Integrating growth damages in IAMs: Persistencies and channels

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Based on work with Anselm Schultes, Gunnar Luderer, Elmar Kriegler, Ottmar Edenhofer, Tobias Geiger, Hazem Krichene, Inga Sauer
Increasing empirical evidence for persistency and for differentiated effects

**Short-term / aggregate level** (high confidence)
- Nonlinear response of economic production to (annual) temperature fluctuations
  - Provides no understanding of the underlying processes / impact channels
  - What is the role of climate extremes?

**Long-term impacts of climate extremes** (low confidence)
- Tropical cyclones and droughts may have adverse impacts on economic development in the long run

Among others: Burke et al. 2015, Kalkuhl & Wenz 2018, Pretis et al. 2018, 2018

[Berlemann & Wenzel 2016/18,. Hsiang & Lina, 2014]
**Basis:** Cross sectoral consistent bio-physical impact simulations – The Inter-Sectoral Impact Model Intercomparison Project (ISIMIP)

### Climate data
- (daily, 0.5° x 0.5°)
- Historical observations + Projections CMIP 5/6

### Socio-economic input
- (population, land-use, GDP, agricultural + water management)
- Historical observations + Future Projections (SSP)

### Impact Models (global + regional)
- Water
- Agriculture
- Coastal infrastructure
- Biomes
- Health
- Permafrost
- Energy
- Biodiversity
- Marine Ecosystems

### Main objectives
- Temporally and spatially explicit impact simulations
- Impact attribution
- Future projections of climate risks

- Permits separation of climate and socio-economic drivers
Global area affected by climate extremes

Colors = Climate models
Shading = Impact model uncertainty

Work in progress

[Lange et al., submitted]
People affected globally by climate extremes

Colors = Climate models
Shading = Impact model uncertainty

Historical warming has almost tripled global population annually exposed to extreme events

Work in progress

[Lange et al., submitted]
Direct losses: Past economic losses of river floods – East Asia

Short-term loss variability captured well by river flood simulations driven by observed weather

[Geiger, Reese et al. in prep.]
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Socioeconomic vulnerability:

$$\log\left(\frac{D^{obs}}{D^{mod}}\right) = \alpha_j + \beta_j \log(GDP_{cap})$$

[Geiger, Reese et al. in prep.]
Direct losses: Past economic losses of river floods – East Asia

Recent loss reductions in East Asia could be explained by substantial investments in flood protection in China
Reproducing past economic losses of river floods – Global

[Geiger, Reese et al. in prep.]
Persistencies of damages

- For each disaster category:
  Correlate historical economic growth rates with **people affected** by climate extremes

\[ g_{j,t} = g_{j,t}^0 + \sum_{l=0}^{L} \beta_l P_{j,t-l} \]

- unperturbed growth path (country fixed effects)
- climate losses

\[ \beta_0 \quad \beta_1 \quad \beta_2 \]

[Hsiang, 2014]
[Berlemann & Wenzel (2016 & 2018)]
Long-term impacts of tropical cyclones & fluvial floods (global)

• Cumulative growth-effect k years after exposure:

\[ \Omega_k = \sum_{l=0}^{k} \beta_l \]

Tropical cyclones and fluvial floods reduce GDP growth in the long-term

[Krichene et al., in prep]
From event-based to temperature-dependent damage functions

• Ensemble of timeseries of growth losses from ISIMIP
  • 2 RCP x 4 GCM x N impact models x SSP2
  • Hope
    • For each SSP scenario, share of affected people can be expressed as function of global mean temperature change

\[
\delta_{j,t}(\{P_{j,t-l}\}_{l=0}^L) = \sum_{l=0}^L \beta_l P_{j,t-l}
\]

\[
\delta_j(t, \Delta T) = \delta_j(P_j(\Delta T))
\]

[Geiger et al., in prep]
Integration in IAMs
Integrated assessment with soft-coupled damage and climate module

→ Impacts internalized through social cost of carbon as a price on emissions

→ Advantage: higher process detail and flexibility on climate and damage modeling side

Schultes et al. (in prep.)
Analytical expression of the Social Cost of Carbon

For output damages:

$$SCC_t = \sum_r \sum_{t'=t}^T \Phi_{t',t} Y_{r,t'} D_{r,t'} \sum_{t''=t}^{t'} \Theta_{r,t',t''}(T) \kappa_{r,t''} \Delta T_{t''}$$

- $\Phi_{t',t}$: discount factor
- $Y_{r,t'}$: damage factor
- $D_{r,t'}$: unperturbed income
- $\Theta_{r,t',t''}(T)$: marginal damage from incremental temperature increase
- $\kappa_{r,t''} \Delta T_{t''}$: regional temperature response at time $t''$ to emissions at $t$

- $\Theta_{r,t',t''}$: marginal damage from incremental temperature increase

Schultes et al. (in prep.)
Persistence as key characteristic of damages

- Few empirical constraints – literature points to about 15 years

- Our channel study:
  - half-life time depends on channel & dynamics (endogenous vs. exogenous growth, savings rate)
  - accumulation of shocks with higher persistence leads to high damages

One-time shock on different production factors/productivity

Accumulating shocks
Burke-based damages with different degrees of persistence – uncertainty & adaptation

\[ D_{r,t} = \prod_{t'=1}^{t}(1 + \delta_{r,t'}2^{-(t-t')/\tau_H}) \] with \( \delta_{r,t} = \beta_1(T_{r,t} - \bar{T}_r) + \beta_2(T_{r,t}^2 - \bar{T}_r^2) \)

Response to temperature shock

Cumulative effect for step change in T

Schultes et al. (in prep.)
Effect of persistence on near-term carbon prices

- CBA analysis in REMIND IAM
- Uncertainty from climate and socioeconomics (SSP1,2,5)

<table>
<thead>
<tr>
<th></th>
<th>$\beta_1$</th>
<th>$\beta_2$</th>
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<tr>
<td>DICE2013</td>
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<tr>
<td>Burke short run</td>
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</tr>
<tr>
<td>Burke long run</td>
<td>-0.0037</td>
<td>-0.0001</td>
</tr>
</tbody>
</table>
What is the welfare optimal response to global warming?

Least total cost (LTC):
- Minimizing the cost of abatement and damage under climate target
- Hedge against long-term changes & tipping points as well as account for near-term marginal damages

Cost-effectiveness (CEA):

Cost-benefit (CBA):

Schultes et al. (in prep.)
Least total cost: More ambitious near-term mitigation

Ensemble:

- **Socio-economics**: SSP1, SSP2, SSP5
- **Climate uncertainty**: 5th, 30th, 50th, 70th, 95th percentiles of 2100 temperature distribution in ensemble of RCP2.6 runs with MAGICC6
- **Impacts**: Burke short-term and long-term specifications, persistence times of 0, 5, 15, 30, ∞

Carbon price = SCC + guardrail tax
Carbon price = SCC + guardrail tax

[Graphs showing carbon tax vs. time and annual global emissions]

- **Line**: Ensemble median
- **Dark shading**: 20-80th percentile
- **Light shading**: full ensemble

Schultes et al. (in prep.)
Next step: Closing the loop with ISIMIP impacts

• Channel-specific impacts – expressed either via output effects or directly

• Damages on capital stock from floods & tropical cyclones:
  • $K_{t+1} = (1 - \delta)\delta_t^K K_t + I_t \rightarrow$ for analytical expression of SCC we need to separate perturbed and unperturbed growth path of capital:
    $$K_t = \prod_{t'=0}^{t} (1 + \tilde{\delta}_{t'}^K) K_0$$
  • Later: labor productivity damages, other channels?

→ What do different damage categories contribute to the SCC?
Conclusions

• Framework to move from biophysical to economic impacts with different steps in evaluation
  • people affected as unifying metric
  • econometric analysis of growth effects
  • use time series directly or construct temperature-dependent damage functions

• Persistence key parameter

• Soft-coupled approach internalizing damages via SCC for more complex damage and climate modules – how far can that go in taking up channel-specific damages (or distributional effects of impacts)

• Least total cost approach to ensure near-term climate action based on comprehensive cost assessment - supports more ambitious near-term mitigation