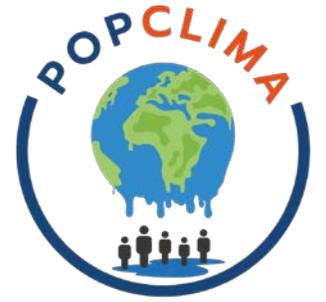




ALMA MATER STUDIORUM
UNIVERSITÀ DI BOLOGNA



POPCLIMA (Grant agreement: 101002973)



Population dynamics in a warming world: Synthesizing evidence on climate impacts on fertility, mortality, and migration

Raya Muttarak

Department of Statistical Sciences, University of Bologna

Prince Mahidol Award Conference – PMAC 2026, Bangkok,
30 January 2026

Asia: Floods in Indonesia, Sri Lanka, Thailand and Malaysia kill more than 1,400



03/12/2025

'It's like living in an oven': Pakistan and India crushed by deadly heat waves



July 6, 2024

Since May, a series of heat waves have swept across the northern part of the Indian subcontinent causing hundreds of deaths, particularly in large cities. The region's impoverished inhabitants are the first to suffer.



"We have to go": Climate change driving increased migration from Central America

February 17, 2021



Climate change is making people think twice about having children





CLIMATE CHANGE

Greenhouse gas emissions

CLIMATIC HAZARDS

Rapid-onset events

Sudden extreme weather events e.g. flooding, windstorms, mudslides, wildfires

Slow-onset events

Long-term climate-related changes e.g.,

- Increasing mean temperatures
- Sea level rise
- Glacial retreat
- Salinisation
- Desertification
- Loss of biodiversity

Individual and household Socioeconomic factors

Demographic characteristics
Education Occupation Income

↓

Differential exposure, vulnerability & adaptive capacity

↑

Macro-level factors

Infrastructure & services	Social safety nets
Governance & policy	Community & social capital

Population dynamics time t

FERTILITY (Icon: baby)

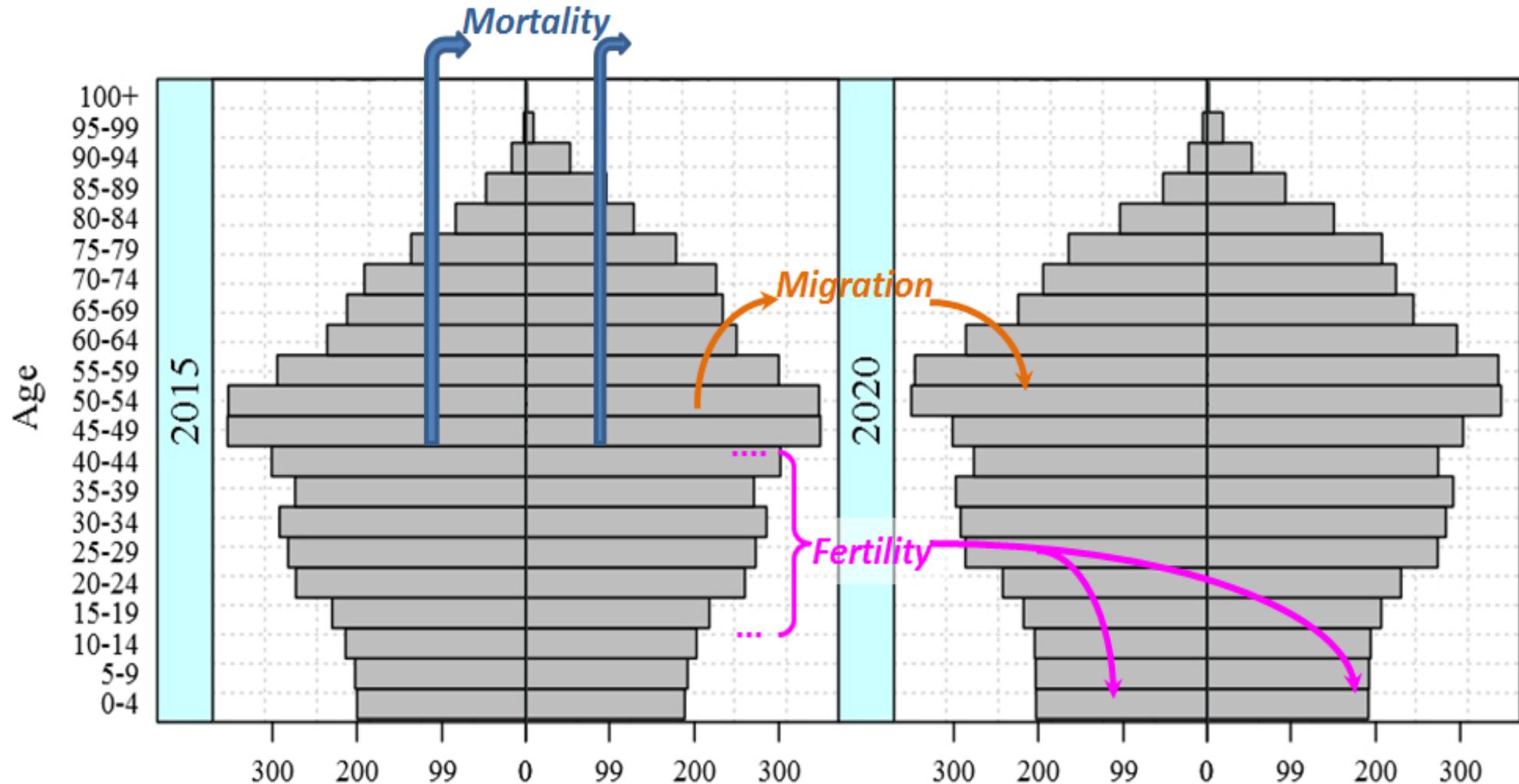
MORTALITY (Icon: tombstone)

MIGRATION (Icon: person with suitcase)

↓

Future population t+1,

Cohort-component population projections require knowledge about fertility, mortality and migration



Outline of the talk

- Why considering the climate feedback on population dynamics?
- **Synthesizing the evidence** — What do we know about ...?
 - Climate impact on **migration**
 - Climate impact on **mortality**
 - Climate impact on **fertility**
- Key findings and way forward



CLIMATE IMPACT ON MIGRATION

Will there be mass migration of climate migrants coming to Europe?

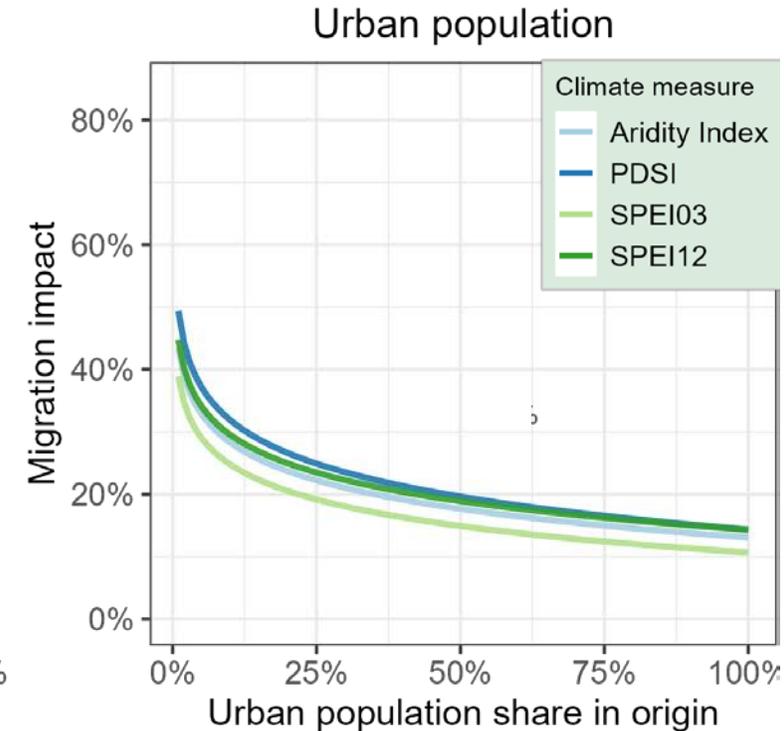
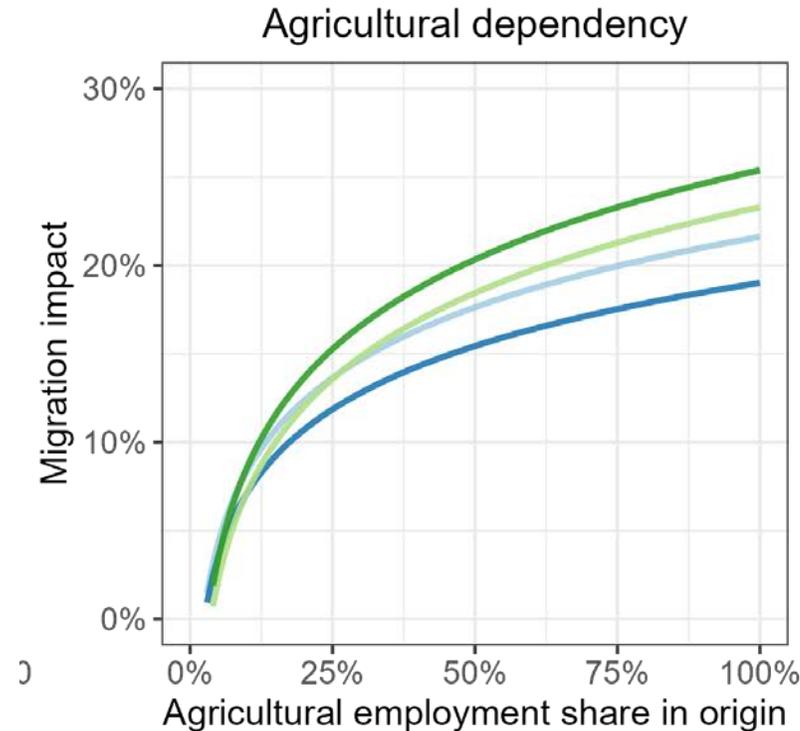


Will greater frequency and intensity of climate hazards push vulnerable populations out of their home also in Europe?



Systematic literature review and meta-analysis suggest some consistent patterns

- Often involve **shorter distance** or **internal migration** (Borderon et al. 2019; Hoffmann et al. 2020, 2021; Thiede et al. 2024)
- Those who migrated are **not the poorest**, nor the richest (Hoffmann et al. 2020; Sedova et al. 2021)
- Climate-related migration more frequent in **agriculture-dependent, rural areas**
- **Conflict mediates** the relationship between exposure to climatic shocks and migration (Abel et al. 2019; Hoffmann et al. 2020)



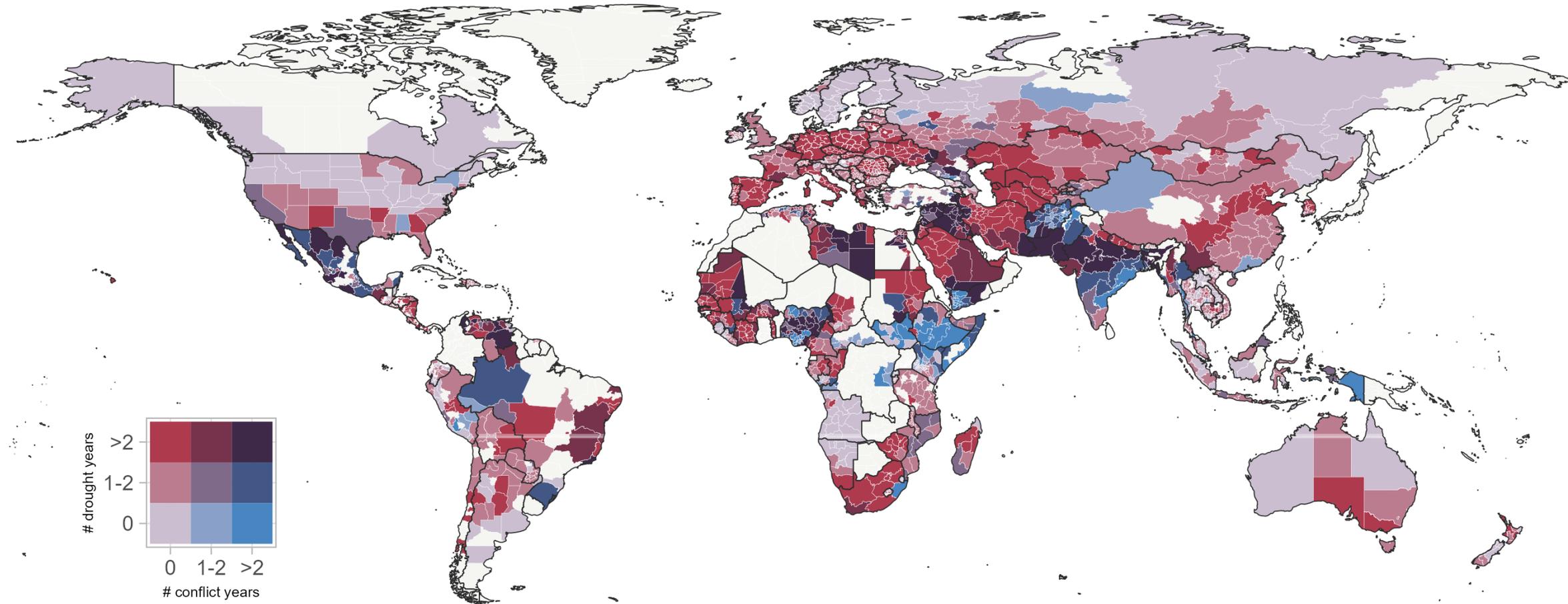
Source: Hoffmann, R., Abel, G., Malpede, M., Mutarak, R. & Percoco, M. (2024). [Nature Climate Change](#).



Does conflict amplify the impact of climate on migration? – Compound risks

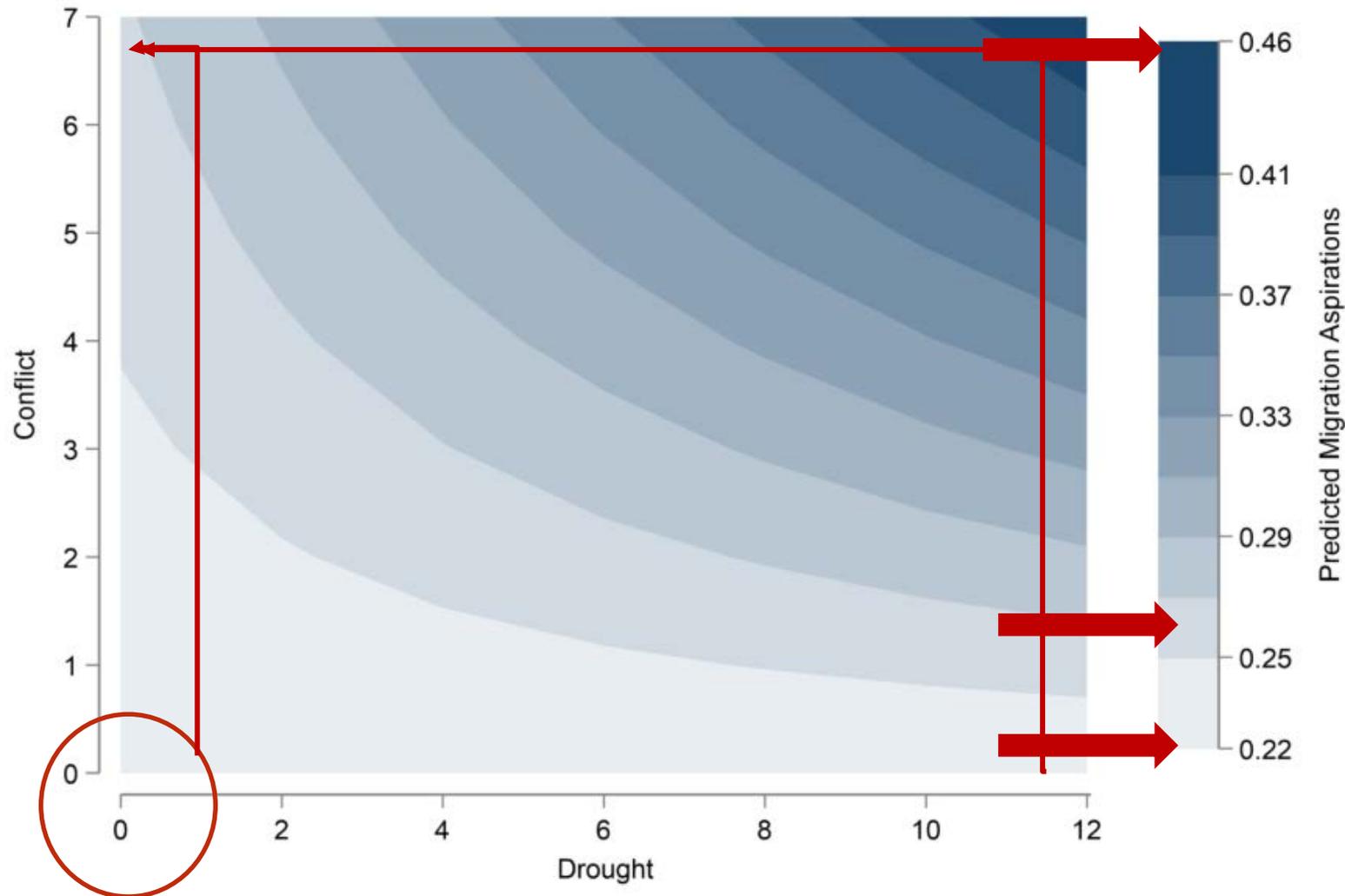
Overlap between conflict and drought risks worldwide

Number of years with drought and conflict in subnational regions, 2010-2019



Source: Kavakli, K., Deuster, C., Ghislandi, G., Hoffman, R., Kemp, W., Muttarak, R. [Wittgenstein Centre Conference 2025](#).

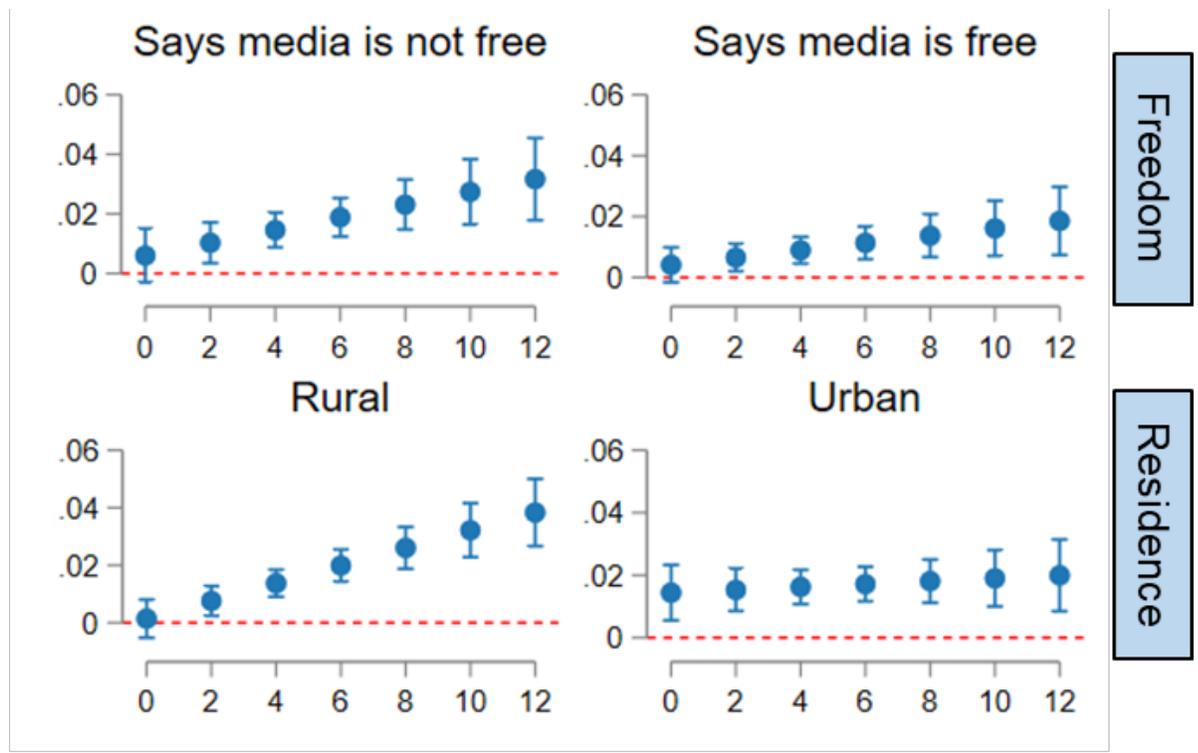
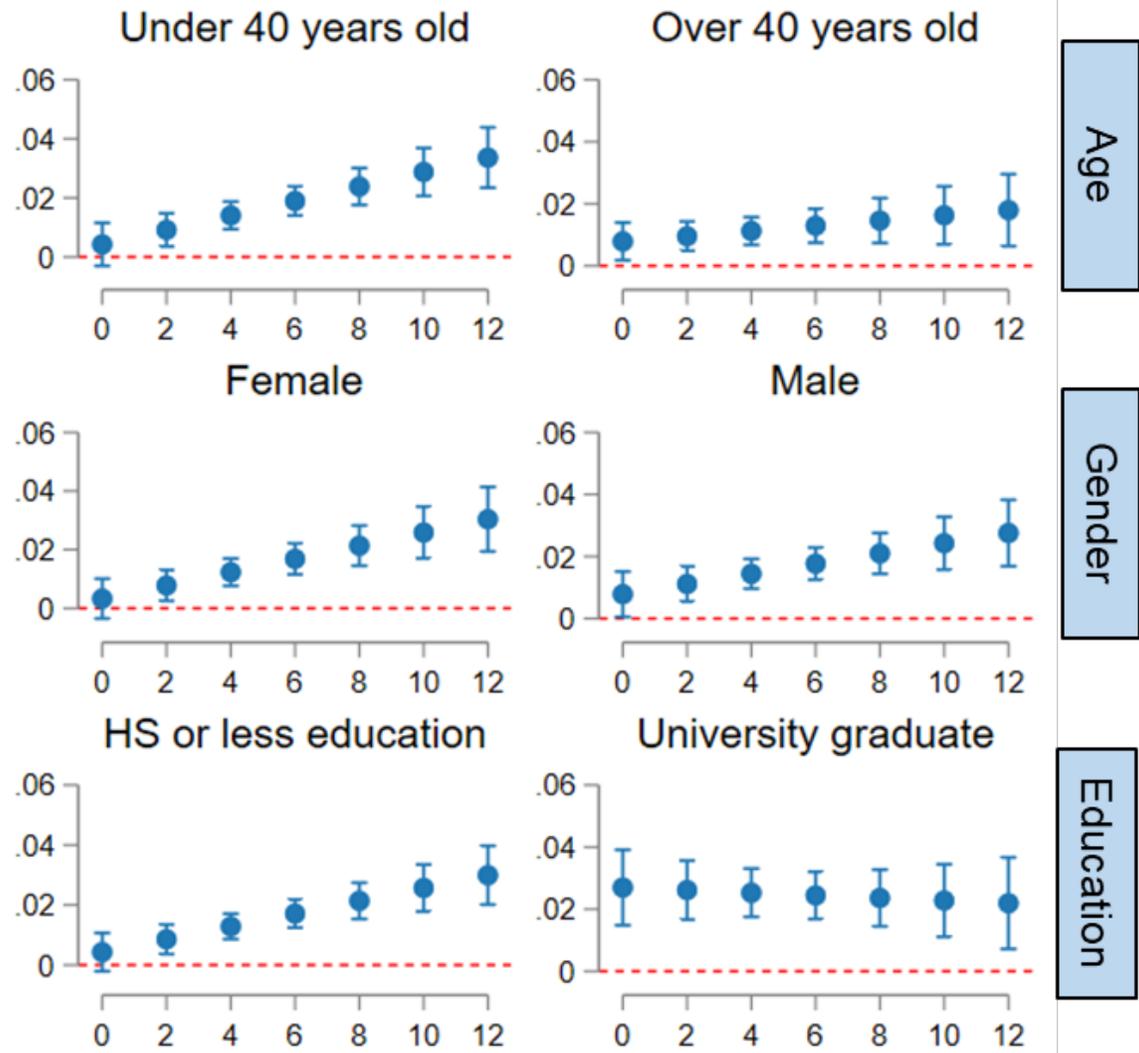
Predicted probability of migration aspiration by conflict intensity and drought exposure



- When both conflict and drought exposure are high, the predicted probability of migration aspiration reaches approximately **0.45**
 - an absolute increase of **23 percentage points** above the sample mean (0.22) percent.
- This is **twice** as much as the baseline value!



Demographic heterogeneity in the marginal effect of conflict intensity on migration aspiration

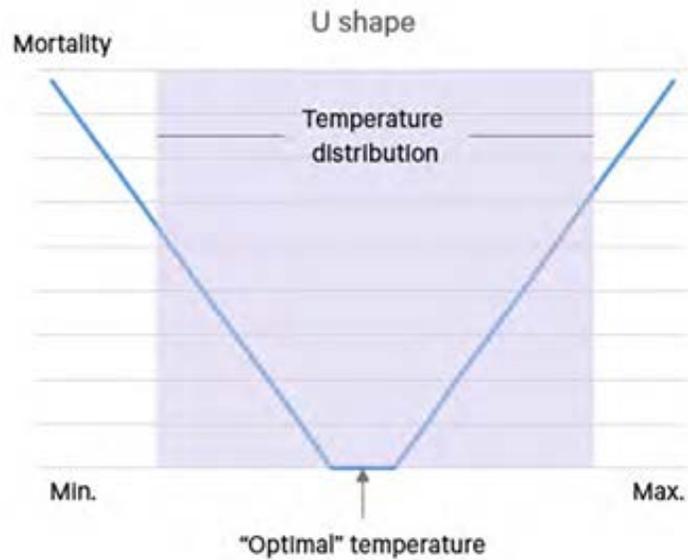


Drought

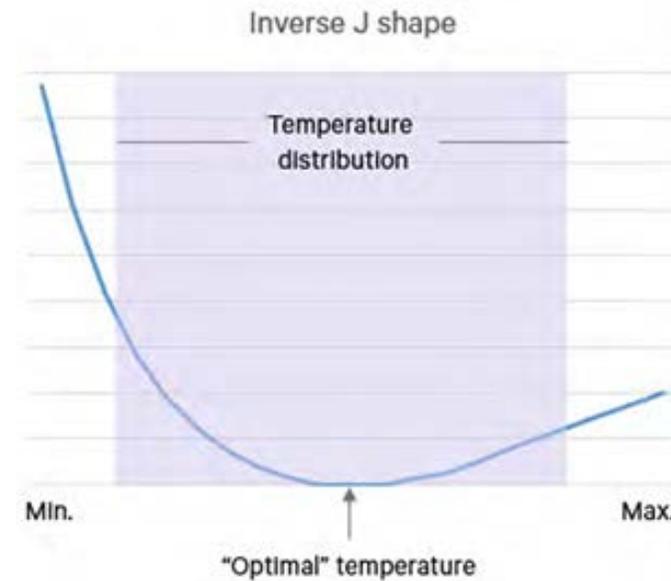
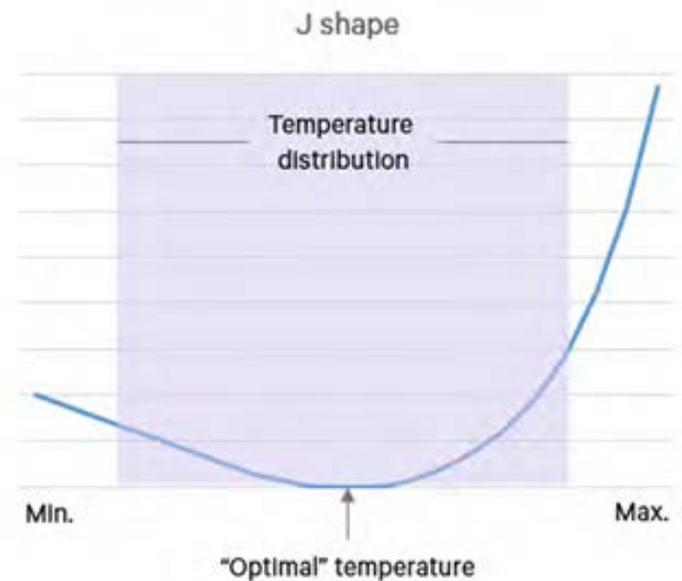
Note: Drought shows the number of months in the last year that the district experienced drought conditions (i.e. SPEI < -1). Conflict shows the (logged) number of conflict-related deaths in the district in the past month.



CLIMATE IMPACT ON MORTALITY

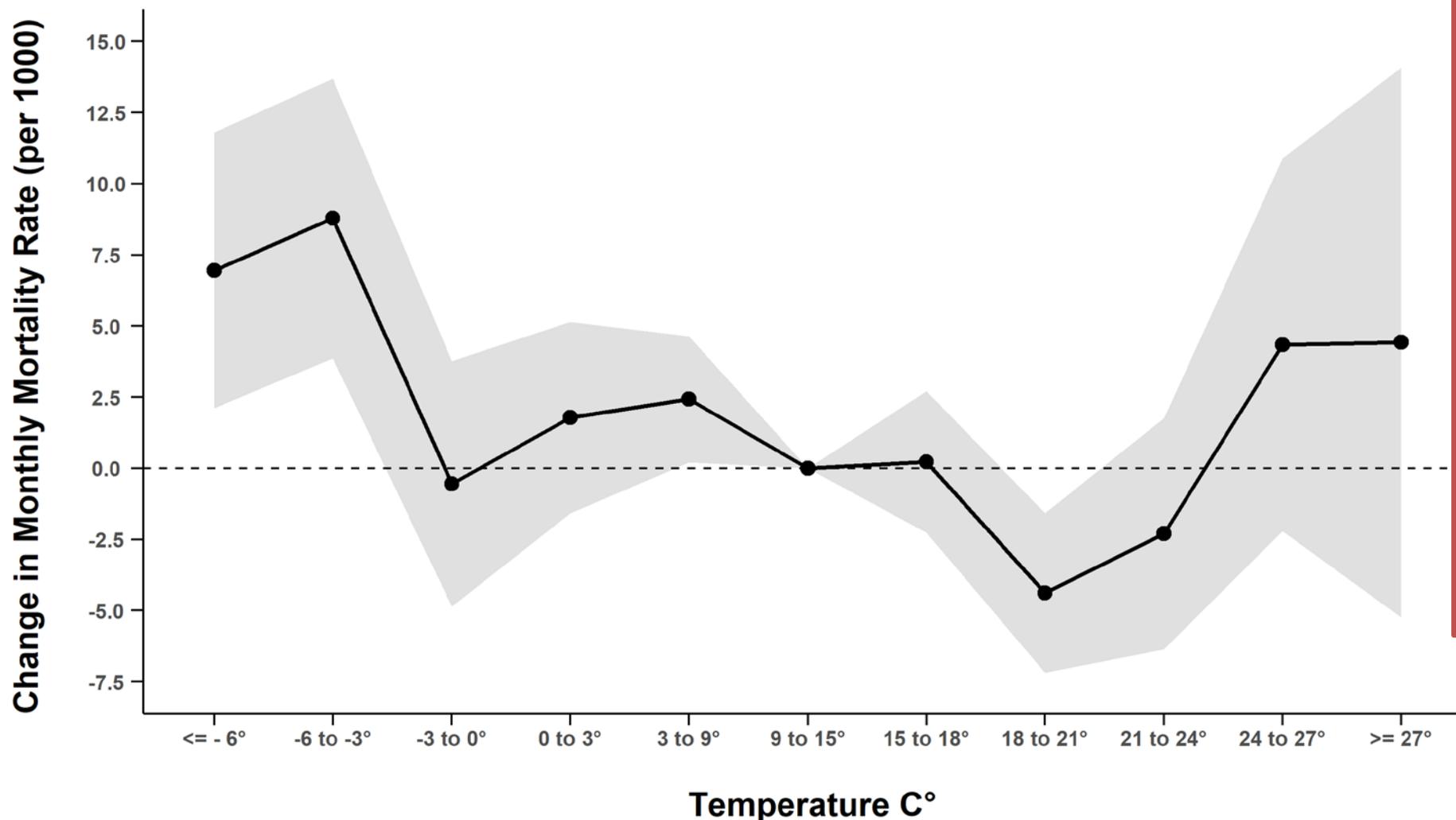


Which do you think causes more deaths on average: extreme cold or extreme heat?



Projecting future temperature-related mortality

Estimate temperature-related deaths among individuals 65+ across 244 regions located in 25 European countries (2014 – 2022)



An additional day in the coldest temperature range increase the monthly mortality rate of older persons by 7 per 1,000.

An additional day in the hottest temperature range increase the monthly mortality rate of older persons by 4.4 per 1,000.



Excess death ratios (per 100,000) by NUTS 2 and scenarios (2090-2099)

SSP-RCP Framework

- Shared Socioeconomic Pathways (SSPs) scenarios
- Representative Concentration Pathways (RCPs) scenarios
- Assessing future temperatures related-mortality (2030–2099) under four scenarios:

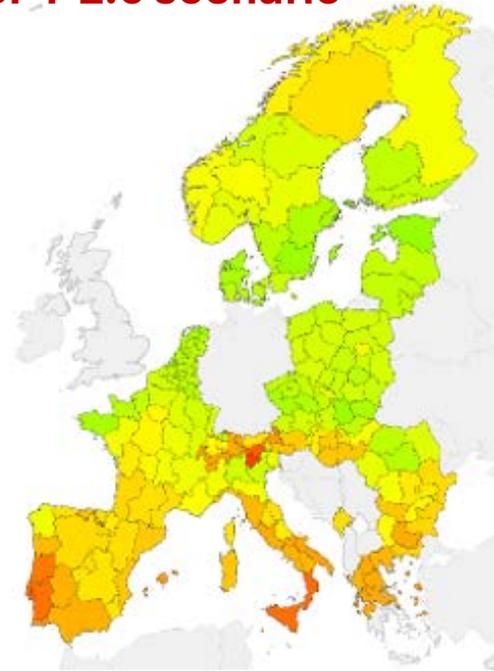
(1) **SSP1-2.6** (~1.5°C warming) green growth scenario

(2) **SSP2-4.5** (~2.7°C warming) **global development trends continue as the present**

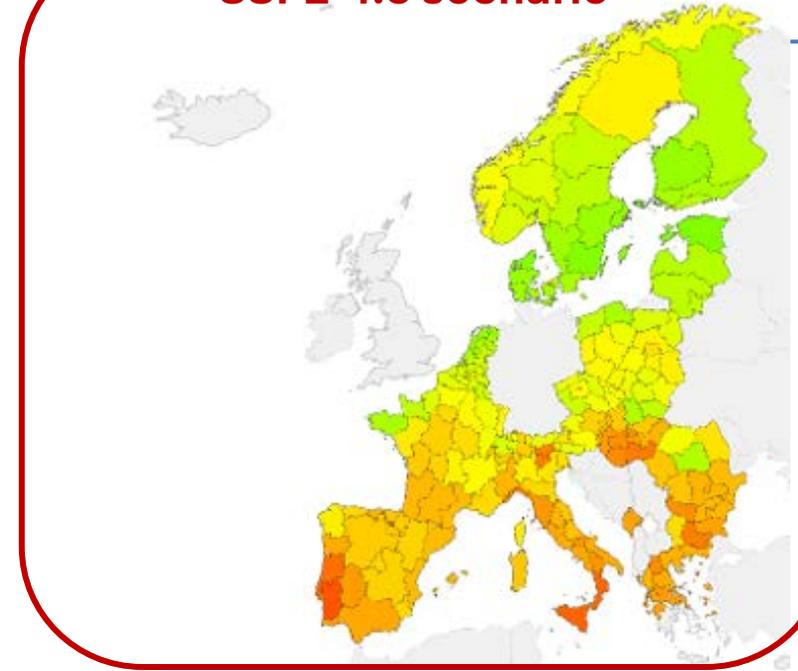
(3) **SSP3-7.0** (~3°C warming) high-fragmentation and inequalities

(4) **SSP5-8.5** (~5°C warming) a world focused on fossil fuel use and **very high emissions**

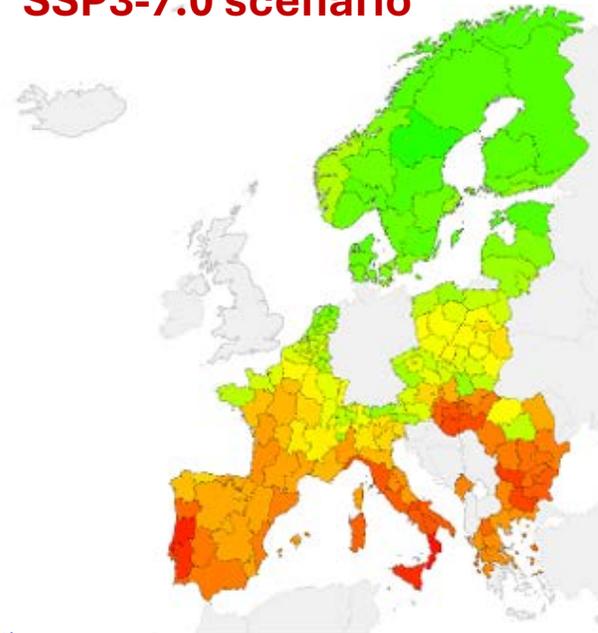
SSP1-2.6 scenario



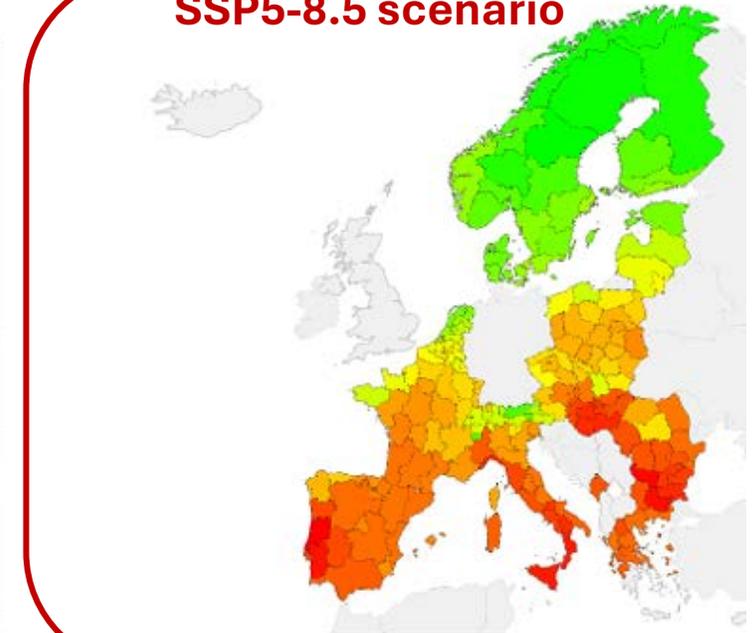
SSP2-4.5 scenario



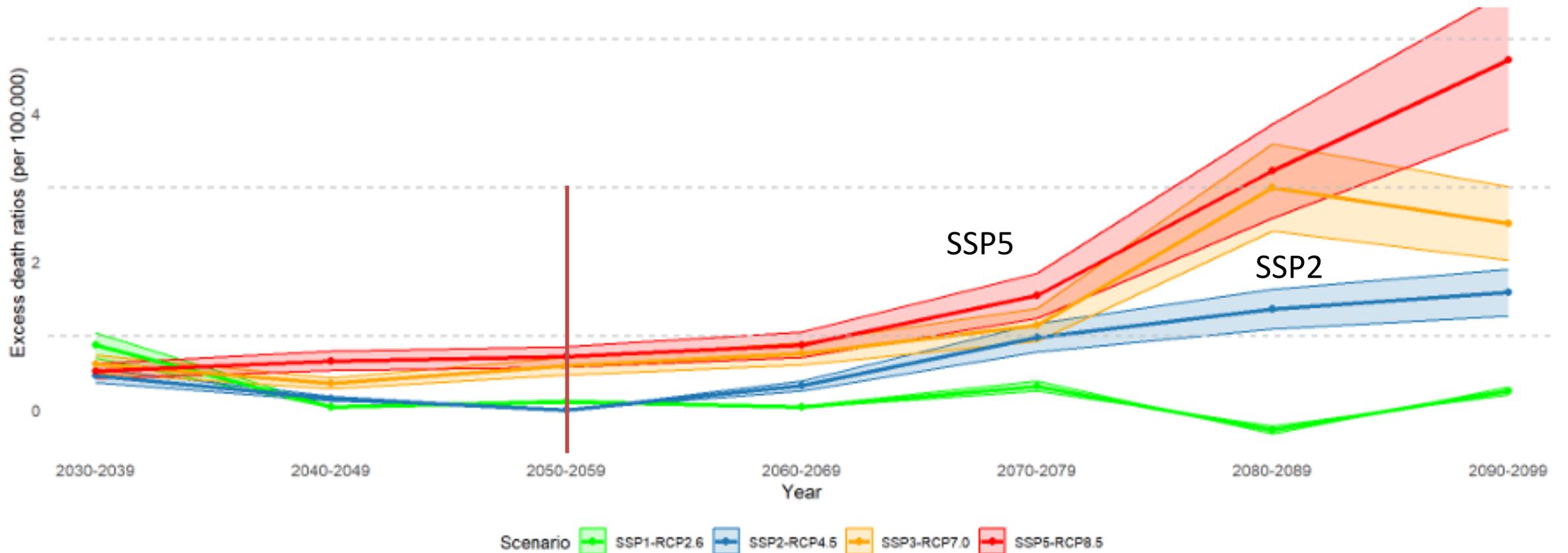
SSP3-7.0 scenario



SSP5-8.5 scenario



Projected Excess Death ratios (per 100,000) by SSP-RCPs (2030-2100)



Source: Gualdi, R., Conte Keivabu, R. and Muttarak, R. (2025). [30th IPC Conference](#).



CLIMATE IMPACT ON FERTILITY

The Washington Post

Should you not have kids because of climate change?

December 2, 2022



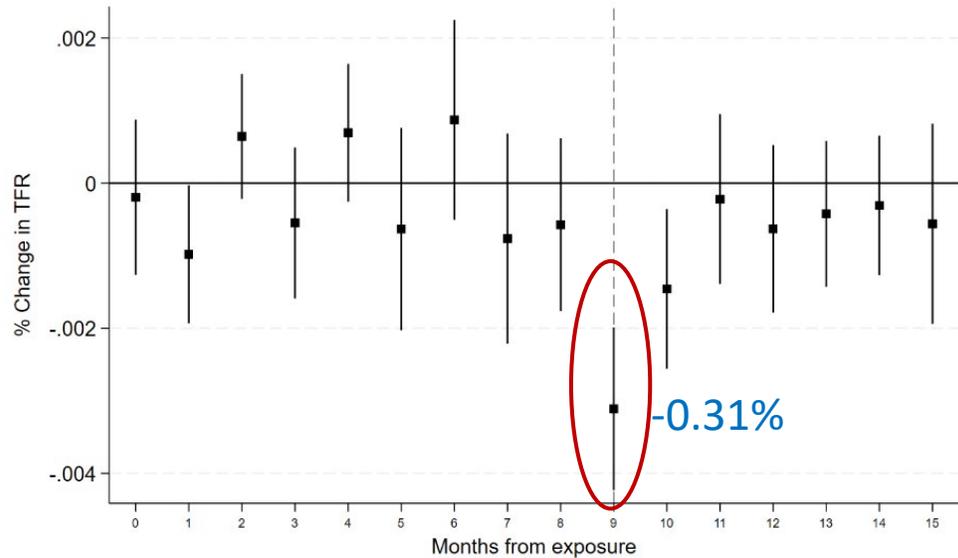
Is **Climate Change**
Making It Harder For Couples To
CONCEIVE?

Does climate change influence fertility? If so, how?



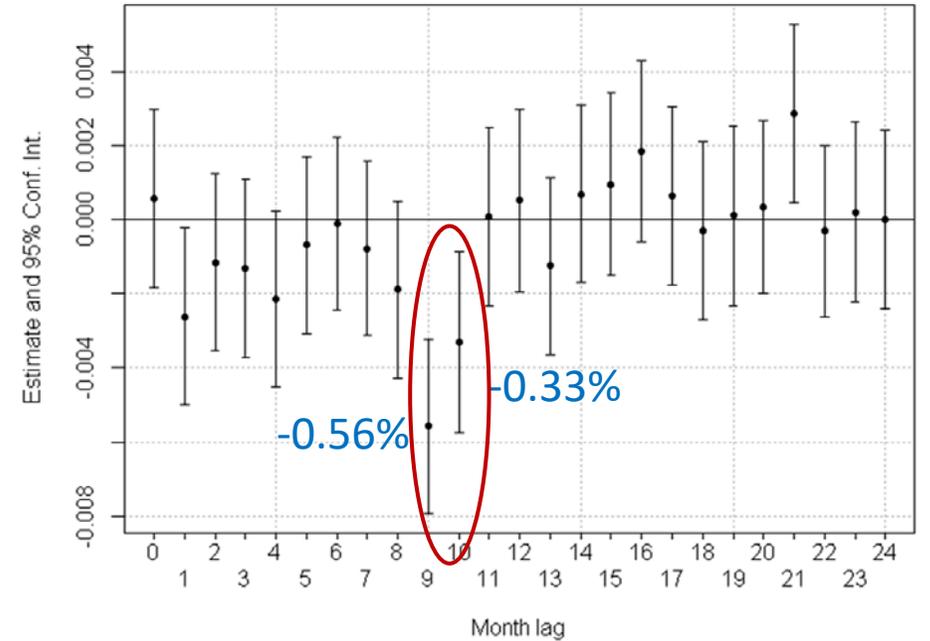
Evidence on heat exposure and fertility for Italy, Mexico and 65 low- and middle-income countries (sub-national level)

Impact of heat exposure (>25°C) on changes in TFR in Italy



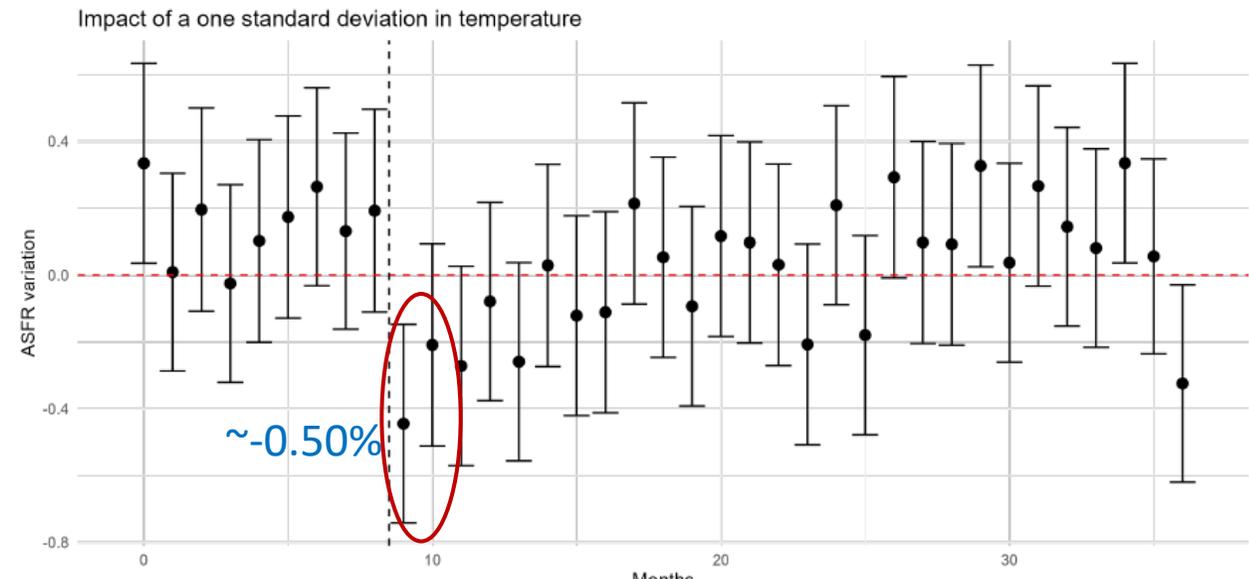
Source: Barba, M. Muttarak, R. & Querin, F. (2025). [Dondena Working Paper](#).

Temperature anomaly and birth rate: Mexico



Source: Olguín, I., Cheritel, C. & Muttarak, R. (2025) [30th IPC Conference](#).

Temperature anomaly and birth rate: 65 DHS countries



Source: Cheritel, C., Hoffmann, R. & Muttarak, R. (2025). [30th IPC Conference](#).

Towards population projections accounting for the climate feedback

Evidence of the impact of climatic shocks on demographic outcomes by far:

- **Fertility** – short-term negative effect, no recuperation (so possibly not due to postponement)
- **Mortality** – likely to increase under more warming
- **Migration** –
 - 1) displacement and internal migration are likely to increase;
 - 2) limited evidence on international migration;
 - 3) climate-induced migration within Europe is plausible.



THANK YOU!

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This presentation describes the main objectives and methodologies of POPCLIMA covering all 4 strands.

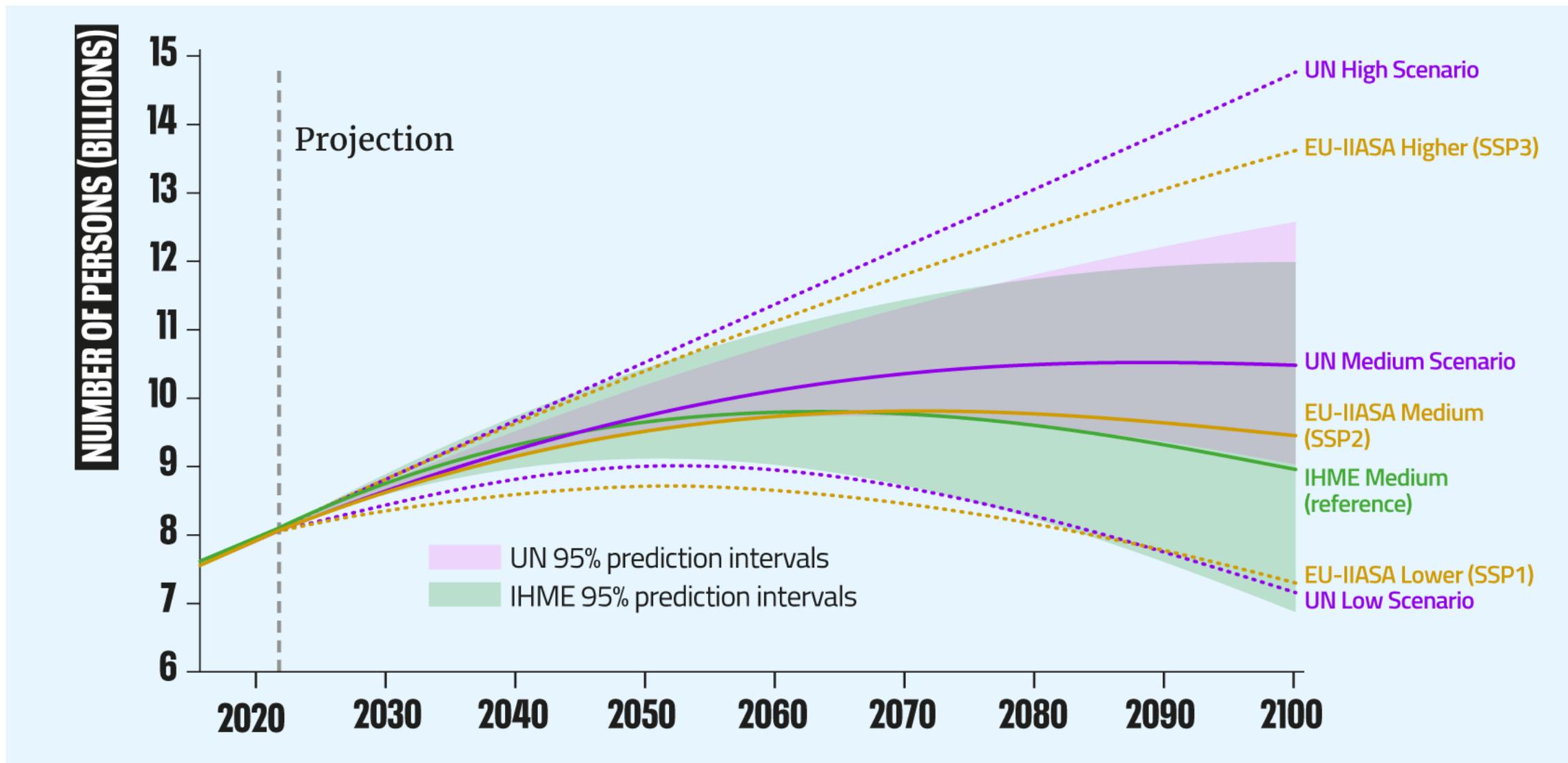


What do you think the world population will be in the year 2100?

- A. 9 billions
- B. 10 billions
- C. 11 billions
- D. 12 billions



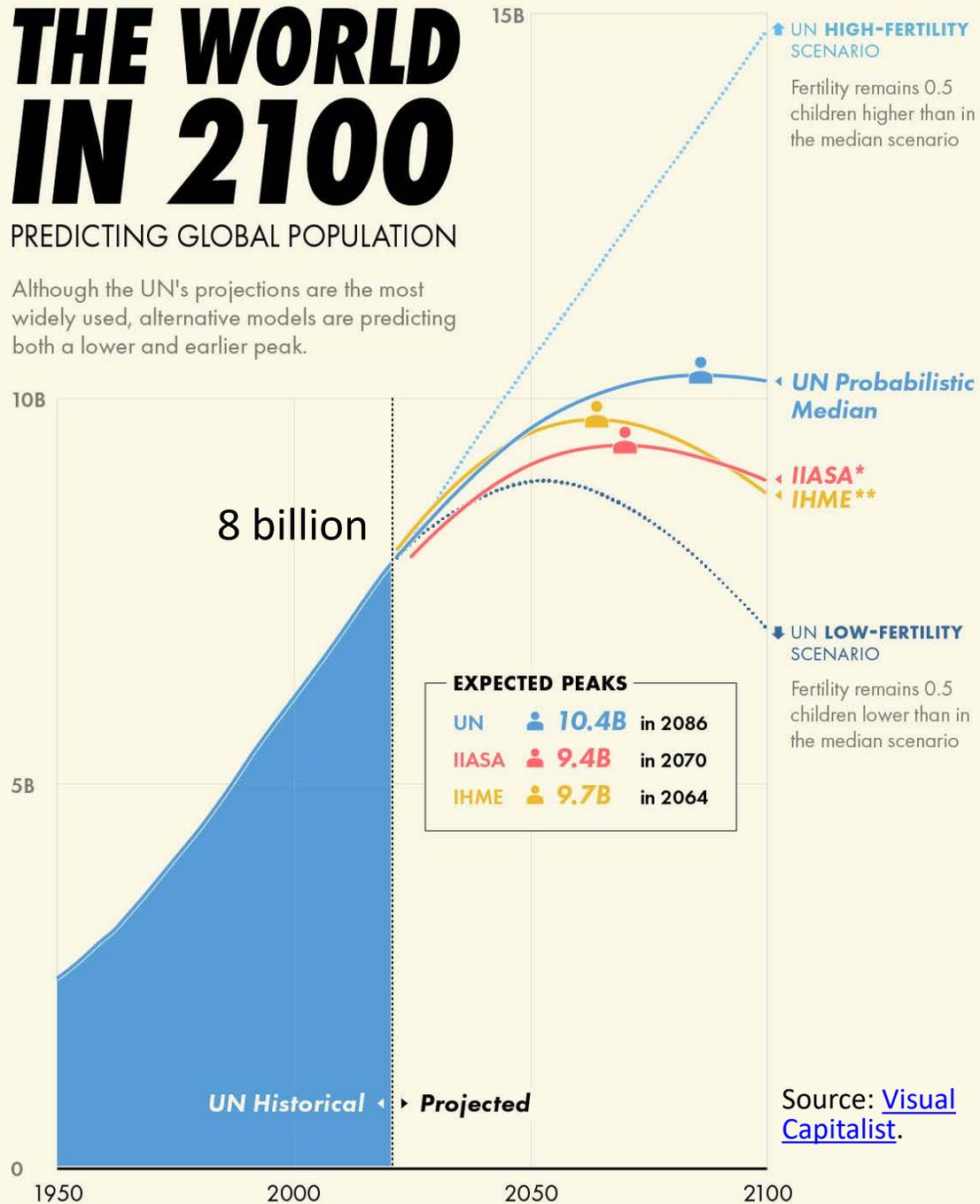
Global population projections to 2100 comparisons



THE WORLD IN 2100

PREDICTING GLOBAL POPULATION

Although the UN's projections are the most widely used, alternative models are predicting both a lower and earlier peak.



Global population projections

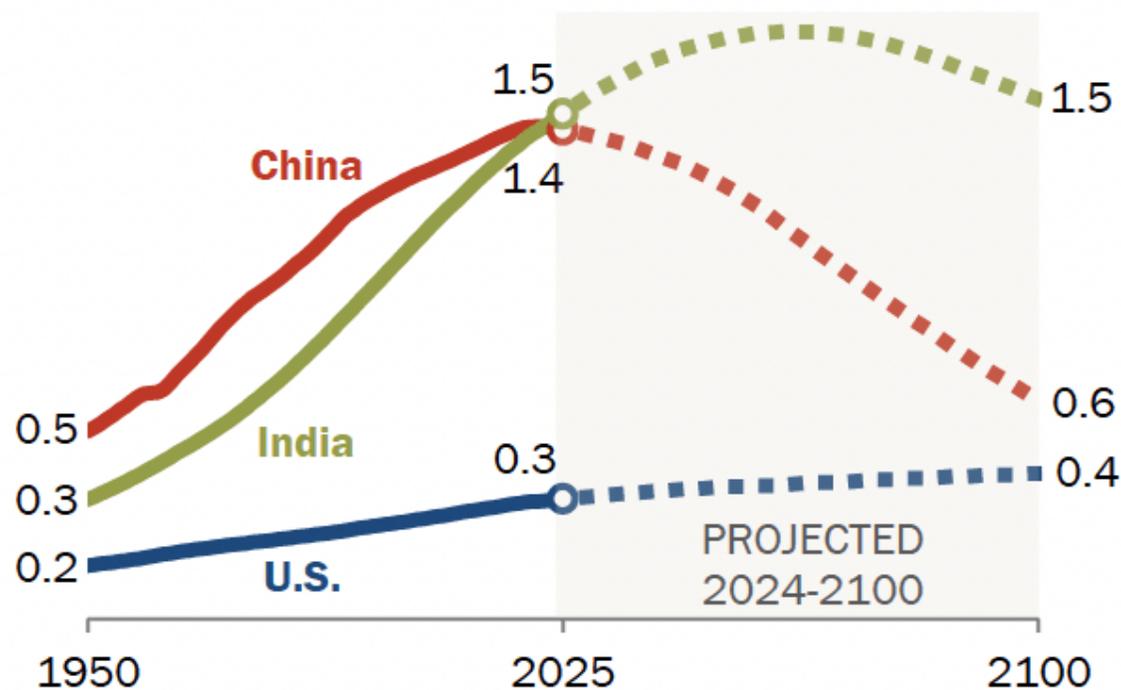
Source	Methods	Population peak and assumptions
United Nations	Probabilistic projection using Bayesian models	Peak mid-2080s at ~10.4B. Assumes continued gradual fertility decline.
IIASA/Wittgenstein Centre	Cohort-component model combined with scenario frameworks (SSPs)	Peak varies by scenario: SSP2 peak in 2080 at 10.13B. Development pathways strongly shape demography.
Institute for Health Metrics and Evaluation (IHME)	Statistical model linking fertility, mortality, migration to education & contraceptive access	Peak ~2064 at ~9.7B. Assumes faster fertility decline driven by female education and access to contraception.



Differential demographic challenges

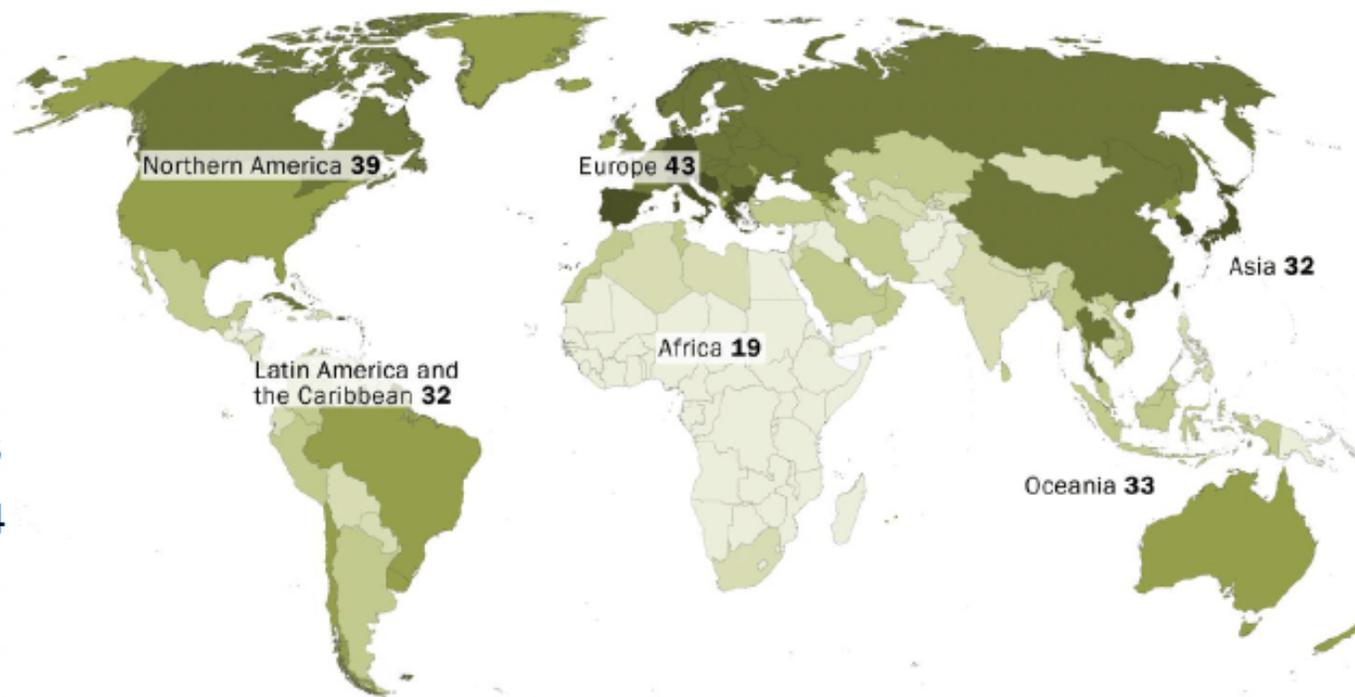
By 2100, China's population is projected to shrink by more than half

World population, in billions



Today, Europe has the oldest population of any region; Africa has the youngest

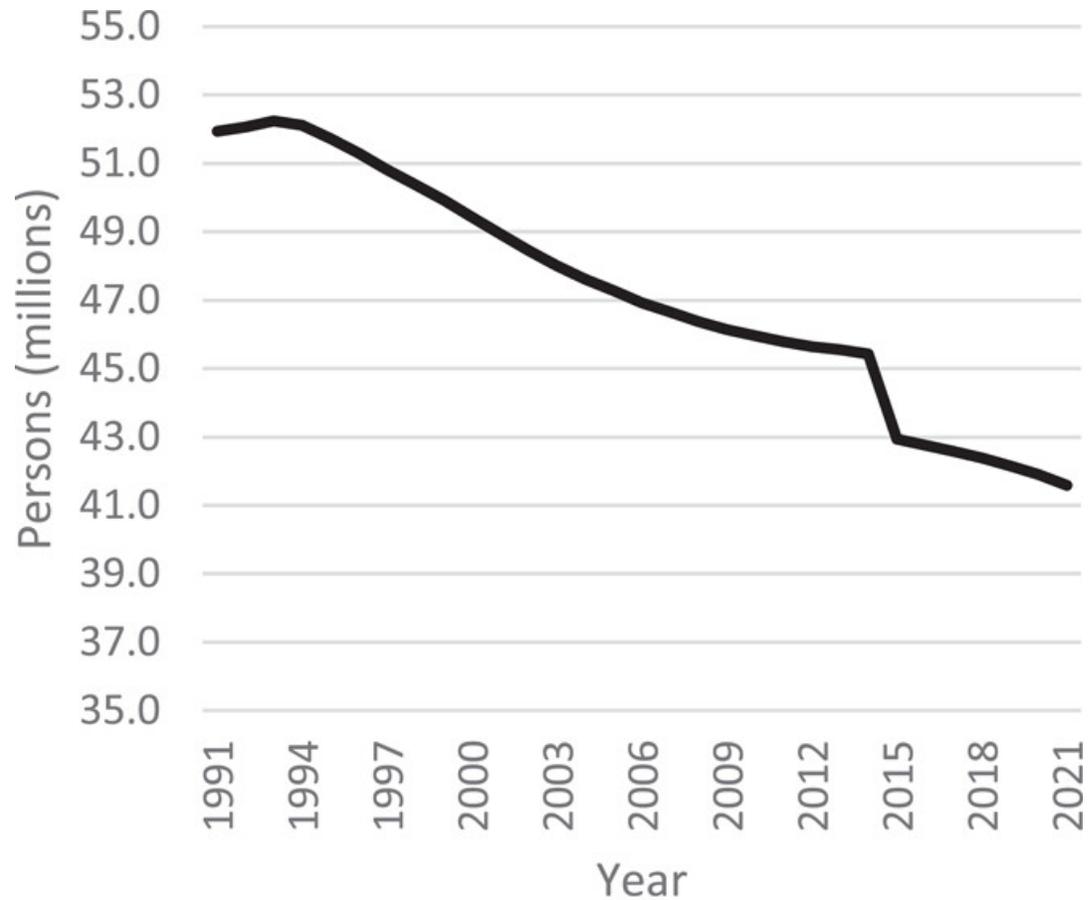
Median age in 2025, by country and region



Source: [Pew Research Center](#).

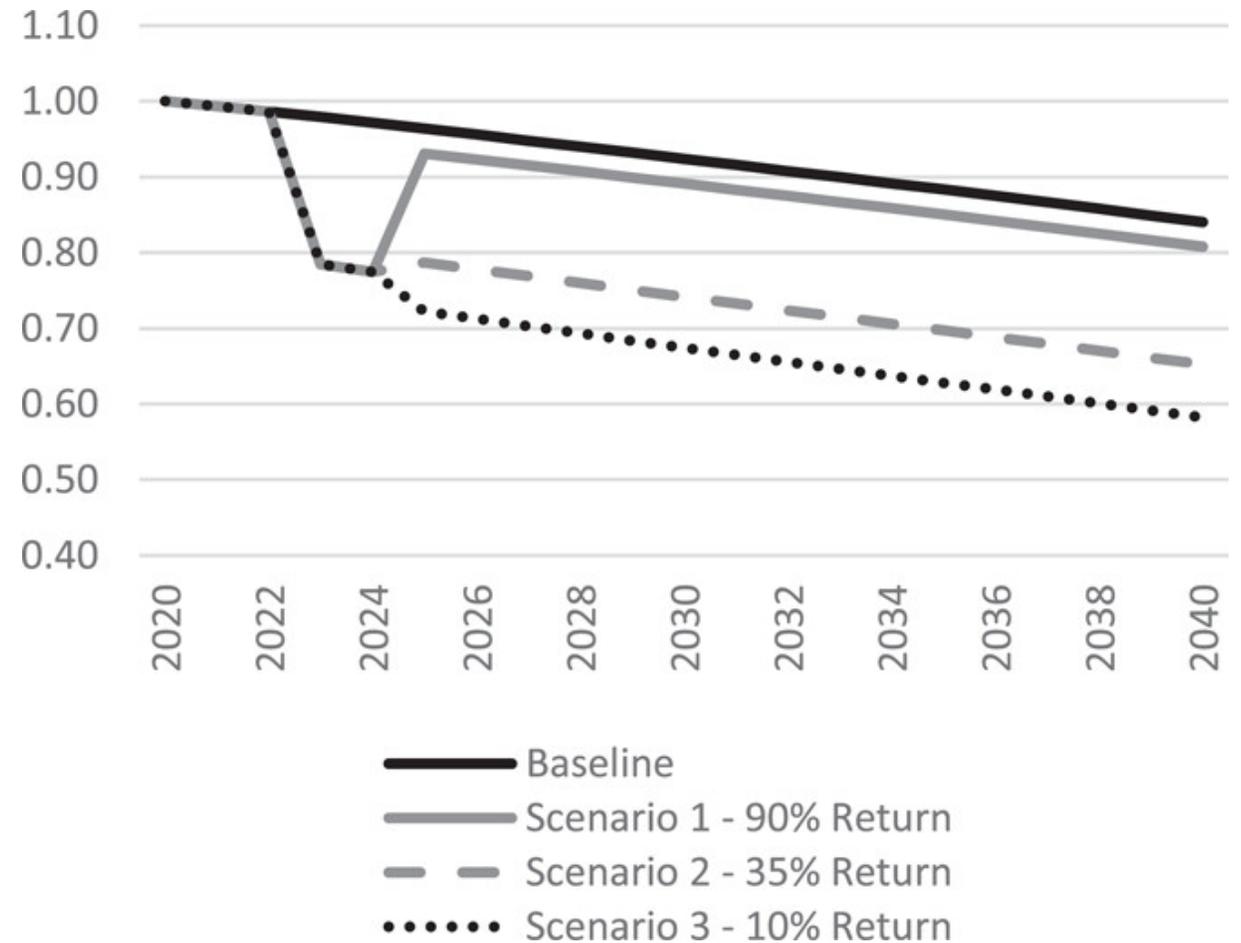


Ukraine's population, 1991–2021



— Total population

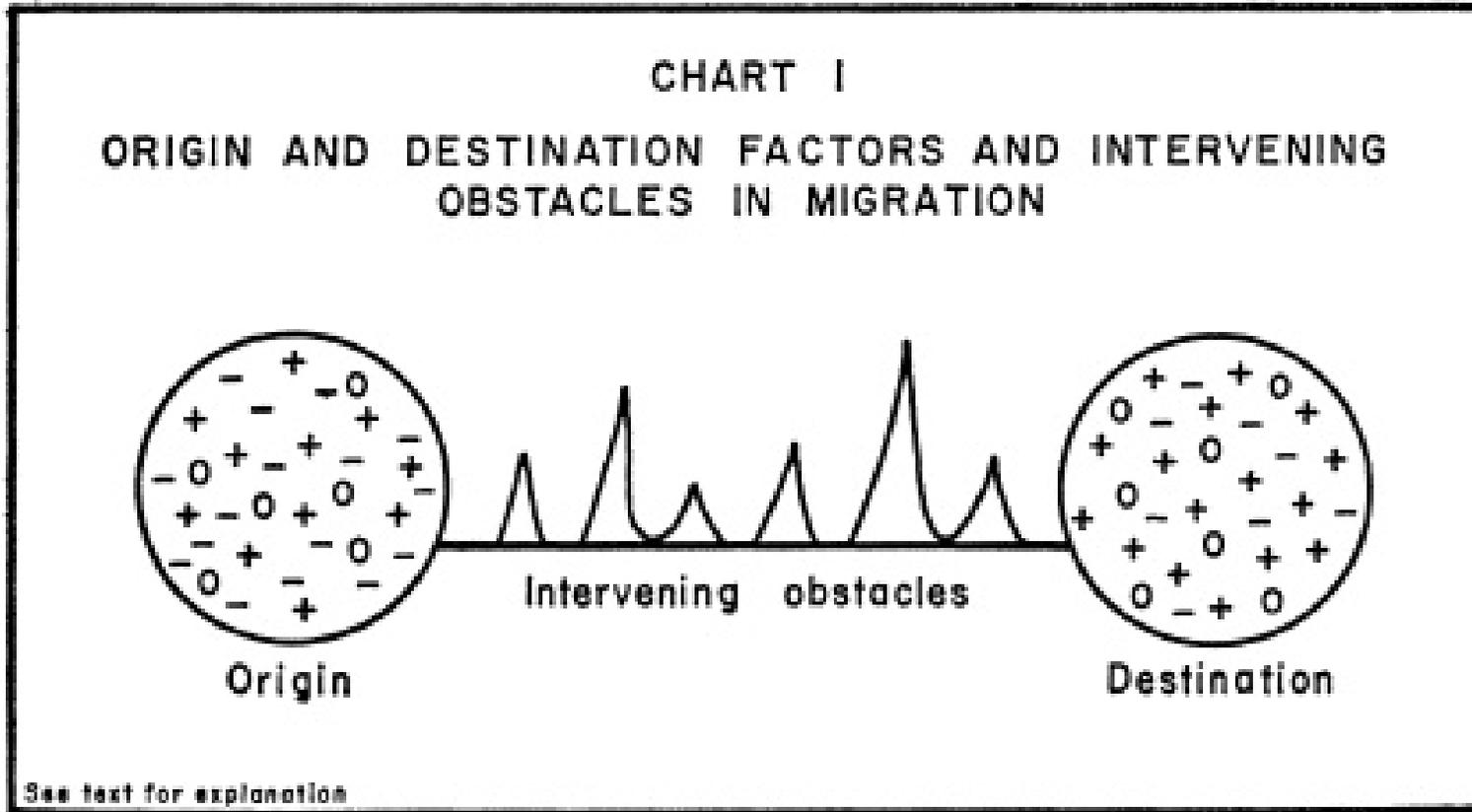
Projected relative population change in Ukraine, 2020–2040



0. Baseline: Pre-war trends in fertility, mortality, and migration continue.
 1.8 million refugees, 90% return.
 2.8 million refugees, 35% return.
 3.8 million refugees, 10% return.



Push-pull migration theory (Everett S. Lee)



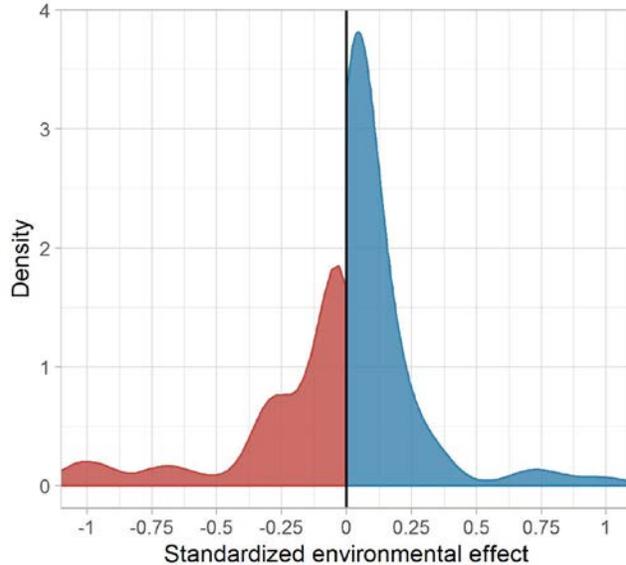
Source: Lee, E.S. (1966). A theory of migration. *Demography* 3, 47-57.



Source: [BBC Bitesite](#).

Research to date shows mixed results on whether and how climate affects migration patterns

A. Distribution of significant coefficients

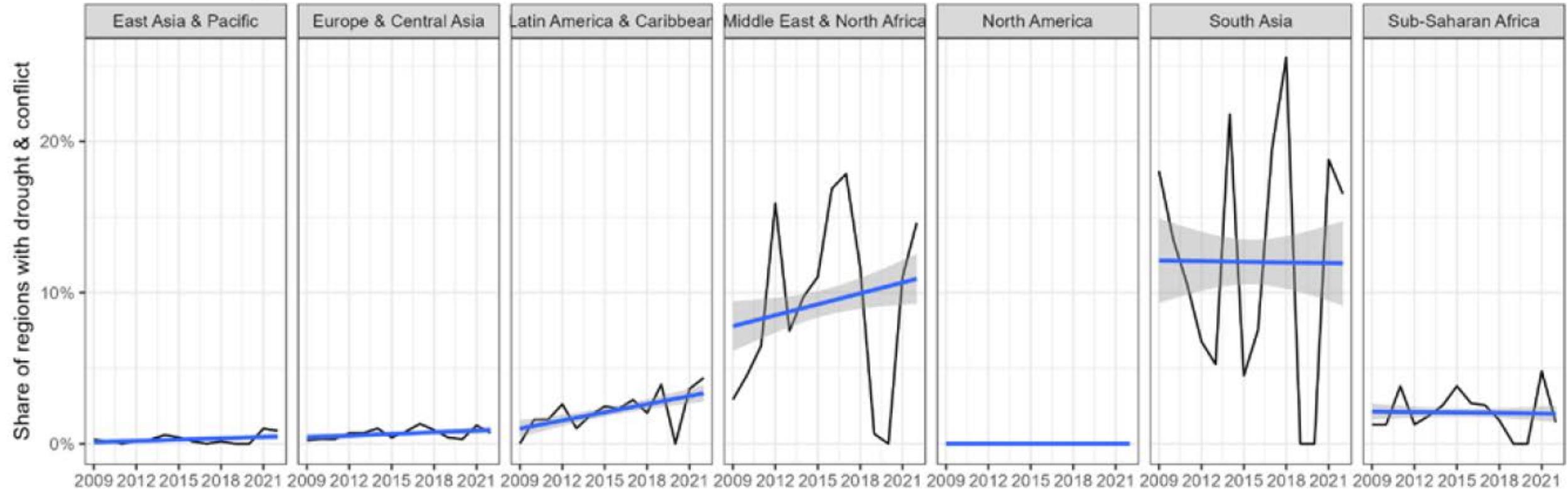


International migration

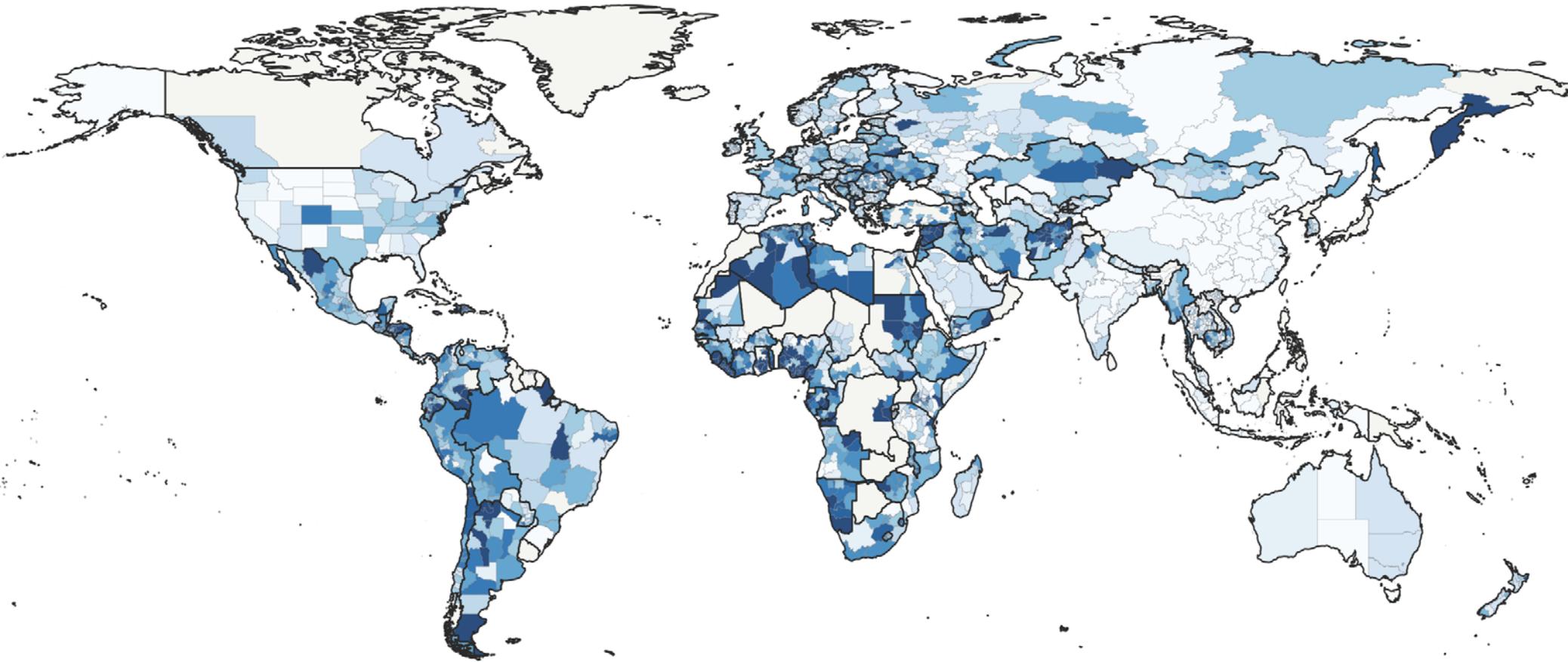
Paper	Pub.	Period	Years	Region	Prec.	Temp.	Rapid.
1 Naude 2009 (ref. ¹⁶)	X	1965–2005	5	SSA			2
2 Ruysen & Rayp 2014 (ref. ¹⁷)	X	1980–2000	10	SSA		2	2
3 Naude 2010 (ref. ³⁷)	X	1965–2005	5	SSA			3
4 Damette & Gittard 2017 (ref. ²⁸)	X	1960–2000	1	SSA	2	2	
5 Cattaneo & Peri 2016 (ref. ²³)	X	1960–2000	1	Non-OECD	95	98	4
6 Gröschl & Steinwachs 2017 (ref. ²⁹)	X	1980–2010	10	World	4	2	32
7 Beine & Parsons 2017 (ref. ²⁵)	X	1960–2000	10	Non-OECD	8	8	8
8 Maurel & Turchio 2016 (ref. ²⁴)	X	1960–2000	10	World	3	3	
9 Beine & Parsons 2015 (ref. ¹⁹)	X	1960–2000	10	World	38	38	46
10 Marchiori et al. 2017 (ref. ³²)	X	1960–2000	1	SSA	10	10	
11 Cattaneo & Bosetti 2017 (ref. ²⁶)	X	1960–2000	10	World	12	6	12
12 Gröschl 2012 (ref. ⁴¹)		1960–2010	10	World			95
13 Marchiori et al. 2012 (ref. ⁴³)	X	1960–2000	1	SSA	14	14	
14 Hanson & McIntosh 2012 (ref. ⁴²)	X	1980–2005	10	Latin America			8
15 Mahajan & Yang 2017 (ref. ³¹)		1980–2004	1	World			13
16 Alexeev et al. 2010 (ref. ³⁸)		1986–2006	1	World			10
18 Peri & Sasahara 2019 (ref. ³⁵)		1970–2000	10	World		31	
19 Spencer 2018 (ref. ³⁴)	X	1989–2005	1	LAC			16
20 Cai et al. 2016 (ref. ²²)	X	1980–2010	1	World	269	276	
21 Drabo & Mbaye 2014 (ref. ⁴⁴)	X	1975–2000	5	World	14	14	24
22 Backhaus et al. 2015 (ref. ¹⁸)	X	1995–2006	1	World	10	10	
23 Coniglio & Pesce 2015 (ref. ²⁰)	X	1990–2001	1	World	84	20	64
24 Bettin & Nicolli 2012 (ref. ³⁹)		1960–2000	1	World	18	18	18
25 Reuveny & Moore 2009 (ref. ²⁷)	X	1988–2000	1	World			3
26 Wesselbaum & Aburn 2019 (ref. ³⁶)	X	1980–2015	1	World	2	14	24



Trends in drought and conflict cooccurrence

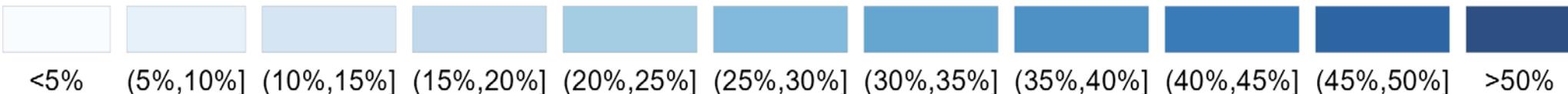


Migration aspirations across 144 countries: Gallup World Poll 2009-2022



“Ideally, if you had the opportunity, would you move permanently to another country, or would you prefer to continue living in this country?”

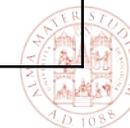
Share of respondents with migration intentions



Higher migration aspirations among individuals facing both drought and conflict

VARIABLES	Migration aspiration				
	(1)	(2)	(3)	(4)	(5)
	Conflict deaths in previous 1 month				Conflict deaths in previous 1 year
Conflict	0.012*** (0.002)		0.012*** (0.002)	0.005* (0.003)	0.000 (0.002)
Drought		0.005 (0.005)	0.004 (0.005)	0.000 (0.005)	-0.005 (0.005)
Conflict # Drought				0.024*** (0.007)	0.016*** (0.004)
Individual-level controls	Yes	Yes	Yes	Yes	Yes
District FE	Yes	Yes	Yes	Yes	Yes
Month FE	Yes	Yes	Yes	Yes	Yes
World-region # Year FE	Yes	Yes	Yes	Yes	Yes
Observations	1,409,072	1,409,072	1,409,072	1,409,072	1,409,072
R-squared	0.164	0.164	0.164	0.164	0.164

Note: Robust s.e. clustered by district-year are in parentheses. * p < 0.1, ** p < 0.05, *** p < 0.01.

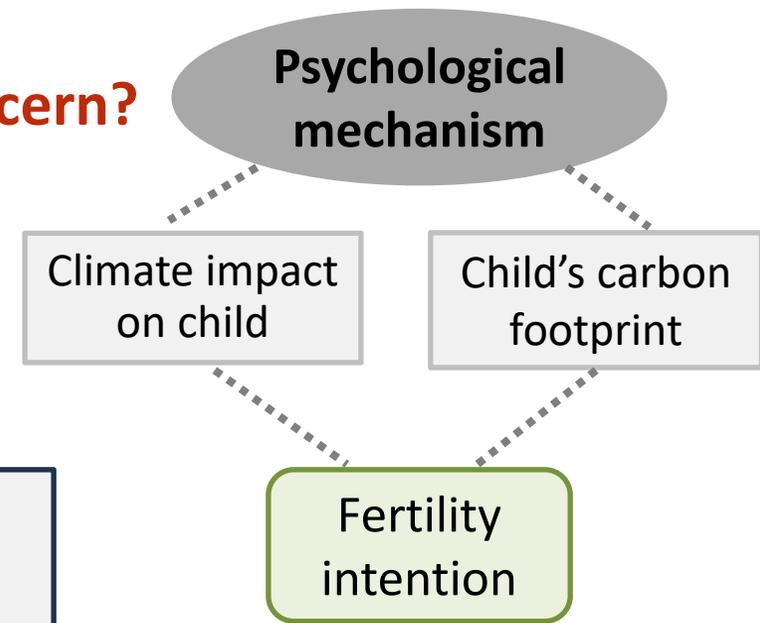


Not having a child due to climate change driven by which concern?

- Study by **Irene Frageri** and colleagues under POPCLIMA project
- Survey of young adults aged 18 – 34 (N = 5,948) in five European countries (**Italy**, Spain, France, United Kingdom and Germany).

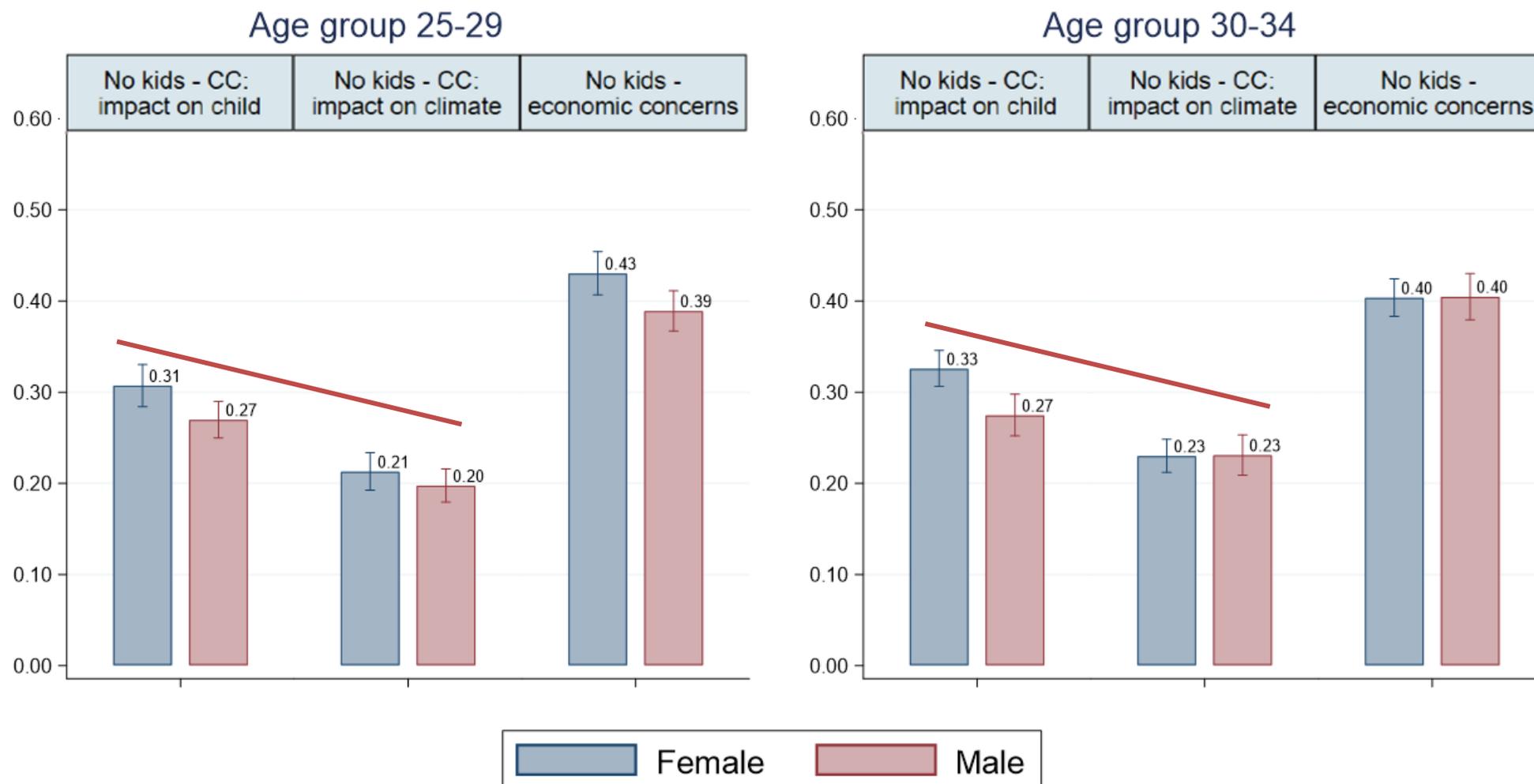
«Do you plan to have a child in the next 3 years?» Probably/ surely no (59%)

- a) Having kids is not part of my life project (*not in life project*)
- b) I'm single (*single*)
- c) Health reasons (personal or of the partner) (*health*)
- d) It is not compatible with either my or my partner's employment (*work-family conflict*)
- e) I should change my lifestyle/give up my interests (*change of lifestyle*)
- f) I cannot financially afford a(nother) child (*financial hardship*)
- g) I don't have any childcare support (grandparents, kindergartens, babysitters, etc.) (*no care support*)
- h) I would be too worried about the future that awaits the child because of climate change (*climate change impact on a child*)**
- i) I would be too worried about the future that awaits the child because of the economic situation of the country (*future economy*)
- j) Each new human being has an environmental impact on the planet (*child impact on climate*)**

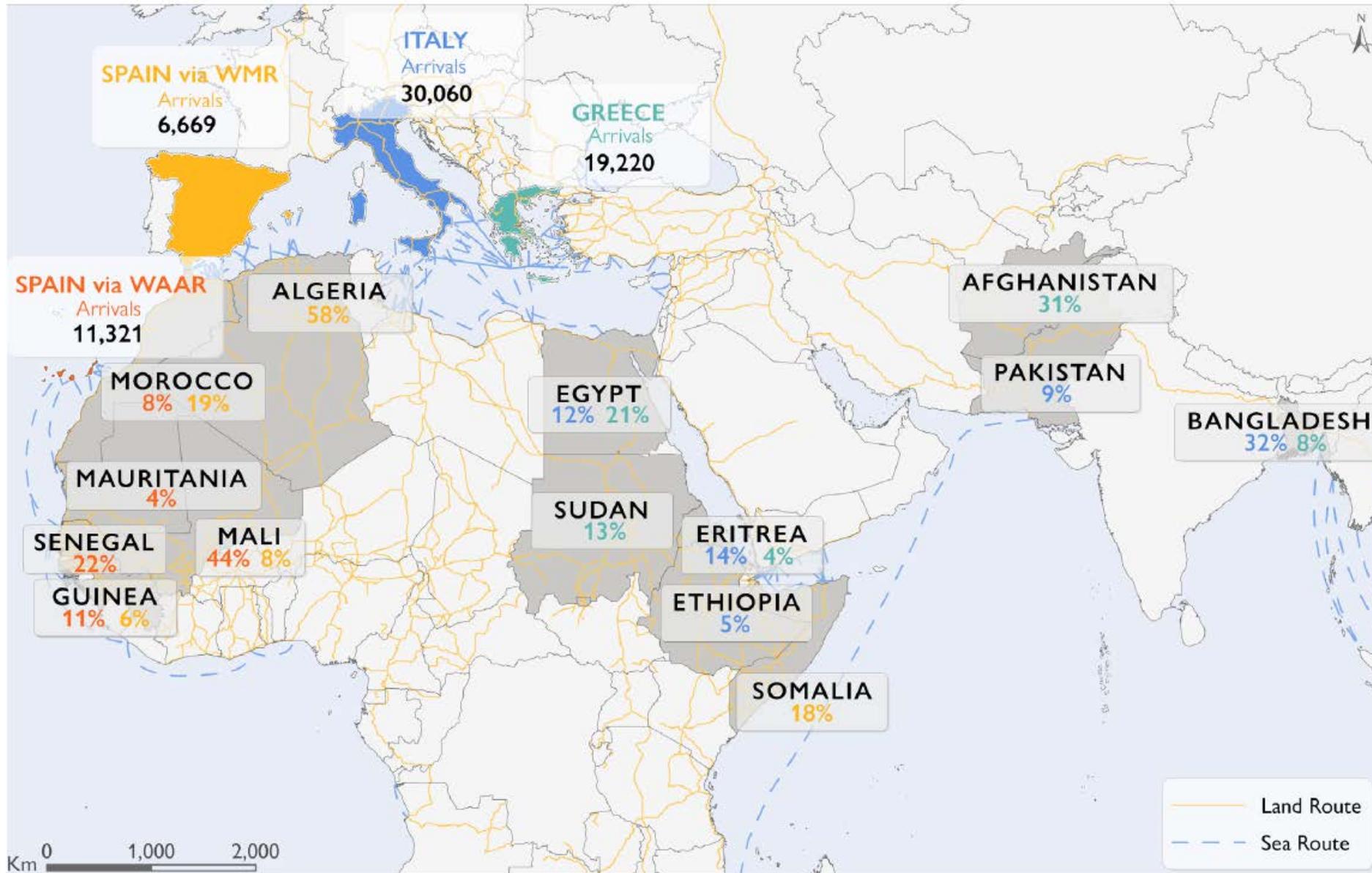


Not having a child due to climate change driven by which concern?

- **More people mention a concern about the climate impact on their child than a child impact on the climate**
- **Compounding with other reasons e.g. economic concerns**



Where do/will climate migrants go?



Main countries or areas of origin for arrivals in Greece, Italy, and Spain, January – June 2025

Source: [IOM 2025](#).



Are climate migrants legally recognised under international law?

Who is a refugee under international law?

- **1951 Refugee Convention** – only binding global treaties that address the rights and legal status of refugees
- “Refugee” is a legal term which has a very specific meaning centering on as an individual who is outside their country of origin and who, *“owing to well-founded fear of being persecuted for reasons of [redacted] is unable or . . . is unwilling to return to [their country of origin].”* (Art. 1, 1951 Refugee Convention).
- **Common European Asylum System** is not specifically designed to address environmental migration

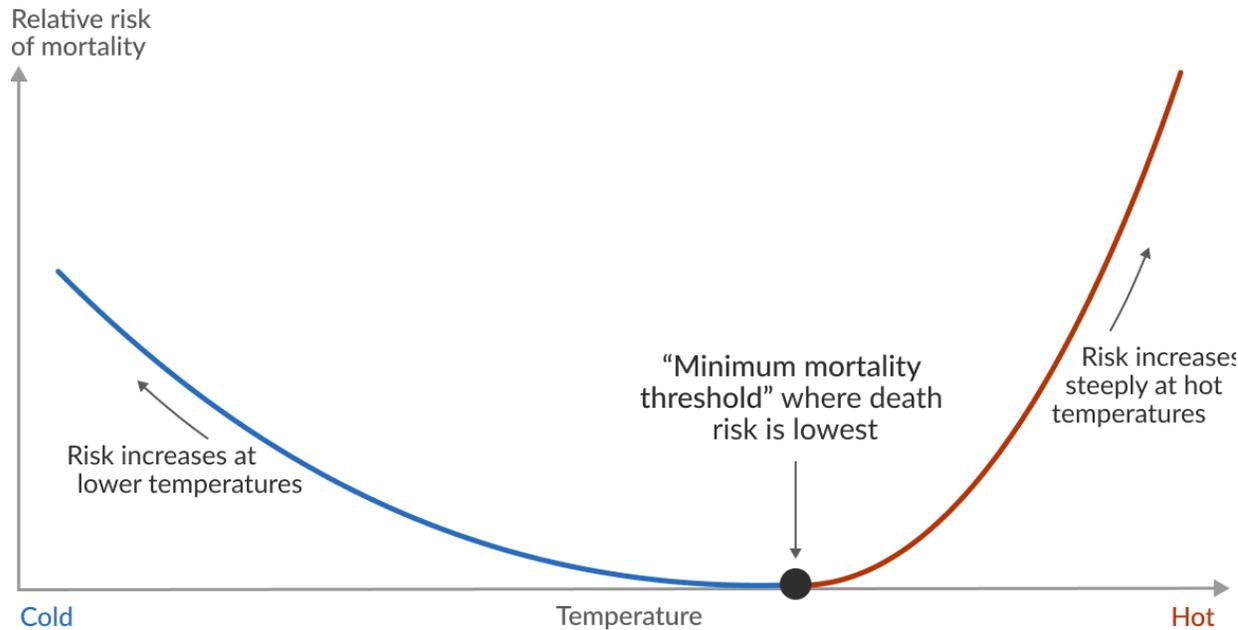
Which country in the EU provide protection for climate migrants?

- **Italy** – the only EU Member State with specific legislation to offer explicit and multiple protection statuses to people displaced due to disasters and climate change
- **Article 20 of the Consolidated Act on Immigration (CAI) 2018** provides collective and temporary protection measures for extraordinary humanitarian needs, including natural disasters (in Italian, *disastri naturali*), which occurred in non-EU countries.
- **153 residence permits** issued by Italian Questure from 2018-2023

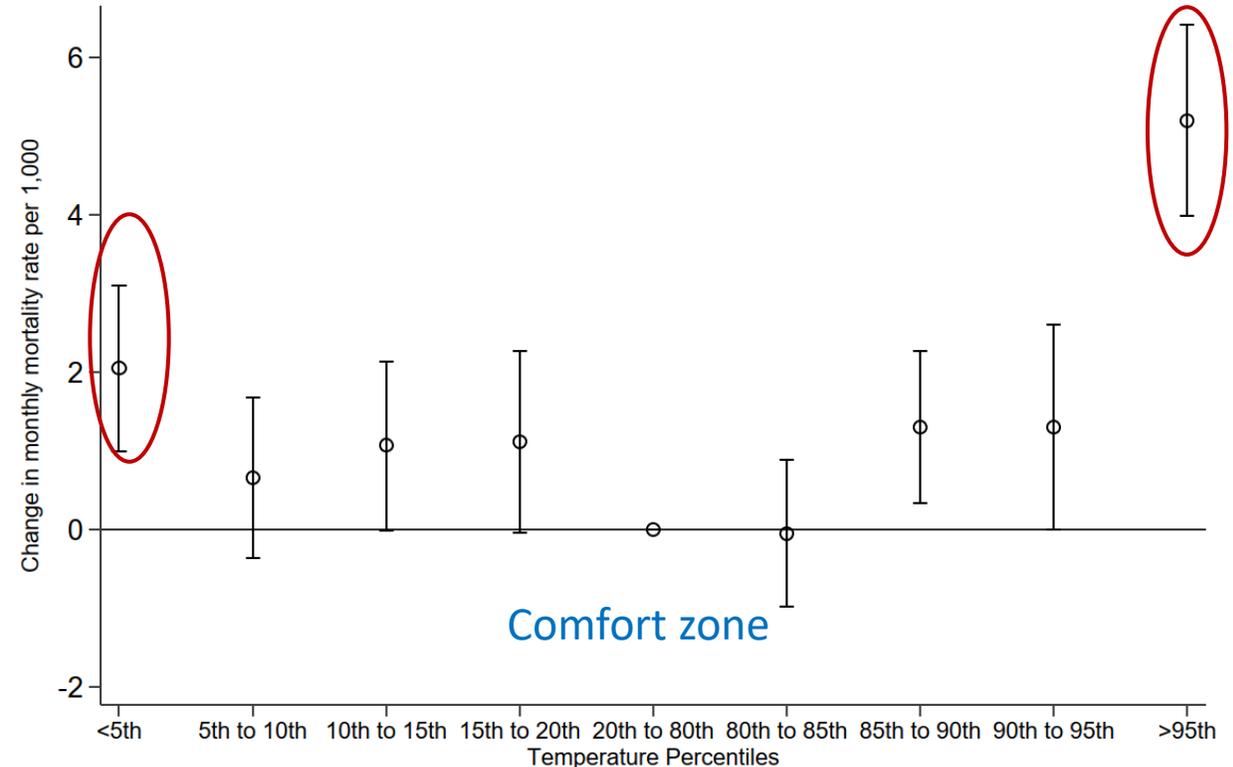


Evidence on climate change and mortality

Mortality-temperature curve



Extreme temperature and mortality rates in Italy: 2011-2022

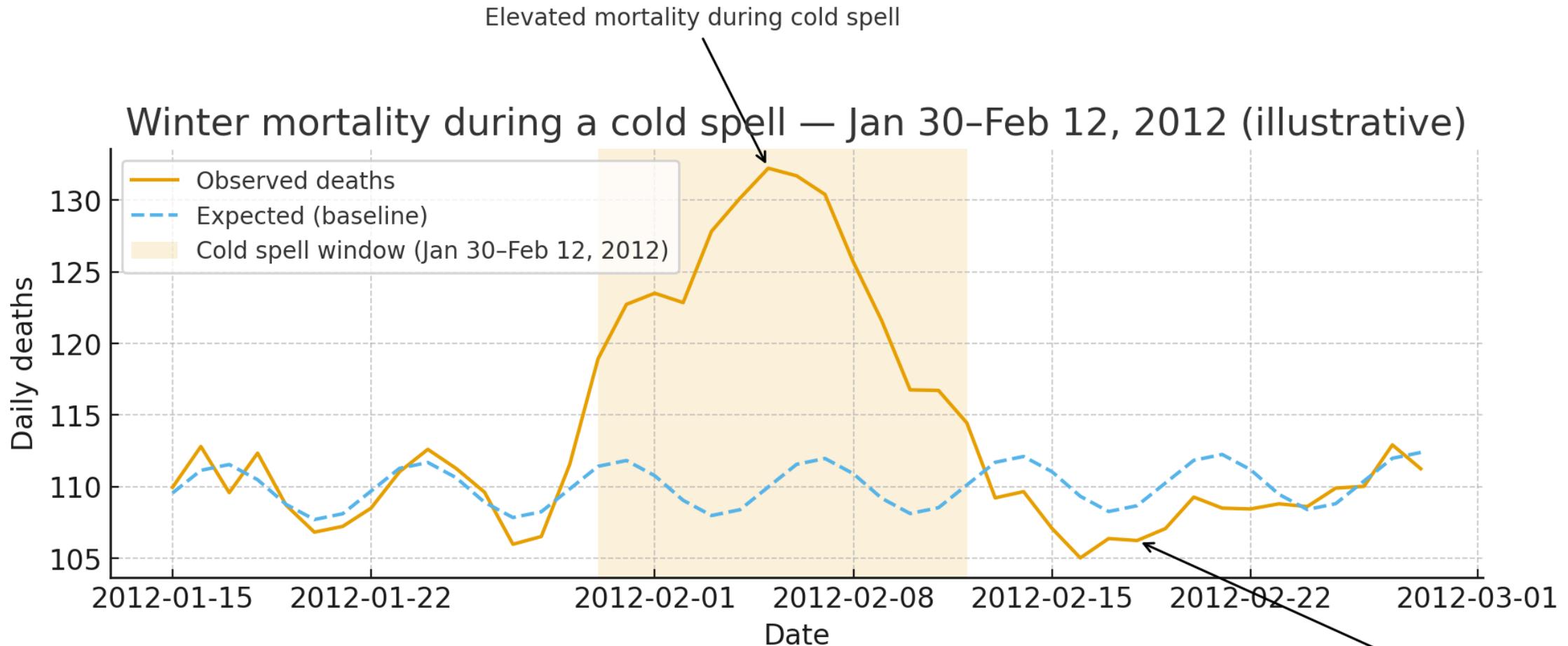


Source: [Our World in Data](https://ourworldindata.org/).

Source: Joseph, V., Conte Keivabu, R., Mutarak, R., Zagheni, E. & Mazzuco, S. (forthcoming). *European Journal of Population*.



Will climate change shift the seasonal burden of temperature-attributable mortality from cold to heat?

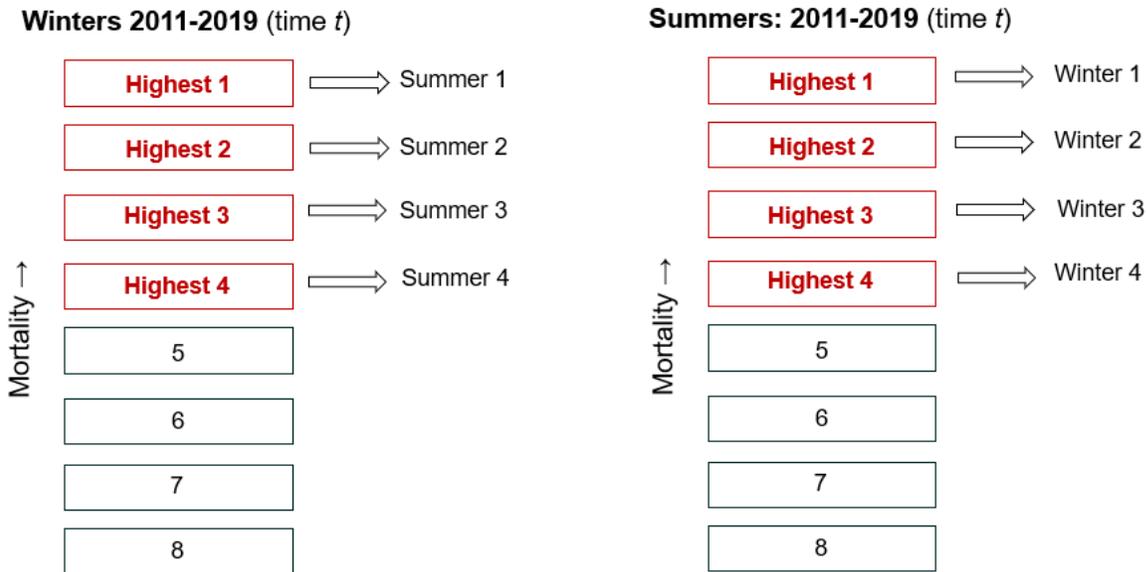


Harvesting (mortality displacement) – a heat/cold spike offset by below-baseline deaths in the following weeks (short-term advance of deaths among frail individuals)

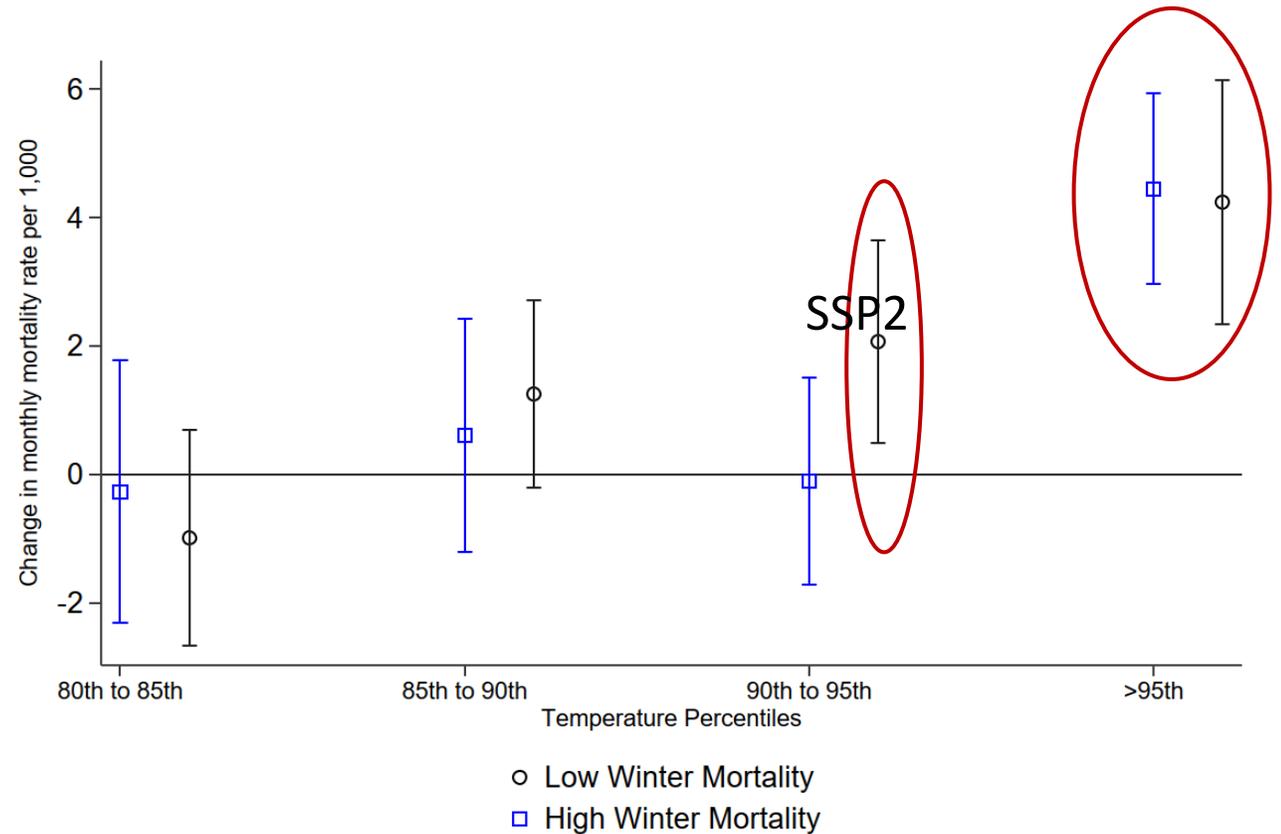
Modest post-event deficit (harvesting)

Some evidence of harvesting effect for Italy, but very warm days are still fatal

Measuring the harvesting effect

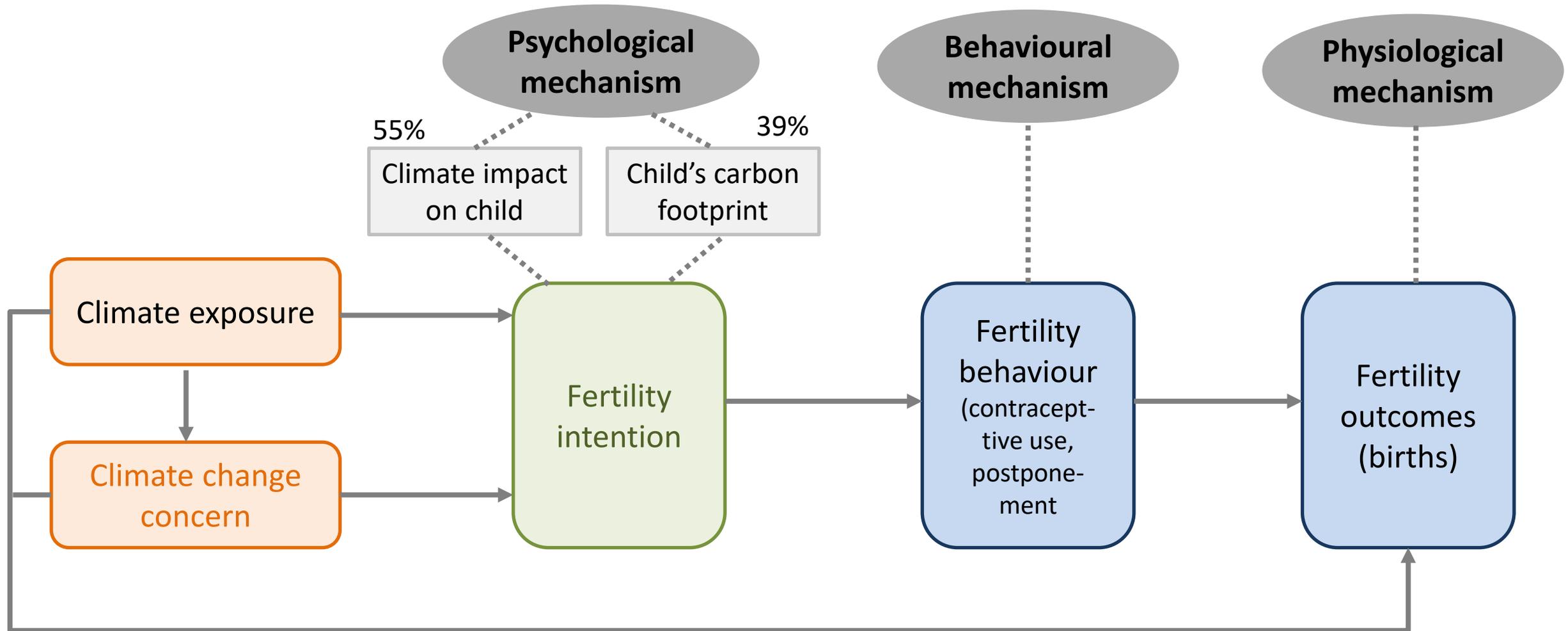


Heat and mortality in summer by winter mortality



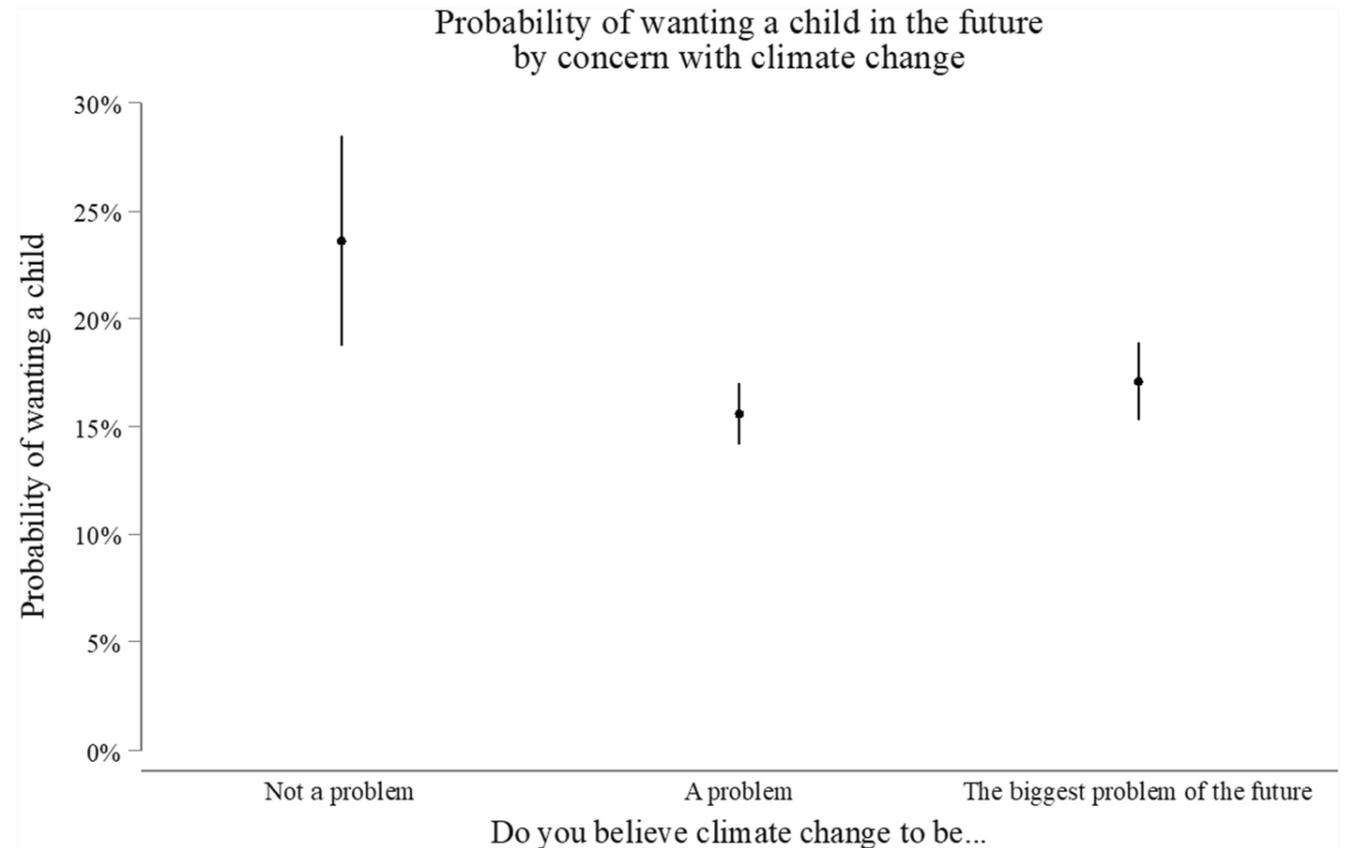
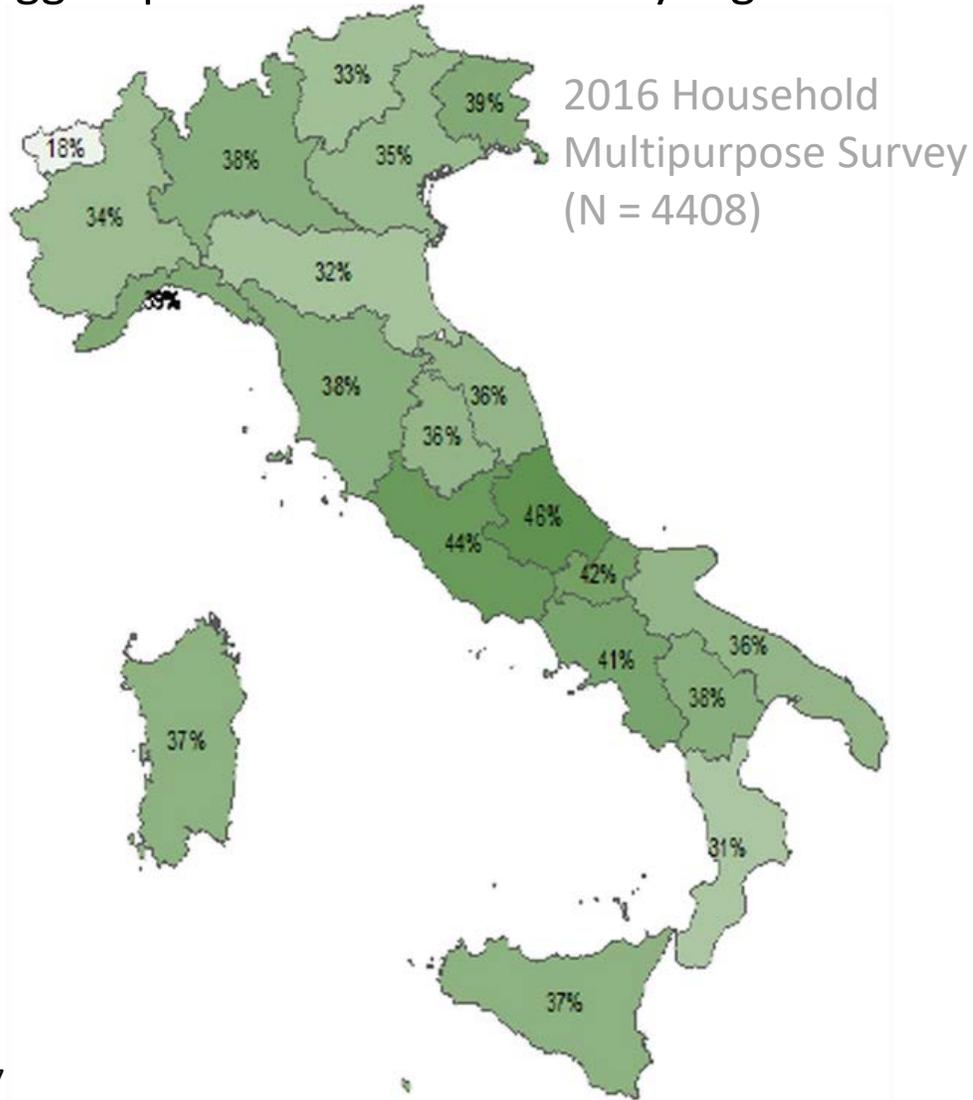
Source: Joseph, V., Conte Keivabu, R., Muttarak, R., Zagheni, E. & Mazzucco, S. (forthcoming). *European Journal of Population*.

Climate impact on fertility



Evidence on climate change concern and fertility intention

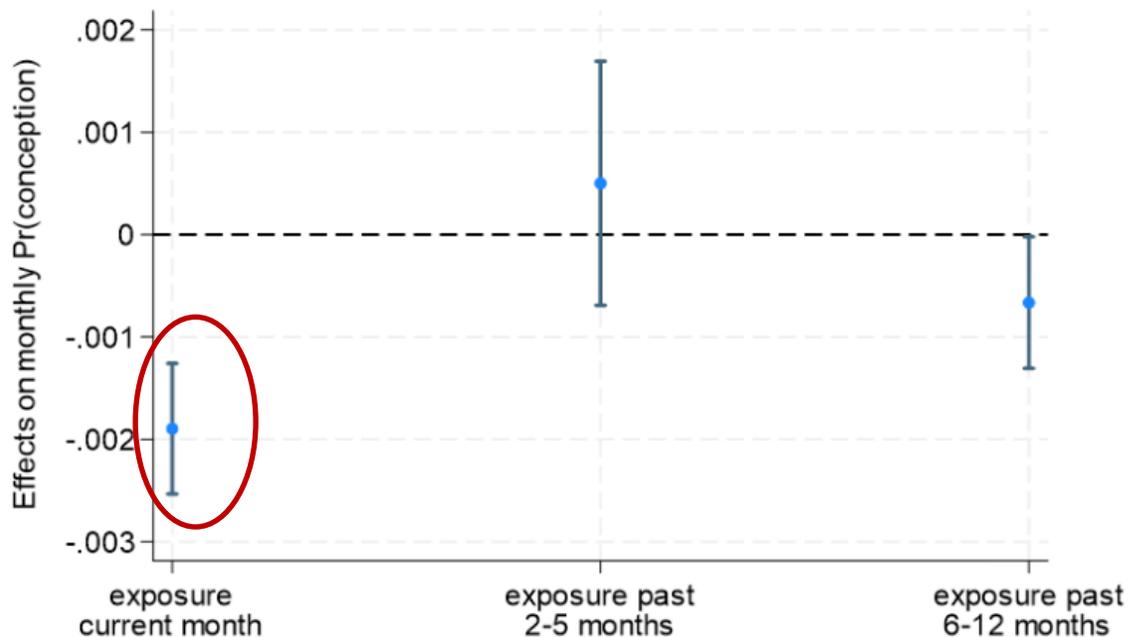
Proportion (%) reporting climate change to be the biggest problem of the future by region



Source: Puglisi, C., Muttarak, R. & Vignoli, D. (2025). [Genus](#).

Consistent findings using individual-level, longitudinal data (UKHLS, sample of childless individuals aged 16-45)

Exposure to heatwave. Average marginal effects with 95% CIs



Probability of conception declines significantly by 0.19 percentage points

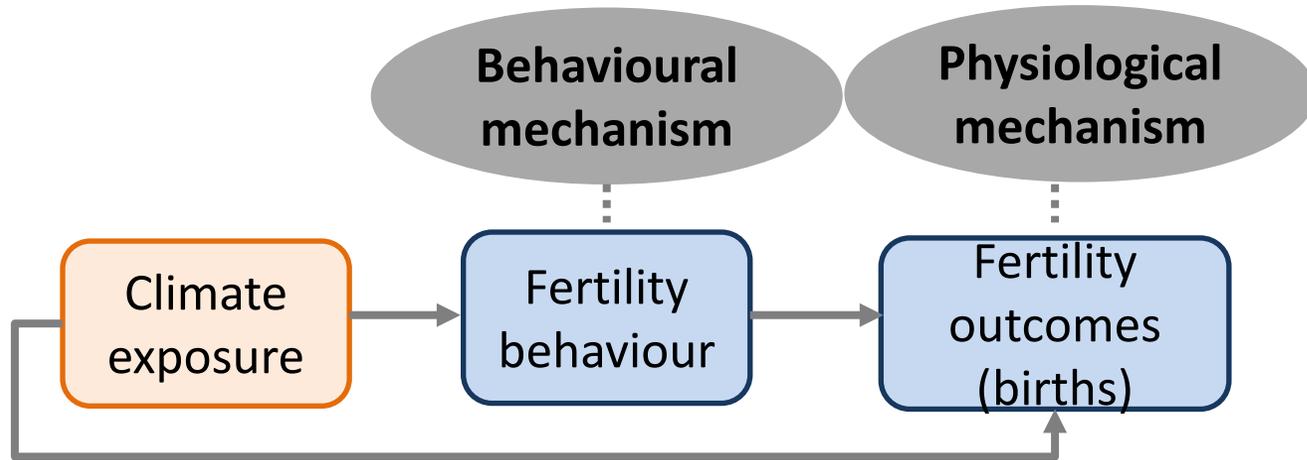
Exposure to flood. Average marginal effects with 95% CIs



Limited evidence of a negative relationship (-0.075 percentage points) between flood exposure and conception probability



Pathways from climate exposure to fertility outcomes

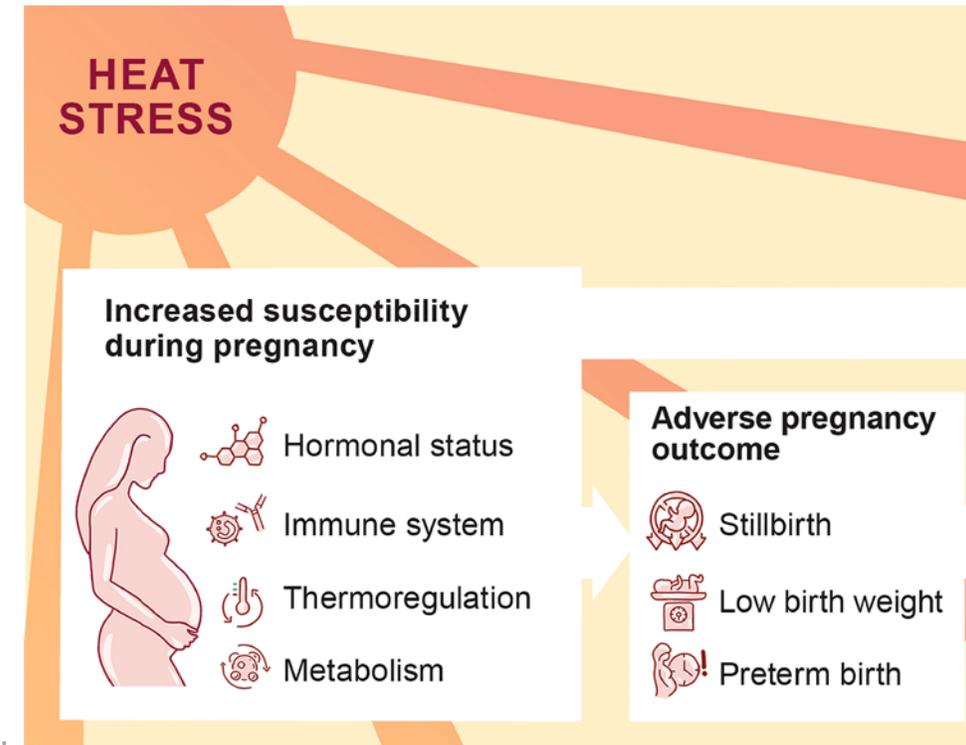


Behavioural mechanism

- Altered time-use patterns and fewer social interactions
- Changes in sexual behaviour and coital frequency
- Fertility goals and planning, contraceptive use
- Early marriage for girls
- Household resource constraints
- General maternal and child health
- Psychological well-being, concern about climate change

Physiological mechanism

- Spermatogenesis, sperm quality
- Ovulation cycle
- Ovarian reserve and placental development
- Reduced gestational length
- Increase risk of spontaneous abortion in the first trimester
- Increase risk of fetal loss and stillbirth



Towards population projections accounting for the climate feedback

Evidence of the impact of climatic shocks on demographic outcomes by far:

- **Fertility** – short-term negative effect, no recuperation (so possibly not due to postponement)
- **Mortality** – likely to increase under more warming
- **Migration** –
 - 1) displacement and internal migration are likely to increase;
 - 2) limited evidence on international migration;
 - 3) climate-induced migration within Europe is plausible.

Work in progress: Adding the climate feedback in population projections

- [Subnational population projections for Mexico](#) as a case study, adjusting for already existing state-level projections by Shared Socioeconomic Pathways (SSPs) – Cohort-component methods
- [Province-level projections for Italy](#) as a case study – integrate climate measures as covariates in probabilistic models of for mortality, fertility and migration
- [Global population projections](#) – adding climate covariates in the UN probabilistic projection models (country level)

