Toward Assessment of the Costs of the Next Generation of Climate Change Impacts: Empirical Bases, Modeling Options, Old and New Challenges

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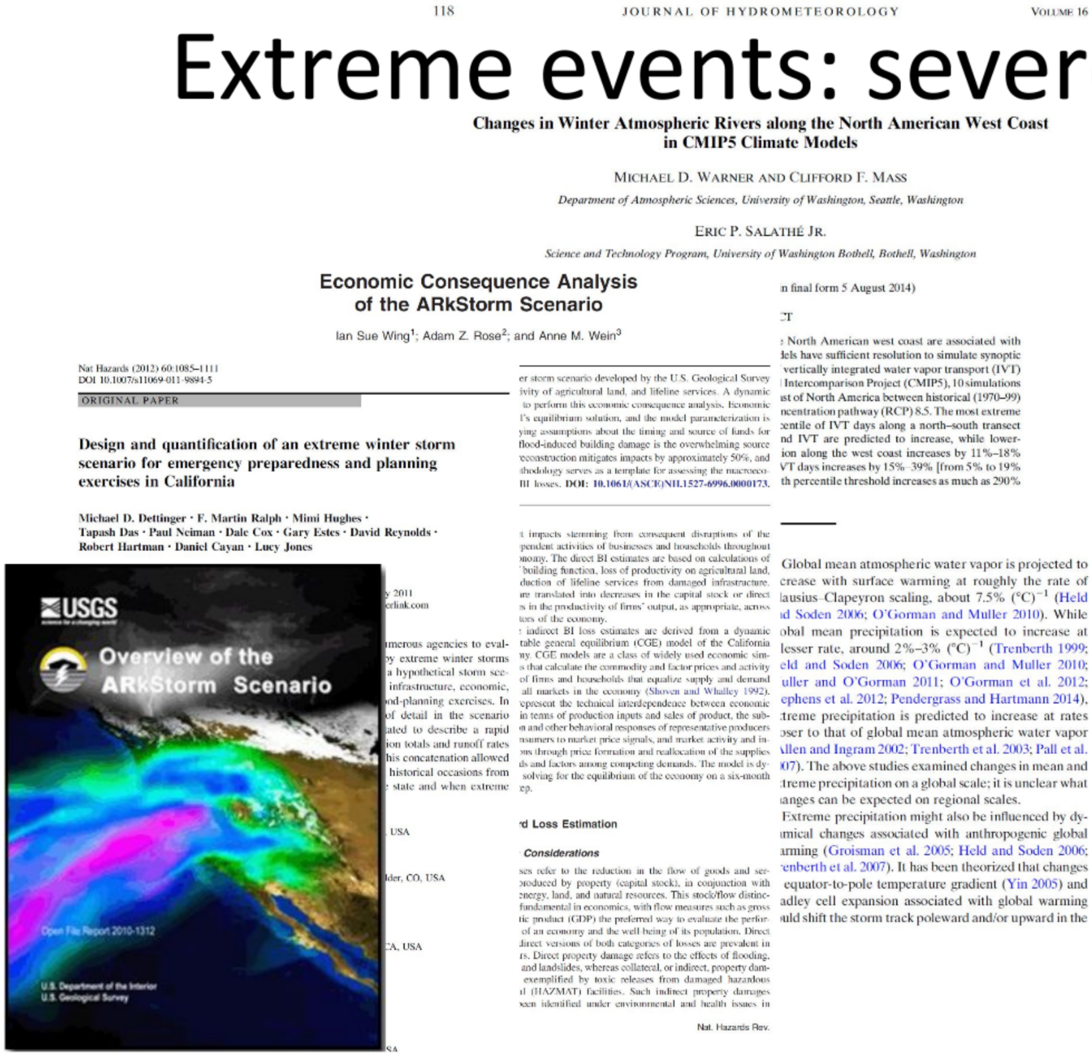
C2: Advancing the Economic Assessment of Climate Change. Gaps and future research

Agenda

- Major categories of impacts
  - Geographically localized, short duration extreme weather events
  - Inter- and intra-national migration
  - Health and labor productivity
  - Ecosystems and ecosystem services
- Key considerations
  - Spatial scale of analysis
  - Meteorological precursors, ability of earth system models to resolve them
  - Empirical basis for translating biogeophysical impacts into shocks to economic activities
  - Opportunities and pitfalls in connecting these shocks to models’ stylized representations of producer and consumer behavior

Extreme events: severe storms and floods



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Changes in Winter Atmospheric Rivers along the North American West Coast in CMIP5 Climate Models

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Economic Consequence Analysis of the ARkStorm Scenario

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Nat Hazards (2012) 60:1085–1111
DOI 10.1007/s11069-011-9894-5

ORIGINAL PAPER

Design and quantification of an extreme winter storm scenario for emergency preparedness and planning exercises in California

Michael D. Dettinger · F. Martin Ralph · Mimi Hughes · Tapash Das · Paul Neiman · Dale Cox · Gary Estes · David Reynolds · Robert Hartman · Daniel Cayan · Lucy Jones

USGS

Overview of the ARkStorm Scenario

Open File Report 2010-1312

U.S. Department of the Interior
U.S. Geological Survey

Focus: rich characterization of economic consequences of **singular** extreme weather events occurring on relatively short time-scales over a limited geographic domain

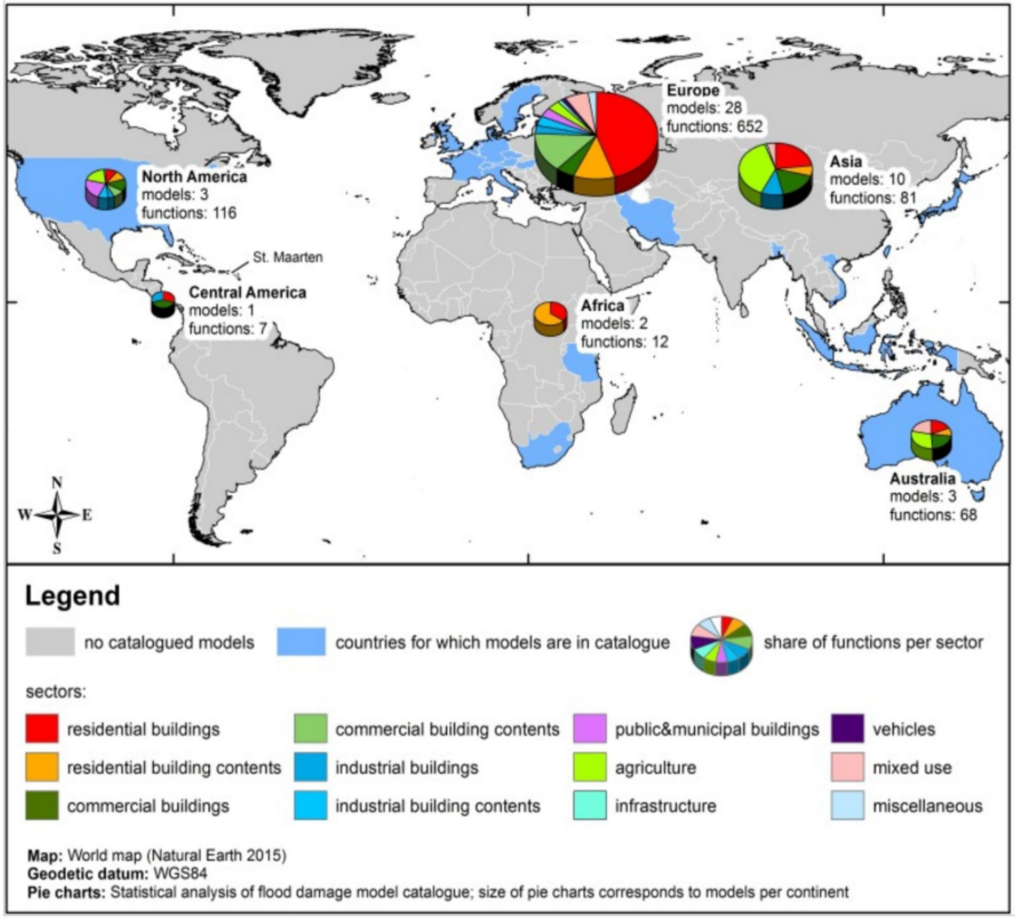
Key prototype: USGS ARkStorm scenario

- Scenario-driven, high-resolution meteorological modeling (WRF) of precipitation fields over California from an atmospheric river (AR) storm (Dettinger et al, 2012)
- Basis for scenario was historical record (1861-2)
- Major difficulty: lack of a comprehensive flood model, forcing the use of GIS flood maps + hydrographs + simple calculations to estimate inundation (Porter et al, 2012)
- WRF wind fields, flood depth/duration used as inputs to a readily available US engineering/GIS-based damage estimation tool: HAZUS-MH
- HAZUS estimates of capital stock losses by sector and county were normalized to % damage, fed into an inter-regional CGE model (Sue Wing et al, 2015)

Ex-post climate change link: ARs worsen (Warner et al, 2015)

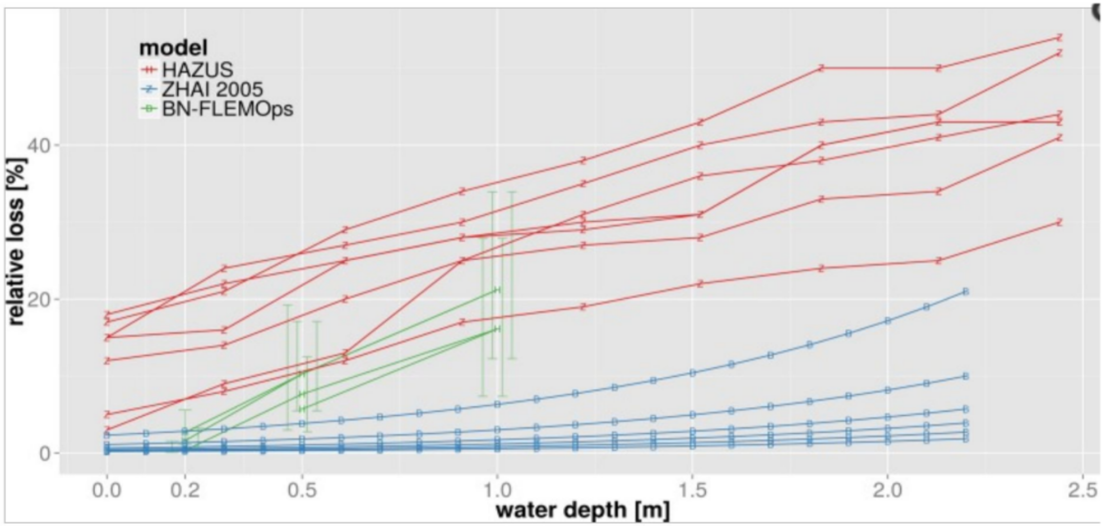
Dettinger et al (2012). Design and quantification of an extreme winter storm scenario for emergency preparedness and planning exercises in California, Natural Hazards 60:1085-1111; Warner et al (2015). Changes in winter atmospheric rivers along the North American west coast in CMIP5 climate models, J. Hydrometeorol. 16: 118-128; Porter, K., et al (2010). Overview of the ARkStorm scenario: U.S. Geological Survey Open-File Report 2010-1312; Sue Wing et al (2015). Economic Impacts of the ARkStorm Scenario, Natural Hazards Review 10.1061/(ASCE)NH.1527-6996.0000173, A4015002.

Scaling up: Analyzing riparian flood impacts on major global urban areas?



ISI-MIP hydrology a great start (Dankers et al, 2014), yet many substantial data and analysis gaps need to be overcome:

- Detailed hydraulic modeling of local flood depth/duration
- Extend geographic coverage of flood loss modeling capability
- Harmonize depth damage/loss of function relationships
- Develop/refine spatially disaggregated estimates of vulnerable capital stocks (e.g., the Global Exposure Database)



Gerl et al (2016). A Review of Flood Loss Models as Basis for Harmonization and Benchmarking, PLoS One 11(7): e0159791; Dankers et al (2014). First look at changes in flood hazard in the Inter-Sectoral Impact Model Intercomparison Project ensemble, PNAS 111: 3257-3261.

Migration: Across regions, across countries

- Flurry of recent empirical research
  - Intra-national: Africa (Cattaneo & Massetti, 2015; Henderson et al, 2017); India (Colmer et al, 2016); C. America/Caribbean (Baez et al, 2017); S. America (Thiede et al, 2016)
  - International: 163 countries to OECD (Cai et al, 2016); 115 countries (Cattaneo & Peri, 2016)
  - **Impacts on local livelihoods (esp. agriculture) appear to be the key "push" factor** (but what about extreme events? conflict? (Bohra-Mishra et al, 2014))
  - Implication: need to get primary impacts right!
- Intra-national/intra-regional economic effects already largely covered by CGE models
  - Adverse impacts on agriculture induces declines in factor hiring, releasing labor that is reabsorbed by other (industrial!) sectors ⇒ climate shocks as a structural driver of industrialization
  - Neglected issues are **adjustment costs and distributional effects in poor countries**, as labor-intensive industries often in cities, distant from agriculture:
    - Movers ⇒ rural-urban migration, urban unemployment/poverty
    - Stayers (of which there may be more due to income effects on ability to migrate!–Cattaneo & Massetti/Cattaneo & Peri) ⇒ rural unemployment/poverty/undernourishment
- International consequences less well studied, contested
  - ↑ ΔT migration ↑ migration from agriculture-dependent countries to OECD countries
  - Likely impact of ↑ ΔT is ↑ migration from middle-income to nearby destinations (mostly non-OECD!), ↓ migration from poor countries

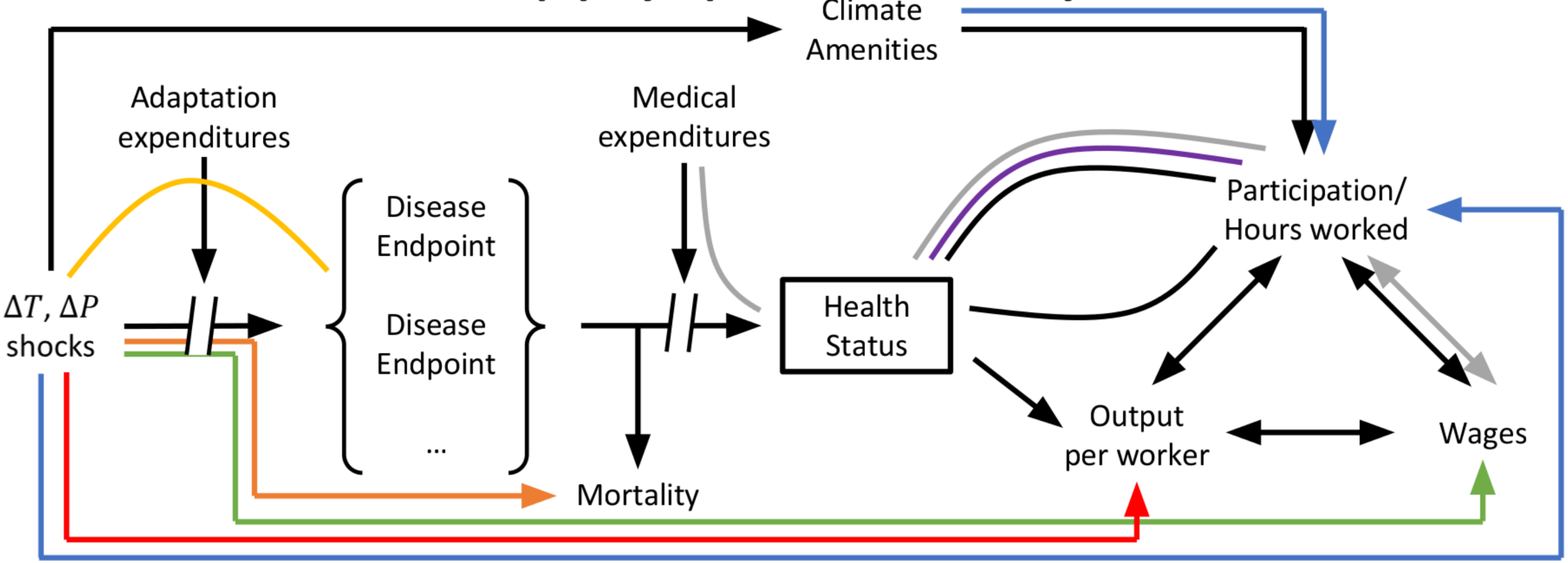
Baez et al (2017). Heat Exposure and Youth Migration in Central America and the Caribbean AER 107: 446-450. Bohra-Mishra et al (2014). Nonlinear permanent migration response to climatic variations but minimal response to disasters, PNAS 111: 9780-9785. Cai et al (2016). Climate variability and international migration: The importance of the agricultural linkage, JEEM 79: 135-151. Colmer, J. (2016). Weather, Labor Reallocation and Industrial Production: Evidence from India, mimeo. Thiede et al (2016). Climate variability and inter-provincial migration in South America, 1970–2011, Glob. Env. Change 41: 228-240. Henderson et al (2017). Has climate change driven urbanization in Africa? JDE 124: 60-82. Cattaneo, C. and G. Peri (2016). The migration response to increasing temperatures, JDE 122:

Migration in IAMs

- Clear path forward: reduced-form emulators based on empirical literature
  - May need to refine Peri & Cattaneo empirical models to account for changes in exposure to T, P bins—identification likely a challenge, focus on extremes
  - Combine empirical movement elasticities with gridded population maps for SSPs (Jones & O'Neill, 2016), ESM simulations of ΔT, ΔP
- Global PE/GE models
  - Emulator can easily compute regional net Δ Pop
  - Key questions: how big is the impact, what to do with this info in the model
  - Naïve approach: Δ Labor endowment = Δ Pop, but this ignores skills of migrants vs domestic labor force, medium-run transition/adjustment costs, esp. economic costs of operating institutions to assimilate migrants ("climate refugees") into labor market, broader society
  - Need labor economists to trace through structural linkages, suggest reduced-from representations
- Much richer implications for shifts in the urban hierarchy, increasing returns/structural change and the morphology of cities
  - Only viable in OECD countries with well-functioning housing markets
  - State of the art: developing/applying locational sorting models estimated on geolocated census microdata or property transactions linked to individual characteristics
  - Structural approach allows direct integration with labor market representations within interregional CGE models (Fan et al, 2016a,b)
  - Advantage: robust estimates of WTP encompassing climate's joint effect on income, amenities

Jones, B. and B. O'Neill (2016). Spatially explicit global population scenarios consistent with the Shared Socioeconomic Pathways, ERL 11: 8. 3. Fan et al (2016a). Does Extreme Weather Drive Interregional Brain Drain in the U.S.? Evidence from a Sorting Model, Land Econ. 92: 363-388. Fan et al (2016b). Climate Change, Migration, and Regional Economic Impacts in the U.S., JAERE in review.

Health-labor supply/productivity nexus


Climate Amenities
Adaptation expenditures
Medical expenditures
ΔT, ΔP shocks
Disease Endpoint
Disease Endpoint
…
Mortality
Health Status
Participation/ Hours worked
Output per worker
Wages

Multiple studies

Deryugina, T., and S. Hsiang (2015). Does the Environment Still Matter? Daily Temperature and Income in the United States, NBER WP #w20750. (US)

Burke et al (2015). Global non-linear effect of temperature on economic production, Nature 527: 235-239. (World)

Barreca et al (2016). Adapting to Climate Change: The Remarkable Decline in the US Temperature-Mortality Relationship over the Twentieth Century, JPE 124: 105-59.

Park, J. (2017). Will We Adapt? Labor Productivity and Adaptation to Climate Change, Harvard Environmental Econ. Program DP 17-73. (US)

Cai (2014). The effects of health status and health shocks on hours worked, Health Econ. 23: 516-528. (Australia)

Goryakin et al (2014). The effect of health on labour supply in nine former Soviet Union countries, Eur J Health Econ. 15: 57-68. (CIS)

Skuterud, M. and J. Shi (2014). Gone Fishing! Reported Sickness Absenteeism and the Weather, Econ. Inquiry 53: 388-405. (Canada)

Zander et al (2015). Heat stress causes substantial labour productivity loss in Australia, Nature Climate Change 5: 647-651. (Australia)

Hokayem, C., and J. Ziliak (2014). Health, Human Capital, and Life Cycle Labor Supply, AER 104: 127-131. (US)

Climate and the shape of ecosystems: Mechanisms

- Unifying economic equilibrium framework for ecosystem assessments (cf FISH-MIP)
- Extend ideas of Tschirhart, Mullon. Red: potential impact pathways of ΔT, other variables.

Indexes: i, j = species, r = abiotic resources

Parameters: $\boldsymbol{\theta}$ = diet matrix; β_j = basal metabolism; μ_j = natural mortality; σ_j = input elasticity of substitution; s_j = starting biomass; Z_r = endowments of abiotic resources

Variables: $\hat{x}_j = p_j$ = energy expenditure per unit biomass (bioenergetic opportunity costs ⇔ Walrasian allocation!); $\hat{z}_{r,j}$ = producer j's resource consumption; $\hat{c}_{i,j}$ = predator j's consumption of prey i's; a_j = biomass addition; e_j = ending biomass

Optimizing primary producer's problem: $\min_{\hat{z}_{r,j}} \left\{ \hat{x}_j = \beta_j + \Sigma_i w_r \hat{z}_{r,j} \;\middle|\; 1 \leq \left(\Sigma_r \theta_{r,j} \hat{z}_{r,j}^{(\sigma_j - 1)/\sigma_j} \right)^{\sigma_j/(\sigma_j - 1)} \right\}$

Optimally foraging predator's problem: $\min_{\hat{c}_{i,j}} \left\{ \hat{x}_j = \beta_j + \Sigma_i p_i \hat{c}_{i,j} \;\middle|\; 1 \leq \left(\Sigma_i \theta_{i,j} \hat{c}_{i,j}^{(\sigma_j - 1)/\sigma_j} \right)^{\sigma_j/(\sigma_j - 1)} \right\}$

Solutions: conditional demands for resources, prey biomass: $\hat{z}_{r,j} = \theta_{r,j}^{\sigma_j} w_r^{-\sigma_j} p_j^{\sigma_j}$, $\hat{c}_{i,j} = \theta_{i,j}^{\sigma_j} p_i^{-\sigma_j} p_j^{\sigma_j}$

Mass, energy conservation ⇒ comparative static bioenergetic CGE model in a complementarity format:

Zero profit biomass addition: $$p_j \leq \beta_j + \begin{cases} \left(\Sigma_r \theta_{r,j}^{\sigma_j} w_r^{1-\sigma_j} \right)^{1/(1-\sigma_j)} & \text{primary producers} \\ \left(\Sigma_i \theta_{i,j}^{\sigma_j} p_i^{1-\sigma_j} \right)^{1/(1-\sigma_j)} & \text{predators} \end{cases} \qquad \perp a_j \qquad (1)$$

Market clearance total biomass: $$s_i(1 - \mu_i) + a_i - \Sigma_j \theta_{i,j}^{\sigma_j} p_i^{-\sigma_j} p_j^{\sigma_j} \left(s_j (1 - \mu_j) + a_j \right) \geq e_i[a_i, p_i] \qquad \perp p_i \qquad (2)$$

Market clearance resources: $$Z_r \geq \Sigma_j \theta_{r,j}^{\sigma_j} w_r^{-\sigma_j} p_j^{\sigma_j} \qquad \perp w_r \qquad (3)$$

Woollacott, J. (2015). Modeling economies and ecosystems in general equilibrium, PhD dissertation, Boston University. Tschirhart, J. (2000). General equilibrium of an ecosystem, J. Theoretical Biology 203: 13-32. Mullon et al (2009). NEATS: A network economics approach to trophic systems, Ecol. Modelling

Climate change and ecosystems: So what?

- Challenges
  - Assembling benchmark calibration datasets into bioenergetic accounting matrices (BAMs), the ecological analogue of a SAM. Woollacott (2015) develops techniques for a marine ecosystem dataset. Significant potential given vast number of Ecopath-Ecosim studies.
  - Specifying ending biomass function—”demand” for offspring that constitute next period’s starting biomass
  - Translating fundamental biology of impacts of temperature (other variables?) on metabolism, fecundity, etc. into reduced-form representations
  - Ecological basis for how changes in vectors $\mathbf{s} \to \mathbf{e}$ leads to Δ supplies of ecosystem services, Δ marginal productivity of affected market and non-market sectors
  - Bottom line: a long-term research agenda, a lot to do before this can even make it near IAMs!
- What’s the alternative? Uneven potential for linking existing (ISI-MIP) large-scale global ecosystem process simulations to economic models
  - Terrestrial vegetation: main outputs NPP/GPP (e.g., Chen et al, 2017) aggregated “ecosystem change” indexes (Warszawski et al, 2013). Immediate use: capturing climate-driven shifts in productivity of land-water fixed-factor in IAMs’ forestry sectors. Potential linkages beyond this unclear.
  - Marine ecosystems: main outputs total/potentially harvestable biomass by species groups. Immediate use: capturing climate-driven shifts in productivity of resource stock fixed-factor in IAMs’ fishery sectors.
  - Neither effect likely to exert huge impacts, esp. with highly aggregated regional groupings
- Action is in **non-market impacts** on directly-consumed amenities. Key unknown pathway of impact is **nonseparability**: potential complementarity with/substitutability for factor supplies (Carbone & Smith, 2013)

Chen et al (2017). Regional contribution to variability and trends of global gross primary productivity, ERL 12: 10. Warszawski et al (2013). A multi-model analysis of risk of ecosystem shifts under climate change, ERL 8: 4. Carbone, J. and V. Smith (2013). Valuing nature in a general equilibrium, JEEM 66: 72-89.