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CROSSEU lessons & findings: Climate Change Risks and Solutions

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UEA and UCL

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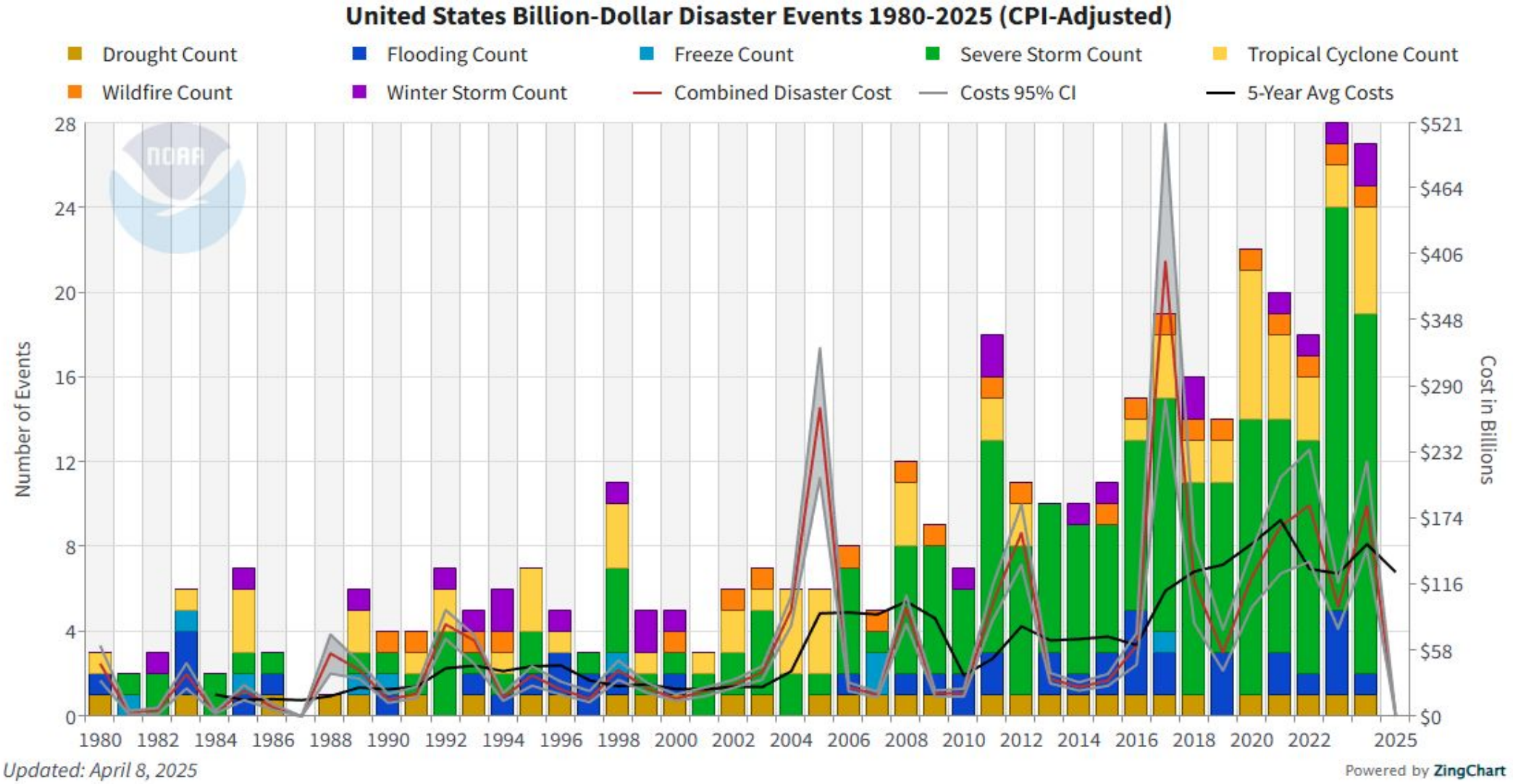

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Lesson 1: climate extremes are distributional shocks

Aggregate losses hide who is losing most.

Inequality

144

countries combined with percentile-level income data

P10

lower tail of the distribution is repeatedly exposed



Gini and 90/10 ratios under several hazards

Empirical finding

Heatwaves, droughts and extreme precipitation tend to reduce incomes more strongly at the lower end of the distribution, widening inequality.

Interpretation

Climate shocks interact with labour markets, sectoral dependence, institutional capacity and financial buffers. Vulnerability is structural, not incidental.

Methodology – Models

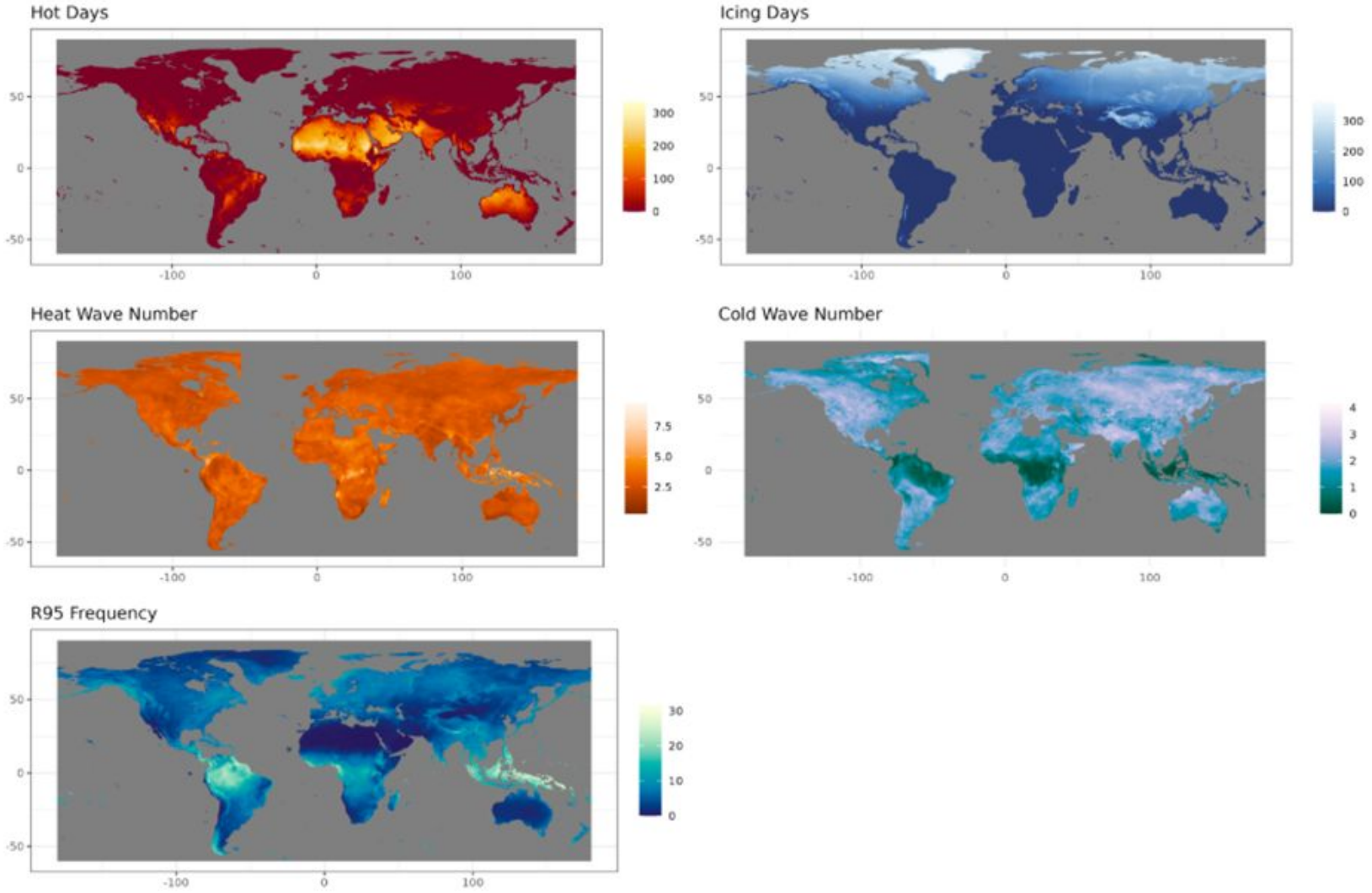
Baseline model

$$\ln_ave_inc_{i,t}^{q} = \alpha + \boldsymbol{\beta_1 CR_{i,t}} + \beta_2 \ln_real_sectorGDP_{i,t}^{s} + \boldsymbol{\beta_3 X_{i,t}} + \gamma_i + \theta_t + \epsilon_{it}$$

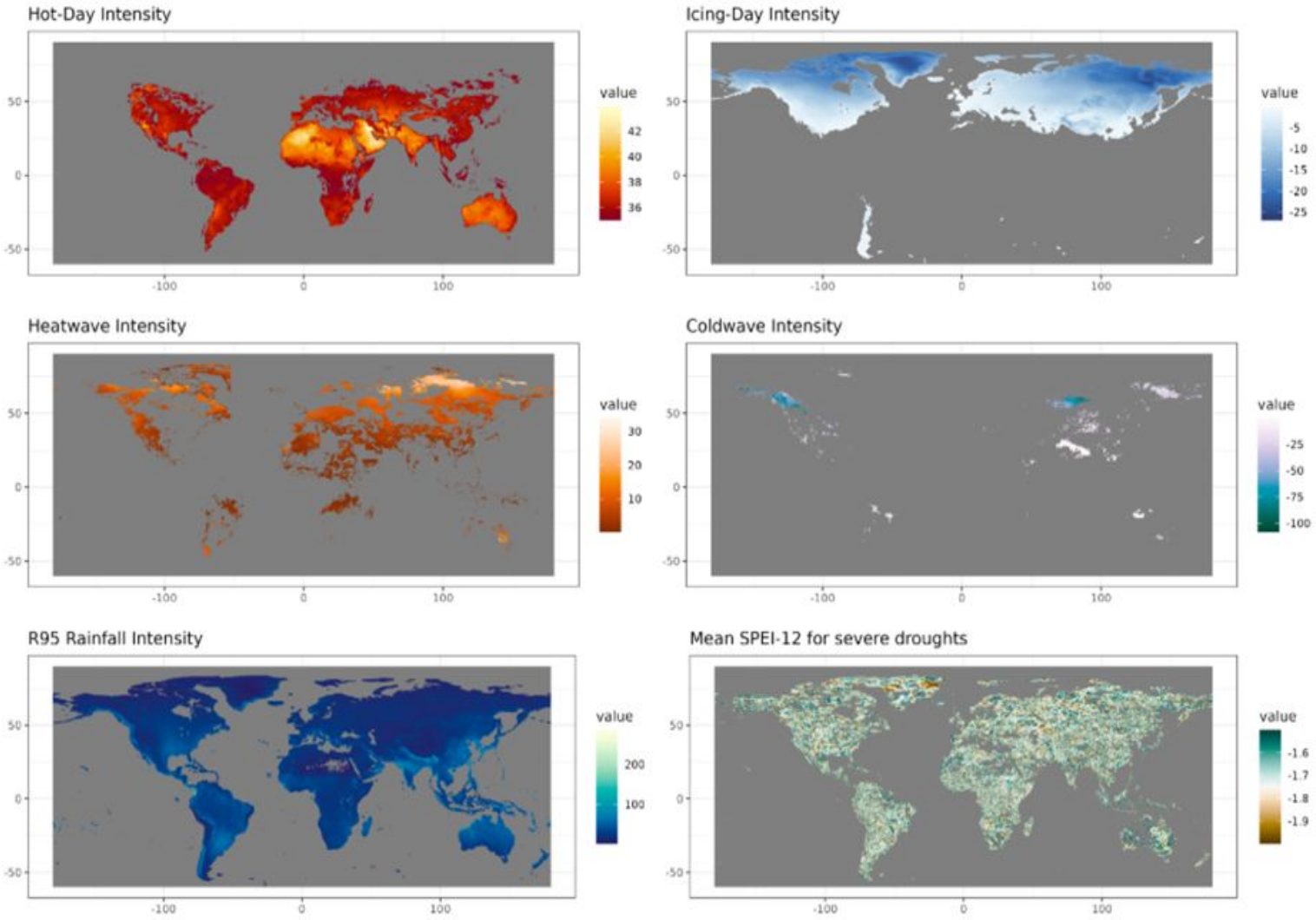
where

- $ln_ave_inc_{i,t}^{q}$ denotes our measure of income inequality in country i and year t, represented as the logarithm of the average income of decile q.
- $\boldsymbol{CR_{i,t}}$ is a vector of EWE, including HW_IF, CW_IF, $Icing_IF$, and Hot_IF.
- $ln_real_sectorGDP_{i,t}^{s}$ captures either three sector-specific specifications of real GDP, where s refers to $\ln_real_Agri_GDP_{i,t}$, $\ln_real_Ind_GDP_{i,t}$, or $\ln_real_Serv_GDP_{i,t}$.
- The vector $\boldsymbol{X_{i,t}}$ refers to the control variables.
- γ_i and θ_t represent country and time fixed effects, respectively; ϵ_{it} is the error term; and α is the intercept.

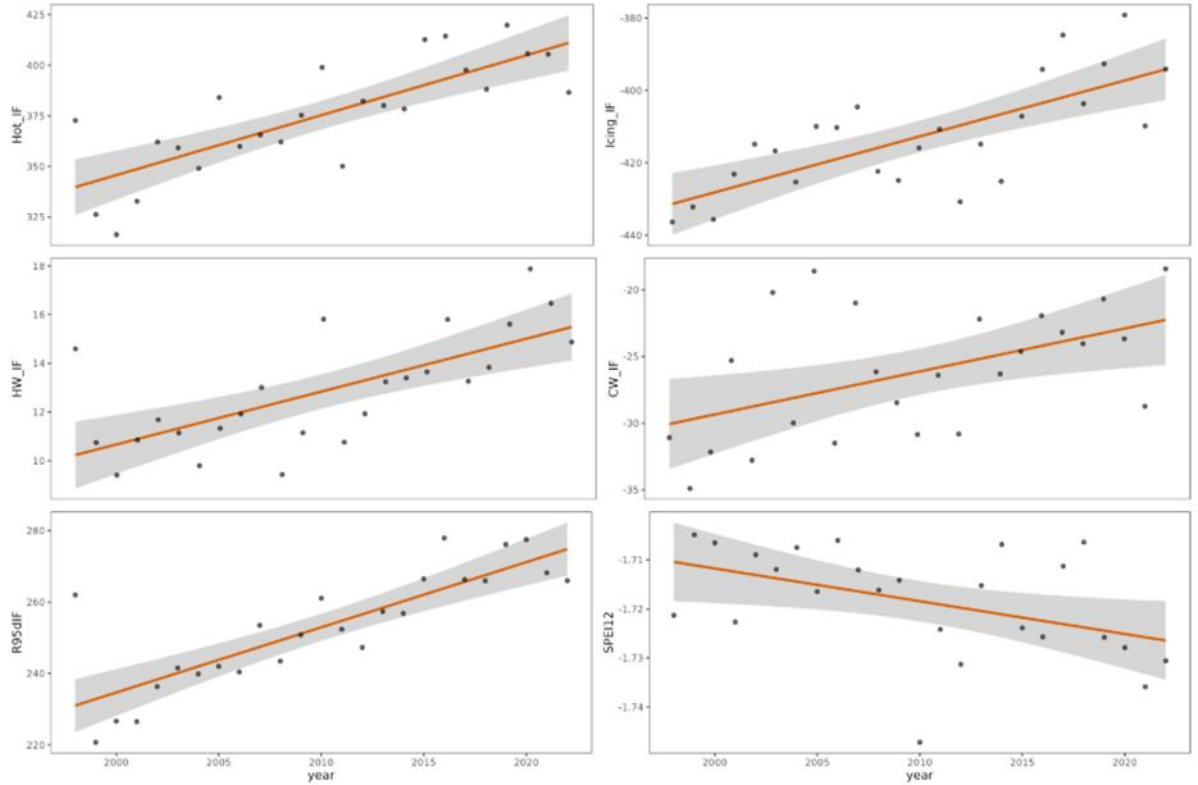
The modelled frequency of key climate variables aggregated over the time-period 1992-2022



The modelled intensity of key climate variables aggregated over the time-period 1992-2022.



Global trend in the interaction between intensity and frequency of modelled climate variables from 1992-2022 .



Results

VARIABLES	(1) 90-10th ratio ln_r_avg_wel	(2) 90-10th ratio ln_r_avg_wel	(3) 90-10th ratio ln_r_avg_wel	(4) 90-10th ratio ln_r_avg_wel	(5) Gini ln_r_avg_wel	(6) Gini ln_r_avg_wel	(7) Gini ln_r_avg_wel	(8) Gini ln_r_avg_wel
HW_IF	0.021***	0.021***	0.021***	0.023***	0.003***	0.003***	0.002***	0.003***
	(0.006)	(0.006)	(0.006)	(0.006)	(0.000)	(0.000)	(0.000)	(0.000)
CW_IF	0.034***	0.032***	0.034***	0.038***	0.002***	0.002***	0.003***	0.003***
	(0.004)	(0.004)	(0.004)	(0.004)	(0.000)	(0.000)	(0.000)	(0.000)
Icing_IF	0.006***	0.007***	0.007***	0.006***	0.000**	0.000***	0.000***	0.000*
	(0.001)	(0.001)	(0.001)	(0.001)	(0.000)	(0.000)	(0.000)	(0.000)
Hotdays_IF	0.009***	0.007**	0.007**	0.007**	0.002***	0.001***	0.001***	0.001***
	(0.003)	(0.003)	(0.003)	(0.003)	(0.000)	(0.000)	(0.000)	(0.000)
R95dIFmax	0.008***	0.005	0.003	0.007**	0.004***	0.004***	0.004***	0.004***
	(0.003)	(0.003)	(0.003)	(0.003)	(0.000)	(0.000)	(0.000)	(0.000)
ln_r_Agri_GDP	-0.937***				-0.243***			
	(0.010)				(0.002)			
ln_r_Ind_GDP		-0.896***				-0.235***		
		(0.010)				(0.002)		
ln_r_Serv_GDP			-0.922***				-0.239***	
			(0.010)				(0.002)	
PC_GDPsip				-1.343***				-0.348***
				(0.014)				(0.003)
Constant	-39.535***	-40.246***	-37.536***	-57.154***	-1.777***	-1.847***	-1.083***	-6.834***
	(1.838)	(1.840)	(1.828)	(1.805)	(0.178)	(0.179)	(0.181)	(0.156)
Observations	153,492	153,592	153,692	153,492	153,492	153,592	153,692	153,492
Time Effect	YES	YES	YES	YES	YES	YES	YES	YES
Country Effect	YES	YES	YES	YES	YES	YES	YES	YES

Results

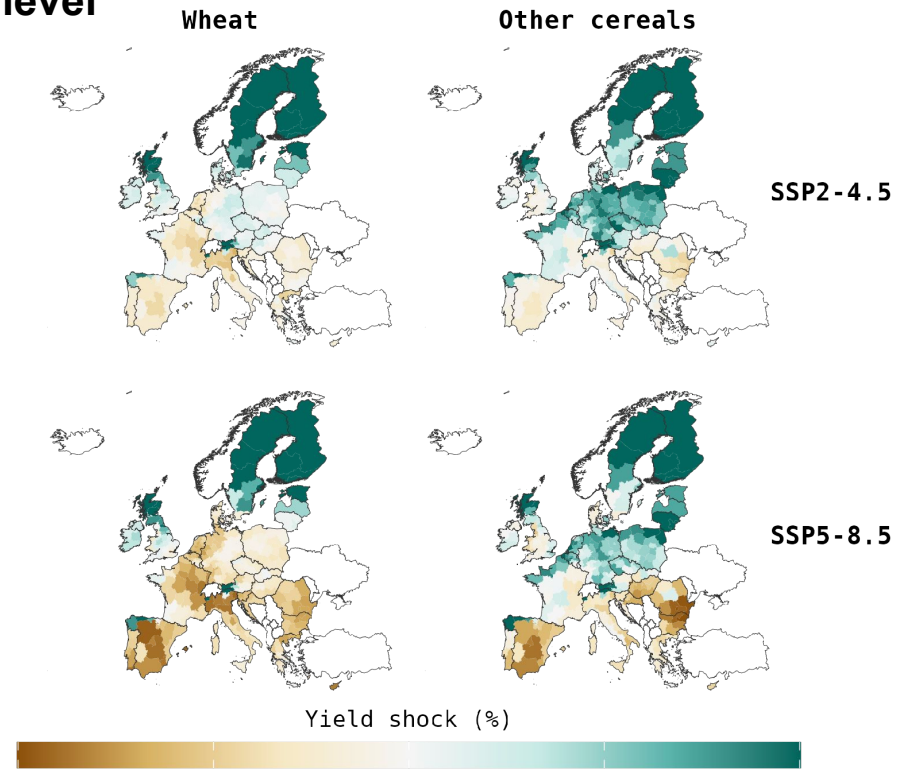
VARIABLES	(1) 90-10 ln_r_avg_wel	(2) 90-10 ln_r_avg_wel	(3) 90-10 ln_r_avg_wel	(4) 90-10 ln_r_avg_wel	(5) Gini ln_r_avg_wel	(6) Gini ln_r_avg_wel	(7) Gini ln_r_avg_wel	(8) Gini ln_r_avg_wel
Drought_IF	0.001***	0.001***	0.001***	0.001***	0.000***	0.000***	0.000***	0.000***
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
ln_r_Agri_GDP	-0.740***				-0.259***			
	(0.010)				(0.003)			
ln_r_Ind_GDP		-0.714***				-0.249***		
		(0.010)				(0.003)		
ln_r_Serv_GDP			-0.714***				-0.252***	
			(0.010)				(0.003)	
PC_GDPsip				-1.069***				-0.371***
				(0.015)				(0.004)
Constant	-46.256***	-42.169***	-43.756***	-58.999***	-1.623***	-1.011***	-0.469**	-6.616***
	(2.239)	(2.219)	(2.232)	(2.223)	(0.208)	(0.208)	(0.219)	(0.189)
Observations	111,193	111,393	111,393	111,193	111,193	111,393	111,393	111,193
Country Effect	YES	YES	YES	YES	YES	YES	YES	YES

Results -- Full distribution (Agricultural sector)

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
	Agri	Agri	Agri	Agri	Agri	Agri	Agri	Agri	Agri	Agri
VARIABLES	ln_ave_inc1	ln_ave_inc2	ln_ave_inc3	ln_ave_inc4	ln_ave_inc5	ln_ave_inc6	ln_ave_inc7	ln_ave_inc8	ln_ave_inc9	ln_ave_inc10
HW_IF	-0.016***	-0.013***	-0.013***	-0.013***	-0.013***	-0.013***	-0.013***	-0.013***	-0.013***	-0.011***
	(0.005)	(0.004)	(0.003)	(0.003)	(0.003)	(0.003)	(0.003)	(0.003)	(0.003)	(0.004)
CW_IF	-0.012**	-0.010**	-0.009**	-0.008**	-0.009**	-0.009**	-0.009**	-0.009**	-0.009**	-0.009**
	(0.006)	(0.004)	(0.004)	(0.004)	(0.004)	(0.004)	(0.004)	(0.004)	(0.004)	(0.004)
Icing_IF	-0.022**	-0.016**	-0.011	-0.006	-0.005	-0.006	-0.006	-0.007	-0.007	-0.010
	(0.010)	(0.007)	(0.007)	(0.007)	(0.007)	(0.007)	(0.007)	(0.007)	(0.007)	(0.007)
Hotdays_IF	-0.022***	-0.015***	-0.012**	-0.011**	-0.011**	-0.011**	-0.012**	-0.010*	-0.011**	-0.011*
	(0.008)	(0.006)		(0.005)	(0.005)	(0.005)	(0.005)	(0.005)	(0.005)	(0.006)
ln_real_Agri_GDP	0.027***	0.024***	0.021***	0.019***	0.018***	0.019***	0.019***	0.019***	0.019***	0.009
	(0.009)	(0.007)	(0.006)	(0.006)	(0.006)	(0.006)	(0.006)	(0.006)	(0.006)	(0.007)
ln_Pop_1564	-0.489***	-0.644***	-0.681***	-0.690***	-0.680***	-0.677***	-0.666***	-0.662***	-0.662***	-0.716***
	(0.068)	(0.049)	(0.047)	(0.046)	(0.047)	(0.047)	(0.047)	(0.047)	(0.046)	(0.050)
Unemp_rate	-1.840***	-1.408***	-1.325***	-1.267***	-1.269***	-1.297***	-1.301***	-1.282***	-1.249***	-1.394***
	(0.189)	(0.138)	(0.131)	(0.130)	(0.131)	(0.131)	(0.131)	(0.131)	(0.130)	(0.139)
Female_rate	-0.234	-0.189	-0.173	-0.180	-0.180	-0.154	-0.128	-0.124	-0.143	-0.247**
	(0.161)	(0.117)	(0.112)	(0.111)	(0.111)	(0.112)	(0.112)	(0.112)	(0.111)	(0.119)
Trade_Openess	0.197**	0.201***	0.194***	0.198***	0.210***	0.202***	0.204***	0.205***	0.208***	0.199***
	(0.089)	(0.065)	(0.062)	(0.061)	(0.061)	(0.062)	(0.062)	(0.062)	(0.061)	(0.066)
DCPS	0.057**	0.078***	0.082***	0.081***	0.079***	0.076***	0.078***	0.081***	0.085***	0.105***
	(0.026)	(0.019)	(0.018)	(0.018)	(0.018)	(0.018)	(0.018)	(0.018)	(0.018)	(0.019)
IQ_PC	0.077***	0.077***	0.085***	0.089***	0.091***	0.090***	0.090***	0.090***	0.089***	0.071***
	(0.013)	(0.009)	(0.009)	(0.009)	(0.009)	(0.009)	(0.009)	(0.009)	(0.009)	(0.010)
polarisation	-5.414***	-3.628***	-2.789***	-2.273***	-1.834***	-1.393***	-0.959***	-0.501***	0.040	1.353***
	(0.165)	(0.120)	(0.114)	(0.113)	(0.114)	(0.114)	(0.114)	(0.114)	(0.113)	(0.121)
Constant	13.908***	16.320***	16.909***	17.090***	16.966***	16.913***	16.744***	16.709***	16.803***	18.188***
	(1.089)	(0.790)	(0.753)	(0.749)	(0.750)	(0.754)	(0.754)	(0.753)	(0.749)	(0.801)
Observations	1,300	1,300	1,300	1,300	1,300	1,300	1,300	1,300	1,300	1,300
R-squared	0.682	0.721	0.698	0.672	0.646	0.621	0.596	0.570	0.543	0.498
Number of country_id	145	145	145	145	145	145	145	145	145	145
Fixed Effects	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES

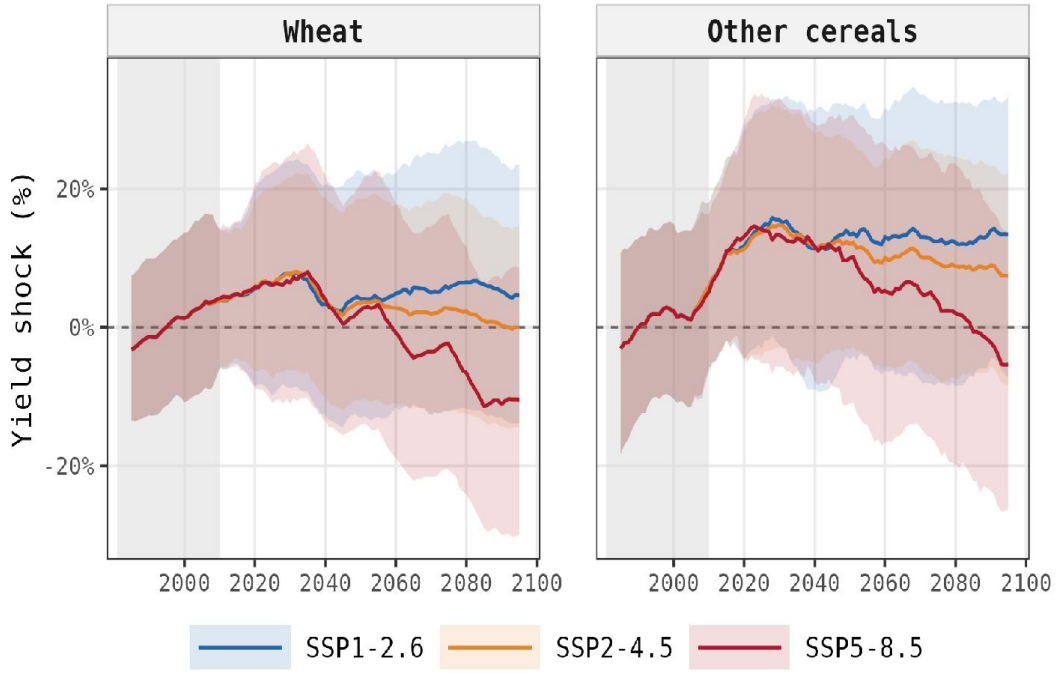
Lesson 2: climate change leads to spatially heterogeneous impacts

National aggregation masks regional climate impacts, motivating the introduction of shocks at NUTS2 level



End-of-century attainable yield shocks. Wheat (left column) and other cereals (right column) under SSP2-4.5 (upper row) and SSP5-8.5 (lower row) across EU27 (NUTS2) and UK (ITL2) regions`

NUTS2-level yield shocks are incorporated into ENGAGE as regional agricultural productivity changes



Area-weighted EU27+UK mean attainable yield shocks. Wheat (left), and other cereals (right) over the period 1981–2100 under SSP1-2.6 (blue), SSP2-4.5 (orange), and SSP5-8.5 (red).

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Lesson 2: climate change leads to spatially heterogeneous impacts

ENGAGE modelling framework

Climate-induced shocks

- crop-yield shocks
- Labour productivity shocks

Adaptation policy levers

- Crop management
- Irrigation
- Mechanization

Model shocks

Subnational ENGAGE

Spatial Unit covers 296 regions:

- 237 EU regions
- 46 UK regions
- 13 Main Trade partners[1]

Sectors include 11:

Six agricultural sectors including Wheat (WHT), Paddy Rice (PDR), Other Grains (GRO), Oilseeds (OSD), Other Crops (OCR), and Other Agriculture (OTH, including forestry and fishing);

Extractive Industries (EXT, including mining, energy, and water); Manufacturing (MAN); Construction (CNS); Transport and Storage (TRN); and Services (SER).

Model Outputs

Model Outputs

- GDP
- Welfare
- Change in sectoral output
- Change in sectoral prices
- Change in exports/imports

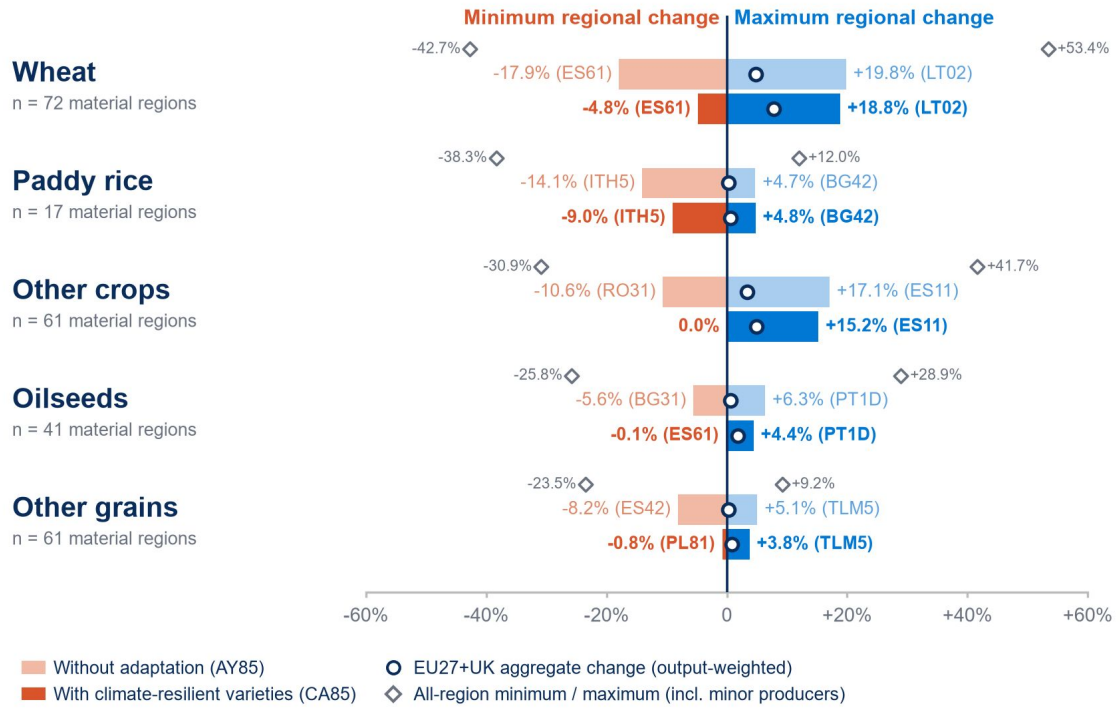
The modelling goal is not only to estimate losses, but to see where shocks relocate activity and where adaptation leaves residual risk.

1 Main trade partners are presented at country level and include: Argentina, Australia, Brazil, Canada, Switzerland, China, Indonesia, India, Japan, South Korea, Mexico, Norway, Russia, Saudi Arabia and South Africa

Lesson 3: modest aggregate losses can mask large regional divergence

leading for policy.

Under the high-emissions scenario, modest changes in aggregate European crop output mask substantial regional differences, with some regions experiencing considerable production losses



Regional variation in crop output under the high-emissions scenario (RCP8.5) in 2050, relative to the baseline. Bars show the largest output declines and increases among material producing regions, with and without climate-resilient crop varieties. Circles indicate output-weighted EU27+UK aggregate changes, while diamonds represent the full regional range, including minor producers.

Aggregate change is small. EU27+UK output changes are at or slightly above zero for the crop groups considered.

Regional change is not. the largest losses among material regions[1] reach −17.9% (wheat). Including minor producers, wheat ranges from −42.7% to +53.4%.

Adaptation measures can help offset those loses. Wheat −17.9% to −4.8% and other crops −10.6% to 0.0%.

Policy implication

Adaptation cannot be designed from national or European averages alone. Losses concentrate in southern and south-eastern producing regions, so it needs spatial targeting.

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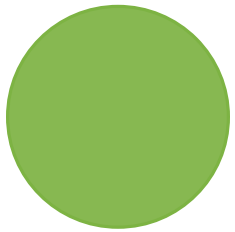
Lesson 4: adaptation reduces cost of damages, residual risk remains

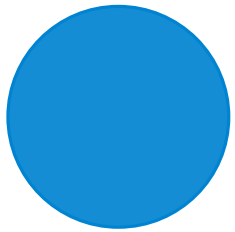
tion acts on a different part of the system.



Climate-resilient crop varieties

Reduce yield losses through farm management / cultivar adaptation.

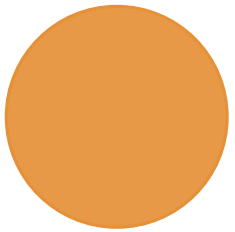
Crop-productivity channel



Irrigation expansion

Maximum use of equipped irrigation potential; changes land-water allocation.

Rainfed to irrigated production



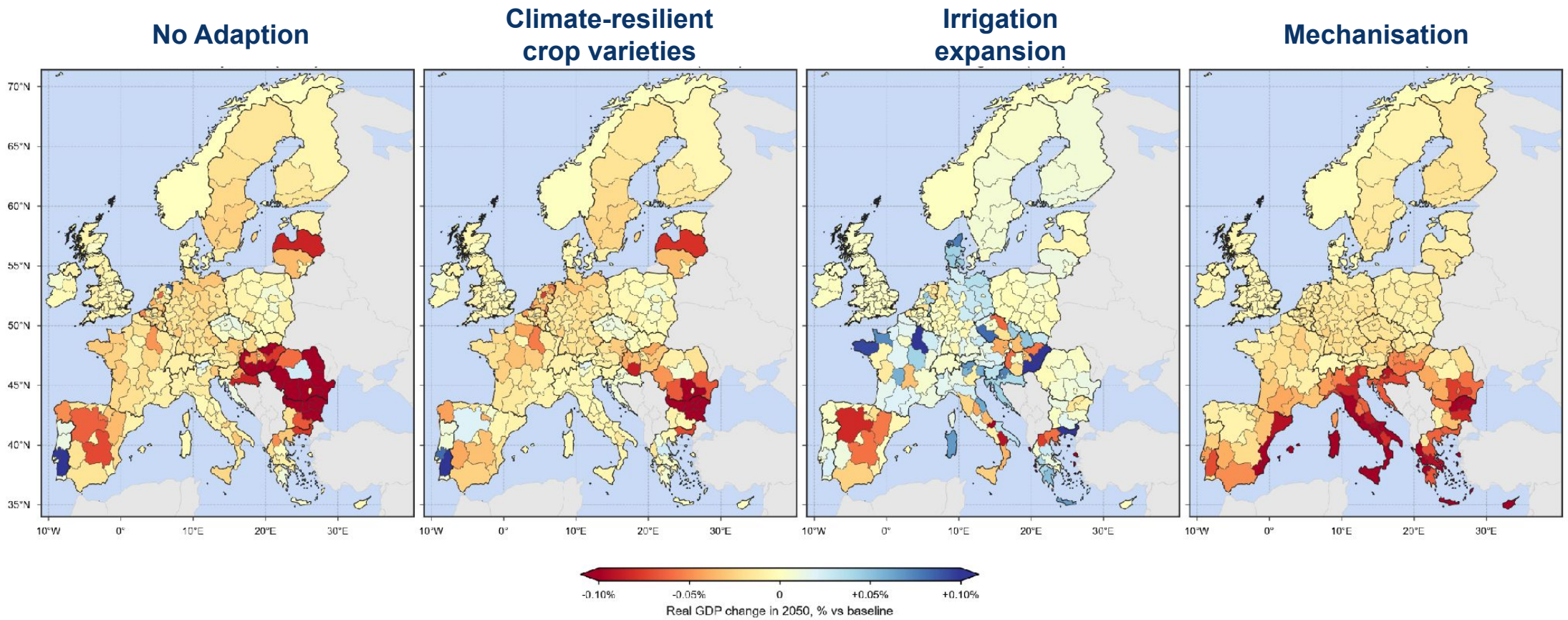
Mechanisation

30% increase in value-added substitution elasticity as a proxy for capital–labour flexibility under heat stress.

Heat-stress labour channel

Combined adaptation helps identify avoided damages and residual climate risk after multiple measures are applied simultaneously.

Lesson 4: adaptation reduces cost of damages, residual risk remains



Yield losses hit agriculture-dependent economies hardest: Romania, Bulgaria, Hungary, Latvia, central Spain

Climate resilient crop varieties offsets some losses. GDP persist via price and trade effects (similar hotspots but smaller)

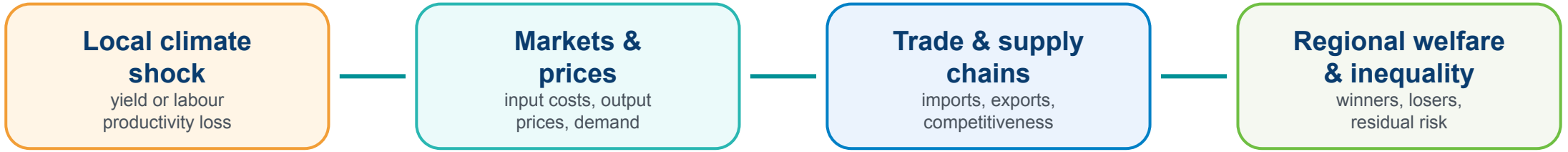
Gains where unused irrigation capacity raises output, including France, Hungary, Czechia, Greece; Central Spain still highly exposed

Heat stress on labour persists. Mechanisation only partly offsets it, so losses stay highest in hottest regions (Mediterranean region)

Lesson: adaptation is necessary, but it is not a substitute for mitigation or social protection.

Lesson 5: climate risks spill over through the economy

Local shocks can propagate through prices, trade, supply chains and welfare.

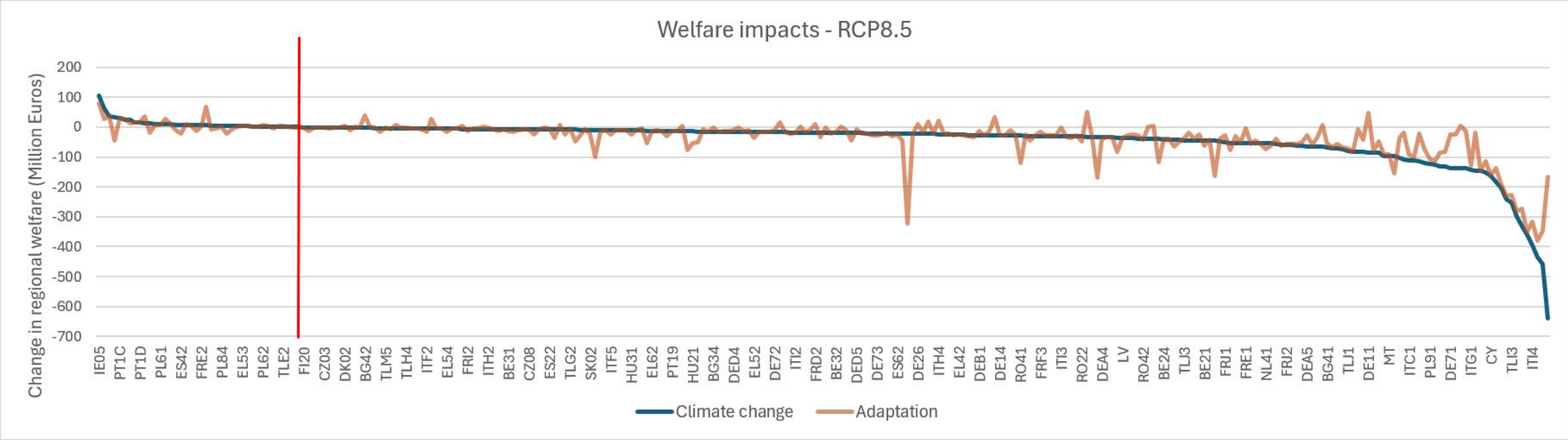


The relevant boundary is the economic system, not the location of the weather event.

What this means for adaptation policy

1. Do not assess adaptation only at the point of impact.
2. Trace price, trade and supply-chain channels.
3. Monitor who gains, who loses and what residual risk remains.

Lesson 5: climate risks spill over through the economy



- **Adaptation** mitigates some of the negative impacts of climate change.
- The individual **regional impact of adaptation** depends on the combination of direct and indirect impacts.

Policy takeaway: ask not only where the hazard occurs, but where its economic effects travel.

Lesson 6: risk changes the economics of timing (PAGE)

Accounting for environmental risk strengthens the case for earlier action.

Standard Ramsey intuition

$$SDR = \delta + \eta g$$

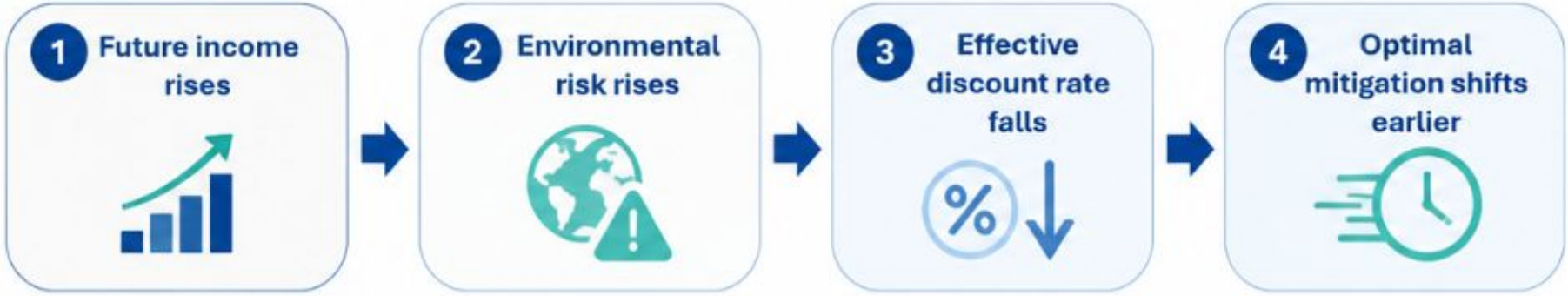
δ: pure time preference
η: elasticity of marginal utility of consumption
g: consumption growth

CROSSEU extension

discounting adjusts for growth in environmental risk per capital.

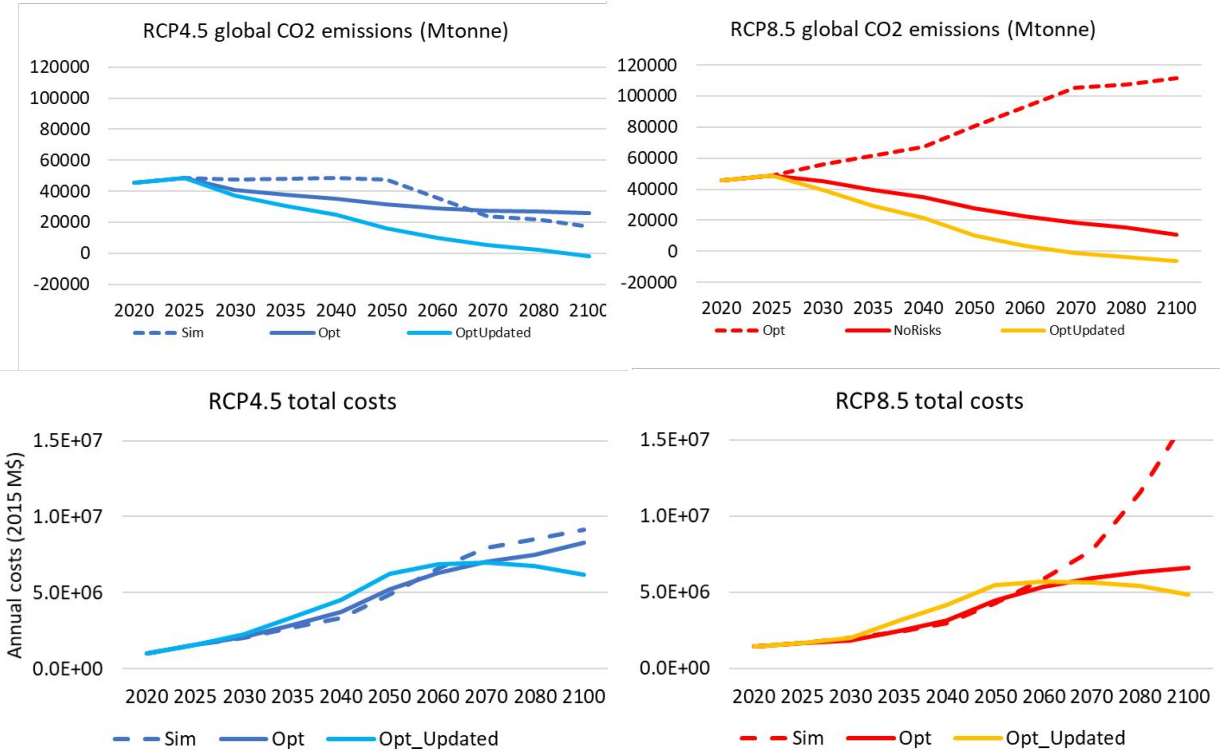
The elasticity of marginal utility of environmental risk exposure is estimated using the behavioural experiment of Xie, Liu and She (2014).

Future generations may be richer in consumption terms, but they may also face higher environmental risk; calibration should account for both.



Lesson 6: risk changes the economics of timing (PAGE)

Accounting for environmental risk strengthens the case for earlier action.



Standard discounting focuses on consumption growth. CROSSEU extends the logic to environmental risk exposure: future generations may be wealthier, but they also face higher climate risk.

When environmental risk is incorporated into the social discount rate, future damages receive more weight and earlier mitigation becomes more attractive.

Original SDR → **Risk-adjusted SDR** → **Earlier action**

Adaptation and mitigation are linked through risk: the less risk we reduce now, the more we transfer to future welfare.

Policy implications

Adaptation should be designed as economic resilience policy.

1 EWE are distributional shocks (not just aggregate output shocks)	RIF results show regressive effects, particularly for lower-income groups.
2 Economic structure & adaptive capacity determine who absorbs the losses	Agriculture, climate zone, institutions and financial depth condition the sign and magnitude of impacts.
3 CC reshapes economic geography & competitive advantage	Climate change reorganises comparative advantage, production costs and regional trade.
4 Adaptation reduces damages but leaves uneven residual risk	Irrigation, crop varieties and mechanisation leave uneven residual risk and sometimes trade-offs.
5 Climate risks spillover through prices, trade & supply chains	These spillover effects must be accounted for when designing regional/national adaptation policy frameworks.
6 Risk-aware welfare strengthens early action	PAGE extension makes future risk exposure a welfare-relevant discounting parameter.

Adaptation is most effective when it is treated as part of an integrated economic resilience strategy.

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Scenario design: climate shocks and adaptation pathways

Scenario group	IDs	Model input / representation
Baseline	SSP2	Population and GDP to 2050; no additional climate impacts or adaptation
Agri-yield impacts	AY45 / AY85	Agricultural productivity shock from crop-yield impacts
Labour productivity	LP45 / LP85	Effective productivity shock from heat-related labour losses
Combined impacts	AL45 / AL85	Crop-yield + labour-productivity shocks
Adaptation	CA45 / CA85	Climate-resilient crop varieties reduce crop-yield losses
Adaptation	IA45 / IA85	Irrigated land expansion and land-use substitution
Adaptation	ME45 / ME85	Higher value-added substitution under heat stress
Adaptation	CO45 / CO85	Combined crop varieties + irrigation + mechanisation

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NUTS2 region codes

Code	Region	Country	Comment
FRJ1	Languedoc-Roussillon	France	Former region, now part of Occitanie
ITH4	Friuli-Venezia Giulia	Italy	North-eastern Italy
ITF6	Calabria	Italy	Southern Italy
ES62	Región de Murcia	Spain	South-eastern Spain
ITH1	Provincia Autonoma di Bolzano / Bozen, South Tyrol	Italy	Alpine north-east Italy
AT33	Tirol	Austria	Western Austria
PT11	Norte	Portugal	Northern Portugal
PT19	Centro	Portugal	Central Portugal
ITC2	Valle d'Aosta / Vallée d'Aoste	Italy	North-western Italy
FI1D	North and East Finland	Finland	Finnish NUTS2 macro-region

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