CHALLENGES AND PATHWAYS TO CONSTRUCTING SECTORAL EMPIRICAL DAMAGE FUNCTIONS

NAVIGATE/ENGAGE Expert Workshop

James Rising

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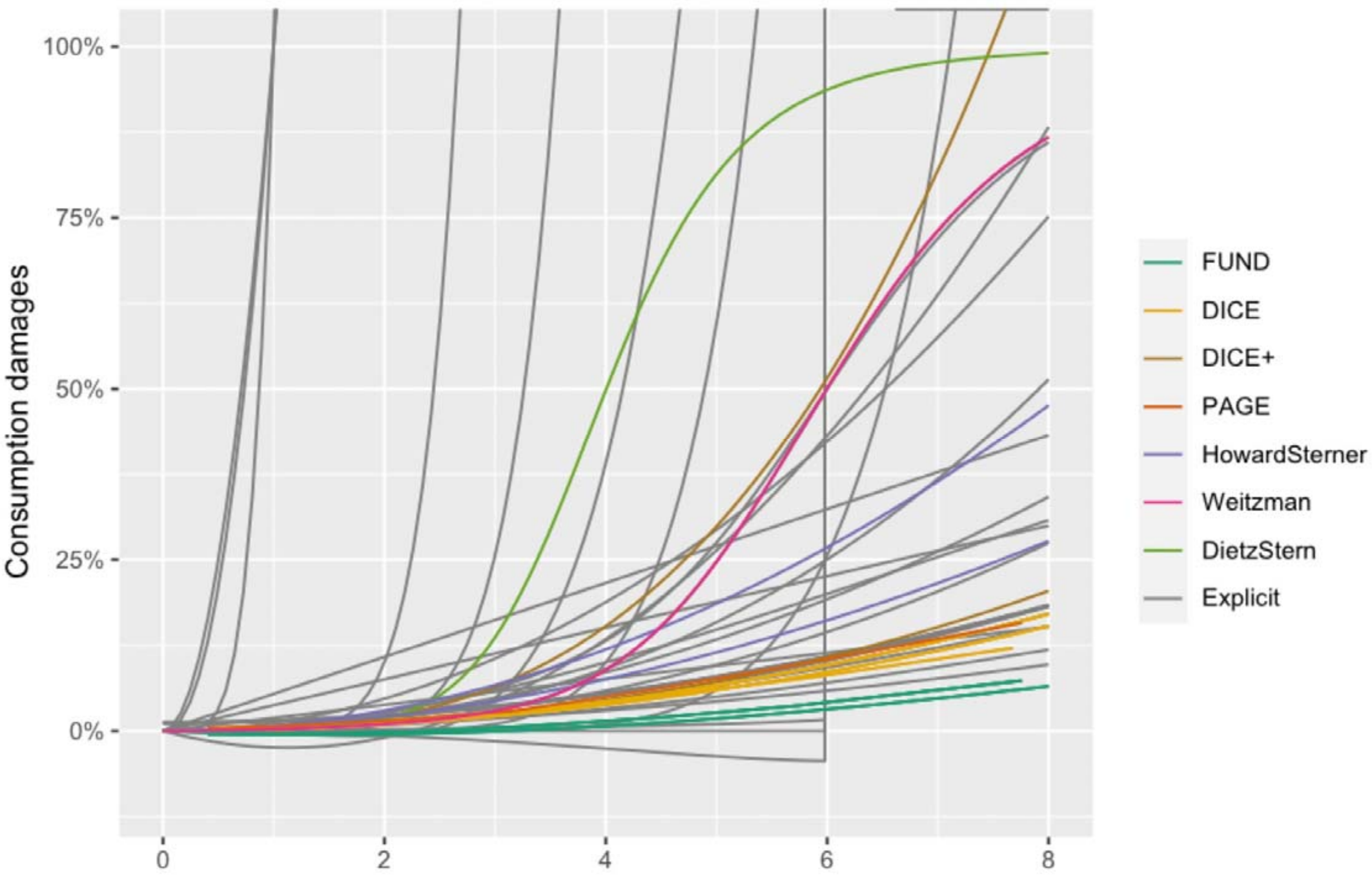
Goals

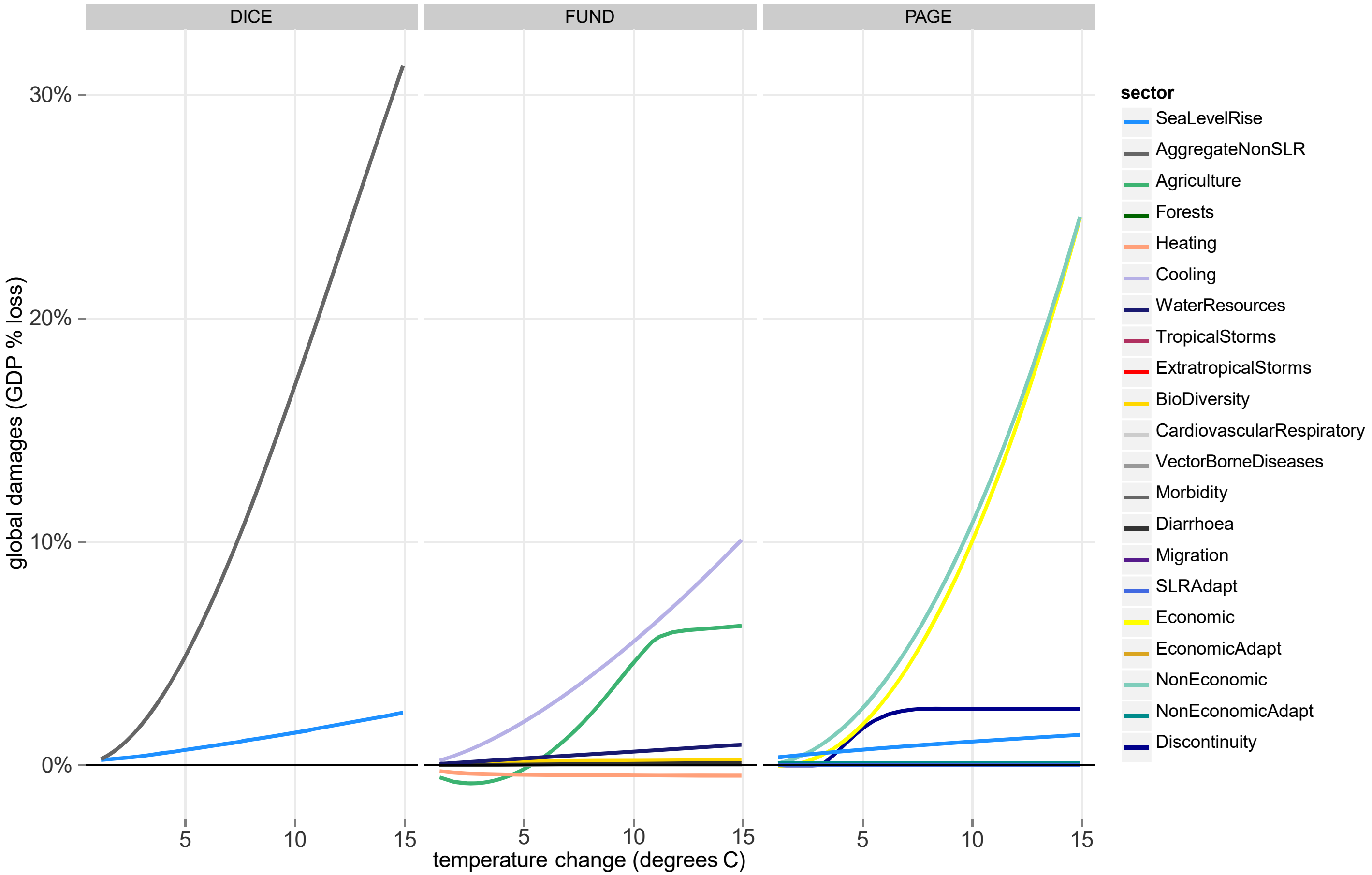
- Distinguish econometric dose-response functions, process-based impact functions, and (sectoral/total) damage functions
- Some recipes for getting damage functions
- Challenges of uncertainty and aggregation

The recent state of damage functions



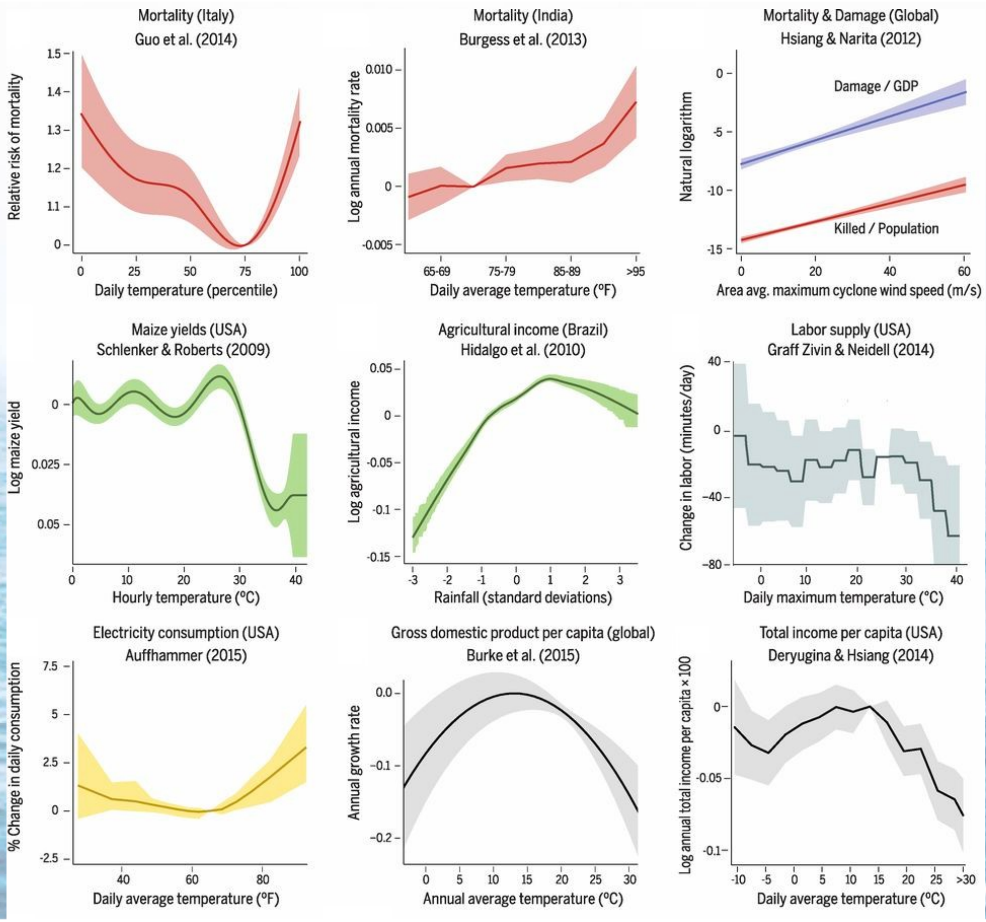
Moore et al. WP

Some sectoral damage functions



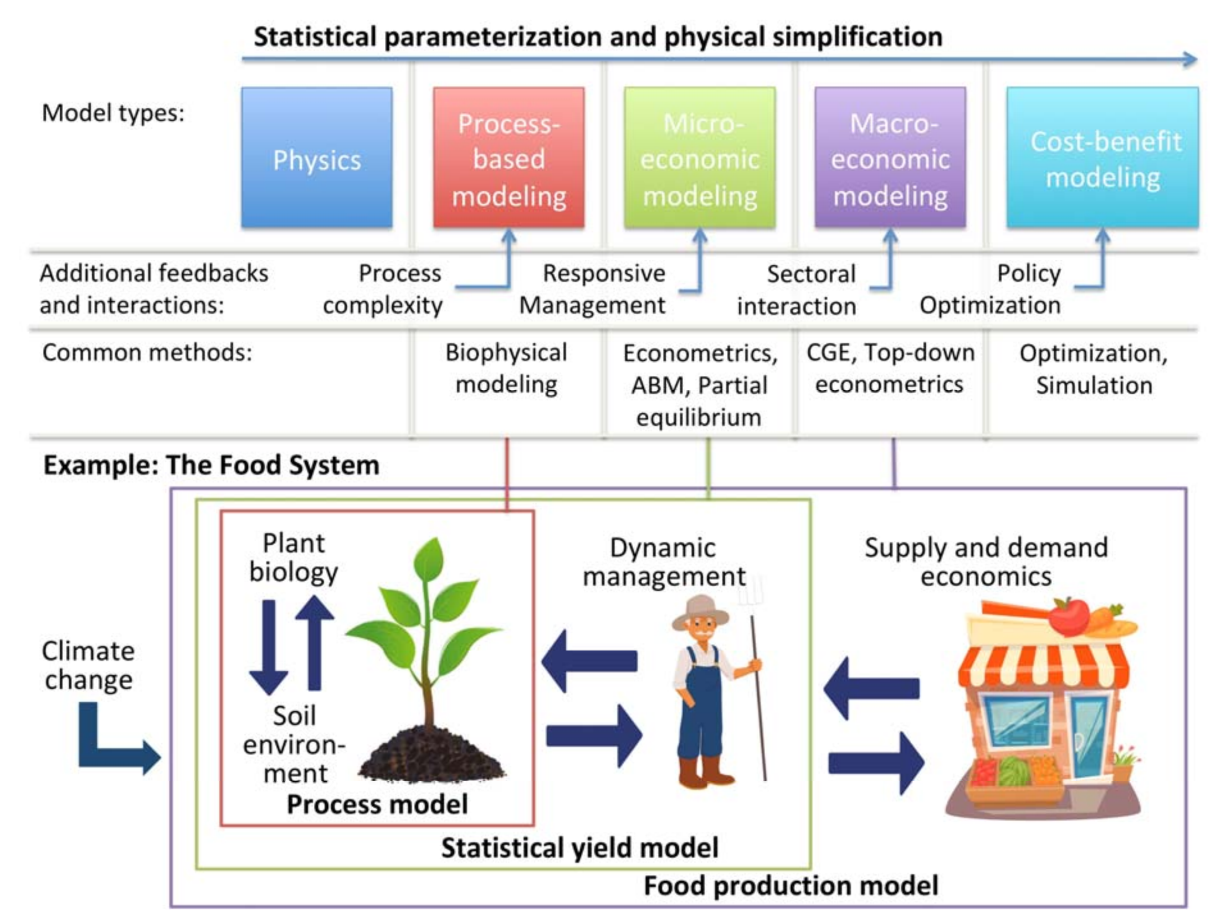
Diaz 2014 / Rose, Diaz, Blanford 2017

Explosion of empirical dose-response functions



Carleton & Hsiang 2016

Distinguishing between impact functions



Sources of impact functions

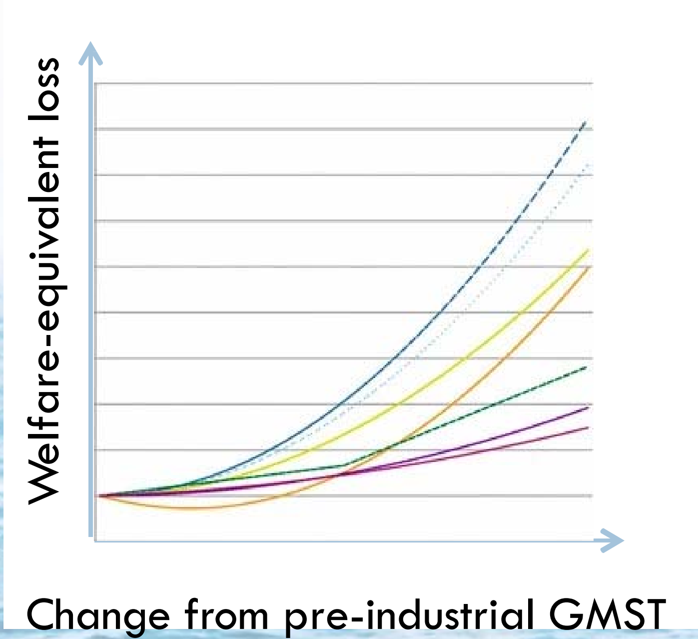
	Process-based	Econometrics
Calibration	Experiments; controlled sites (best with local calib.)	Aggregate, passively collected data
Adaptation	According to designated scenarios	Inclusive of autonomous adaptation ("dynamic management")
Parameter uncertainty	Generally missing	Considered essential
Extrapolation	Grounded in process physics	Grounded in data from current extreme regions

Clear opportunity to combine strengths:

- Build econometric "wrappers" on process-based projections.
- Rely on the extrapolation capacity of process-based models
- Add in the autonomous adaptation and uncertainty.

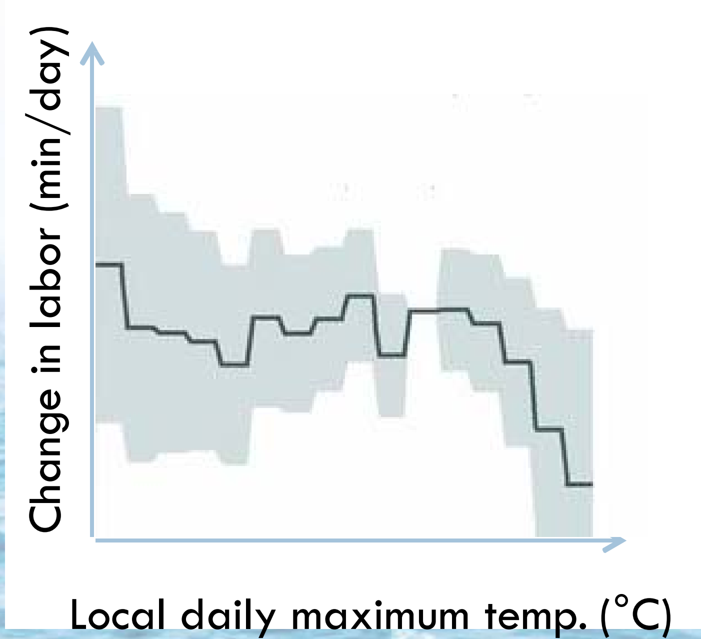
Dose-response vs. damage functions

- Damage functions



  - Can have sector-specific output, but to determine need equilibrium.

- Dose-response functions

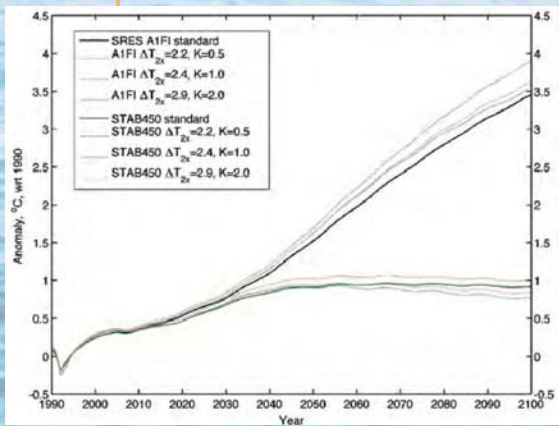


  - Can do total GDP losses, but still need to estimate non-market sectors.

Appropriate future projection approaches

- Damage functions

Simple climate model → Damage function



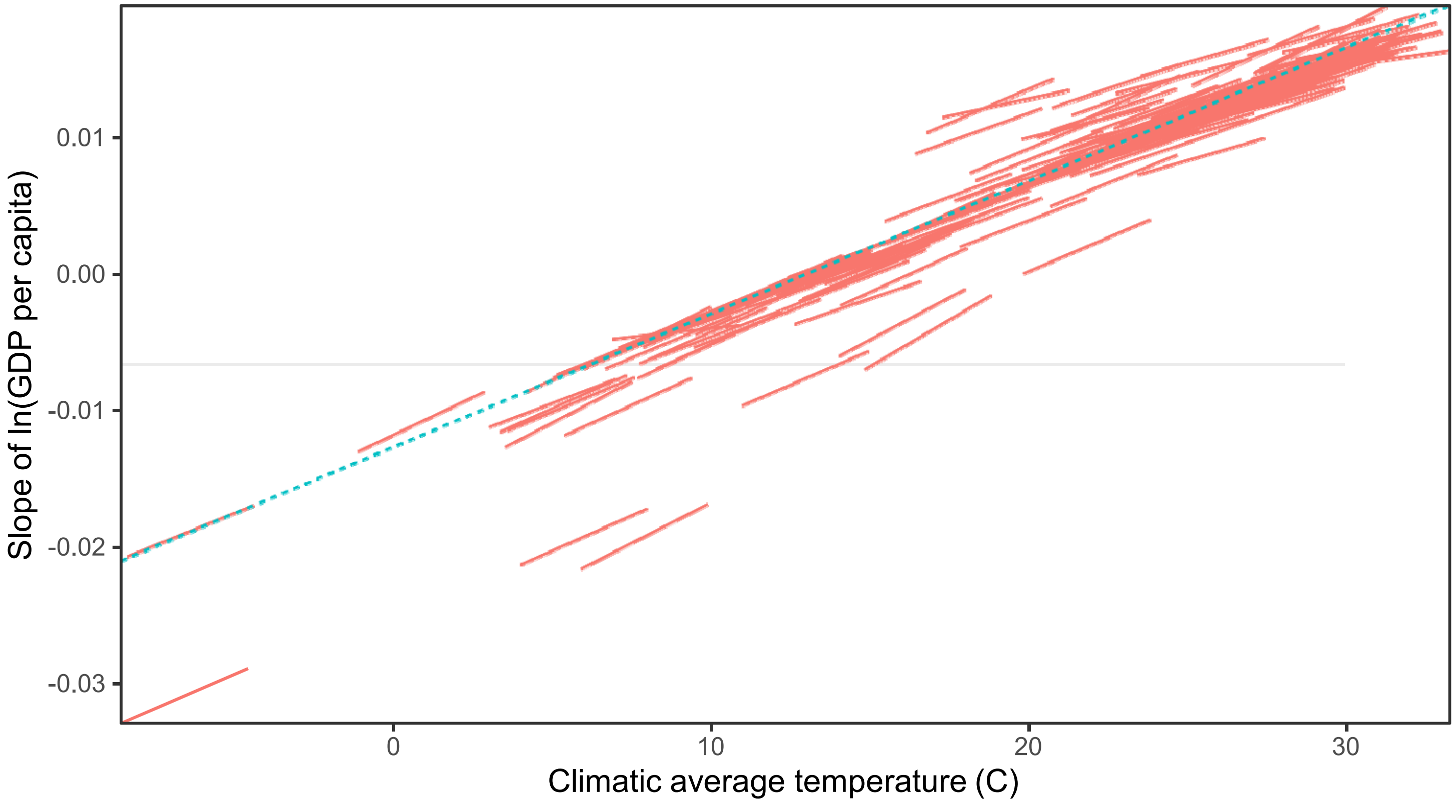
- Dose-response functions

BCSD GCM → Dose-response function → CGE or Valuation + SWF

Social welfare function translates consumption to welfare:

$$W = \sum_t \sum_r P_{tr} U(c_{tr})(1+\rho)^{-t}$$

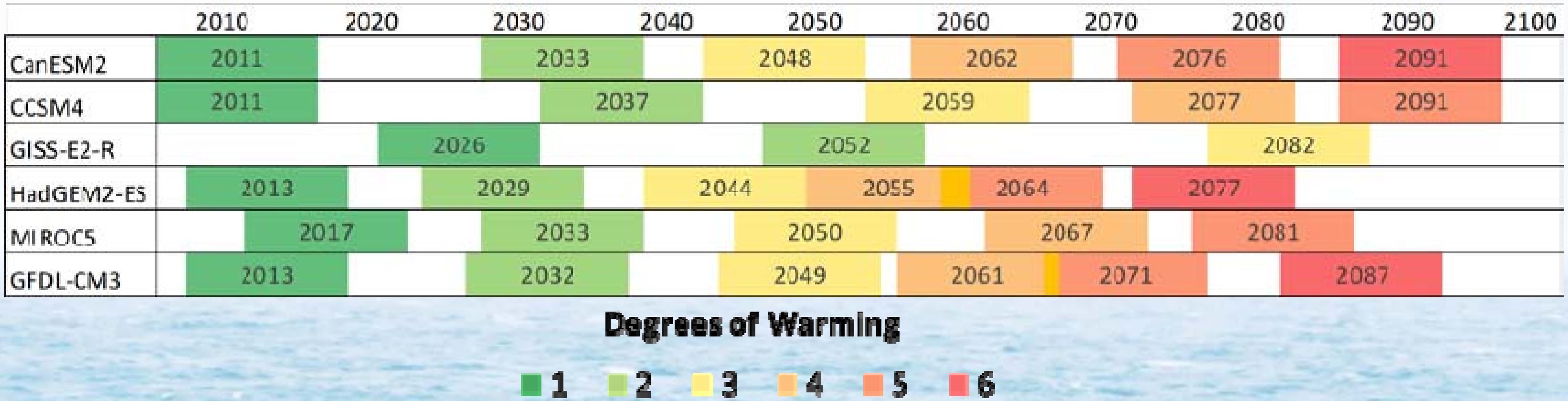
Size of mismatch for Burke et al.



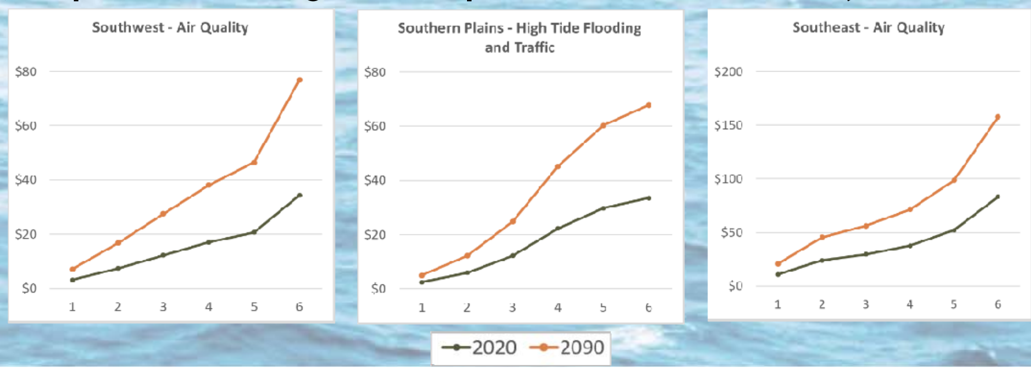
Adjusted marginal effect by country Burke et al. (2015)

Options for DFs: EPA Temperature Binning Framework

- **Average** projected impacts over period that GCMs reach temperatures:

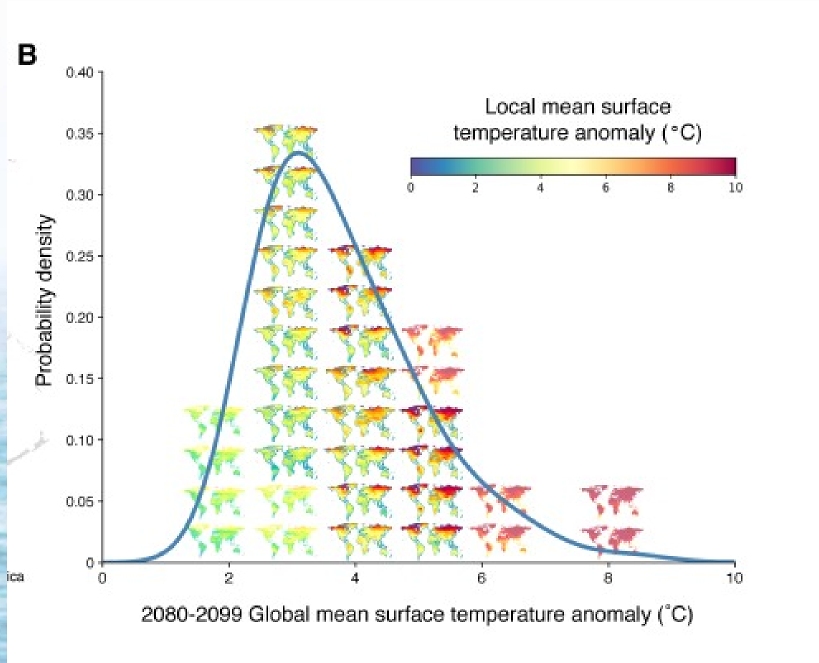


- Normalize by socioeconomics, report average "temperature binned" (linear spline) damage functions:



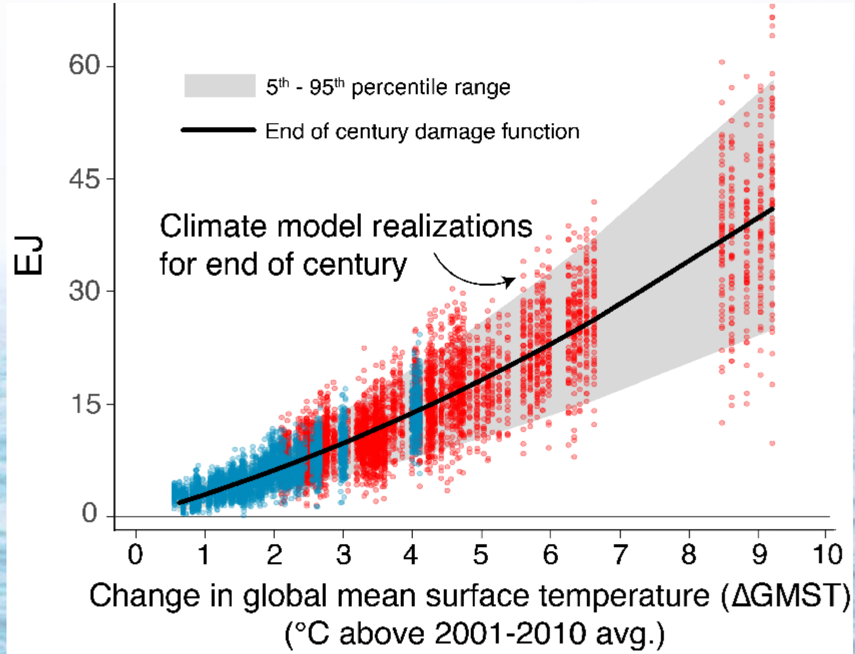
Considerations for uncertainty

- Econometric projections have uncertainty over:
  - Econometric parameters (requires VCV matrix)
  - Econometric specifications (e.g., functional forms)
  - Spatial patterns of warming
  - Temporal patterns of warming
  - Socioeconomic uncertainty (space & time)
  - Annual variability



Options for DFs: CIL Time-varying DFs

- Fit quadratic to Monte Carlo distribution by year, quantile regressions for uncertainty.



- Use multiple GCMs for temperature range
- **Conditional on an SSP.**

Considerations for aggregation

Scale-independent?

- Most properly done econometric projection is scale independent:
  - Assumed that data-generating process is at point-level.
  - Use aggregate data to infer point-level dose-response function.
  - Estimation and projection both use "transformation-before-aggregation": e.g., the weighted average of polynomial terms of weather, rather than the polynomial of weighted average of weather.
- Depends on dependent variable being linear (so, not for growth rates).

Aggregation dependent?

- CIL damage functions also conditional on welfare assumptions for aggregation.
- Welfare losses are not scale independent.
- Aggregates over space are conditional on inequality aversion.
- Aggregates over time are conditional on risk aversion and insurance assumptions.

Options for DFs: CIL-RFF/Rising-Anthoff

- Fit sectoral damage function of the form

$$M_{it} = (\alpha_i T_t + \beta_i T_t^2) Y_{it}^{\gamma}$$

  - Across **high-res regions** i (25,000 for CIL damages). T_t is change from pre-industrial.
    Y_{it} is income, and damages affected by elasticity.
- Generally report in physical units (M for mortality rate changes).
- Valuation, aggregation, Monte Carlo modeling all left to the IAM.

Some challenges to note

- Want damage = 0 at T = 0, but econometrics relative to known projection period.
  - Solution: Assume $N_{it} = M_{it} + \delta_i Y_{it}^{\gamma}$, can estimate intercept and then drop.
- Nonlinear function to fit to high number of MC runs.
  - Solution: Fit elasticity first, under non-parametric assumption; then fit polynomial under quantiles of elasticity.

$$\log N_{it} = \log(\delta_i + \alpha_i T_t + \beta_i T_t^2) + \gamma \log Y_{it}$$

$$\log N_{it} = \sum_k \theta_{i,k(T_t)} + \gamma \log Y_{it} + \delta_t$$

Some challenges to note

- Individual region impacts are correlated.
  - Solution: Maintain covariance ρ_i between θ_i and global $\bar{\theta}$.
- Full uncertainty not captured by uncertainty in γ, α_i, β_i.
  - Solution: Describe uncertainty as Monte Carlo draws k:

$$M_{itk} = (\hat{\alpha}_{ik} T_t + \hat{\beta}_{ik} T_t^2) Y_{it}^{\hat{\gamma}_k} + \hat{\theta}_{ik} T_t Y_{it}^{\hat{\gamma}_k} + \hat{\phi}_{kit}$$

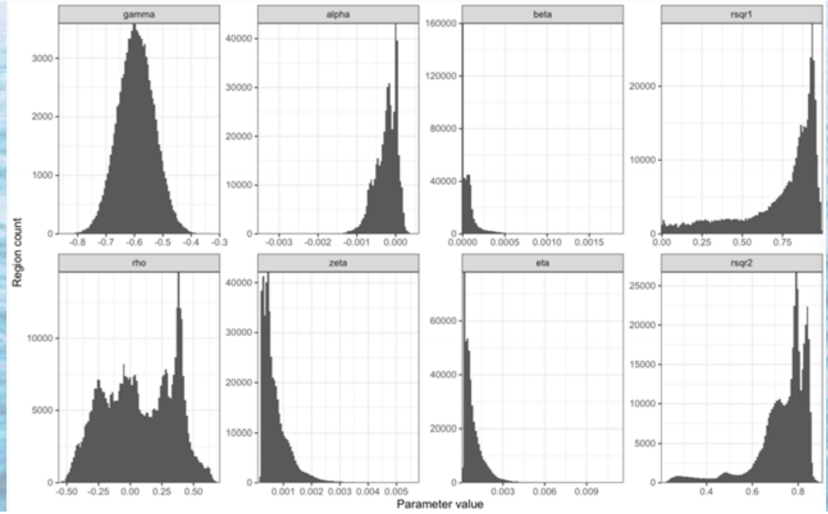
  - With γ, α_i, β_i ~ MVN, $\hat{\theta}_{ik}$ ~ N(0, ζit), $\hat{\phi}_{kit}$ ~N(0, η_{ik})
  - Essentially parameterized range of uncertainty.

Some challenges to note

- Elasticity estimates are very non-robust.

	Dependent variable:							
	log deaths							
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
log GDP p.c.	−0.636***	−1.092***	−0.686***	−1.117***	−0.472***	−1.085***	−0.506***	−1.069***
	(0.003)	(0.004)	(0.003)	(0.004)	(0.003)	(0.004)	(0.003)	(0.004)
Incl. costs?	no	no	no	no	yes	yes	yes	yes
Pop. weight?	no	no	yes	yes	no	no	yes	yes
Obs. included	All	Pos.	All	Pos.	All	Pos.	All	Pos.

- Many different outcomes across high-res regions.



Some considerations in DF choice

	Temp. Binning Framework	CIL Time-varying	Rising-Anthoff
X-axis: Temperature relative to…	Pre-industrial	2001-2010	Pre-industrial
Y-axis or Valuation process	Physical units	Pre-valuated	Physical units
Socioeconomics	Linear after normalization	Specific to projected scenario	Elasticity parameterized
Statistical uncertainty	None	Perfectly correlated along quantiles	Parameterized quantiles
Temporal variability	None	5-year functions, but averaged out	Modeled annual variability
Spatial resolution	US regions	Global	Projection-level
Fitting weaknesses	Only uses integer atemperatures	Data-intensive	Sensitive to poorly-estimated income elasticity.
Availability	16 sectors, coordinated with authors (soon)	5 sectors from CIL (soon)	CIL sectors as published (soon)
Provided as	R package with socioeconomics normalization	Python package with SSP x time-specific DF quantiles	Julia package with region x distribution parameters

THANK YOU

jrising@udel.edu