central Europe at -5.35% and those of northern Europe at -5.07% ; without a migration cost the three incidences are nearly the same and the Union as a whole stands at -6.99% , a larger cost. The friction concentrates the cost on the exposed group. Europe without the friction shares the cost more evenly and bears more of it, so that mobility redistributes the cost of climate change rather than reducing it.

Third, the climate uncertainty is worth a small gain to the average worker, not a cost. The premium is 0.39% , and it is the sum of two pieces of opposite sign. The price of risk, what the worker would pay to face the mean climate rather than the lottery, is -0.04% . The gain from convexity, what the lottery is worth to a risk-neutral agent because the economy responds to the climate convexly, is 0.43% : the capital stock responds to a destruction rate as one over the sum of depreciation and destruction, the location choice is a log-sum-exp of values, and the frequency of hazards is log-linear in temperature, so that good draws help more than bad draws hurt. At log preferences the second piece outweighs the first for every worker and for the average unit of today's capital; it stops doing so for capital owners above a relative risk aversion of 1.24, first

where the final climate destroys the stock. What the premium prices is the physical uncertainty of one emissions path: the level of the final warming, its geography, and the weather drawn from it. It does not price the choice of the path or the estimation of the damages, and neither would turn the sign: to second order the premium is the variance of the final climate times a term that does not depend on it, so a larger lottery scales the premium without turning it. One thing would turn it: a risk aversion above the threshold the economy's own adjustment sets. Losses large enough to leave the second order change the accuracy of the expansion, not the sign of the exact premium, which is read at every location.

Fourth, part of the risk cannot be moved. No spatial reallocation of labour reduces the component of climate risk common to all regions, at any migration friction and any cost of switching sector; it bounds what any European mutualisation can reach. A purely intra-European fund cannot insure the part of the risk that loads uniformly within a sector, which lies inside that common layer; the layer carries 79% of the workers' premium, so that the mutualisable part of European climate risk is at most 21% of it.

Fifth, the capital-weighted expected cost of capital owners is -3.92% , but they gain at 68.4% (316 of 462) of the locations, because the migration of workers toward the regions the climate spares raises the return on the capital that is already there; where capital is destroyed its owner bears the loss alone, and it is there that the premium is largest. The gap between risk-neutral and risk-averse valuation of the same capital, the value of being able to diversify, is 1.50% for the average unit of capital and concentrated on the destroyed locations under our assumptions.

Finally, the cost arrives within decades, not centuries. The economy does not return to its steady state at one speed: rebuilding or running down capital within a region is fast, redistributing the population of Europe across regions through the migration friction is slow, with half-lives of centuries. What the final climate asks of the economy is mostly the fast kind of rearrangement: within thirty years the capital stock has completed 67% of its move to the new steady state and the population 17% of its own. The cost also depends on where the climate settles, and it grows with the level of warming at a decreasing rate: for the average worker, from -1.24% at 1.5 degrees to -7.71% at 4.0, each further degree adding less than the one before, a property of the model's adaptation and of its fixed event intensities rather than a finding about the climate.

The paper makes four main contributions. First, I measure the premium of climate uncertainty per agent and per location, and split it into a price of risk and a convexity gain, in a spatial dynamic economy with endogenous exposure, exactly and decomposed by layer. The literature on climate risk prices a premium in one-region economies (Cai and Lontzek, 2019; Lemoine, 2021; Dietz et al., 2018; Barnett et al., 2020); the spatial literature measures expected damages along a deterministic path (Desmet and Rossi-Hansberg, 2015; Desmet et al., 2018; Conte et al., 2021; Cruz and Rossi-Hansberg, 2024; Bilal and Rossi-Hansberg, 2023). Here the premium has a geography, and the geography responds to the risk. Second, I decompose European climate risk by source and ask which part of it Europe can pool. The component common to all regions, the level of the final warming, cannot be reduced by any spatial reallocation of labour, at any migration friction and any cost of switching sector, because migration conserves the mass of workers; this is a statement about the flows, not a calibrated magnitude. The regional pattern of warming and the weather drawn from it are the parts a European mutualisation can reach, and the decomposition says how much of the premium they carry. Third, I solve the stochastic steady state of a heterogeneous-agent spatial economy under aggregate climate risk by expanding the Master Equation of Bilal (2023)

to second order, the order at which the premium appears, with the capitalist block closed order by order at the steady state. I then check the expansion against the premium re-solved exactly at the quadrature nodes of the climate distribution. The check finds the second order faithful as a local object, which makes its decomposition by layer reliable, and poor as a global one, by a factor I report; the paper therefore takes the level of the premium from the exact solution and its decomposition from the second order. Fourth, I bring the exercise to the European economy at the regional scale. The spatial work that reaches Europe treats it as one region of a global grid, as [Conte et al. \(2026\)](#) do for an EU carbon tax and [Cruz and Rossi-Hansberg \(2024\)](#) for warming, or works at the country scale, as [Feyen et al. \(2020\)](#) does; the incidence across European regions, and what a European fund can and cannot insure, are questions these models are not built to answer.

The economy is that of [Bilal and Rossi-Hansberg \(2023\)](#), who solve a spatial dynamic economy with migration and local capital on the United States by the first-order Master Equation and measure the expected cost of climate change through hazards estimated on county panels; I keep their empirical template for hazards and their welfare convention, extend the economy to two sectors and risk-averse capitalists and workers, and solve to second order. The second-order Master Equation is [Bilal \(2023\)](#); the perturbational solution of heterogeneous agent models with aggregate risk is also developed by [Bhandari et al. \(2023\)](#); [Alvarez et al. \(2023\)](#) analyse a mean-field game by perturbation around its steady state, without aggregate risk. Dynamic spatial models with migration frictions and forward-looking agents include [Caliendo et al. \(2019\)](#) and [Kleinman et al. \(2023\)](#). The climate risk premium in one-region stochastic models is also studied by [Bansal et al. \(2016\)](#). The distinction between global and local temperature in damages is the subject of [Bilal and Känzig \(2026\)](#) and [Nath et al. \(2024\)](#); the hazards of this paper depend on local temperature by construction, and the common layer is the uncertainty on the global mean that reaches each region through its pattern. On Europe, the PESETA projects ([Ciscar Martinez et al., 2018](#)) and [Kalkuhl and Wenz \(2020\)](#) measure expected damages at the regional level.

Section 2 states the environment, the climate module, the three layers of uncertainty, the solution method and the welfare objects. Section 3 describes the data and the empirical chain: hazard panels, event studies, attribution, downscaling. Section 3.4 inverts the observed economy and runs the indirect inference. Section 4 answers the paper’s four questions in turn: how much the expected final climate costs and to whom, what the uncertainty on it is worth, who bears the pure risk component, and when the cost arrives.

2 Model

The economy is a spatial dynamic representation of European regions, with two sectors, trade between regions, and a risk-averse owner of local capital; the climate enters it through a closed list of hazards whose frequencies depend on local temperature. Climate uncertainty is carried by a small vector of factors, and the economy is solved by the Master Equation of [Bilal \(2023\)](#), expanded to second order. The expansion is taken at today’s economy, with its stocks and prices, and the shocks it receives are the loadings of the factors at the final climate: where the derivatives are taken and how large the shocks are stay two separate choices. The premium and its decomposition by layer appear at second order; the premium’s level itself is measured exactly, by re-solving the economy at each point of the distribution of the final climate.

2.1 Environment

Regions $i \in \{1, \dots, N\}$ are the NUTS2 regions of the Union ($N = 231$); sectors $s \in \{\text{ag}, \text{na}\}$ are agriculture and the rest of the economy. A location is a pair $x = (i, s)$ of a region and a sector, and there are $I = NS$ of them. Time is continuous. Workers form a unit mass, mobile across locations; their individual state is their location and their distribution is $\mathbf{N}_t \in \mathbb{R}^I$. Capitalists are immobile owners of the local capital $K_{x,t}$; their mass at a location is a fixed share of the observed stationary population, $\mu_x = \psi N_x^{\text{obs}}$, held fixed across climates, so that per-capitalist consumption is an intensive quantity and the second-order objects do not depend on how the economy is cut into locations; ψ is a normalisation. The aggregate state is $(\mathbf{N}_t, \mathbf{K}_t) \in \mathbb{R}^{2I}$, together with the exogenous vector of climate factors $\mathbf{z}_t$, defined below, and calendar time through the deterministic climate path. Prices are not part of the state: they are determined statically as functions of the state, which is what keeps trade free in state dimension.

A worker has flow utility $U_x = A_{i,t} + u(C_x)$ with u of constant relative risk aversion γ , $A_{i,t} = A_i + a_{i,t}$ a permanent amenity and its climate component. Amenities are indexed by region, not by location, because the inversion has no sectoral moment to separate them. C_x is a Cobb–Douglas composite of housing and a goods basket, the basket being a Cobb–Douglas aggregate over sectors of Armington aggregates over origins with elasticity σ_s . Workers discount at ρ , receive moving opportunities at rate μ , and choose a destination under Gumbel preference shocks of dispersion ν and a bilateral cost

$$\tau_{xx'} = \tau_{ij} + \kappa \mathbf{1}\{s \neq s'\}, \quad (1)$$

where τ_{ij} is a parametric geographic friction and κ the cost of switching sector. The migration block is extended from regions to locations:

$$\rho V_x = U_x + \mu \left(\frac{1}{\nu} \log \sum_{x'} e^{\nu(V_{x'} - \tau_{xx'})} - V_x \right) + \frac{\mathbb{E}[d_t V_x]}{dt}, \quad m_{xx'} = \frac{e^{\nu(V_{x'} - \tau_{xx'})}}{\sum_{x''} e^{\nu(V_{x''} - \tau_{xx''})}}, \quad (2)$$

and the population evolves by the Kolmogorov forward equation $\dot{\mathbf{N}} = M^*(V)\mathbf{N}$ with $M^* = \mu(m^\top - \text{Id})$. The sector-switching cost is not identified by the data; it is declared at its closed limit $\kappa = \infty$, so that the two sectors are two closed labour markets linked by trade, migration being within sector across regions.

Production at x is $Y_x = Z_{x,t} S_x^\alpha (N_x^P)^{1-\alpha}$, with S_x commercial structures and N_x^P labour in goods production; $Z_{x,t} = Z_x e^{\chi_{x,t}}$, where $\chi_{x,t}$ is the climate component of productivity, indexed by location and therefore by sector, which is the door through which the sectoral discriminant enters. The sector- s good of region i is sold in j at the iceberg cost $\tau_{ij}^s \geq 1$, with the usual CES price index and expenditure shares π_{ij}^s . Buildings are produced from capital, land and construction labour and costlessly repurposed between housing and commercial structures at a common rental rate; this block is the channel through which capital depreciation reaches workers through rents.

The capitalist of x holds the local capital, holds no bonds and cannot insure. The capitalist consumes the real return on capital plus the real land payment net of investment and its adjustment cost (both deflated by the regional basket price), $C_x^c = R_{K,x}K + \pi_x - c_x(I/K)K$, with the adjustment cost homogeneous of degree one in (I, K) , and has CRRA preferences with risk aversion γ_c :

$$\rho P_x(K) = \max_I u_c(C_x^c/\mu_x) + P_{x,K}(I - \Delta_{x,t}K) + \frac{\mathbb{E}[d_t P_x]}{dt}, \quad \Delta_{x,t} = \Delta_x + \delta_{x,t}. \quad (3)$$

Writing $q_x = P_{x,K}/u'_c$ for Tobin's q in consumption units, the first-order condition is the investment policy of [Bilal and Rossi-Hansberg \(2023\)](#), $\iota_x = c_{x0}q_x^\zeta$, and at the steady state their Euler condition is recovered term by term, because marginal utility is constant there and cancels (Appendix A). What $\gamma_c > 0$ changes is the dynamics, not the steady state: the interest rate is no longer pinned to ρ , intertemporal smoothing goes only through local accumulation, and the second-order welfare of the capitalist carries a curvature term that vanishes as $\gamma_c \rightarrow 0$. That term is the value of diversified capital ownership that the diversification result measures.

Given $(\mathbf{N}, \mathbf{K}, \mathbf{z}, t)$, the static conditions are the firms' first-order conditions, the construction labour condition, housing-market clearing by region, and trade balance for each $x = (i, s)$,

$$p_i^s Y_{(i,s)} = \sum_j \pi_{ij}^s \alpha_s [(1 - \beta) E_j^W + E_j^c], \quad (4)$$

with E_j^W the wage bill of region j and E_j^c the whole non-labour income of its capitalists, capital return and land rent together, since adjustment costs are purchases of goods and capitalists do not consume housing. The system is homogeneous of degree zero in prices and determines the factory prices up to the numeraire by an Alvarez–Lucas fixed point. It returns wages, rents, capital rentals and price indices as smooth functions of the state and of the shocks, and it is these functions, not the prices, that enter the Master Equation. The state itself moves slowly: population follows the Kolmogorov forward equation and capital follows $\dot{K}_x = (c_{x0}q_x^\zeta - \Delta_{x,t})K_x$.

One property of migration carries most of what the paper says about the common component of climate risk: a shock that hits every location of a sector alike cannot be escaped by moving, and the premium on it is borne where one stands, whatever the migration friction. The uncertainty on the global level of warming comes close to such a shock. The property holds for three reasons. First, migration only moves workers from one location to another. Around the steady state a change in the values of locations moves the population through a reallocation matrix G , built from the stationary flows; a change that is the same everywhere is annihilated by G , because if every location becomes equally worse nobody has a better place to go. With two closed sectoral labour markets this holds sector by sector, and G has exactly two such directions, one per sector. Second, the option to relocate is worth nothing against such a shock. Its value, at second order, is the convexity of the location choice in the differences between values, and a shock common to all locations leaves those differences where they were. Third, none of this depends on a number I estimate. It follows from the conservation of the mass of workers, so it holds at any migration friction τ , any taste dispersion ν and any sector-switching cost κ .

The property has three limits. It does not extend to trade, which moves goods rather than people. It does not extend to capital accumulation, which can smooth a common shock over time. And at a finite switching cost it holds only for the component common to all locations of both sectors, since workers could otherwise change sector. What a European mutualisation can reach is therefore the rest of the risk: the part of the pattern layer that differs across regions, and the realisations of the hazards.

This is a statement about the premium, not about the expected cost. A certain loss can be redistributed between regions but not insured, so the question of what a fund can reach only arises for the risk. The expected cost of the common layer, for its part, is far from uniform: it falls where the attributed trends are, and its incidence moves with the friction.

2.2 Climate module

The deterministic central path $\bar{T}_t^D$ of global mean temperature above pre-industrial is exogenous and conditional on one emissions scenario. I focus on the central scenario SSP2-4.5 and agents face no scenario uncertainty. Pre-industrial is the 1850–1900 mean. Around the path, a factor vector $\mathbf{z}_t$ with diagonal Ornstein–Uhlenbeck dynamics $d\mathbf{z}_f = -\theta_f \mathbf{z}_f dt + \sigma_f dW_f$, $\mathbb{E}[dW dW'] = \Sigma_W dt$, sets the local temperature seen by region i ,

$$T_{i,t} - T^P = \bar{T}_t^D (1 + z_{S,t}) p_i(\mathbf{z}_{P,t}), \quad (5)$$

where z_S is the uncertainty on the global level through the climate’s sensitivity and $\mathbf{z}_P$ the uncertainty on the regional pattern per degree of global warming, $p_i(0) = \bar{p}_i$ being the mean pattern. This generalises the scalar, uniform shock of previous models.

The climate reaches the economy through three hazards: heat, extreme precipitation and drought. Heat is the fraction of days above the 95th percentile of a historical national base; it damages amenities and productivity. Extreme precipitation is the annual maximum of daily precipitation above the 99th percentile of the residuals; it depreciates buildings. It is the European counterpart of the hurricane in the United States: there, what destroys capital and rises with temperature is the storm; here it is the rain, the half of the storm whose European trend the panel attributes. Drought is the annual minimum of the standardised precipitation–evapotranspiration index, SPEI-12 in the main specification and SPEI-6 as a robustness check, below the 1st percentile; it can reach both agents, agricultural productivity on the workers’ side and the depreciation of buildings on clay soils on the capital owners’ side. Each hazard is turned into an event by residualising the gridded variable on region and year fixed effects and thresholding it at the stated percentile, and its effects are estimated by exposure group: the AR6 European reference regions (northern, western and central, Mediterranean) for every hazard except heat, whose group is the regions above the median temperature, because the damage of a hot day depends on how hot the region already is, and this partition groups the regions where the mechanism is the same rather than the regions that are near one another. Table 1 says which structural object each hazard may damage: productivity χ_x , amenity a_i or the depreciation of buildings δ_x , with sector-specific magnitudes where a discriminant is expected.

hazard	χ_{ag}	χ_{na}	a	δ
heat	$\Gamma_{\chi,ag}^{\text{heat}}$	$\Gamma_{\chi,na}^{\text{heat}}$	$\eta \Gamma^{\text{heat}}$	—
extreme precipitation	—	—	—	$\Gamma_{\delta,s}^{\text{prec}}$
drought	$\Gamma_{\chi,ag}^{\text{dr}}$	$\Gamma_{\chi,na}^{\text{dr}}$	—	$\Gamma_{\delta}^{\text{dr}}$ on clay soils
cold (placebo)	—	—	—	—

Table 1: Where each hazard may enter the model. Rows are the hazards; columns are the three structural objects a hazard can damage: productivity in agriculture (χ_{ag}) and in the rest of the economy (χ_{na}), amenities (a) and the depreciation of buildings (δ).

The climate reaches the economy in three steps, and one equation holds them together. Events of hazard h arrive in region i as a counting process $N_{i,t}^h$ whose intensity depends on the region’s temperature; each event adds the magnitude Γ^h to a damage stock that decays at the hazard’s own

rate; and the stocks lower productivity and amenity and raise the depreciation of capital:

$$\lambda_{ih}(T_i) = \lambda_{ih}(T_i^{\text{obs}}) \exp\left(\frac{\beta_{hg(i)}}{\bar{p}_i} (T_i - T_i^{\text{obs}})\right), \quad dD_{i,t}^h = -\theta_h D_{i,t}^h dt + \Gamma^h dN_{i,t}^h, \quad (6)$$

$$\log \chi_{x,t} = \log \bar{\chi}_x + \sum_h D_{x,t}^{h,\chi}, \quad a_{i,t} = \bar{a}_i + \sum_h D_{i,t}^{h,a}, \quad \delta_{x,t} = \bar{\delta} + \sum_h D_{x,t}^{h,\delta},$$

where $g(i)$ is the exposure group of the region, β the attributed trend of Section 3, $\bar{p}_i$ the region's mean pattern per degree, and the superscripts on the stocks say which structural object the hazard loads on. The intensity is the one extrapolated to the final climate, $\lambda_i^h = -\ln(1 - q_i^h)$ for an annual frequency q_i^h , log-linear in local temperature and anchored on the observed rate, the slope being identified per exposure group on global temperature and carried to the region through its mean pattern. Because the damage is a stock, a permanent shift of the frequency by dq moves the level of the damage state by $\Gamma^h dq / \theta_h$, and the depreciation magnitude is read from the cumulative response as $\Gamma^\delta = \theta_h D_h$. The region's temperature at the final climate is the one of equation (5). Figure 1 draws the chain.

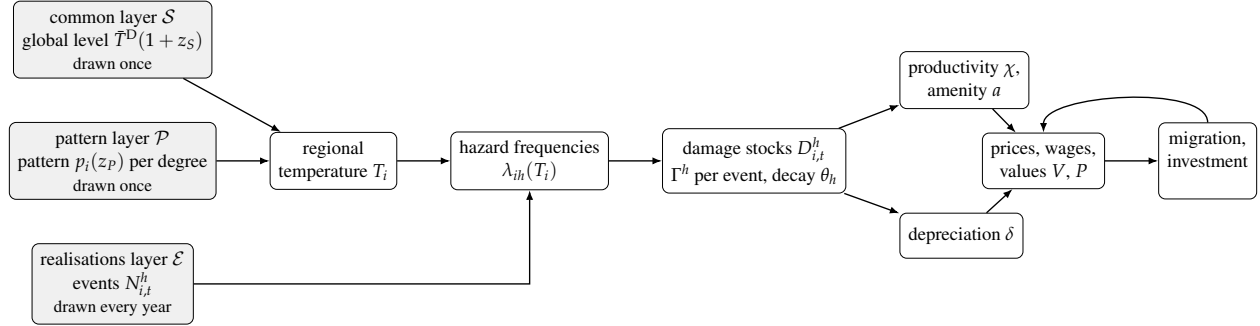


Figure 1: How the climate reaches the economy. The two draw layers set the regional temperature and, through it, the frequencies; the realisations layer draws the events; the damage stocks lower productivity and amenity and raise depreciation; prices and values respond, and so do migration and investment, which feed back on the values.

Climate uncertainty enters this chain through three layers, of two kinds. Two are draws made once, on where the climate will settle. The common layer $\mathcal{S}$ is the draw z_S on the global level of warming, from the AR6 assessed distribution of the climate's sensitivity, wider than the spread of the models themselves; I call it common because every region draws the same number. The pattern layer $\mathcal{P}$ is the draw z_P on the region's pattern per degree, among 31 climate models that disagree on how each region warms. Neither has innovations after the draw ($\theta = 0$): the uncertainty is about where the climate will settle, not about how it fluctuates. The third layer is a process: the realisations layer $\mathcal{E}$ is the counting processes $N_{i,t}^h$, one factor per hazard and location, decaying at the hazard's own rate $\theta_h > 0$ and fed every year by new events whose spatial covariance is the one measured on the indicators. The economy is hit, adjusts, and is hit again, and the contribution of this layer to the premium is a flow.

The difference between a draw and a process matters in two places. The first is how each is weighted in the premium. A process keeps shocking the economy, so its variance grows with time, and the second-order method treats it as the diffusion it is. A draw is made once: what is unknown about it has a fixed variance, Σ_z , that does not grow. The economy's state responds to

the draw through a matrix X , the uncertainty it leaves on the final state is $X\Sigma_zX^\top$, and the draw's contribution to the premium is the curvature of value against that uncertainty, once. Treating the draw as a process would let its variance grow without bound, as if the climate's sensitivity were redrawn every year, which it is not. The second is where the premium sits. At today's climate the two draws are already known, the level and the pattern of the warming that has happened, and only the events still move; the whole cost of the uncertainty the draws carry therefore lies in the difference between the final climate and today's, which is how the premium of the paper is defined.

Hazards are discrete events, while the solution method is written for shocks that move continuously, and the two agree to the order the paper works at. A hazard that strikes a region at some annual rate, adding a fixed amount to its damage stock each time, has the same mean and the same variance per year as a continuous shock with a drift equal to the expected damage and a variance equal to the rate times the square of the damage; the two differ only at higher order, in the size of the damage per event. The mean is what a deterministic damage function carries; the variance is the risk. Across regions the risk has a covariance, that of the event indicators of the two regions times the two damage magnitudes, and I measure it on the co-occurrence of events, not on economic outcomes, so that the year fixed effects of the event studies do not absorb it. The second-order method therefore applies to hazard realisations as they are. What it leaves out is the tail: rare events large enough that the size of the damage per event matters.

Two things are not layers of climate uncertainty in the model. Internal climate variability is already in the realisations layer, through the frequency of events. The uncertainty of my own estimates is reported as intervals around the numbers and never enters the premium: an agent in the model does not face the econometrician's doubt.

2.3 Master Equation, first and second order

The expansion follows the idea of any perturbation method, applied to a value function that depends on the whole distribution of workers and capital. The value of a worker at a location is written as a function of the climate factors and of the aggregate state, and expanded in the size of the shocks. At first order the value moves in proportion to the shocks: this is the impulse response of the economy, and it carries the expected cost but no price of risk, because a linear function of a shock has the same expectation as its value at the expected shock. At second order three curvatures appear, and together they are the premium.

Values depend on the aggregate state, $V_x = V_{x,t}(\mathbf{z}, \mathbf{N}, \mathbf{K})$ for a worker at x and P_x for the capitalist. Applying the chain rule to the expected time derivative in the worker's Bellman equation (2) turns it into a partial differential equation on the state,

$$\begin{aligned} \rho V_x = & \underbrace{U_x + \mu \left(\frac{1}{v} \log \sum_{x'} e^{v(V_{x'} - \tau_{xx'})} - V_x \right)}_{\text{the location's own problem}} \\ & + \underbrace{\partial_t V_x + \mathcal{A}(\mathbf{z})[V_x]}_{\text{the climate}} + \underbrace{\sum_{x'} \partial_{N_{x'}} V_x \dot{N}_{x'} + \sum_{x'} \partial_{K_{x'}} V_x \dot{K}_{x'}}_{\text{drift of the economy}} \end{aligned} \quad (7)$$

where $\mathcal{A}(\mathbf{z})[\phi] = -\sum_f \theta_f z_f \partial_{z_f} \phi + \frac{1}{2} \sum_{f,g} \Sigma_W^{fg} \sigma_f \sigma_g \partial_{z_f z_g}^2 \phi$ describes how the factors move, their return to the mean and their diffusion, and $\dot{N}$ and $\dot{K}$ are the laws of motion of Section 2.1, which

depend on the values themselves through migration. The three parts read as follows. The first line is what the location offers on its own, the utility of living there and the option to leave. The second part is the climate, its deterministic path through ∂_t and its random factors through $\mathcal{A}$. The third part is where the rest of the economy enters: wages and prices at x move because people and capital move everywhere, with or without a shock, and this term carries that movement into the value. The capitalist's equation has the same three parts, with investment in place of migration. The equation is exact, and it cannot be solved as it stands, because V_x is a function of $2I$ state variables.

Let ϵ scale the size of the shocks, and write the state in logs around the stochastic steady state, $n = (\log \mathbf{N} - \log \mathbf{N}^{\text{ss}}, \log \mathbf{K} - \log \mathbf{K}^{\text{ss}}) \in \mathbb{R}^{2I}$, itself of order ϵ . The value at a location then reads

$$V_x = V_x^{\text{ss}} + \underbrace{\epsilon (v_x n + \omega_x \mathbf{z})}_{\text{first order}} + \underbrace{\frac{\epsilon^2}{2} (n' \mathbb{V}_x n + 2 \mathbf{z}' \Gamma_x n + \mathbf{z}' \Delta_x \mathbf{z} + \Lambda_x)}_{\text{second order}} + O(\epsilon^3). \quad (8)$$

Each coefficient has a meaning. At first order, $v_x \in \mathbb{R}^{2I}$ says how the value responds to the state and $\omega_x \in \mathbb{R}^F$ how it responds to each of the F factors. At second order, $\mathbb{V}_x$ is the curvature of the value in the state, Δ_x its curvature in the factors, Γ_x the cross term between the two, and Λ_x is a constant. The first order is the expected path and the second order the curvatures, and the constant is the premium: taking the expectation of (8) over the factors at the steady state and subtracting its value at the expected factors, nothing of the first order survives, and what is left is $\frac{\epsilon^2}{2} \Lambda_x$ together with the second moments of the factors through Δ_x , of the state through $\mathbb{V}_x$, and of their covariance through Γ_x .

The first order is the first-order Master Equation of [Bilal and Rossi-Hansberg \(2023\)](#). Collecting the terms of order ϵ in (7), the response of the value to the state solves:

$$\rho v = \underbrace{D}_{\text{prices}} + \underbrace{\mathbb{M}v + v \mathbb{M}^*}_{\text{the state moves the value}} + \underbrace{v \mathbb{P} v}_{\text{the value moves the state}}, \quad (9)$$

which is quadratic because the population moves with the values, through migration, and I take its stable solution. Given v , the loading ω of each factor solves a linear system with two pieces: what the factor does directly to productivity and depreciation, and what it does through the state, carried by v . The deterministic part of this order is the expected path of the economy under the final climate, and no risk object enters it.

Collecting the terms of order ϵ^2 gives four linear equations, one for each coefficient of (8), where A is the linear operator of the value equation at the steady state, B^* the drift of the state once migration and investment respond to it, and B its transpose:

$$\mathbb{V} \times_1 A + \mathbb{V} \times_2 B + \mathbb{V} \times_3 B = D^{(2)}, \quad (10)$$

$$(A - \theta_f \text{Id}) \Gamma^f + \Gamma^f B^* = C^f, \quad (11)$$

$$(A - (\theta_f + \theta_g) \text{Id}) \Delta^{fg} = E^{fg}, \quad (12)$$

$$A \Lambda = - \sum_{f,g} \Sigma_W^{fg} \sigma_f \sigma_g \Delta^{fg}. \quad (13)$$

Equation (10) is the curvature of the economy in its own state. It sees no factor, it is the expensive block, and it is solved once for all layers. Equation (11) says how a shock bends the response

to the state, and (12) how the value curves in the shocks themselves. Equation (13) is the only one that sees the covariance of the shocks, and its solution is the premium of a process layer. Two consequences are used in the results. First, Λ is linear in the factor covariance Σ_W , so the premium splits exactly into one term per layer and one per pair of layers, $\Lambda_x = \sum_{f,g} \Sigma_W^{fg} \lambda_x^{fg}$, with coefficients that are part of the solution. The decomposition by source that the paper reports is read off them: it is additive, it has no remainder, and it does not depend on the order in which the layers are switched on, none of which holds for the exact premium, where the layers interact. This is why the paper takes the level of the premium from the exact solution and its decomposition from the second order. Second, the two layers that are draws rather than processes have no diffusion term in (13): what they contribute is the curvature of value against the uncertainty they leave on the final state, once, not a variance that accumulates year after year.

The right-hand sides of (10) to (12) are built from three curvatures of different signs, and the premium is their sum. The first is the curvature of felicity, $u'' < 0$, which is risk aversion in the usual sense; on the worker's side it is the whole of the utility term, since workers have no consumption policy. The second is the convexity of damages in temperature: the frequency law is log-linear, so the expected frequency rises faster than the temperature, and this Jensen term is present even under risk neutrality. The third is the convexity of the migration choice, which is the option value of being able to move: the log-sum-exp in (7) is convex in the values it compares, and an option is worth more when the outcomes differ more. The second order therefore does not vanish when the agent is risk-neutral. It would if consumption responded to the climate in a straight line; it does not, because capital, migration and the frequency of hazards all respond with a curve. The capital owner's problem is solved at the steady state, where capital is neither growing nor shrinking, so that each order of the expansion can be closed before the next. At second order the equation for his value has two solutions, one along which the economy returns to its steady state after a shock and one along which it drifts away; the paper takes the first. What that solution carries, beyond the owner's aversion to risk, is how his consumption curves when the damage stock and the price of capital move: investment has already done what it can at first order, and what remains at second order is the shape of what is left to consume.

The sign of the premium can be read on one location taken alone, and the example says at which risk aversion it turns. Let the effective depreciation of the location's capital be $m = \delta + d$, with d the destruction rate set by the climate draw, and let the steady-state consumption of its agent be a power function of it, $c(m) = c_0 m^{-\varphi}$ with $\varphi > 0$. In the model this is how the capital stock, and the wages and rents that depend on it, respond to the rate at which the stock is destroyed, and φ is the elasticity of that response. Let the draw move the effective depreciation by a small amount, $m = \bar{m}(1 + \epsilon z)$ with z of mean zero and unit variance. Expanding expected utility to second order in ϵ and dividing by the marginal utility of consumption gives the premium in consumption units,

$$\frac{\mathbb{E} u(c(m)) - u(c(\bar{m}))}{u'(\bar{c}) \bar{c}} = \frac{\epsilon^2}{2} \varphi \left[\underbrace{(1 + \varphi)}_{\text{convexity of the adjustment}} - \underbrace{\gamma \varphi}_{\text{risk aversion}} \right] + O(\epsilon^3). \quad (14)$$

The first term in the bracket is the convexity of c in m . A stock that responds to its destruction rate as a power loses less from a rise in the rate than it gains from an equal fall, so the consumption it supports, averaged over the draws, is above the consumption at the average draw. The second term is the cost of bearing the variance of consumption that this same response creates, and it grows

with the square of the elasticity. The premium is a gain if and only if

$$\gamma < \gamma^* = 1 + \frac{1}{\varphi}. \quad (15)$$

Three things follow, and the paper meets all three. At log preferences the premium is a gain for every elasticity, because the bracket equals one whatever φ : the convexity of the adjustment always wins. Just above log preferences the premium turns into a loss first where the adjustment is most elastic, since γ^* falls toward one as φ grows; the locations where the final climate destroys the stock are the ones where consumption responds most to the destruction rate, so they turn first, and the capital owners, whose consumption is that response, turn before the workers. And the convexity of the frequency law adds to the first term, because the destruction rate is itself a convex function of the temperature draw, so that the bracket of (14) understates the convexity the model carries. What the example leaves out is the option of moving, a second convex term that only workers have. It raises their γ^* further, and it is why the workers' premium keeps its sign over the range on which it can be measured while the capital owners' does not.

2.4 Welfare

The paper measures the expected cost and the premium of climate uncertainty. First, the expected cost is how much worse off an agent is at the final climate than at today's, when the final climate is taken at its expected value: the economy is inverted at the observed climate, re-solved at the final one with the hazards at their expected frequencies, and the two steady states are compared. This is the object of [Bilal and Rossi-Hansberg \(2023\)](#). Second, the premium is what the uncertainty about the final climate is worth on top of that: expected welfare over the draws of the final climate, minus welfare at its expected value. Writing $W_x(C)$ for the welfare of an agent at location x when the climate settles at C , C_{obs} for today's climate, C_{fin} for the final one drawn from the common and pattern layers and $\bar{C}_{\text{fin}}$ for its expected value,

$$\text{expected cost}_x = W_x(\bar{C}_{\text{fin}}) - W_x(C_{\text{obs}}), \quad \text{premium}_x = \mathbb{E} W_x(C_{\text{fin}}) - W_x(\bar{C}_{\text{fin}}). \quad (16)$$

Both are computed exactly, by re-solving the economy at each climate: the expectation is a Gauss–Hermite quadrature over the two layers, and the second-order premium of the expansion is read against the exact one. The expected frequencies themselves are expectations over the layers, since the frequency law is not linear in temperature.

The premium itself is the sum of two pieces of opposite sign, and the paper reports them apart. Write $\tilde{c}_x(C)$ for the consumption of the agent when the climate settles at C , relative to its consumption at the expected climate $\bar{C}_{\text{fin}}$, and CE_x for the certainty equivalent of a random consumption under the agent's utility. Then

$$\text{premium}_x = \underbrace{\text{CE}_x[\tilde{c}_x(C_{\text{fin}})] - \mathbb{E} \tilde{c}_x(C_{\text{fin}})}_{\text{the price of risk}} + \underbrace{\mathbb{E} \tilde{c}_x(C_{\text{fin}}) - \tilde{c}_x(\bar{C}_{\text{fin}})}_{\text{the convexity gain}}, \quad (17)$$

an identity, since the certainty equivalent of the lottery is the premium plus one and the two middle terms cancel. The two pieces answer two different questions. The price of risk is the risk premium in the usual sense: what the agent would pay to replace the random consumption by its mean. It

is never positive, it is zero for a risk-neutral agent, and it grows with risk aversion and with the variance of consumption that the climate draws create. The convexity gain is what the uncertainty is worth to a risk-neutral agent, and it does not depend on risk aversion at all. Its sign is the shape of the response of consumption to the climate draw.

The response is convex, and the gain positive, when a good draw helps more than an equally bad draw hurts, so that consumption averaged over the draws exceeds consumption at the average draw. The model makes it so in three places: a capital stock that is not rebuilt after a bad draw and grows after a good one; a worker who leaves a region that turns out badly; a frequency of hazards that rises faster than the temperature. The response is concave, and the gain negative, in one place: for a capital owner whose gain from the lottery is the inflow of workers that a bad draw elsewhere sends him, because the return on a fixed stock rises less than proportionally with the labour that arrives. The sign of the premium is therefore the sign of a contest between the convexity gain and the price of risk, and the risk aversion at which they cancel is the threshold the paper calls γ^* .

Every welfare change is expressed as a consumption equivalent: the proportional change in steady-state consumption, held for ever, that would give the agent the same value as the counterfactual, per agent and per location; at $\gamma = 1$ it is $e^{\rho \text{dV}} - 1$. Capitalists are treated the same way on their own value function. Because CRRA felicity is bounded on one side, the equivalent exists only on a range of risk aversion.

3 Data and empirical chain

3.1 Sources

The domain is the 231 NUTS2 regions of the Union. Three kinds of data describe it: how people move between regions, what the climate does to each region, and what each region produces.

Migration between regions is observed only where a national statistical institute publishes an origin–destination matrix in open access. These countries cover 58% of the Union’s population, and they are the core on which the migration friction is estimated; the estimate is then validated out of sample on the net migration balances that Eurostat reports for every region. Estimated matrices exist for the other countries, and I do not use them as inputs, because an estimated matrix would carry its own assumptions about frictions into the identification of the paper’s. Trade between regions is not observed at all, since intra-national trade crosses no customs border, so trade costs are parametric and borrowed from the literature.

Weather comes from the E-OBS gridded daily observations of temperature and precipitation from 1950, averaged over the area of each region. The drought index is the standardised precipitation–evapotranspiration index, which I compute from the same grid for every region rather than take from a third-party product, so that its definition and its reference period are the same everywhere. Global mean temperature is from HadCRUT5. Regions are grouped into the three European reference regions of the IPCC’s Sixth Assessment Report, the Mediterranean (MED), western and central Europe (WCE) and northern Europe (NEU); the hazards are attributed to warming and their responses estimated by group, and the results are read by group throughout. Figure 2 maps the domain, the countries with an observed migration matrix and the three groups.

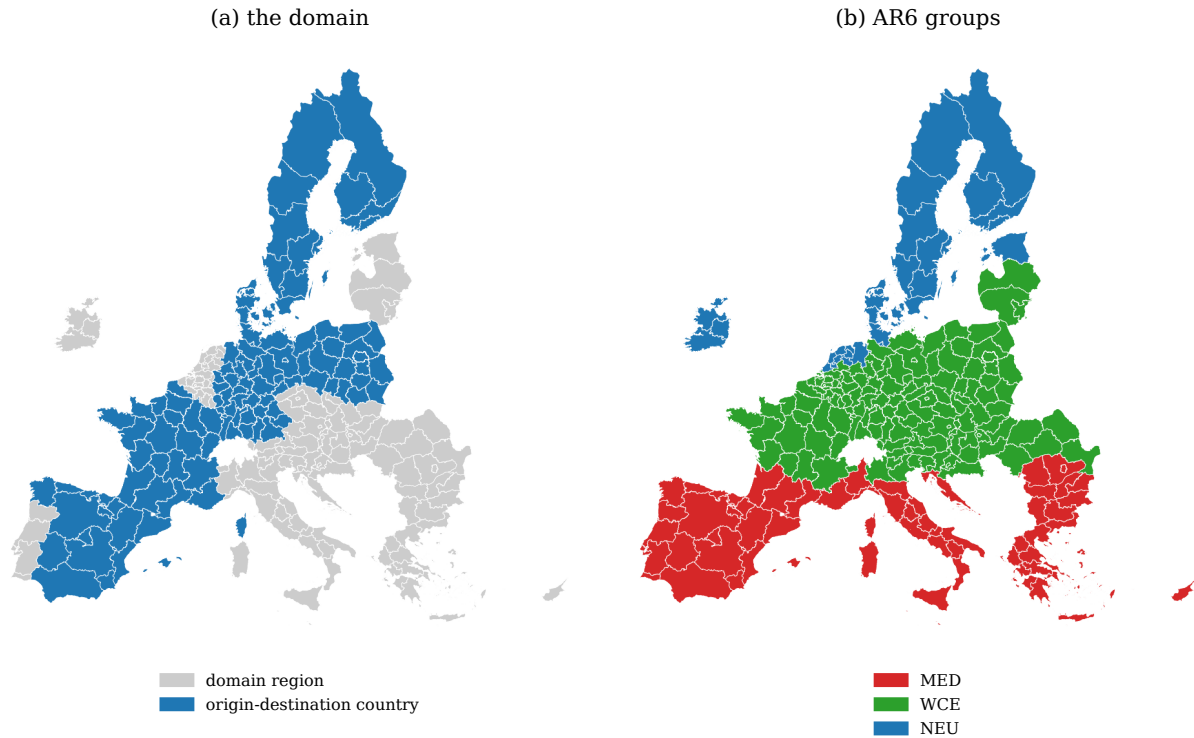


Figure 2: The domain. (a) The 231 NUTS2 regions, those of the 7 countries with a migration matrix marked. (b) The AR6 groups: 66 regions in MED, 131 in WCE, 34 in NEU.

The uncertainty about the final climate has two measured sources. The common layer is the distribution of the equilibrium climate sensitivity assessed by the Sixth Assessment Report, which I read as the variance of the global level of warming. The pattern layer is the disagreement among 31 CMIP6 climate models on how each region warms per degree of global warming; the models are those whose regional pattern does not depend on the emissions scenario, and their patterns are brought to a common fine grid before being averaged over regions¹. Table 2 describes the hazards:

¹The 10 regions with no cell centre on that grid, Cyprus because it lies south of it, have no pattern of their own and take the pattern of their geographic neighbours, 2 of which lie outside the Union.

group	regions	panel	events	regions without an event	share of the group
heat (window 1996–2025)					
MED	66	1950–2025	470	14	21%
WCE	131	1950–2025	230	69	53%
NEU	34	1950–2025	178	14	41%
all regions	231	1950–2025	878	97	42%
extreme precipitation (window 1950–2025)					
MED	66	1950–2025	59	40	61%
WCE	131	1950–2025	108	66	50%
NEU	34	1950–2025	9	25	74%
all regions	231	1950–2025	176	131	57%
drought (window 1950–2025)					
MED	66	1951–2025	121	15	23%
WCE	131	1951–2025	31	105	80%
NEU	34	1951–2025	22	15	44%
all regions	231	1951–2025	174	135	58%
cold (placebo) (window 1996–2025)					
MED	66	1950–2025	322	19	29%
WCE	131	1950–2025	387	77	59%
NEU	34	1950–2025	169	11	32%
all regions	231	1950–2025	878	107	46%

Table 2: The hazard panels by hazard and AR6 group: regions, panel years, events, and regions without an event in the window of the realisations layer, in number and in per cent of the group.

The regional economy comes from the ARDECO regional accounts at NUTS2 by NACE branch: gross value added, employment and gross fixed capital formation. Two features of these series matter. ARDECO extends every series into forecast years, which I cut at the last observed year of each series and country before any regression; and it extends them backward before the first year Eurostat reports, by chaining the growth rates of earlier accounting vintages, and I use those back-cast values as such. Population by region is from Eurostat, and the event studies weight regions by their mean population over 1980–1999.

3.2 Hazard panels and event studies

Each hazard is turned into an annual binary event per region in two steps. The gridded variable w_{it} of hazard h (the fraction of hot days, the annual maximum of daily precipitation, the annual minimum of the drought index) is first residualised on region and year fixed effects over the whole panel, $w_{it} = \alpha_i + \gamma_t + r_{it}$, and an event is a residual beyond a percentile p_h of the residuals pooled over the panel, fixed in advance for each hazard (below it, with the inequality reversed for drought):

$$e_{it}^h = \mathbf{1}\{r_{it} > q_{p_h}(r)\}. \quad (18)$$

Residualising removes the region’s climate and the year’s weather common to Europe, so that an event is a year unusual for that region; thresholding at a high percentile keeps the tail, where the damage is. Events so defined are not spread evenly over regions: in the window the covariance of heat events is built on, 97 of the 231 regions have none.

The response of an outcome to an event is estimated by an event study with 5 leads and 10 lags, region and year fixed effects, population weights and standard errors clustered by region,

separately by exposure group g :

$$\log y_{it} = \sum_{k=-5}^{10} \beta_k^g e_{i,t-k}^h + \alpha_i + \gamma_t + \varepsilon_{it}, \quad D_h^g = \sum_{k=0}^{10} \beta_k^g, \quad (19)$$

where D_h^g , the cumulative response at the horizon of the last lag, is the magnitude the model receives. The leads test that events are not preceded by a trend; the lags trace how long the damage lasts, and their decay from the peak gives the persistence θ_h where the fit is clear, and a borrowed persistence otherwise. The outcomes are value added per worker by sector, total and agricultural employment, and investment, each the door through which one structural object of the model is reached: productivity, amenities, the stock of capital.

The cumulative response is the sum of the lag coefficients; its reference level is the region-years with no event in the window, and the leads are estimated and never cumulated into the estimand, as in [Bilal and Rossi-Hansberg \(2023\)](#).² Because the hazards of this paper are threshold events, frequent and serially correlated, the leads are a test rather than a placebo; Appendix E reports it for every cell and says what it changes. Whether a cell, a hazard acting on an outcome in a group, enters the model is decided by power, not by significance. Before any estimation, I fixed for each cell the smallest effect worth detecting, the ten-year response that [Bilal and Rossi-Hansberg \(2023\)](#) estimate for the same outcome, and computed the probability that the design would detect an effect of that size. A cell whose power falls below the pre-registered floor is reported as not identified and enters the model at zero, with that label. This is not a finding of no effect: the design could not have seen one. Figure 3 draws the four cells that carry a magnitude or the migration moment; Appendix D draws every cell, and Table 9 gives the power and the verdict of each.

channel	group		Γ	interval	leads = 0 (p)	Γ , leads as reference [interval]	unit	half-life θ_h
heat								
amenity	warm exposure		-0.008	[-0.013, -0.002]	—	—	log consumption	5 borrowed
productivity, agriculture	warm exposure	zero (not identified)	—	—	—	—	log productivity	5 borrowed
productivity, rest	warm exposure		-0.024	[-0.041, -0.007]	0.003	-0.008 [-0.028, 0.012]	log productivity	5 borrowed
extreme precipitation								
depreciation	WCE		0.341	[0.125, 0.556]	0.143	0.193 [0.000, 0.386]	log capital, per event	5 borrowed
drought								
productivity, agriculture	MED	zero (not identified)	—	—	—	—	log productivity	5 borrowed
productivity, rest	MED		-0.096	[-0.175, -0.017]	<0.001	-0.130 [-0.185, -0.075]	log productivity	5 borrowed
depreciation, clay soils	MED	zero (no design power)	—	—	—	—	log capital, per event	5 borrowed

Table 3: The structural magnitudes by hazard and channel: Γ with its interval, the half-life of its persistence in years with its source; a zero by declaration says so. Depreciation is in D_h , the unit estimated; the rate $\theta_h D_h$ has no interval written by the chain.

²The specification is borrowed from a setting where the years before an event are ordinary years, the rare and unforeseen storms of [Bilal and Rossi-Hansberg \(2023\)](#). The hazards of this paper are frequent and serially correlated, and the years before one need not be ordinary. Appendix E tests this cell by cell: the test rejects in two of the three cells that carry a magnitude. This version keeps the declared magnitudes and says what the rejection changes; the reference level, the migration elasticity identified on it and three other features of the design are being re-estimated.

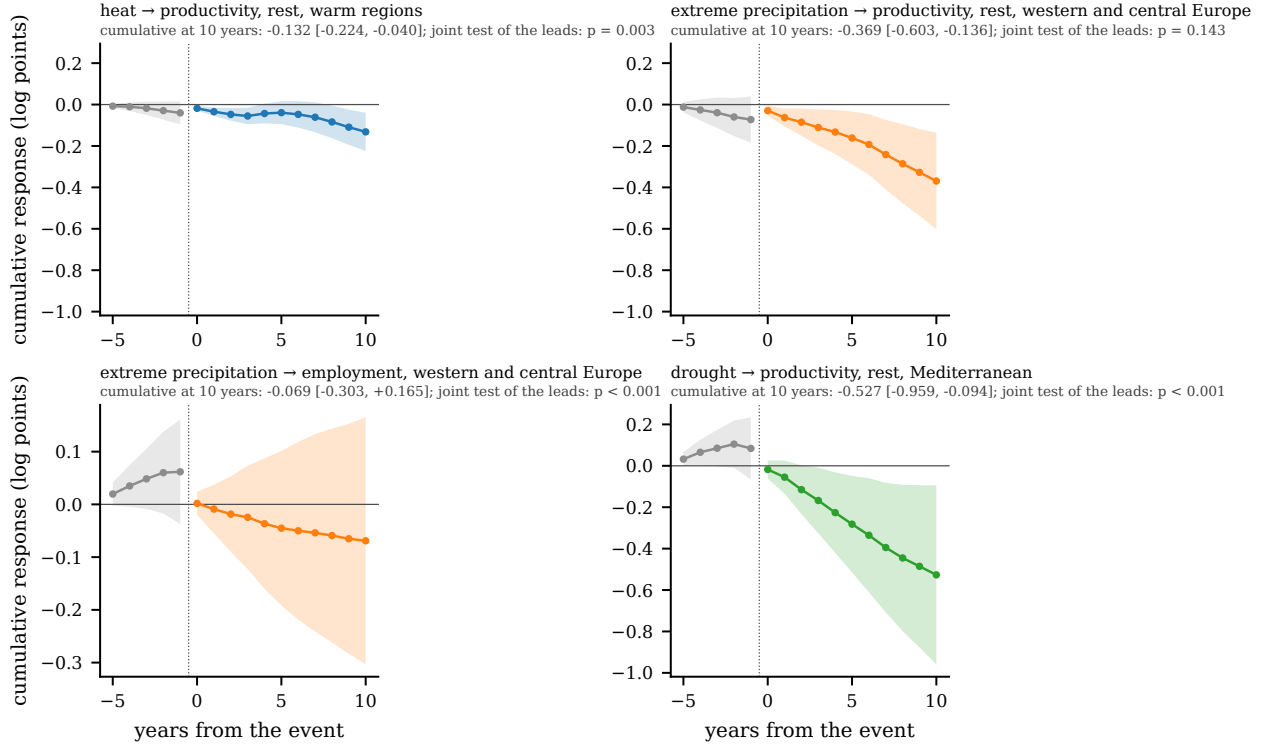


Figure 3: Event-study responses in the four cells that carry a magnitude or the migration moment, one colour per hazard: the cumulative response by horizon, the sum of the lag coefficients from the event to year h , with its interval clustered by region; in grey, left of the event, the cumulative lead coefficients, which a response without pre-trend keeps at zero. Above each panel, the cumulative response at ten years and the joint test that the five leads are zero. Coefficients by year, for all cells, are in Appendix D.

3.3 Frequencies, attribution and downscaling

The damage of a hazard at the final climate is its magnitude times the change in its frequency, so the second half of the empirical chain is to say how the frequency of events moves with the climate. For each hazard and exposure group, the annual frequency of events q_{gt}^h is regressed on global mean temperature over the panel,

$$q_{gt}^h = a_g^h + b_g^h \bar{T}_t + u_{gt}, \quad (20)$$

and the trend is attributed when the Newey–West interval of b_g^h excludes zero. Where the trend is attributed, the frequency is carried to the final climate through the intensity $\lambda = -\ln(1 - q)$, which is log-linear in temperature and anchored on each region’s observed rate,

$$\lambda_i^h(T_i) = \lambda_i^h(T_i^{\text{obs}}) \exp\left(\frac{\beta_g^h}{\bar{p}_i} (T_i - T_i^{\text{obs}})\right), \quad (21)$$

with the slope β_g^h estimated apart from b_g^h , by maximum likelihood on the region-years of the group, on global temperature, and brought to the region’s own temperature through its mean pattern per degree $\bar{p}_i$. Working with the intensity rather than the frequency keeps the extrapolated frequency below one, and anchoring on the observed rate keeps each region’s level while moving its trend. Where the trend is not attributed, the frequency is held at its observed value at the final climate: the hazard still strikes, and enters the risk the economy faces, but it carries no expected damage, because I do not extrapolate a slope the data do not support. The mean pattern that carries global to local temperature is in Figure 4.

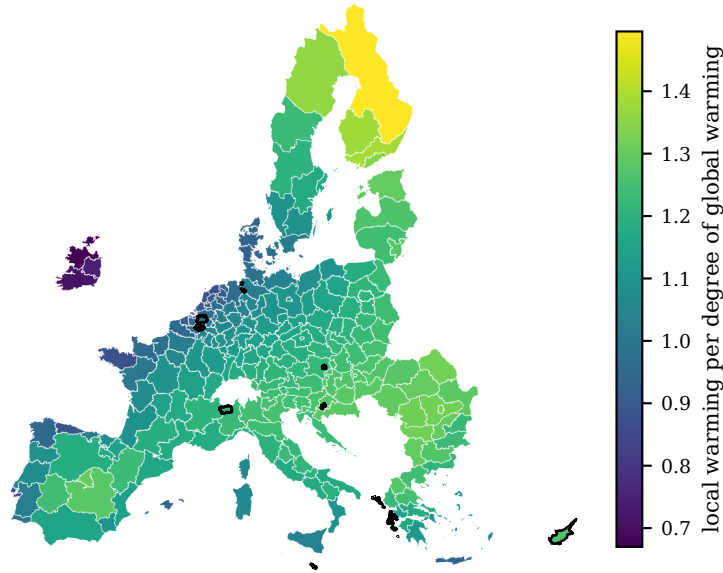


Figure 4: Mean pattern of local warming: the mean over 31 CMIP6 models of each region’s warming per degree of global warming; 10 outlined whose pattern is imputed from their neighbours.

Two more objects are read from the panel: how events co-occur across regions, and how long their damage lasts.

First, the realisations layer needs the covariance of events across regions, because a heatwave that hits Andalusia and Sicily in the same year is a different risk from two heatwaves in different years. I measure it directly on the event indicators of equation (18), as the covariance over years of e_{it}^h and e_{jt}^h for every pair of regions, over a window fixed in advance for each hazard; a second window serves as a diagnostic. Measuring it on the indicators rather than on economic outcomes is what keeps it out of the year fixed effects of the event studies: a Europe-wide bad year is absorbed there, but it remains in the co-occurrence of events, where the risk layer reads it.

Second, the persistence of a hazard's damage, θ_h , is read from the lag profile of the event study in one cell chosen in advance for each hazard: the rate at which the coefficients decay from their peak gives the half-life of the damage stock. Where that cell is not identified by power, or its decay does not fit the declared form, the half-life is borrowed from [Bilal and Rossi-Hansberg \(2023\)](#) and the paper says so; every hazard of this version borrows its half-life.

3.4 Inverting the observed economy

At the stochastic steady state the conditions are the stationary Hamilton–Jacobi–Bellman equations of workers and capitalists, the stationarity of the population, the stationarity of capital and trade balance (4). Given the data — wages, employment, investment by location, migration shares where observed, trade shares — and the elasticities $(\nu, \zeta, \kappa, \sigma_s)$, the inversion recovers the fundamentals $\{Z_x, A_i, c_{x0}\}$ uniquely, together with the migration friction in parametric form,

$$\tau_{ij} = \tau(d_{ij}, \mathbf{1}\{\text{border}\}, \mathbf{1}\{\text{language}\}; \beta_\tau). \quad (22)$$

The coefficients of the friction are estimated by gravity in two legs: on the observed origin–destination flows between the regions of the core countries, and on the flows between the countries of the Union. Taking logs of the migration shares of equation (2), the flow from region i to region j in year t is an origin effect, a destination effect that absorbs the value of j , each by year, and the friction between the two:

$$\begin{aligned} \log F_{ijt} &= \alpha_{it} + \gamma_{jt} - \nu\tau_{ij} + \varepsilon_{ijt}, \\ \nu\tau_{ij} &= \begin{cases} \beta_0^R + \beta_d^R \log d_{ij} & \text{regional leg,} \\ \beta_0^I + \beta_d^I \log d_{ij} + \beta_\ell \mathbf{1}\{\text{different language}\} & \text{international leg,} \end{cases} \end{aligned} \quad (23)$$

with d_{ij} the distance between the centroids of the two regions, or the population-weighted distance between the two countries in the international leg, and standard errors clustered by pair.

Each coefficient of the model's friction is taken from the leg that identifies it. The observed core holds no pair across a border, so the level and the distance slope come from the regional leg, the only one that measures a move between two regions of one country, and the language term from the international leg, the only one where two languages meet. Across a border the friction is therefore $\beta_0^I + \beta_d^R \log d_{ij} + \beta_\ell \mathbf{1}\{\text{different language}\}$.

The data identify the product $\nu\tau$, the friction in units of the taste dispersion, and the coefficients are estimated in those units. The level of the friction is then set inside the structural estimation, so that the model reproduces the observed interregional out-migration rate, and the fit is checked out of sample on the net migration balances of every region, which Eurostat reports where the flows themselves are not published.

Amenities and frictions are not separately identified beyond this parametric form: a region that attracts few migrants may be unattractive or hard to reach, and only the shape of the friction in distance tells the two apart. This is why the incidence of the cost is reported conditional on the friction, at the estimated value and at the frictionless limit $\tau_{ij} = 0$.

3.5 Elasticities and magnitudes

Four elasticities and the damage magnitudes remain once the economy is inverted. One elasticity is estimated, the migration elasticity ν ; one is declared at its closed limit, the sector-switching cost κ ; two are borrowed from [Bilal and Rossi-Hansberg \(2023\)](#), the investment elasticity ζ and the ratio η of the amenity to the productivity response to heat; and the magnitudes Γ^h are read from the cumulative responses of Section 3.2.

The migration elasticity governs how strongly workers respond to differences in values between locations. It is identified by indirect inference on one moment: after an extreme precipitation event, employment and value added per worker outside agriculture both move, and the ratio of their cumulative responses depends on how many workers leave for a given loss of income, that is on ν , but not on the size of the damage itself, which cancels between numerator and denominator. The moment is taken in the group where both responses are identified by power. The model's value of the ratio is computed by re-solving the economy at each candidate ν , with the level of the migration friction set inside each evaluation so that the model reproduces the observed interregional out-migration rate. With one unknown and one moment there is nothing to minimise: ν is the root of the matching equation, found by bisection to a tolerance of 0.0001 inside a bracket derived from the inverted economy. The root is $\nu = 0.1316$. Table 4 reports the targeted moment, the model's value at the root, and the moments that stand beside the borrowed elasticities.

The number compares directly with the one [Bilal and Rossi-Hansberg \(2023\)](#) estimate for the United States, because the convention is the same: a logit on values in flow utility, with log preferences and the same discount rate, identified by the same moment, the response of employment relative to that of income after a shock. Theirs is 0.56 across counties, identified from the decade that follows a storm, and they report 0.2 for the state-level specification of [Caliendo et al. \(2019\)](#). The European elasticity is a quarter of the county value and two thirds of the state value, for regions that are smaller than American states: Europe's regions move about a quarter as readily as American counties in response to the same permanent difference in value. This is the weak intra-European mobility on which the incidence results of the paper rest.

The cost of switching sector is not identified. The moment that would pin it, the response of agricultural employment to drought, has no power on the European panel. I also profiled, at the estimated ν , an over-identification criterion built on the regional amenity over a grid in $\nu\kappa$: the criterion stays above its value at the closed limit $\kappa = \infty$ at every finite point the stationarity solver can evaluate, by at least 0.0044, and the 27 points at the top of the grid are rank deficient and carry no value. The criterion identifies nothing on the grid. I set $\kappa = \infty$, two closed sectoral labour markets linked by trade, and report the profile as a specification test with no free parameter.

The investment elasticity ζ and the heat ratio η are borrowed from [Bilal and Rossi-Hansberg \(2023\)](#), each with the moment of the panel that would have identified it reported beside it. Once the elasticities are set, the damage magnitudes Γ^h are read from the levels of the cumulative responses, and the depreciation magnitudes through $\Gamma^\delta = \theta_h D_h$, the cumulative loss of investment converted into a rate by the hazard's persistence.

moment	parameter	role	data	interval	model	value	reading
Employment over value added per worker outside agriculture, extreme precipitation, WCE	ν	targeted	0.187	$[-0.506, 0.880]$	0.187	0.1316	matched
Interregional out-migration rate	β_0	concentrated	0.01324	–	0.01324	1.0941	reproduced at every evaluation
Employment over value added per worker outside agriculture, heat, WARM	η	borrowed	0.401	$[-0.413, 1.214]$	–	0.32	compatible, not corroborated
Investment over employment, extreme precipitation, WCE	ζ	borrowed	–10.895	withheld	–	5.10	not corroborated; interval withheld

Table 4: The moments of the calibration: the moment ν targets against the model’s, the out-migration rate β_0 is concentrated on, and the moments of the panel beside the borrowed η and ζ . Each moment is a ratio of two cumulative responses and its interval is by the delta method; the interval of ζ is withheld because its denominator, the employment response, is not distinguishable from zero, and the ratio has no meaningful interval.

The remaining parameters are standard: the rate of time preference, the housing and structures shares, the rate of moving opportunities, the worker’s risk aversion (log preferences in the baseline; the premium is recomputed for risk aversions between one and three), the capitalist’s risk aversion (log preferences in the baseline; recomputed on the range of risk aversions where the consumption equivalent exists), and the persistence of damages where a cell is not identified. The trade elasticities by sector are those of [Caliendo and Parro \(2015\)](#), their trade elasticity plus one, agriculture and the aggregate elasticity for the rest of the economy, and the trade costs in distance and border are built from the structural-gravity estimates of [Head and Mayer \(2014\)](#), elasticities of the flows converted into iceberg costs by $1/(\sigma_s - 1)$;

4 Results

This section compares the economy at the final climate with the economy at the climate Europeans live in today, and reports the difference as a consumption equivalent per agent and per location: the proportional change in consumption that would leave the agent indifferent.

4.1 The expected cost

This subsection answers the first question, how much the final climate costs and to whom. It gives the aggregate cost and its distribution, its sources by hazard and by mechanism, its geography, and the part of that geography the migration friction decides.

The population-weighted expected cost of the final climate under SSP2-4.5 to the average European worker is -6.38% of steady-state consumption. The median location is at -5.09% , the first and ninth deciles at -7.40% and -4.04% , and the equivalent is negative at 462 of the 462 locations. Northern Europe loses too, where [Cruz and Rossi-Hansberg \(2024\)](#) find gains at high

latitudes. The difference is in what the climate does, not in where. Their productivity and amenities are functions of the temperature level, with an optimum below which warming helps; here the climate enters only through hazards whose frequency rises or stays, and the one hazard that recedes with warming, cold, carries no damage the panel identifies. The model has no channel through which a milder winter pays, and a gain in the north would require one. Most of the cost from climate change is still ahead. The warming already realised, observed against pre-industrial, has cost -1.36% ; the whole of the warming, final against pre-industrial, costs -7.77% .

Table 5 splits the cost between the hazards by Shapley value, re-solving the economy with every combination of them switched on. Heat and extreme precipitation carry 49% and 51% of the workers' cost, the same order of magnitude. Drought carries nothing: its frequency trend is attributed in no exposure group and is held at the observed rate, so that drought enters the risk layer but moves no expected cost. For capital owners almost everything comes from one hazard, extreme precipitation, which carries 70% of their cost through the depreciation of buildings; this is the channel that tells the two agents apart.

hazard	workers		capitalists		loading
	$\times 100$	share (%)	$\times 100$	share (%)	
heat	-3.22	49	-3.05	30	estimated on some channels, zero by declaration on the others
extreme precipitation	-3.41	51	-6.99	70	estimated
drought	-	-	-	-	held at the observed frequency, not in the set: no cell of 3 attributed
total	-6.62	100	-10.04	100	

Table 5: Expected cost by hazard: Shapley values over the re-solves of every subset of hazards, weighted means over locations in log consumption equivalent, and shares of the total.

Table 6 cuts the first-order cost at a location into four mechanisms: the direct damage at fixed prices, factor allocation and population; the price response; the migration response; and the capital response. The exact equivalent is reported beside them, and its gap to the first-order sum is the second-order remainder.

	workers	capitalists	capitalists, gaining	capitalists, losing
direct damage	-2.68	-18.89	0.00	-51.65
price response	-0.01	-2.95	-0.10	-7.88
migration response	0.00	1.37	26.23	-41.76
capital response	-9.11	9.56	-5.88	36.34
first-order cost	-11.80	-10.91	20.24	-64.95
exact equivalent	-6.38	-3.92	11.22	-30.20
locations	462	462	316	146

Table 6: The expected cost by mechanism: the pieces of the first-order cost as weighted means over locations, in per cent of consumption, their sum and the exact equivalent; the last two columns split the capitalists by the sign of the exact equivalent.

Two facts are read from the table. First, the first-order expansion overstates the exact re-solve by a factor 1.85 for workers and 2.78 for capital owners, the remainder being of the opposite sign at the aggregate: the economy's adjustment absorbs a large part of the linear damage, and a first-order evaluation of the same economy would overstate the paper's number by those factors. The pieces are therefore reported as shares of the first-order cost, and the paper's number is the exact one. Second, among those shares the direct damage is 22.7% and the capital response 77.2%: the workers' cost comes mostly through the capital stock, buildings destroyed and not rebuilt lowering the marginal product of labour, and not through the hazards' direct hit on productivity and amenities.

Figure 5 maps the cost by location for both agents.

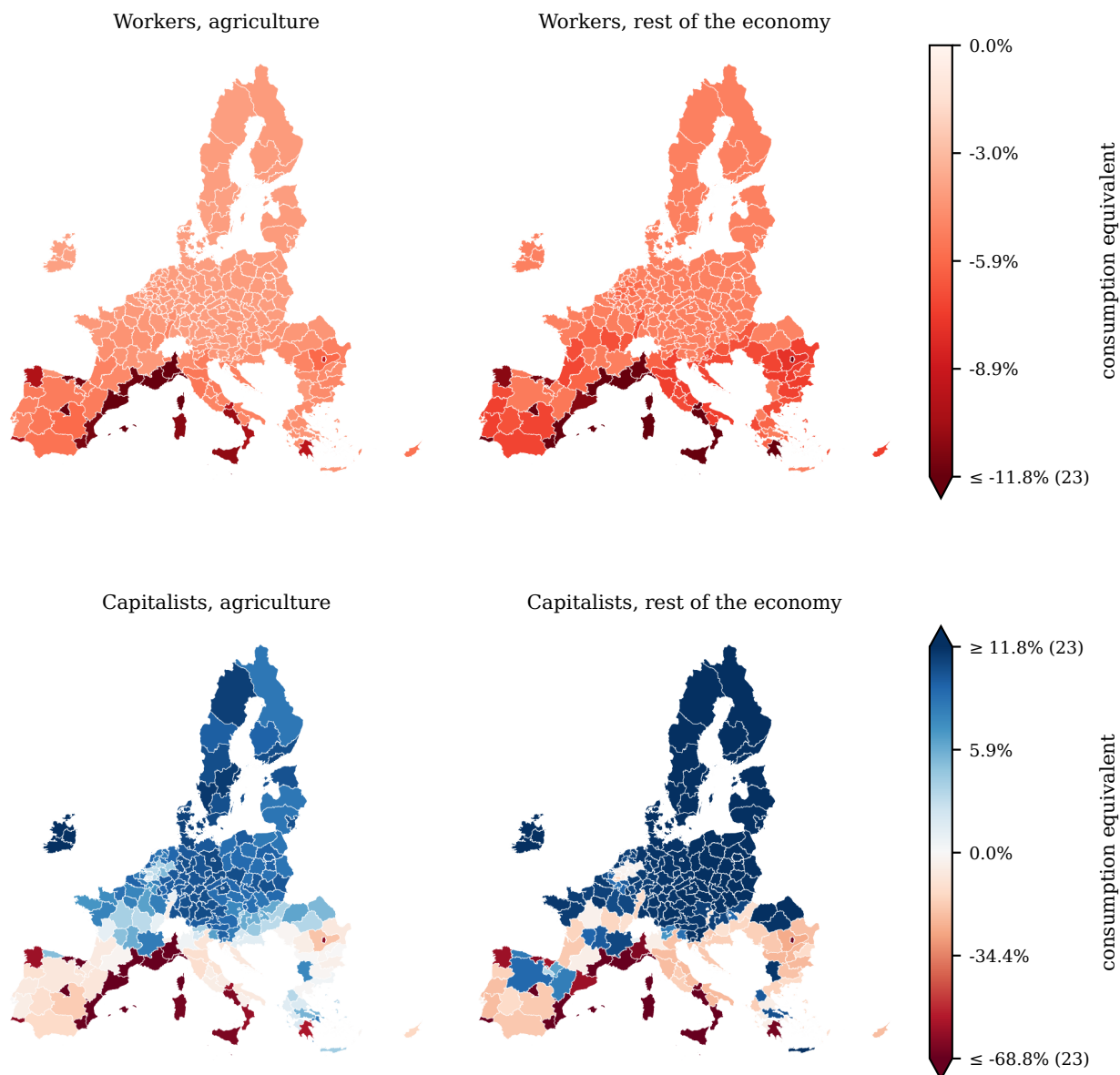


Figure 5: The expected cost per location: consumption equivalent of workers (top) and capitalists (bottom), agriculture (left) and the rest (right). Colour limits: 5th and 95th percentiles.

By country, the workers' aggregate runs from -13.89% in Malta to -5.00% in Poland and

Latvia. By exposure group, it is -9.00% in the Mediterranean group, -5.35% in western and central Europe and -5.07% in northern Europe. By sector, agriculture stands at -5.10% against -6.43% for the rest of the economy; two doors through which the hazards would reach agriculture in particular are closed in this calibration, drought held at its observed frequency and heat's loading on agricultural productivity not identified by the design and at zero, and the sectoral gap is read with them closed.

The migration friction decides how this geography is shared. Without the bilateral friction, at $\tau_{ij} = 0$, the three incidences are -7.12% , -6.94% and -6.93% , within one percentage point of one another against a spread of several points at the estimated friction, and the Union aggregate is -6.99% against -6.38% : a Europe without the friction shares the cost more evenly and bears more of it. The first fact is the spatial equilibrium itself: when moving is free, a change in utility is equalised across locations up to the dispersion the idiosyncratic taste allows, and a location no longer bears the cost of its own climate but a share of the Union's. The second is not a matter of where the population stands: the Union aggregate at $\tau_{ij} = 0$ is the same under the observed population and under the frictionless one (-6.98%); the population does move without the friction, the least exposed group holding 21% more of it at the observed climate, but toward the group the final climate costs least, and the increase of the aggregate is in the equivalents location by location, which rise almost everywhere to the common value.

4.2 The premium

This subsection answers the second question, what the uncertainty on the final climate is worth. It gives the premium and its geography, splits it into what the agent would pay to be rid of the risk and what he gains from an economy that adjusts better to good draws than it suffers from bad ones, asks at which risk aversion its sign turns, and ends with what a second-order expansion taken at today's economy, the usual object of perturbation methods, makes of it.

The premium is measured exactly: the economy is re-solved under each of a finite set of final climates that stands for the law of the global level and the regional pattern, and the premium is welfare averaged over those climates minus welfare under the expected climate, per agent and per location, in consumption equivalent. For the average worker it is 0.39% , a gain; for the average unit of today's capital it is 0.36% . Figure 6 maps it: the workers' premium is positive at 100% of the locations, the capitalists' at 11%.

The two pieces of equation (17) say why the sign differs. For the average worker the price of risk is -0.04% and the convexity gain 0.43% : climate uncertainty costs him almost nothing as risk, and what it does to him is the gain of a response that is convex at every location, a milder climate than expected helping more than a harsher one hurts once capital, people and prices have moved. For the average unit of capital the two pieces are an order of magnitude larger, -1.60% against 1.97% , and nearly cancel; at the median location both are costs, and the median owner's premium, -0.69% , is negative not because he is averse to risk but because his response is concave: at 87% of the locations the owner's gain from the lottery is the inflow of workers that a bad draw elsewhere sends him, which the return on a fixed stock turns into a concave function of the draw. Where the final climate destroys the stock the picture is the opposite one, a large gain against a large price of risk. The sign of the premium is the sign of this contest.

The sign of the premium depends on risk aversion, and not in the same way for the two agents. Holding the allocation of log preferences and re-solving the value under CRRA felicity for each γ

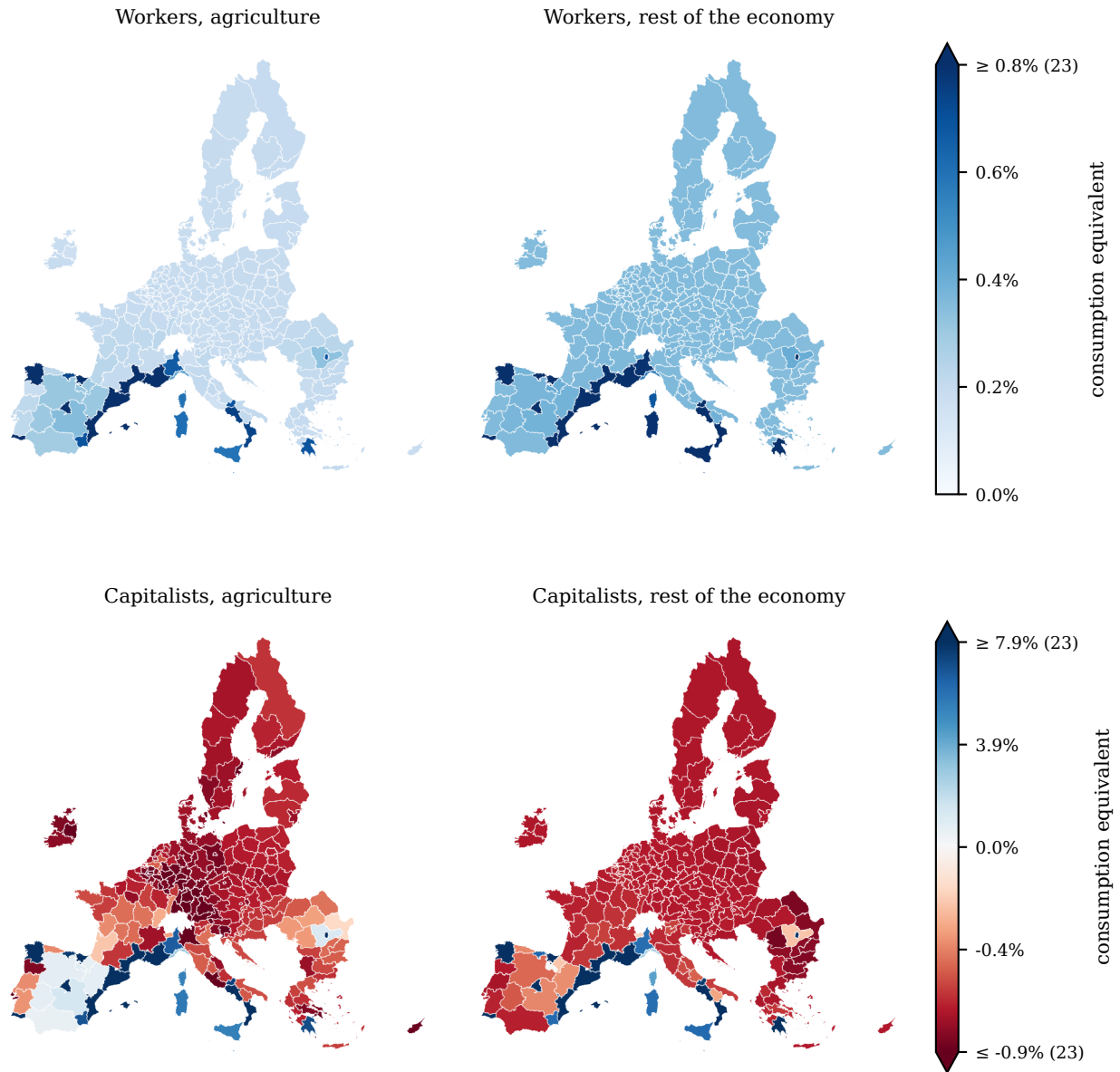


Figure 6: The premium per location: consumption equivalent of workers (top) and capitalists (bottom), agriculture (left) and the rest (right); a positive one is a gain. Colour limits are the 5th and 95th percentiles.

on a grid, the capital owners' aggregate premium turns negative just above log preferences, from $\gamma^* = 1.24$ on, and the locations whose own premium changes sign, 49 of the 462, are almost all in the Mediterranean group (Figure 12). The workers' premium shows no sign change on the range where it can be measured, up to $\gamma = 3$; beyond, with an additive amenity and a felicity bounded above, the consumption equivalent ceases to exist for most of the population, a limit of the unit rather than a sign. The approximation is named: the allocation is that of log preferences and γ changes its valuation only. The sign of the paper's premium is therefore the workers' with some robustness and the capital owners' with none: the owners of the capital the climate destroys gain from uncertainty only as long as they are nearly risk-neutral. A positive premium does not make insurance worthless: it nets the gain from a real adjustment that insurance leaves in place against the cost of bearing the variance of consumption that insurance removes, and the next subsection says how much of that cost a European fund can reach.

Log preferences are the lower end of what the literature on climate risk assumes, and the paper's premium is read as such: the point is not that the premium is positive, but that it is not negative by construction once the adjustment of the economy is netted against the pure cost of risk, and that a higher aversion turns it, for capital owners first. The usual way to raise risk aversion without raising the aversion to intertemporal substitution is Epstein–Zin recursive utility; it is not the route taken here, because such preferences are not monotone with respect to first-order stochastic dominance (Bommier et al., 2017), a property that matters precisely when the object valued is a lottery over final climates, where a worse climate in every state must be worth less. Monotone recursive preferences with risk sensitivity, which keep that property, are the alternative Fillon et al. (2023) use for climate tipping risk, and the premium under them is left to future work.

What a second-order expansion makes of this premium depends on where it is taken. Taken at today's economy, as a perturbation around the current steady state is, it overstates the exact premium by a factor 23.1 for workers, and by nearly the same factor in every country. A ratio this far from one and this uniform is a property of the expansion, not of the places, and shrinking the draw to nothing says which: the exact premium over the second-order one converges to 0.0715 at the final economy and to one at the observed one. The two limits differ by the base economy and by nothing else: the economy that will bear the final climate is far less curved in its direction than today's. The reason is the capital stock, not the option to migrate, which is a small part of the premium at both economies: the curvature of aggregate capital along the common shock falls between the observed and the final economy by more than the premium's does, and a reading consistent with this, and with the fact that the shock cannot be scaled to a quarter of its size at the observed economy without some locations' effective depreciation turning negative, is that today's capital stock, with all its adjustment ahead of it, responds to the final climate close to the region where that response is strongly convex, and the final economy's, smaller and already depreciating faster, far from it.

4.3 Who bears the risk

This subsection answers the third question, who bears the risk. It first asks which part of the premium comes from the global level of warming, the part no pooling within Europe can reach, and then turns to the two agents: what makes the workers' premium large in one place and small in another, and why the capital owners' is a premium on destruction.

Most of the premium is in the common layer. Attributing it by Shapley value to the two layers

drawn once, the uncertainty on how much the planet warms carries 79% of the workers' premium and 79% of the capital owners'; the two layers nearly add, the share is the same at second order to within one percentage point, and the weather, the realisations layer, is the smallest of the three (Appendix C). Why so much? Not because the draw hits every region equally: it hits every region at once, but unequally. The loading of the global level on the values of locations is concentrated where the attributed trends are, 79.5% of its mass in the Mediterranean group, and only 31% of it is uniform within a sector. That uniform part is what the invariance result of Section 2.1 puts beyond any reallocation, and the solution confirms it: by Shapley value, the uniform part's share of the common layer's premium is zero at every location. The common layer's premium comes entirely from the way the draw falls unequally and from what it destroys; split by channel, 61% of it is carried by the destruction of capital and the curvatures of utility and of the frequency law, the rest by the values of locations, the channel migration reads.

What Europe can pool follows. A fund that transfers between regions can reach the pattern layer and the weather, at most 21% of the workers' premium, and nothing of the common layer, whose draw is the same number for every region. Whether a transfer could still smooth that premium by evening its incidence is a question for a model with the transfer in it, and the channel split above is the first fact such a model will have to match.

For workers, the size of the premium follows the composition of the cost. Figure 7 places each location by the share of its first-order cost that runs through the capital stock, on the horizontal axis, against its premium; the dashed lines cut the locations into terciles of that share.

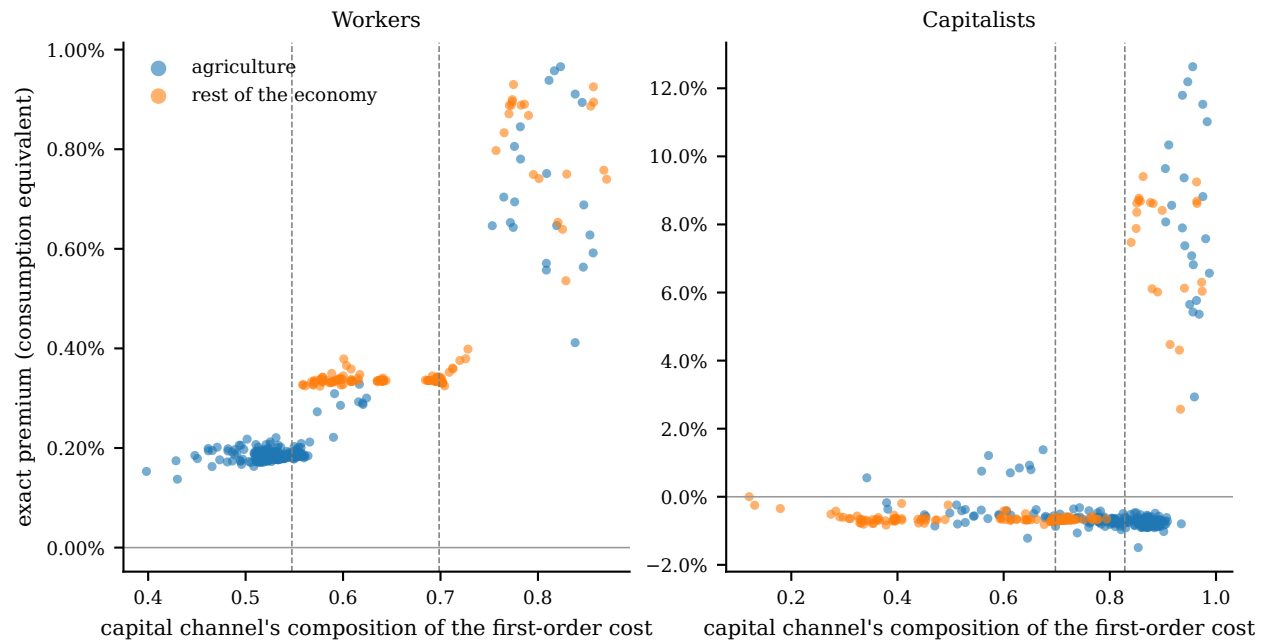


Figure 7: The premium against the share of the first-order cost that runs through the capital stock (absolute values, tercile edges drawn), one point per location, workers (left) and capitalists (right); a positive premium is a gain.

The locations line up in three steps, the three exposure groups, with agriculture below the rest of the economy in each, and the premium rises from 0.19% in the lowest tercile to 0.33% in the highest. Where the climate reaches workers through buildings, the economy's adjustment

has something to work with, since a stock can be rebuilt or not and people can leave; where it reaches them through the direct hit on productivity and amenities, the damage passes through almost linearly and only risk aversion remains. The premium therefore rises with the loss, the places that lose most gaining most from uncertainty, though not in proportion.

Capital owners are not a smaller version of workers. In expectation, their distribution is two-sided where the workers' is one-sided: they lose -3.92% on average but gain at 68.4% of the locations, and the two sides have different mechanisms. Where capital is destroyed, its owner bears the direct loss and no price or population response compensates it, because the owner is immobile and the stock is local. Where it is not, the migration of workers towards that location raises the return on the capital already there, and the owner gains without having done anything. The capitalist's expected cost is thus an incidence of the workers' migration as much as of the climate. In risk, the capital owners' premium follows neither the composition of the cost nor the cost itself; it follows destruction. At the 44 locations where the final climate destroys capital, the premium is positive at 100% of them, elsewhere at 2% ; those locations hold 12.1% of today's capital, and the owners of that capital lose most in expectation and gain most from uncertainty, because a favourable draw spares their stock and an unfavourable one cannot destroy it twice.

4.4 When the cost arrives

This subsection answers the fourth question: when the cost arrives. The paper compares steady states and no transition paths, but two things can be read about time: how fast today's economy moves toward the final one, and how the cost grows with the level at which the climate settles.

How long does the economy take to get from today's steady state to the final one? The paper computes no transition path, but the first-order dynamics around the final steady state answer the question the way [Kleinman et al. \(2023\)](#) answer it for a dynamic spatial economy: the economy does not return to its steady state at one speed, it returns at many. Some rearrangements are fast, such as a region rebuilding or running down its capital; others are slow, such as the population of Europe redistributing itself across regions through a migration friction. Each rearrangement is a pattern of population and capital across locations that fades at its own rate, and the distance between today's economy and the final one is a combination of these patterns. Formally, with y_t the deviation of log population and log capital at every location from their final values,

$$\dot{y}_t = J y_t, \quad y_t = \sum_h c_h e^{\lambda_h t} u_h, \quad (24)$$

where J collects the migration, capital and price responses of the model, u_h are its eigenvectors, the patterns, and $\lambda_h < 0$ their rates ([Appendix A](#)). A pattern's half-life, $\ln 2 / |\lambda_h|$ years, is the time it takes for half of it to disappear; the weight c_h says how much of the climate displacement y_0 rides on it.

Two facts follow. The slowest patterns are the slow ones one expects: in the ten slowest, population and capital move together across regions, with half-lives from 1411 to 817 years; at the estimated friction, Europe redistributes its population across regions over centuries. But the climate asks little of these slow patterns. The move from today's economy to the final one is mostly made of fast rearrangements, capital rebuilt or run down within regions, and only a small part of it is the slow kind, population shifting between regions. Weighting each pattern by how much of the move it carries, the median half-life is 30 years: 40% of the displacement is on patterns with a half-life

below ten years, 47% between ten and a hundred, 11% between a hundred and a thousand, and 2% beyond. What the climate asks of the economy is mostly the fast kind of rearrangement, not the slow one. Along time, Figure 8 says the same thing as the share of the displacement completed at each horizon T , $1 - \|y_T\| / \|y_0\|$, with y taken net of the component that the conservation of population holds fixed and the norm weighted by the block's own population or capital: the capital stock completes 67% of its adjustment within thirty years and 78% within a century, the population 17% and 34%. The stock adjusts within a generation, the people within several, and the cost the paper reports is, for the most part, a cost of the coming century, not of the centuries the slowest patterns suggest.

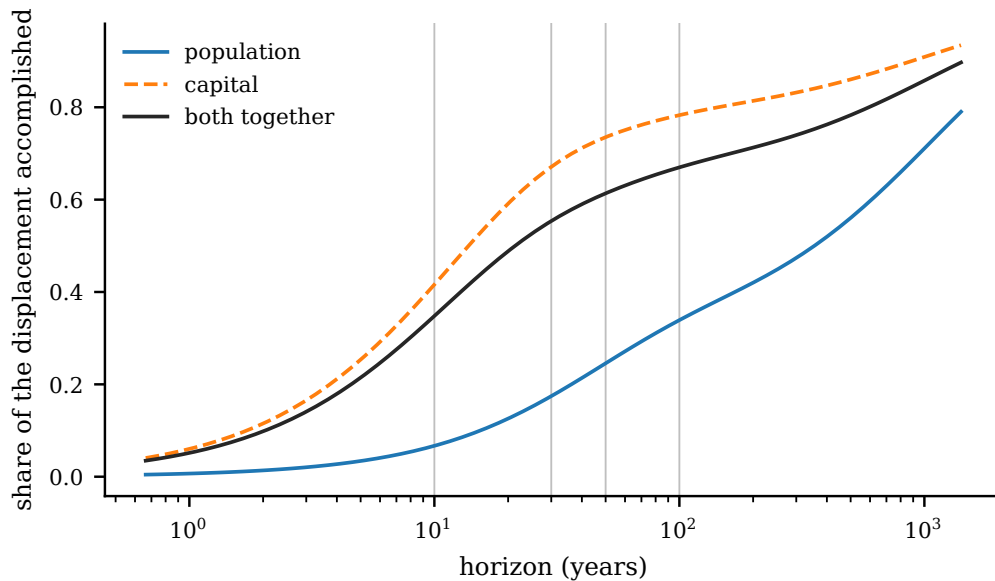


Figure 8: The share of the adjustment to the final climate completed along the first-order path, by horizon (log scale): population, capital and both, net of the conserved component; the four declared horizons are marked.

How the cost grows with warming is read by re-solving the economy at four declared levels of final global warming, 1.5, 2.0, 3.0 and 4.0 degrees above pre-industrial, with the regional pattern per degree and the attributed slopes unchanged. This gives the European damage function of Figure 9: the expected cost to the average worker is -1.24% at the first level, -2.78% at the second, -5.77% at the third and -7.71% at the fourth, and the scenario's own final climate, at 3.26 degrees, sits on the curve. Three facts are read from it. The cost is concave in warming over the four levels read, each further degree adding less than the one before, as Section 4.1 found at the scenario's own climate, where the economy's adjustment absorbs close to half of the first-order damage. This is a property of the model, not a finding about the climate: the hazards reach the final climate through their frequencies alone, an event at four degrees being the event of today's data, only more frequent; the frequency trends are extrapolated from the observed range of warming to levels the panel has not seen; and adaptation through migration and investment is unlimited. Each of the three bends the curve downward, and none holds far from the observed climate. The curve is read as the model's expected cost at each level, not as a damage function of the climate. The geography is the same at every level and widens with it: the Mediterranean group stands at

−10.81% at the fourth level against −6.10% in the north. And the two agents part ways as the climate warms: capital owners in the Mediterranean group stand at −45.75% at the fourth level while those in the north reach 14.03%, the inflow of workers raising the return on the capital already there. The levels are the ones Europe now plans on: the climate resilience framework the Commission presented on 27 October 2026 proposes common warming assumptions of 1.5 degrees by 2030, 2 by 2050 and 3 by 2100 (European Commission, 2026), the first three levels of the curve, and the third is the one on which France plans its adaptation.

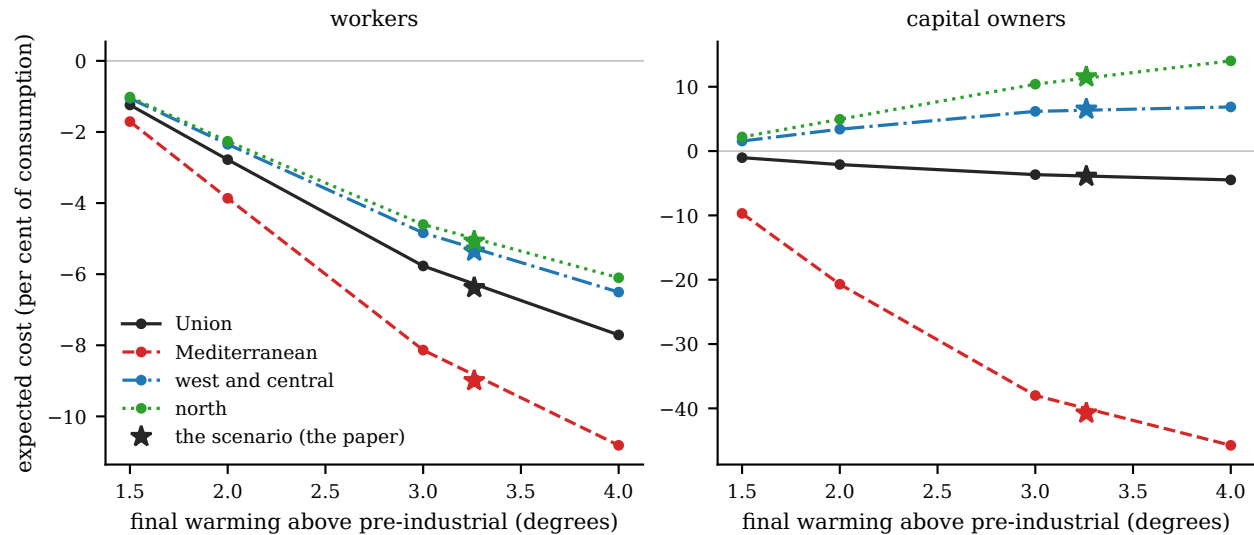


Figure 9: The expected cost of the final climate by level of final global warming, workers (left) and capital owners (right): the Union and the three AR6 groups, consumption equivalents under the observed weights, at the four declared levels; the star marks the scenario's own final climate.

5 Conclusion

Two things the premium of this paper does not price. The first is the uncertainty between emissions scenarios. The climate path is the central path of one scenario, SSP2-4.5, and the three layers are drawn around it: the premium is the price of not knowing where the climate will settle for a given path of emissions, not the price of not knowing the path. A scenario is a choice of policy, not a draw of nature, and the object I price is the one adaptation planning uses: governments plan on a reference trajectory and ask what remains uncertain around it. France, by decree, now for instance sizes its adaptation to a warming of four degrees over its territory by the end of the century, about three degrees globally. The second is the tail. The approximation that lets hazards enter as diffusions holds for shocks of ordinary size and says nothing about rare, violent events, compound events among them.

Under our calibration the cost of climate change to Europeans is a matter of its level more than of its uncertainty: the premium is a small fraction of the expected cost, and the right target of adaptation is the mean, not the variance. The cost is concentrated where the damage falls, and the migration friction keeps it there: the Mediterranean bears nearly twice what the north bears, and

a Europe without the friction would share the cost more evenly without bearing less of it, so that mobility redistributes the cost of climate change rather than reducing it. The risk, as distinct from the cost, is borne by the owners of exposed buildings, who lose most in expectation and cannot move their stock: adaptation of the building stock targets a small set of locations that hold a small share of Europe's capital and most of its climate risk. And the part of the risk that Europe can pool among its regions is bounded, because the uncertainty on how much the planet warms hits every region at once: at most 21% of the workers' premium is within reach of an intra-European fund. The Union's instruments read against this map. The Solidarity Fund compensates realised disasters after the fact and reaches the smallest of the three layers; cohesion policy transfers resources between regions *ex ante* and can redistribute the expected cost the friction concentrates in the south, a matter of fairness rather than of insurance; neither touches the common risk, which only the level of global emissions, or insurance beyond Europe, can reduce. The climate insurance alliance the Commission convened on 27 October 2026, to narrow a gap in which only around a quarter of natural catastrophe losses have been insured ([European Commission, 2026](#)), can therefore reach the weather and the regional pattern, and not the level of the warming itself.

A new version of this paper is in preparation, and it extends the framework in three directions. The first is the estimation of the damages: the event studies are re-estimated against the years before each event, the persistence of each hazard's damage, borrowed here, is estimated on the response paths, and wind, whose series is in hand, enters as its own hazard through the depreciation of buildings. The second is the climate: the frequencies of the hazards at the final climate, extrapolated here from their observed trend on global temperature, will also be read from the daily output of regional climate models, bias-corrected against the observations, so that a hazard the panel cannot attribute, such as drought, still moves. The third is preferences: the premium will be mapped across risk aversion by exact re-solves rather than by revaluation at the allocation of log preferences, and under monotone recursive preferences, so that the sign of the premium is read as a function of the aversion rather than at its lower end. Alongside these, the paper's incidence, by region and by agent, becomes a database on which European instruments are written into the model and priced, cohesion policy read as insurance first: a fund that transfers between regions conditional on the realisations of hazards and on the regional pattern of warming, calibrated on the actual rules of the Solidarity Fund, with the premium measured with and without it, by region.

Further out lie two questions. The hazard list is closed and the approximation excludes the tail: other extremes, and compound events in which several hazards strike together, are outside this version and would need the dependence between hazards measured as the covariance across regions is here. And within a region, who bears the damage: the model carries one worker and one capital owner per location, so that the incidence it maps is between regions and between agents, not within either; a household distribution within each region, with vulnerability to the hazards that differs by income, housing and sector, is the longer road from the geography of climate risk to its distribution among Europeans.

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A Proofs and derivations

This appendix derives four things the text uses: the capital owner's steady-state condition and why the expansion of his block closes one order at a time; why the second-order premium splits exactly across the layers of uncertainty; why a shock common to every location of a sector cannot be escaped by moving; and what the modes of Section 4.4 are.

The capital owner's block

At the steady state, the capital owner's problem (3) gives the usual condition on the price of capital. Differentiating in K and using the envelope condition on investment, $\rho P_K = u'_c \partial_K C^c + P_{KK}(I - \Delta K) + P_K(\partial_K I^* - \Delta)$; the term in $\partial_K I^*$ multiplies the first-order condition and vanishes, and the term in P_{KK} vanishes because investment just covers depreciation at the steady state, $I^* = \Delta K$. Writing $q = P_K/u'_c$ for the price of capital in units of consumption, what remains is $(\rho + \Delta)q = R_K - c(\iota) + \iota c'(\iota)$ together with $q = c'(\iota)$: the standard condition for a capital stock with convex adjustment costs, the one [Bilal and Rossi-Hansberg \(2023\)](#) invert. Marginal utility has cancelled because consumption is constant at the steady state, so the inversion of the fundamentals does not depend on the owner's risk aversion γ_c ; what γ_c changes is how the block moves away from the steady state.

That movement is solved one order at a time. Differentiating (3) n times in K brings in the next derivative of the value, $P_{K(n+1)}$, but always multiplied by the drift of capital, $I^* - \Delta K$, which is zero at the steady state. Each derivative of the value is therefore determined by the derivatives below it and by those of the investment policy, themselves functions of the lower derivatives of the value through the first-order condition. At second order this equation is quadratic and has two real roots; the drift coefficients they imply sum to ρ , and the smaller root is the one along which the economy returns to its steady state after a shock. It is the root the paper takes, and at $\gamma_c = 0$ it reproduces the risk-neutral block.

Why the premium splits across layers

The second-order term Λ is linear in the covariance of the factors, Σ_W . The first-order response to a factor, Γ^f , is linear in that factor's loadings; the second-order response to a pair of factors, Δ^{fg} , is bilinear in the loadings of the pair, and its equation never involves the curvature tensor $\mathbb{V}$ directly, which reaches it only through Γ ; the equation for Λ is then linear in Σ_W , with coefficients $-A^{-1}\sigma_f\sigma_g\Delta^{fg}$. Hence $\Lambda_x = \sum_{f,g} \Sigma_W^{fg} \lambda_x^{fg}$, and the share of each layer, and of each pair of layers, is part of the solution rather than a decomposition made afterwards. Two simplifications follow. When every factor of a layer decays at the same rate θ , the equation for Δ can be summed over the layer before it is solved, one vector equation per layer. And for a layer drawn once, with $\theta = 0$, there is no diffusion term: the second-order contribution is the second moment of the state the draw induces, $\text{tr}(\Delta X \Sigma_z X^\top)$, where X is the response of the state to the draw, computed so that the conserved totals of population do not move, $\ell^\top X = 0$ for every left null vector ℓ of the closed loop; the conserved coordinates of the mean state are fixed by the conservation of population in levels.

The common component is borne where one stands

This proves the invariance result of Section 2.1. Let m be the stationary transition between locations and $\mathbf{N}^{\text{ss}}$ the population it leaves unchanged. The reallocation matrix $G = \mu\nu(\text{diag } \mathbf{N}^{\text{ss}} - m^\top \text{diag}(\mathbf{N}^{\text{ss}})m)$ gives the first-order response of the population to a change in the values of locations, up to the dynamics of the state. When no worker switches sector, $m^\top \mathbf{N}^{\text{ss}} = \mathbf{N}^{\text{ss}}$ sector by sector, and therefore $G\mathbf{1}_s = 0$ for each sector indicator $\mathbf{1}_s$: a change in values that is the same at every location of a sector produces no reallocation. At second order, the option value of being able to relocate is the curvature of the log-sum-exp of values against the covariance of the values; for a change that is uniform within a sector, the differences between values do not move, their covariance is zero, and so is the option value. Neither conclusion uses the size of ν , τ or κ : they hold for every value of the three. At a finite switching cost, the only indicator G annihilates is the total population, and the statement holds for the component common to all locations of both sectors. The result is about labour: trade balance (4) is not of this form, and the law of motion of capital carries a common shock through investment. In the code, the conserved subspace of G is computed by singular value decomposition at run time, its dimension is derived (two at the closed sectoral limit), the sector indicators are verified to lie in it, and a shock with a component on it is refused by name.

The modes of the first-order dynamics

Around the final steady state, the first-order solution makes the state move as $\dot{y} = Jy + Ez$, where y collects the deviations of log population and log capital at every location, z the climate factors, and J the matrix of the migration, capital and price responses of Section 2.3. Writing $J = U\Lambda_J U^{-1}$, each column u_h of U is a pattern of population and capital across locations that decays at its own rate λ_h , with half-life $\ln 2/|\lambda_h|$: these are the modes of Section 4.4. The decomposition is well conditioned on the real economy (reconstruction error 1.2×10^{-14} , condition number of U 166). A displacement x of the state is a combination of the modes, $x = \sum_h c_h u_h$ with $c = U^{-1}x$, and the share of it that each mode carries is $|c_h| \|u_h\|$. Two modes do not decay at all: the kernel of J has dimension 2 and coincides, to 1.0×10^{-12} , with the two sector indicators, the directions along which the reallocation matrix moves nothing. The component of the climate displacement along them, 13.4% of its population-weighted norm, is not an adjustment the economy has left to make: the totals of population by sector are conserved, and this component is only the gap between the mean of the log changes and the log of the conserved mean, a second-order term of the logarithm. It is set aside in the share completed of Figure 8.

B How the model is solved

The model is solved three times, and each solution checks the one before.

The first is the inversion of today's economy. Given the observed populations, capital and flows, the stationarity conditions are solved for the fundamentals that reproduce them. The natural way, iterating the migration map until it settles, does not converge on the European friction: the map does not contract. The stationarity system is therefore solved as a root-finding problem, by Newton's method on its residual, and a solve is accepted only when the residual is within a

tolerance fixed before the solve starts, never because the steps became small.

The second is the re-solve of the economy at other climates, which gives the expected cost and the exact premium. At each climate, the final one and each of the finite set of climates that stands for the law of the draws, the full nonlinear steady state is recomputed by the same method, with the value equation solved by policy iteration inside it, the Jacobian rebuilt by finite differences while the residual does not fall and kept while it does, and with continuation in the climate displacement when the final climate cannot be reached in one step. Figure 10 shows why Newton is needed: the damped substitution the model suggests does not contract at any of the four climates, and the Newton residual falls to its bar at the final climate in 39 outer iterations with 13 Jacobians built. The expected frequencies of the hazards at each climate are integrated by a Gauss–Hermite rule whose number of nodes, from 20, is doubled until every location moves by less than its rounding floor between two successive refinements: 320 nodes for heat, 640 for extreme precipitation.

The third is the second-order expansion of the Master Equation around today's economy. Its curvature terms are not trusted because they are second order; they are checked against the exact re-solves in two ways. At small displacements of the climate, the second difference of the exact nonlinear equilibrium, taken by central differences on a ladder of steps with Richardson extrapolation and a per-location noise floor, must equal the curvature the expansion attributes to each location, in three directions of the shock space; the identity holds at every resolved location before any second-order number is read. And the exact premium under the same law scaled down, divided by the scaled second-order premium and extrapolated to a vanishing draw, must converge at the observed economy to the second-order premium itself, at every location, within a bar derived from the move between the two finest scales and the solves' error bounds. It does, for workers and capital owners, on the common and the pattern layers; the worst location is at 0.04 of its bar on the common layer and 0.35 on the pattern layer, and the median observed order of convergence is 2.18 for workers and 2.18 for capitalists on the common layer, 1.92 and 2.08 on the pattern layer. This is the check the curve of Figure 15 rests on.

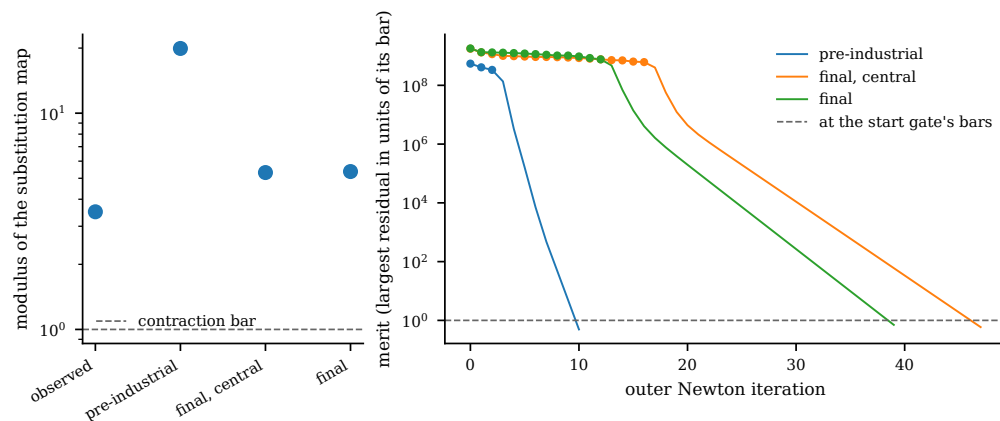


Figure 10: The welfare re-solves. Left: the damped substitution does not contract at any of the four climates, its modulus at the start of each re-solve lying above the contraction bar, which is why the steady state is found by Newton's method. Right: the Newton residual, in units of its bar, falls to the bar at every climate; a dot marks an iteration where the Jacobian was rebuilt.

C Additional tables and figures

	workers' premium	workers' price of risk	workers' convexity gain	capital owners' premium	capital owners' price of risk	capital owners' convexity gain	diversification value
Union	0.39%	−0.04%	0.43%	0.36%	−1.60%	1.97%	1.50%
MED	0.55%	−0.07%	0.62%	3.69%	−6.27%	9.97%	− ^a
WCE	0.33%	−0.02%	0.35%	−0.68%	−0.15%	−0.53%	− ^a
NEU	0.33%	−0.02%	0.35%	−0.70%	−0.07%	−0.62%	− ^a
median location	0.33%	−0.02%	0.35%	−0.69%	−0.07%	−0.62%	0.07%

Table 7: The premium and its two pieces, equation (17), read on the exact re-solves: the price of risk and the convexity gain, workers and capital owners, observed weights; the last column compares the capital owners' price of risk with the diversification value of Section 4.3.

parameter	object	value	reported beside it
ρ	time preference	0.02	—
β	housing share	0.30	—
α	structures share	0.40	—
μ	moving opportunities	2.30	—
ν	migration elasticity	0.1316	its targeted moment
β_0	intercept of the friction	1.0941	the out-migration rate
γ	worker risk aversion	1	sweep
γ_c	capitalist risk aversion	1	sweep; range where the equivalent exists
η	amenity/productivity ratio	0.32	its moment on heat
ζ	investment elasticity	5.10	its moment on precipitation (GFCF cell not identified)
θ_h	persistence, where the cell is not identified	half-life 5 years	elasticity of the second-order premium to it
σ_s	trade elasticity	9.11 (agriculture), 5.45 (rest)	sweep of σ_s (specification test)
τ_{ij}^s	trade costs	distance −1.14, border 1.55 (flow elasticities)	—
ψ	capitalist mass share	1	invariance under doubling
κ	sector-switching cost	∞ , declared at the closed limit	specification test

Table 8: Calibration: borrowed, declared and estimated parameters, with their value and what the paper reports beside each.

object	outcome	group	design	realised	verdict	half-life	θ_h
cold (placebo)							
placebo	employment	all regions	–	–	placebo	–	–
placebo	GVA per worker, rest	all regions	–	–	placebo	–	–
drought, principal scale							
χ , agriculture	GVA per worker, agr.	MED	0.177	0.200	not identified	5.0	borrowed; † borrowed
χ , agriculture	GVA per worker, agr.	WCE	0.154	0.153	not identified	5.0	borrowed
χ , rest	GVA per worker, rest	MED	0.885	0.782	identified	16.3	estimated
χ , rest	GVA per worker, rest	WCE	0.373	0.440	not identified	7.0	estimated
δ , clay soils	investment	MED	–	–	no target	1.4	estimated
κ , denominator	employment	MED	0.573	0.395	not identified	5.0	borrowed
κ	agr. employment	MED	0.167	0.167	not identified	1.8	estimated
drought, robustness scale							
χ , agriculture	GVA per worker, agr.	MED	0.228	0.254	not identified	1.7	estimated; † borrowed
χ , agriculture	GVA per worker, agr.	WCE	0.284	0.284	not identified	5.0	borrowed
χ , rest	GVA per worker, rest	MED	0.832	0.804	identified	1.8	estimated
χ , rest	GVA per worker, rest	WCE	0.543	0.497	not identified	2.3	estimated
δ , clay soils	investment	MED	–	–	no target	3.2	estimated
κ , denominator	employment	MED	0.539	0.374	not identified	3.6	estimated
κ	agr. employment	MED	0.170	0.170	not identified	5.0	borrowed
late frost							
χ , agriculture	GVA per worker, agr.	WCE	–	–	no target	1.5	estimated; † borrowed
heat							
amenity	employment	warm exposure	0.996	0.993	identified	5.0	borrowed
amenity	employment	all regions	0.999	0.997	identified	4.0	estimated
χ , agriculture	GVA per worker, agr.	warm exposure	0.656	0.711	not identified	1.2	estimated
χ , agriculture	GVA per worker, agr.	all regions	0.744	0.744	not identified	2.1	estimated
χ , rest	GVA per worker, rest	warm exposure	1.000	1.000	identified	5.0	borrowed; † borrowed
χ , rest	GVA per worker, rest	all regions	1.000	1.000	identified	5.6	estimated
extreme precipitation							
δ	employment	NEU	0.597	0.483	not identified	5.0	borrowed
δ	employment	WCE	0.989	0.999	identified	4.8	estimated
δ	investment	NEU	0.615	0.668	not identified	2.4	estimated
δ	investment	WCE	0.992	0.933	identified	5.0	borrowed; † borrowed
ν , denominator	GVA per worker, rest	NEU	0.450	0.337	not identified	9.1	estimated
ν , denominator	GVA per worker, rest	WCE	0.962	0.987	identified	13.3	estimated
wind							
δ	investment	WCE	–	–	not estimable	–	–

Table 9: Power and persistence, every cell: design power at the declared minimal effect, which gives the verdict; realised power; half-life in years of the cell’s own decay. †: the cell a hazard’s persistence is read from; rows ν , κ : moment denominators.

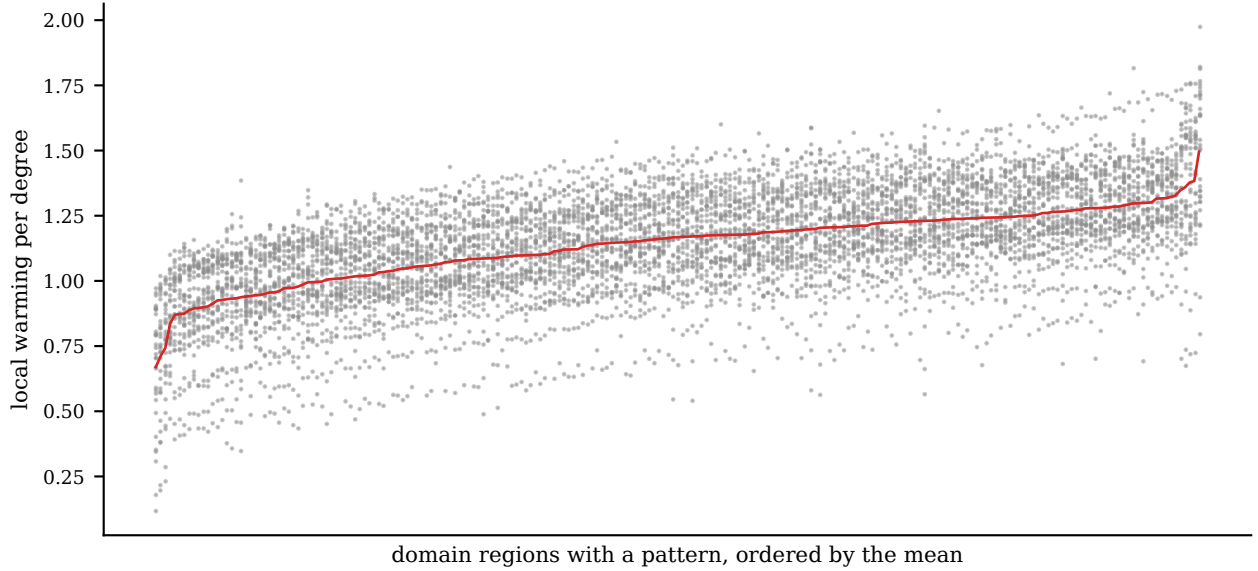


Figure 11: The spread of local warming across models: every model’s pattern for each of the 221 regions with a pattern of their own, the regions ordered by the mean, which is drawn through them.

hazard	group	slope	interval	t	verdict	log-intensity slope	interval
cold	COOL	-0.065	[-0.101, -0.029]	-3.57	attributed	-1.532	[-2.481, -0.584]
cold	WARM	-0.015	[-0.039, 0.009]	-1.23	not attributed	-0.331	[-0.856, 0.194]
drought	MED	0.029	[-0.008, 0.066]	1.54	not attributed	1.100	[0.148, 2.053]
drought	NEU	-0.017	[-0.038, 0.003]	-1.70	not attributed	-3.059	[-6.054, -0.064]
drought	WCE	-0.003	[-0.008, 0.002]	-1.01	not attributed	-0.927	[-2.549, 0.695]
drought_spei6	MED	0.014	[-0.015, 0.043]	0.96	not attributed	0.630	[-0.559, 1.819]
drought_spei6	NEU	-0.009	[-0.018, 0.000]	-2.06	attributed	-0.896	[-1.987, 0.195]
drought_spei6	WCE	-0.004	[-0.009, 0.001]	-1.66	not attributed	-1.257	[-2.743, 0.228]
frost	MED	-	-	-	not estimable	-	-
frost	NEU	-0.060	[-0.099, -0.020]	-2.97	attributed	-2.835	[-4.581, -1.089]
frost	WCE	-0.011	[-0.018, -0.005]	-3.33	attributed	-1.464	[-2.333, -0.594]
heat	COOL	-0.003	[-0.031, 0.024]	-0.25	not attributed	-0.123	[-1.091, 0.844]
heat	WARM	0.067	[0.023, 0.110]	2.99	attributed	0.911	[0.350, 1.472]
precipitation	MED	0.017	[0.002, 0.032]	2.27	attributed	1.337	[0.427, 2.247]
precipitation	NEU	0.000	[-0.006, 0.006]	0.00	not attributed	-0.001	[-1.599, 1.597]
precipitation	WCE	0.005	[-0.002, 0.012]	1.43	not attributed	0.439	[-0.145, 1.023]

Table 10: Attribution of the frequency trends by hazard and group: the slope of the annual frequency on global temperature with its Newey–West interval, t and verdict; the maximum-likelihood slope of the log intensity, which carries the frequency to the final climate.

rank	location	equivalent (%)	log equivalent	rank	location	equivalent (%)	log equivalent
1	MT00 ag	−14.37	−0.1552	1	MT00 ag	−80.59	−1.6393
2	MT00 na	−13.89	−0.1495	2	FRM0 ag	−75.00	−1.3864
3	ES62 na	−13.72	−0.1475	3	ITC3 ag	−74.99	−1.3858
4	ITG2 na	−13.54	−0.1455	4	MT00 na	−74.94	−1.3839
5	ITC3 na	−13.12	−0.1407	5	ES62 na	−74.52	−1.3672
6	ITG1 na	−13.04	−0.1397	6	FRL0 ag	−73.97	−1.3459
7	ES52 na	−12.93	−0.1385	7	ITG2 na	−73.75	−1.3374
8	FRM0 na	−12.92	−0.1384	8	ES30 ag	−73.38	−1.3233
9	ES53 na	−12.86	−0.1377	9	ES53 ag	−73.19	−1.3163
10	ITF3 na	−12.83	−0.1373	10	ITC3 na	−72.25	−1.2818

Table 11: The locations that lose most, workers (left) and capitalists (right): the consumption equivalent of the expected cost in per cent, ranked on the log of one plus the equivalent; locations without one are counted under the table.

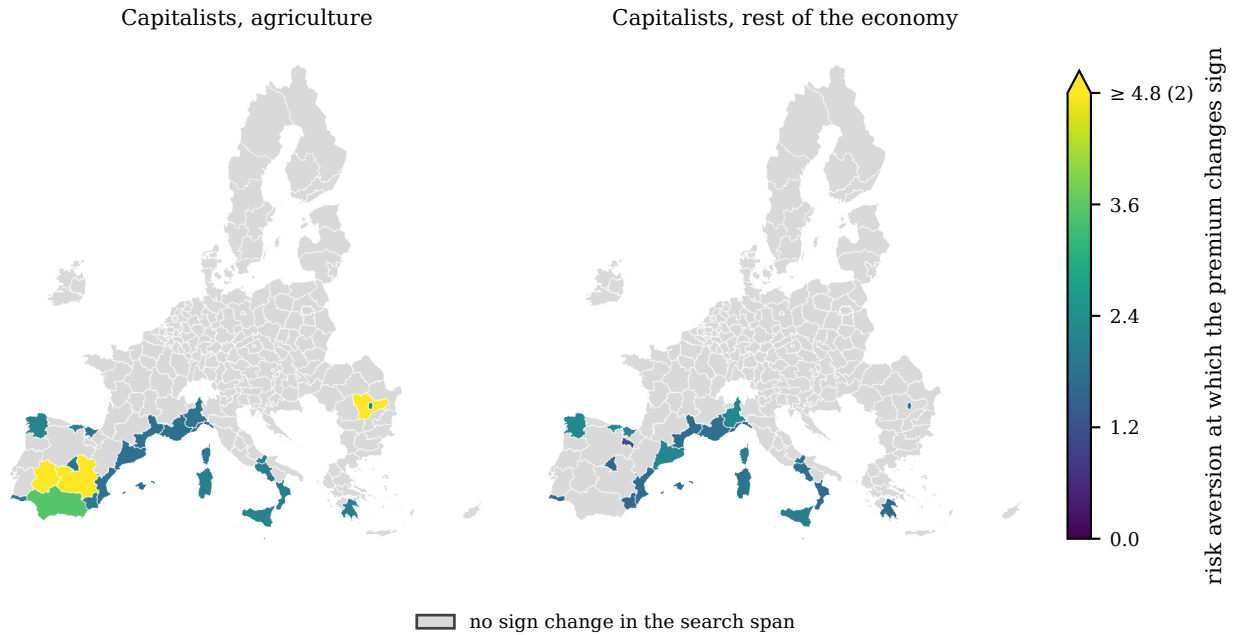


Figure 12: The risk aversion at which the premium changes sign, per location, the allocation of log preferences held: capitalists, agriculture (left) and rest (right). Locations without a sign change, or within interpolation error, have their own symbols. Worker locations are not drawn: none changes sign in the span.

country	W premium	W cost	W ratio	C premium, obs. K	C premium, final K	C ratio
AT	0.33	−5.32	0.041	−0.69	−0.69	0.045
BE	0.33	−5.84	0.041	−0.67	−0.67	0.044
BG	0.31	−6.06	0.041	−0.72	−0.72	0.047
CY	0.33	−7.20	0.041	−0.70	−0.70	0.046
CZ	0.33	−5.06	0.041	−0.70	−0.70	0.046
DE	0.33	−5.20	0.041	−0.69	−0.69	0.045
DK	0.33	−5.06	0.041	−0.70	−0.70	0.046
EE	0.33	−5.05	0.041	−0.70	−0.70	0.046
EL	0.35	−6.28	0.042	−0.18	−0.60	0.070
ES	0.70	−10.02	0.051	5.88	1.70	0.036
FI	0.33	−5.05	0.041	−0.70	−0.70	0.046
FR	0.40	−6.35	0.044	0.44	−0.54	0.032
HR	0.33	−6.93	0.041	−0.69	−0.69	0.045
HU	0.33	−5.78	0.041	−0.68	−0.68	0.044
IE	0.33	−5.04	0.041	−0.70	−0.70	0.046
IT	0.46	−8.39	0.044	1.28	−0.34	0.028
LT	0.32	−5.03	0.041	−0.70	−0.70	0.046
LU	0.33	−5.09	0.041	−0.69	−0.69	0.046
LV	0.32	−5.00	0.041	−0.71	−0.71	0.046
MT	0.65	−13.89	0.051	4.48	4.48	0.054
NL	0.33	−5.38	0.041	−0.68	−0.68	0.045
PL	0.32	−5.00	0.041	−0.71	−0.71	0.046
PT	0.36	−6.91	0.042	−0.17	−0.61	−0.099
RO	0.39	−6.81	0.045	2.88	−0.02	0.040
SE	0.33	−5.06	0.041	−0.70	−0.70	0.046
SI	0.32	−5.03	0.041	−0.70	−0.70	0.046
SK	0.33	−5.06	0.041	−0.69	−0.69	0.045
MED	0.55	−9.00	0.048	3.69	0.41	0.035
WCE	0.33	−5.35	0.041	−0.68	−0.68	0.045
NEU	0.33	−5.07	0.041	−0.70	−0.70	0.046

Table 12: The premium by country and AR6 group (last three rows), observed weights, in per cent. W: workers' premium, expected cost, exact over second-order premium; C: capitalists' premium under observed and final capital, and the same ratio.

rank	location	equivalent (%)
highest exact premium		
1	ES30 ag	0.97
2	ES53 ag	0.96
3	FRL0 ag	0.94
4	PT15 na	0.93
5	ES11 na	0.93
6	ES21 ag	0.91
7	ES53 na	0.90
8	ES52 na	0.90
9	ES51 na	0.89
10	ES51 ag	0.89
11	ES30 na	0.89
12	FRJ1 na	0.89
13	ITF6 na	0.89
14	FRL0 na	0.89
15	ES21 na	0.89
lowest exact premium		
1	EL30 ag	0.14
2	ITI4 ag	0.15
3	ITC4 ag	0.16
4	IE06 ag	0.16
5	LU00 ag	0.17
6	AT34 ag	0.17
7	DE21 ag	0.17
8	DK01 ag	0.17
9	DE11 ag	0.17
10	DE13 ag	0.17
11	DE12 ag	0.17
12	BE24 ag	0.17
13	DE71 ag	0.17
14	SE11 ag	0.17
15	DEA1 ag	0.17
16	BE21 ag	0.17
17	DEA2 ag	0.17
18	DE14 ag	0.17
19	BE31 ag	0.17
20	DE25 ag	0.17
21	SI04 ag	0.17
22	DEC0 ag	0.17
23	AT33 ag	0.17
24	CY00 ag	0.17
25	BE10 ag	0.17
26	DE72 ag	0.17

rank	location	equivalent (%)
highest exact premium		
1	ES30 ag	12.63
2	ES53 ag	12.19
3	FRL0 ag	11.80
4	ES21 ag	11.53
5	ES51 ag	11.02
6	FRJ1 ag	10.34
7	ES52 ag	9.64
8	PT15 na	9.41
9	PT15 ag	9.37
10	ES11 na	9.25
lowest exact premium		
1	EL30 ag	−1.49
2	ITI4 ag	−1.22
3	ITC4 ag	−1.06
4	IE06 ag	−1.02
5	LU00 ag	−0.97
6	AT34 ag	−0.92
7	DK01 ag	−0.91
8	DE21 ag	−0.91
9	DE11 ag	−0.90
10	DE12 ag	−0.90
11	DE71 ag	−0.90
12	DE13 ag	−0.90
13	BE24 ag	−0.90

Table 13: The locations at each end of the premium, workers (left) and capitalists (right): the consumption equivalent of the premium in per cent, a positive one a gain. Ties at the edge of a list are all named.

location	AR6 group
ES13 ag	Mediterranean
ES13 na	Mediterranean
ES62 ag	Mediterranean
ES62 na	Mediterranean
FRM0 ag	Mediterranean
FRM0 na	Mediterranean
ITC1 ag	Mediterranean
ITC1 na	Mediterranean
ITG1 ag	Mediterranean
ITG1 na	Mediterranean
ITG2 ag	Mediterranean
ITG2 na	Mediterranean
MT00 ag	Mediterranean
MT00 na	Mediterranean

Table 14: The locations at which the expansion at the observed economy leaves its domain at a quarter of the shock's size, where the effective depreciation would turn negative, each with its AR6 exposure group.

locations	weight (%)	mean premium (%)	contribution (pp)	mean cost (%)	positive
observed weights					
destruction moves (44)	12.4	0.84	0.10	−12.23	44
destruction does not move (418)	87.6	0.33	0.29	−5.55	418
all locations			0.39	−6.38	
final weights					
destruction moves (44)	5.1	0.85	0.04	−12.12	44
destruction does not move (418)	94.9	0.33	0.31	−5.48	418
all locations			0.36	−5.82	
locations	weight (%)	mean premium (%)	contribution (pp)	mean cost (%)	positive
observed weights					
destruction moves (44)	12.1	7.87	0.95	−67.12	44
destruction does not move (418)	87.9	−0.67	−0.59	4.79	9
all locations			0.36	−3.92	
final weights					
destruction moves (44)	1.4	8.03	0.12	−66.38	44
destruction does not move (418)	98.6	−0.67	−0.66	5.97	9
all locations			−0.55	4.93	

Table 15: The premium where the final climate destroys capital and elsewhere, workers (top) and capitalists (bottom), observed and final weights: weight share, mean premium, contribution, mean expected cost, locations with a positive premium. In per cent; contributions in points.

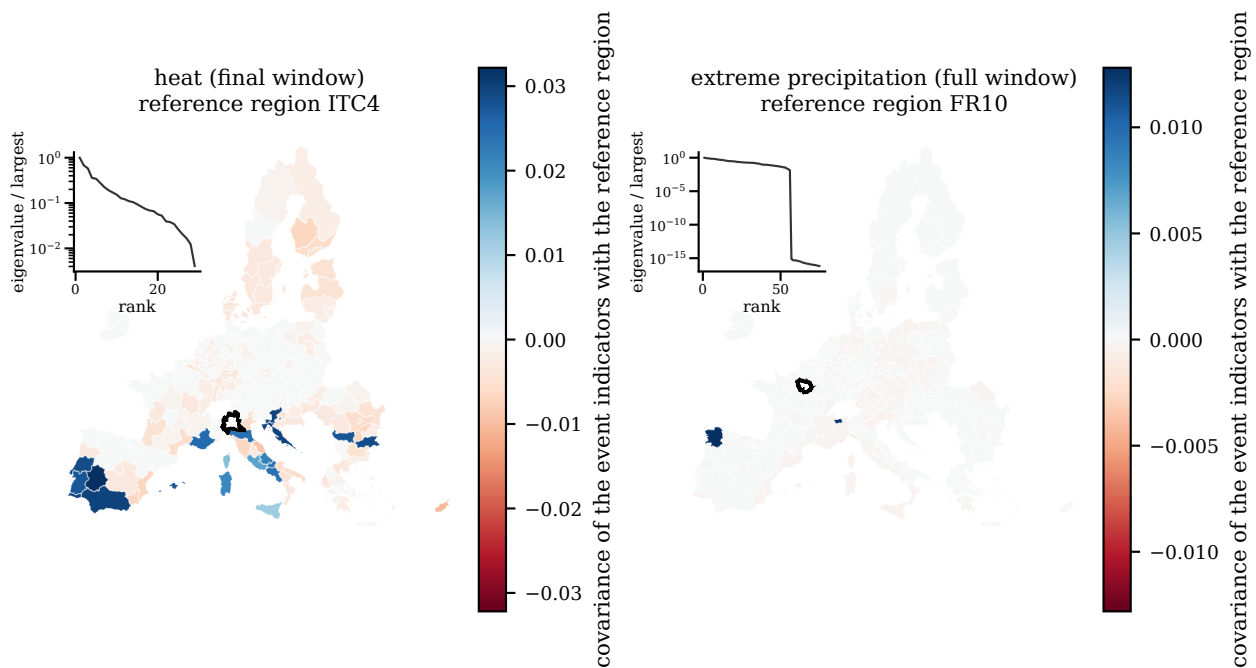


Figure 14: The spatial covariance of the event indicators of heat and extreme precipitation with a reference region's (outlined: the most populous of WCE with events). Of 231 regions, 97 have no heat event and 131 no precipitation event. Inset: eigenvalues over the largest.

	gain in expectation	no gain in expectation
gain from uncertainty	1 (0.05)	52 (12.24)
no gain from uncertainty	315 (63.39)	94 (24.33)

Table 16: The capitalists' two faces: the sign of the premium (rows) against the sign of the expected cost (columns); each cell its number of locations and, in parentheses, its per cent of the observed capital.

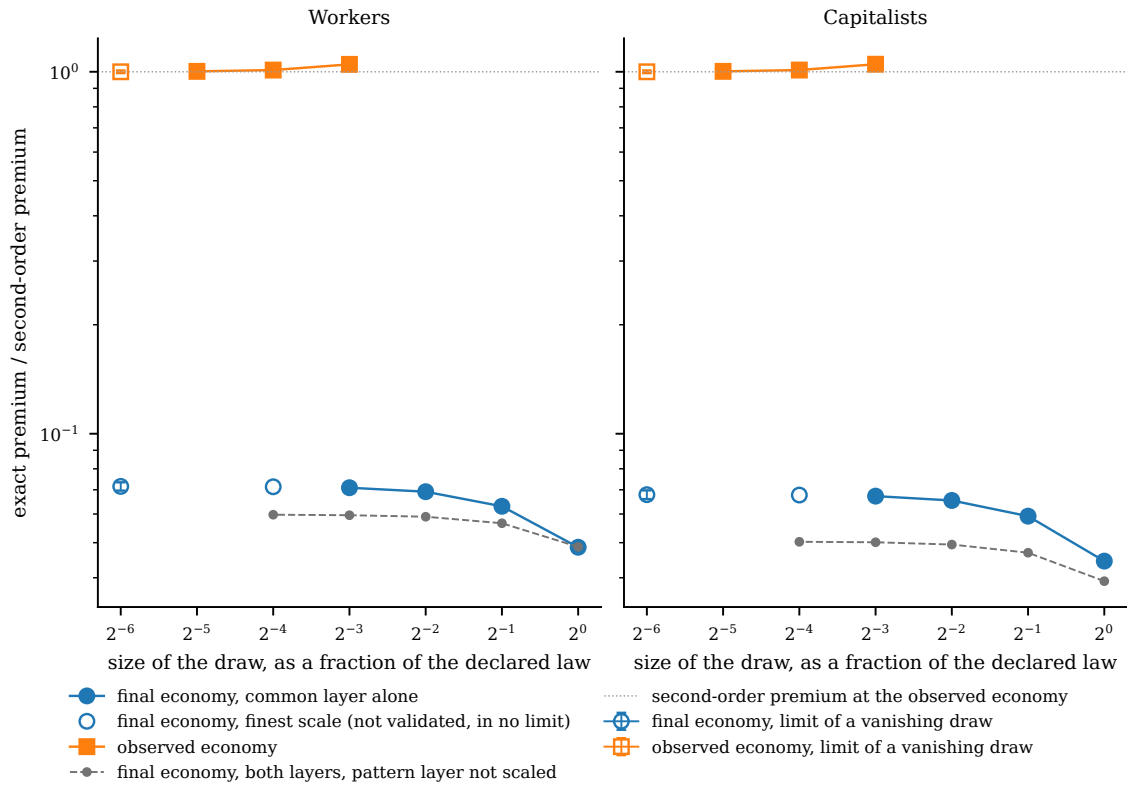


Figure 15: The exact over the second-order premium as the draw shrinks (common layer, median location), workers (left) and capitalists (right); the draw as a fraction of the declared law. The limits of a vanishing draw carry their bars; the hollow finest scale enters no limit.

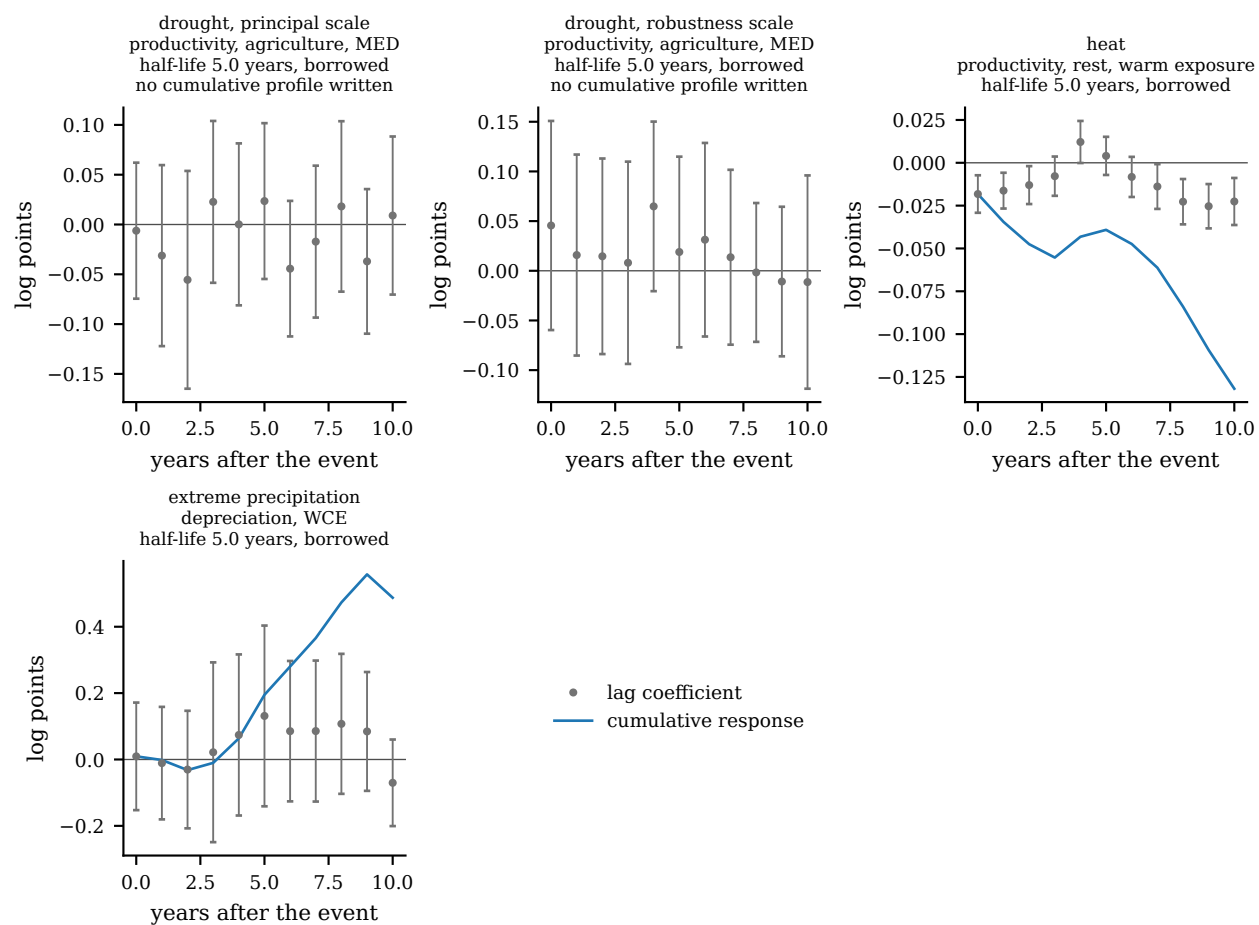


Figure 16: The persistence of damages for the 4 hazards with one, in the cell it is read from: lag coefficients with intervals, the cumulative response where identified, the half-life with its source; 4 borrow it from [Bilal and Rossi-Hansberg \(2023\)](#).

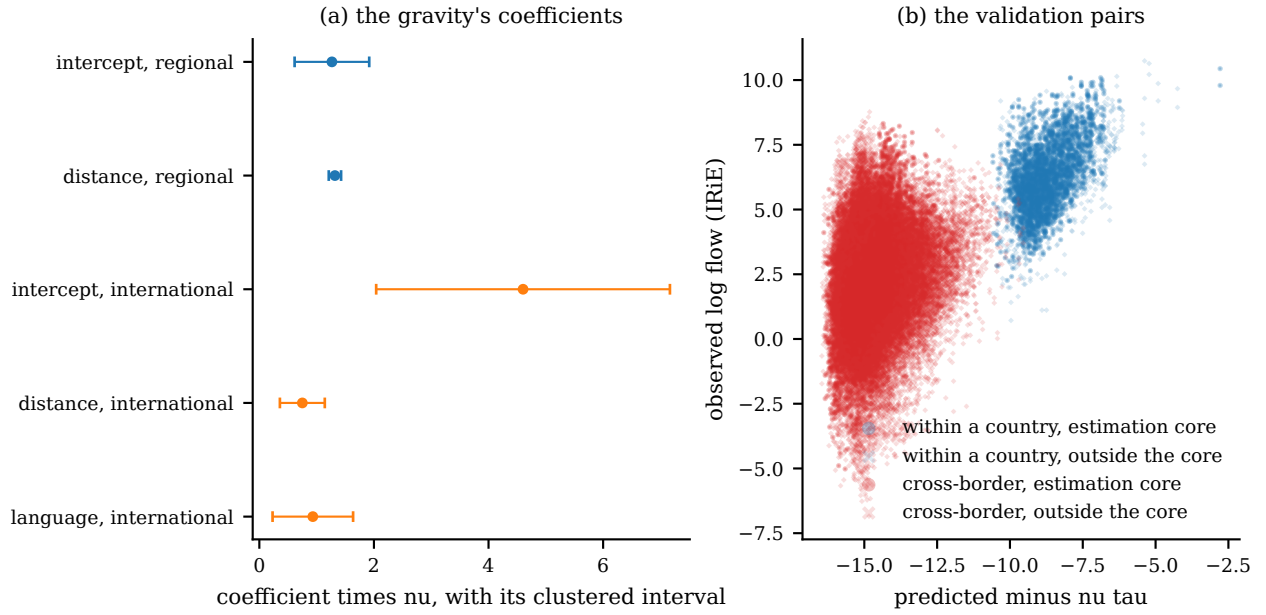


Figure 17: The migration gravity. (a) The coefficients of the regional and international legs times ν , intervals clustered by pair. (b) Predicted $-\nu\tau$ against observed log flows on 51107 validation pairs, 47563 across a border, 39335 outside the estimation core.

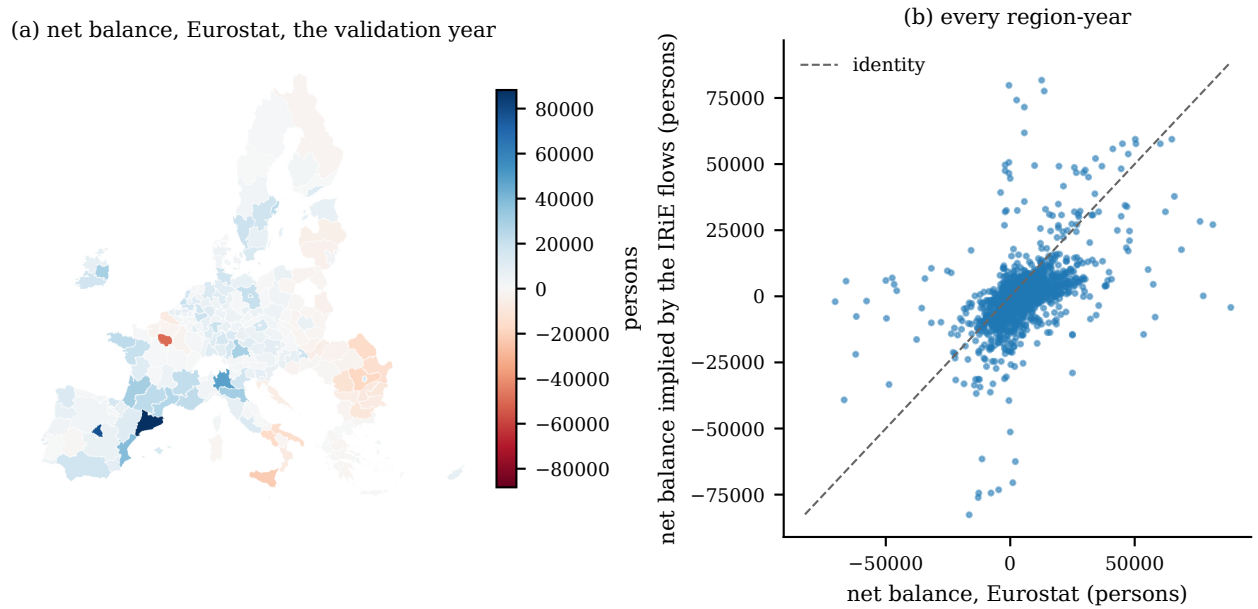


Figure 18: Observed migration. (a) The net balance of every region in 2018, the validation year, as Eurostat records it (227 regions; blank where no balance is recorded). (b) The net balance the IRiE flows imply against Eurostat's, on 1943 region-years, with the identity line.

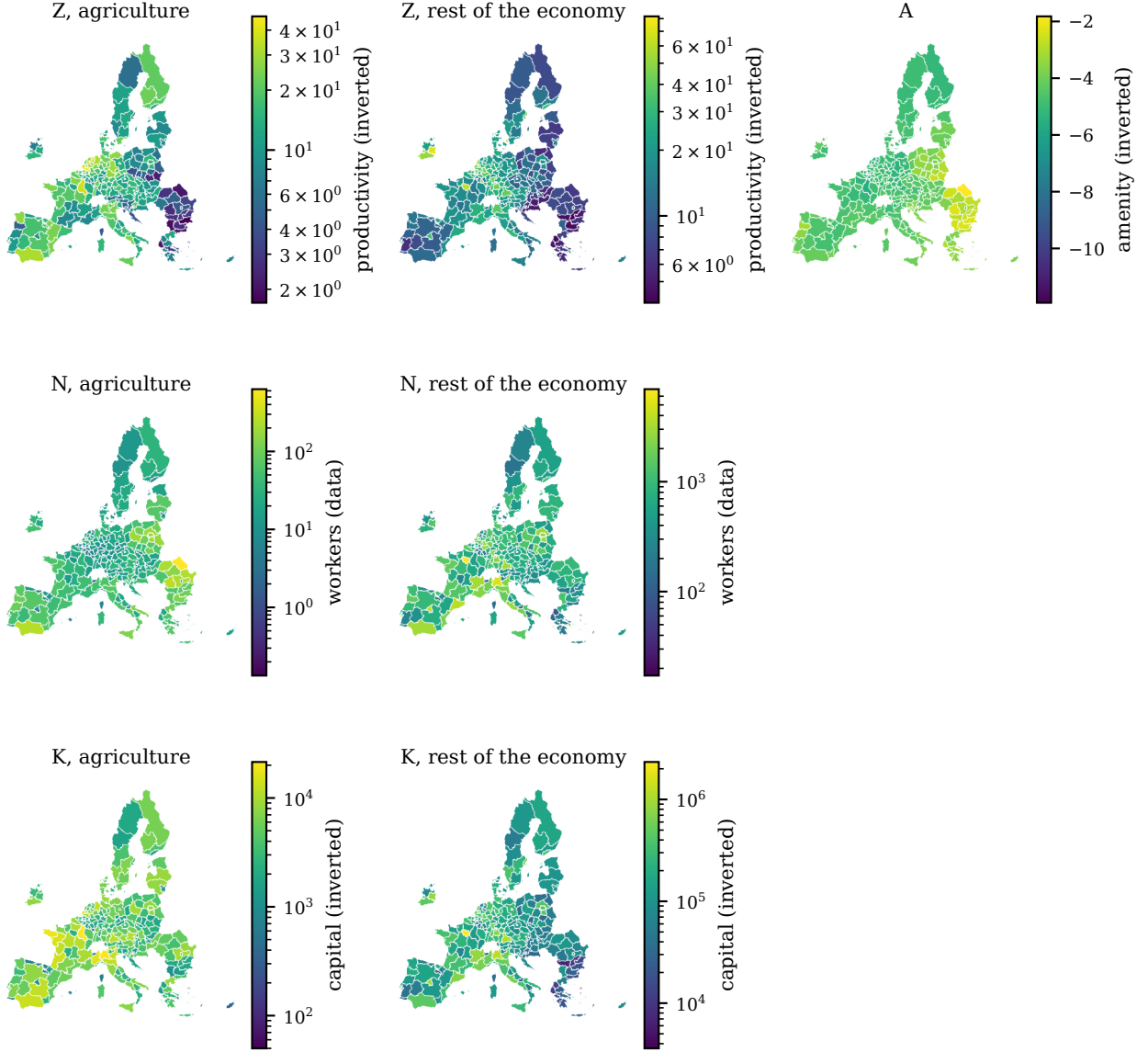


Figure 19: The inverted fundamentals. By location, one column per sector: the productivity Z_x and the capital stock K_x the inversion recovers, and the observed workers N_x it takes as data; by region, the amenity A_i . Logarithmic colour scales except for the amenity, in the inversion's units.



Figure 20: The premium against the expected cost, one point per location sized by its weight in the observed economy, workers (left) and capitalists (right): consumption equivalents on their own base, a negative cost a loss and a positive premium a gain.

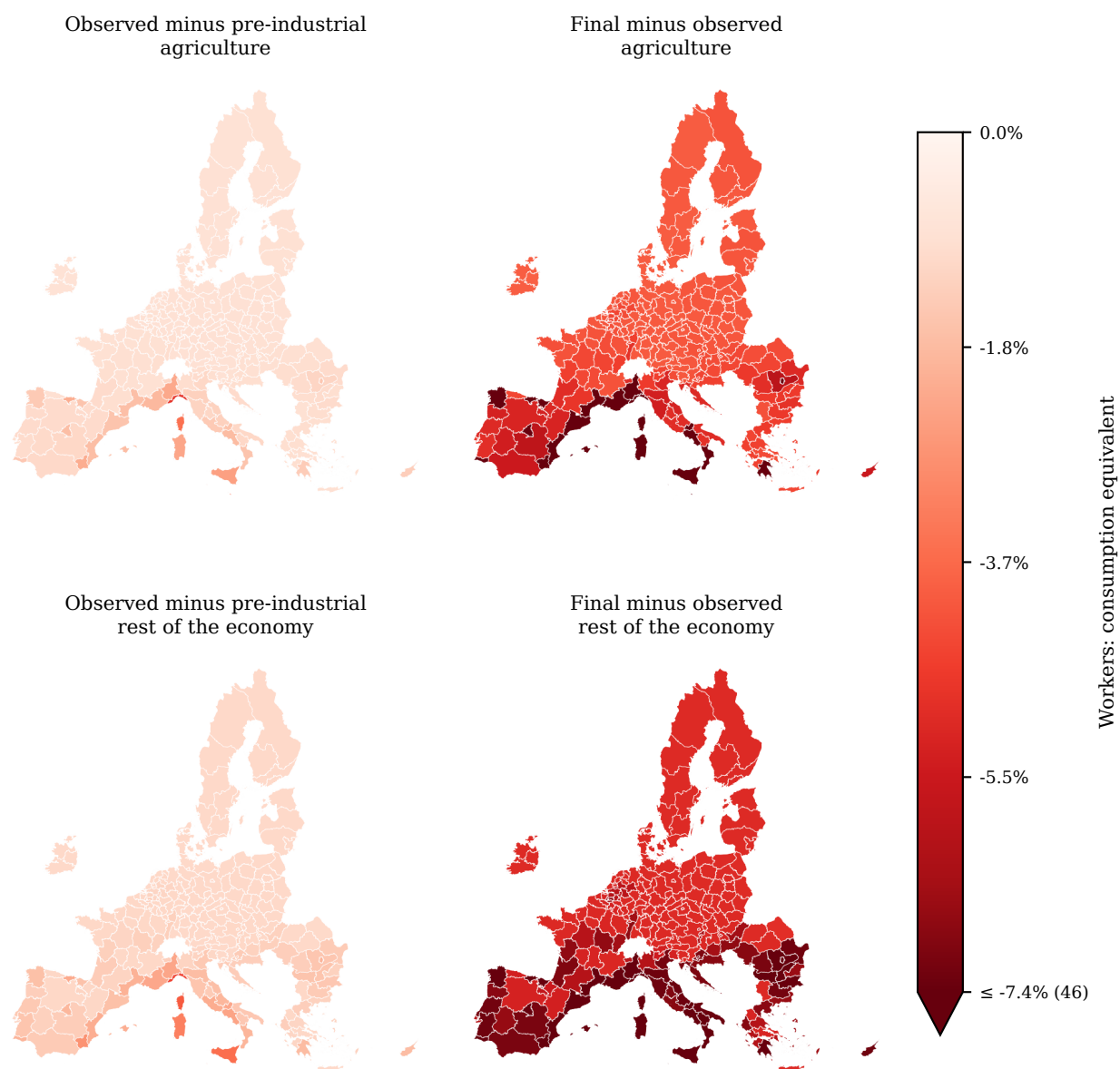


Figure 21: Workers: the cost of the realised warming (observed minus pre-industrial, left) and the expected cost of the final climate (right), per location, agriculture (top) and rest (bottom); a negative equivalent is a loss. Realised: 0 saturated, 0 without an equivalent. Colour limits are the 5th and 95th percentiles of the mapped values across locations; beyond them the colour saturates, and the bar prints the limit and the number of locations beyond it.

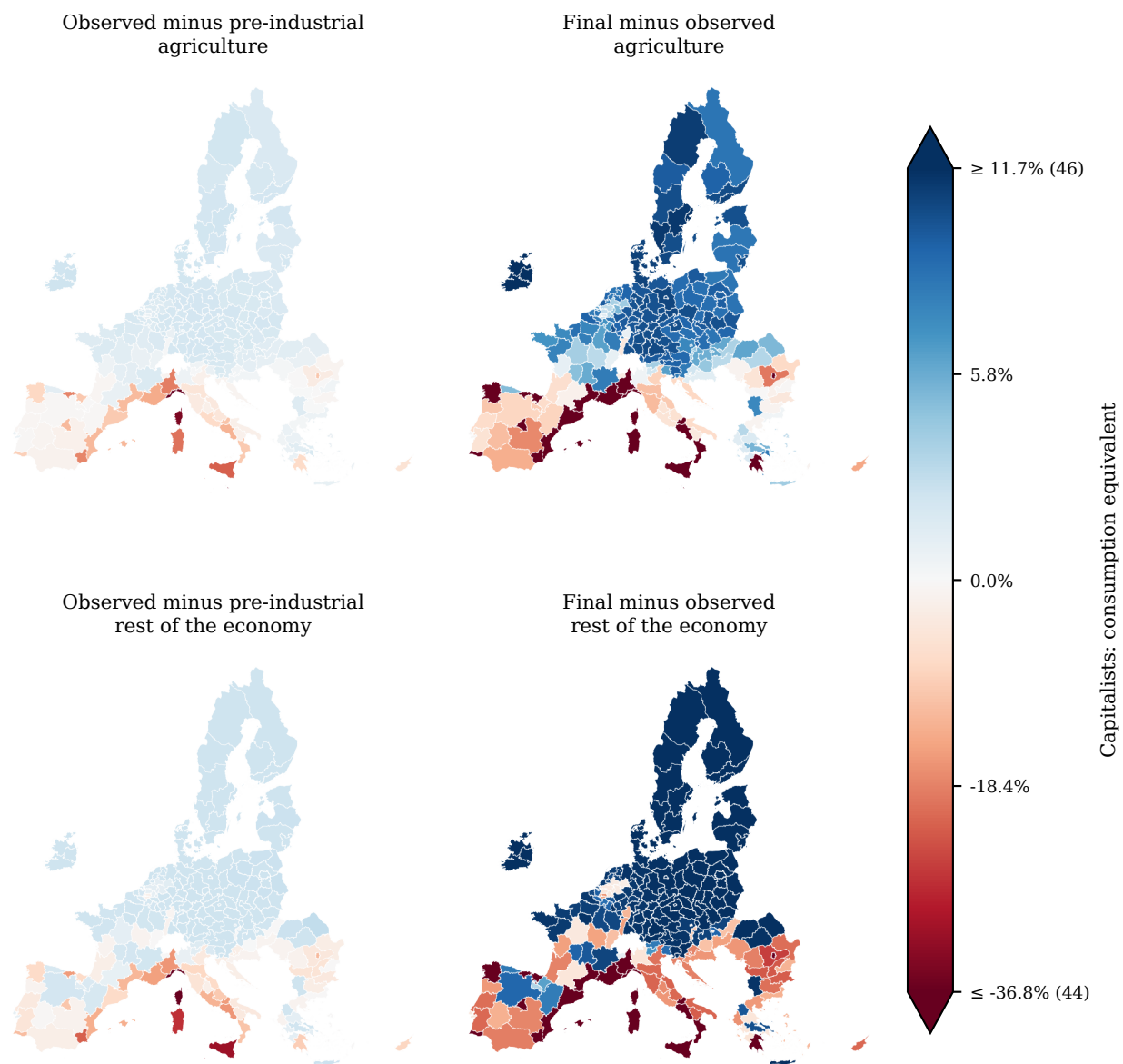


Figure 22: Capitalists: as Figure 21, on the capitalists' own scale. For the realised warming, 0 locations are saturated and 0 have no equivalent. Colour limits are the 5th and 95th percentiles of the mapped values across locations; beyond them the colour saturates, and the bar prints the limit and the number of locations beyond it.

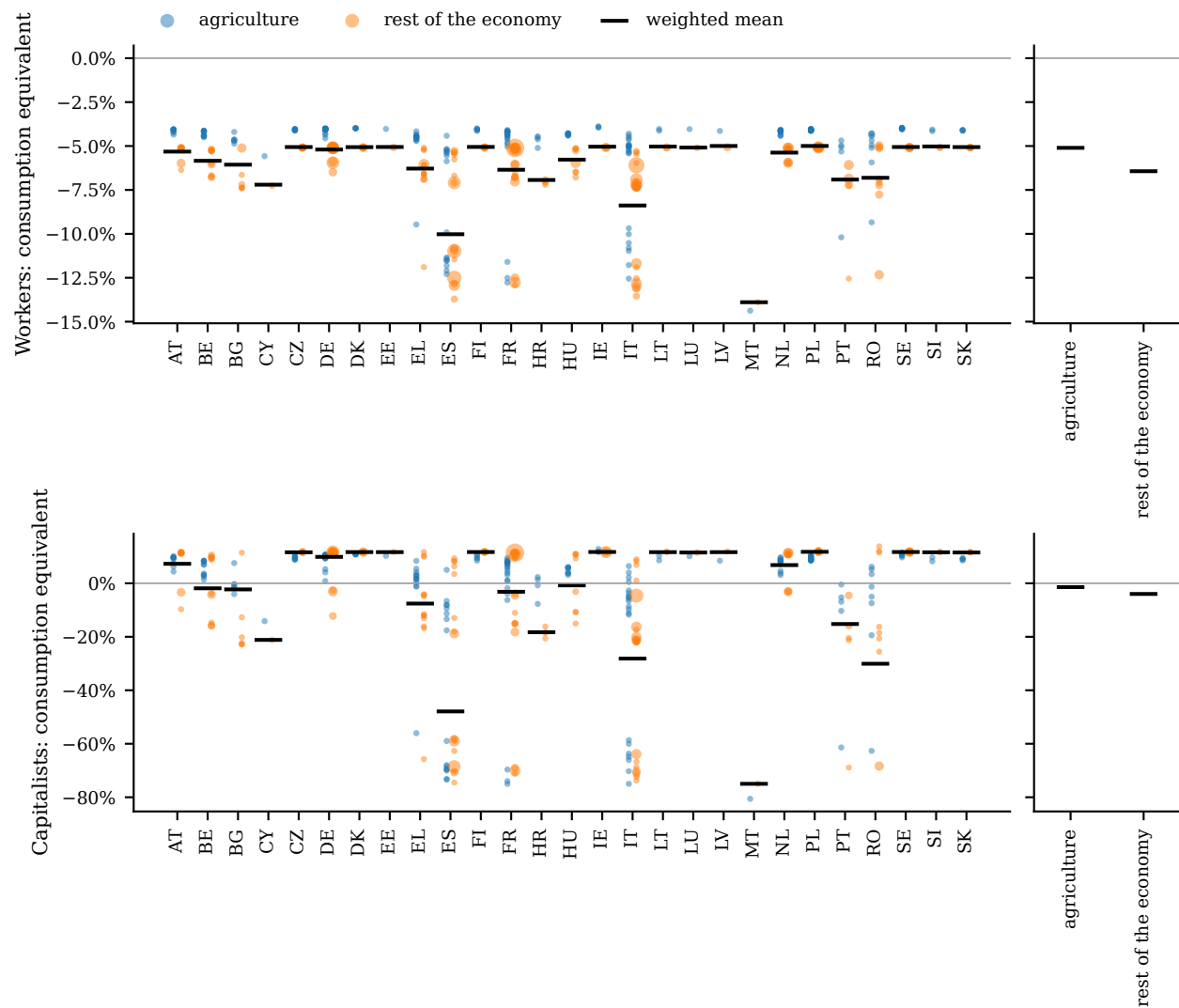


Figure 23: The expected cost by country (27 countries), workers (top) and capitalists (bottom): one point per location sized by its weight, the country's weighted mean as a bar; right, the same by sector. A negative equivalent is a loss.

D Every cell of the event studies

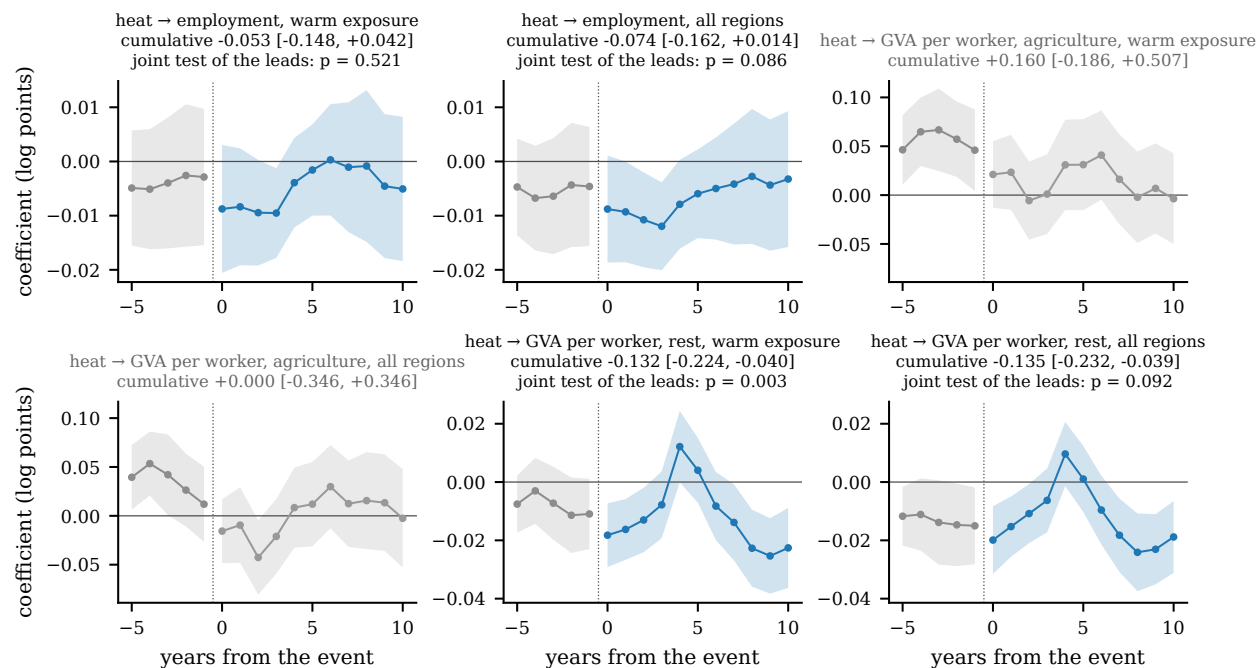


Figure 24: Event-study responses to heat (6 cells, 4 identified by power): coefficients by year from the event with intervals clustered by region; above each panel, the cumulative response at 10 years. Cells not identified (power below 0.80) are grey.

Late spring frost was pre-registered as a secondary leg, a check on the sectoral margin: an agricultural-only shock whose response, had it been identified, would have told whether workers change sector. Its cell has no design power, its loading enters at zero, and its attributed fall in frequency rescales its variance at the final climate and moves nothing else; it is reported here and nowhere else.

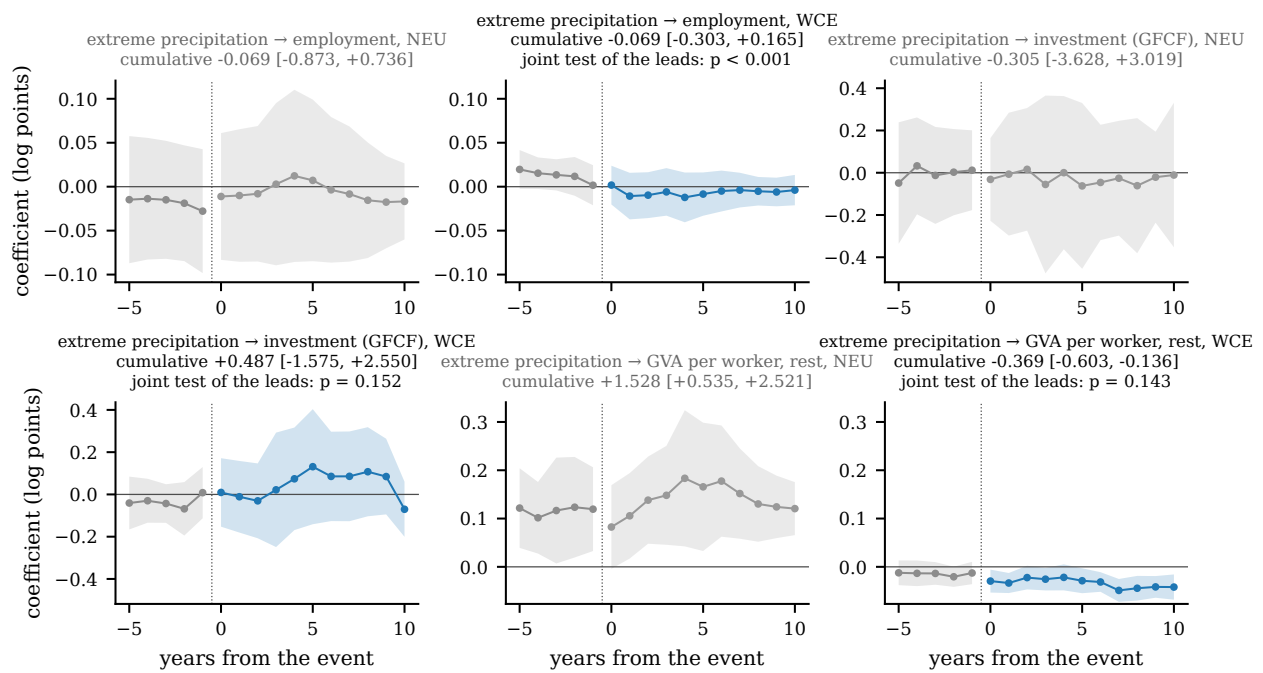


Figure 25: Event-study responses to extreme precipitation (6 cells, of which 3 are identified by power), as Figure 24.

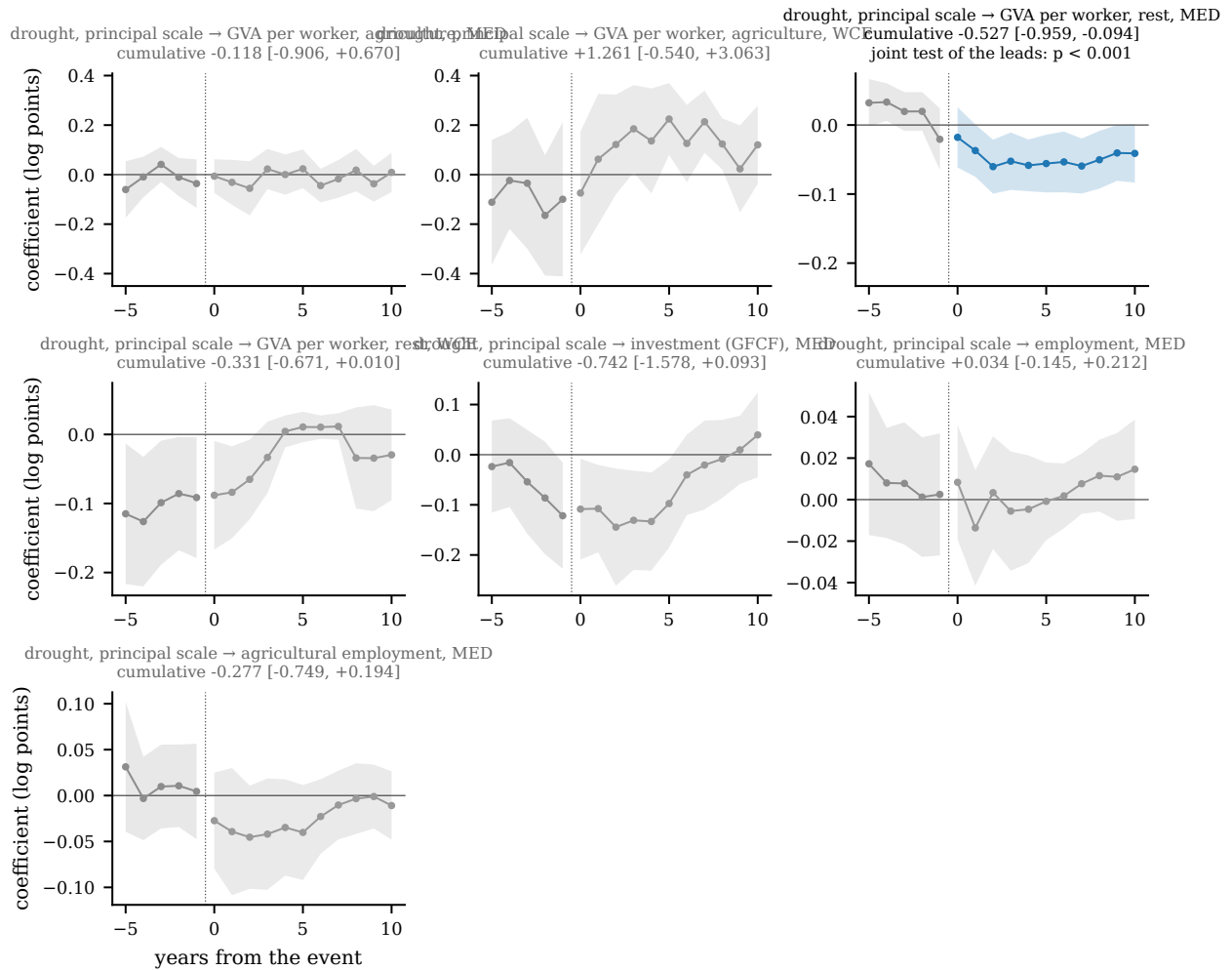


Figure 26: Event-study responses to drought at the principal accumulation scale of the index, SPEI-12 (7 cells; identified by power: 1), as Figure 24.

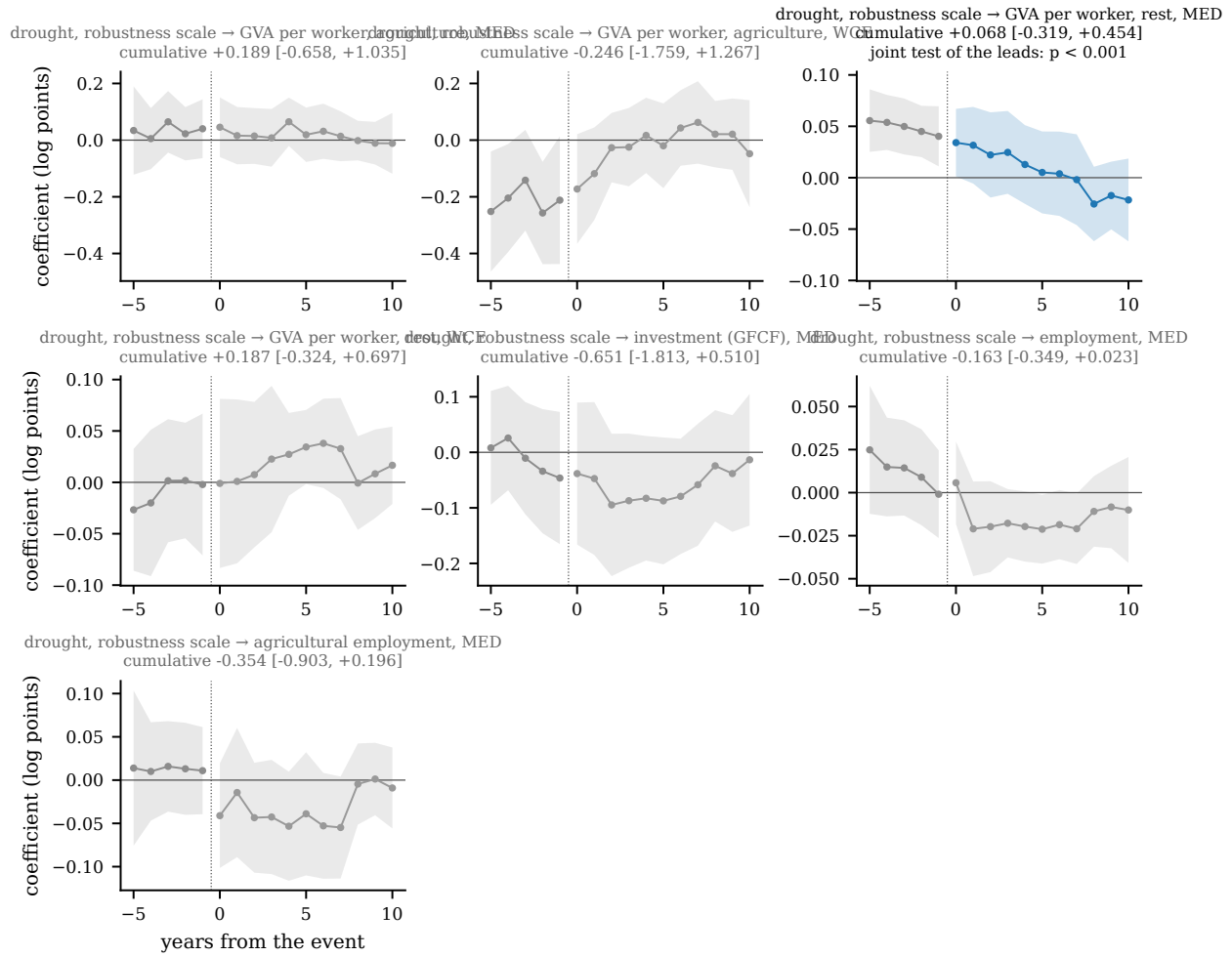


Figure 27: Event-study responses to drought at the pre-registered robustness scale of the index, SPEI-6 (7 cells; identified by power: 1), as Figure 24.

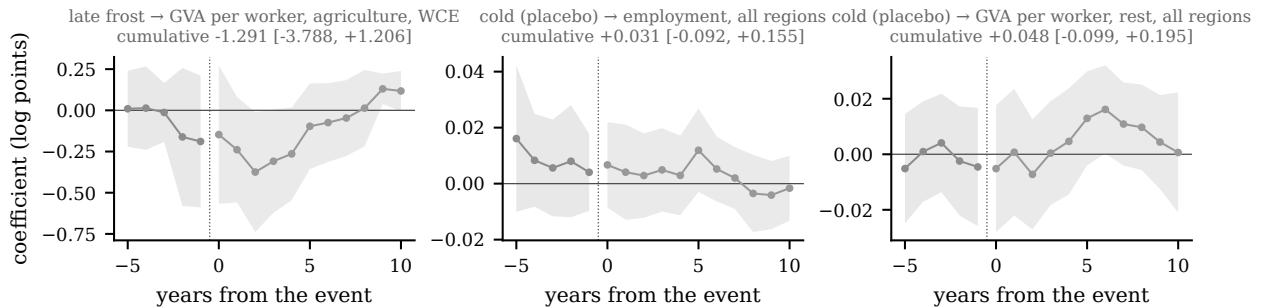


Figure 28: Event-study responses to late frost and to the cold placebo, as Figure 24; no cell has a design target, hence no power verdict. The cold placebo's cumulative responses have t statistics of 0.50 on employment and 0.64 on value added per worker outside agriculture.

E Event-study diagnostics

The event studies of Section 3.2 regress, cell by cell, the log outcome on the event indicator at five leads and eleven lags, with region and year fixed effects, weighted by population, errors clustered by region, and no coefficient omitted. The cumulative response at ten years is the sum of the eleven lag coefficients, and its reference level is the set of region-years with no event in the window; the leads are reported but never enter the estimand. The magnitudes Γ^h of Table 3 are read from this estimand.

The design is the one Bilal and Rossi-Hansberg (2023) use for storms, which are rare and unforeseen, so that the years before a storm are ordinary years and the leads are a placebo. The hazards here are threshold events, frequent and serially correlated: a region above its heat percentile this year was often above it last year, and the years before an event need not be ordinary. The leads are therefore a test, and the main chain cannot run it, because it stores each lead with its own standard error but not the covariance between them. A reader added for this version re-estimates every cell by the same code path, reproduces the main artifact to the bit, keeps the clustered covariance, and reports three things that no number of the paper reads: the joint test that the five leads are zero, the cumulative response by horizon, and the cumulative response at ten years read against the mean of the leads rather than against the event-free years. Table 17 gives them for the nine cells identified by power. In the reader's own simulation under the null the test rejects 7.5% of the time at the five per cent level, so a p -value near the threshold is read with that in mind.

The joint test is stricter than the test of the sum, which rejects nowhere, and it changes the reading of two of the three cells that carry a magnitude (Table 17). Extreme precipitation on productivity in western and central Europe passes, and its magnitude read against the leads is a little smaller than the declared one. Heat on productivity in the warm group fails: the five leads sit below the reference level together, so that part of what the lags measure is already there before the event, and the magnitude read against the leads is not distinguishable from zero. The amenity loading of heat, read from employment, passes and stays indistinguishable from zero under either reference. Drought on productivity in the Mediterranean group fails in the other direction: the four earlier leads sit above the reference level and the last one below them, because an index accumulated over twelve months carries the end of year $t - 1$ into year t , so that the last lead already holds the onset of the drought; read against the leads, the drought magnitude is larger than the declared one. Last, the employment response to extreme precipitation, the numerator of the migration moment, rejects and is larger and significant once read against its leads, so that the moment of Section 3.5 would be several times the declared one.

The model of this version uses the declared magnitudes, and the results of Section 4 inherit three consequences. The expected cost of heat rests on a productivity loading that does not survive a reference level set by the years before the event: that cost is an upper bound on what the lead-adjusted estimand would give, and since the amenity loading of heat is a fixed multiple of the productivity loading, it moves with it. The drought and precipitation loadings keep their sign under either reference, drought larger and precipitation smaller, so the ranking of hazards in the risk layer is not at stake but their levels are. And the migration elasticity is identified on a moment whose numerator depends on the reference level, so the speed at which workers leave a damaged region, hence the time profile of Section 4.4, is known with less precision than its interval says.

The re-estimation under way replaces the reference level by a single omitted coefficient, the

year before the event, two years before for the accumulated indices so that the mechanical lead falls inside the window rather than inside the reference. It also treats four features of the design that no reader can correct after the fact, each named here with what it does to the present estimates. Events recur: a region of the warm group has up to twenty heat events in the window, so the leads of one event are the lags of the one before and the event-free region-years that serve as reference are few exactly where events are frequent; the estimates are less precise than independent events would give, and the re-estimation bins the ends of the window, as distributed-lag models with recurrent events require. Events are binary: the depth of a drought or the excess of a rainfall maximum above its threshold is not used, which is much of why intervals summing eleven indicator coefficients are as wide as they are; the re-estimation adds the intensity of each hazard beside its indicator. Errors are clustered by region only, while events are correlated across neighbouring regions in the same year, a correlation the paper measures for its own risk layer; the intervals understate the uncertainty, and the re-estimation clusters by region and year and reports spatially robust errors beside them. Events near the edges of the window enter partially: a large share of the heat events of the warm group fall before the first outcome year, most of them in a single year, and reach the estimates through their later lags only, while those after the last outcome year enter through the leads only (Table 17 gives the counts). Finally, the investment cell is identified by power but its response is indistinguishable from zero, so no magnitude is read from it and the persistence of damages, which the decay of the paths would have given, is borrowed; the re-estimation refits it on the normalised paths.

cell	p joint	Σ leads (s.e.)	c_{10} [interval]	c_{10}^{adj} [interval]	Γ declared	Γ lead-adjusted [interval]
heat $\rightarrow$ productivity, rest, warm	0.003	-0.040 (0.028)	-0.132 [-0.224, -0.040]	-0.043 [-0.151, 0.064]	-0.024	-0.008 [-0.028, 0.012]
heat $\rightarrow$ productivity, rest, all regions	0.092	-0.066 (0.031)	-0.135 [-0.232, -0.039]	0.011 [-0.097, 0.118]	-	-
heat $\rightarrow$ employment, warm	0.521	-0.019 (0.030)	-0.053 [-0.148, 0.042]	-0.010 [-0.130, 0.109]	-	-
heat $\rightarrow$ employment, all regions	0.086	-0.027 (0.026)	-0.074 [-0.162, 0.014]	-0.015 [-0.116, 0.086]	-	-
precipitation $\rightarrow$ productivity, rest, WCE	0.143	-0.073 (0.057)	-0.369 [-0.603, -0.136]	-0.209 [-0.419, 0.000]	0.341	0.193 [0.000, 0.386]
precipitation $\rightarrow$ employment, WCE	<0.001	0.062 (0.051)	-0.069 [-0.303, 0.165]	-0.205 [-0.348, -0.062]	-	-
precipitation $\rightarrow$ investment, WCE	0.152	-0.174 (0.258)	0.487 [-1.575, 2.550]	0.869 [-0.962, 2.700]	-	-
drought $\rightarrow$ productivity, rest, MED	<0.001	0.084 (0.077)	-0.527 [-0.959, -0.094]	-0.712 [-1.012, -0.412]	-0.096	-0.130 [-0.185, -0.075]
drought (robustness) $\rightarrow$ productivity, rest, MED	<0.001	0.244 (0.066)	0.068 [-0.319, 0.454]	-0.470 [-0.778, -0.162]	-	-

Table 17: Event-study diagnostics for the nine cells identified by power: joint test that the five leads are zero (Wald, five degrees of freedom, p -value), sum of the leads with its standard error, declared cumulative response at ten years and the same response read against the mean of the leads, each with its interval, and, for the three cells that carry a magnitude, the lead-adjusted magnitude beside the declared one. Heat events of the warm group before and after the outcome window: 35 and 13, the former mostly in 1976. Intervals clustered by region. No magnitude of the paper reads this table.