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

ts: severe storms and floods Extreme even

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

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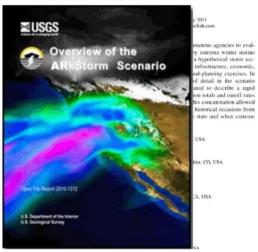
Economic Consequence Analysis of the ARkStorm Scenario

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Nat Hazards (2012) 60:1085-111 DOI 10:1007/s11069-011-9894-5

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 Cavan · Lucy Jones



ivity of agricultural land, and lifeline services. A dynamic I's equilibrium solution, and the model parameterization is flood-induced building damage is the overwhelming source odology serves as a template for assessing the macroeco-BI losses. DOI: 10.1061/(ASCE)NIL1527-6996.0000173. th percentile threshold increases as much as 290%

vertically integrated water vapor transport (IVT) Intercomparison Project (CMIP5), 10 simulati st of North America between historical (1970-99 ncentration pathway (RCP) 8.5. The most extreme ons about the liming and source of funds for econstruction mitigates impacts by approximately 50%, and ion along the west coast increases by 11%-18% VT days increases by 15%-39% [from 5% to 19%

dels have sufficient resolution to simulate synoptic

n final form 5 August 2014)

t impacts stemming from consequent disruptions of the sendent activities of businesses and households throughou ire translated into decreases in the capital stock or direct

indirect BI loss estimates are derived from a dynamic trous agencies to eval-extreme winter storms

table general equilibrium (CGE) model of the California ny, CGE models are a class of widely used economic sims that calculate the commodity and factor prices and activity of firms and households that equalize supply and demand all markets in the economy (Shoven and Whalley 1992). represent the technical interdependence between economic d to describe a rapid totals and runoff rates assumers to market price signals, and market activity and inds and factors among competing demands. The model is dy-solving for the equilibrium of the economy on a six-month

d Loss Estimation

nergy, land, and natural resources. This stock/flow distinc-indamental in economics, with flow measures such as gross in product (GDP) the preferred way to evaluate the perforof an economy and the well-being of its population. Direct direct versions of both categories of losses are prevalent in rs. Direct property damage refers to the effects of flooding. and landslides, whereas collateral, or indirect, property dan exemplified by toxic releases from damaged hazardous il (HAZMAT) facilities. Such indirect property damages seen identified under environmental and health issues in

mony. The direct BI estimates are based on calculations of building function, loss of productivity on agricultural land, duction of lifeline services from damaged infrastructure. crease with surface warming at roughly the rate of lausius-Clapeyron scaling, about 7.5% (°C)-1 (Held id Soden 2006: O'Gorman and Muller 2010). While obal mean precipitation is expected to increase at lesser rate, around 2%-3% (°C)-1 (Trenberth 1999; eld and Soden 2006: O'Gorman and Muller 2010: uller and O'Gorman 2011; O'Gorman et al. 2012; ephens et al. 2012: Pendergrass and Hartmann 2014). detail in the scenario in tenns of production inputs and sales of product, the sub-treme precipitation is predicted to increase at rates oser to that of global mean atmospheric water vapor ms through price formation and reallocation of the supplies. Allen and Ingram 2002; Trenberth et al. 2003; Pall et al. 07). The above studies examined changes in mean and treme precipitation on a global scale; it is unclear what langes can be expected on regional scales.

Extreme precipitation might also be influenced by dyimical changes associated with anthropogenic global arming (Groisman et al. 2005; Held and Soden 2006; enberth et al. 2007). It has been theorized that changes produced by property (capital stock), in conjunction with equator-to-pole temperature gradient (Yin 2005) and adley cell expansion associated with global warming suld shift the storm track poleward and/or upward in the

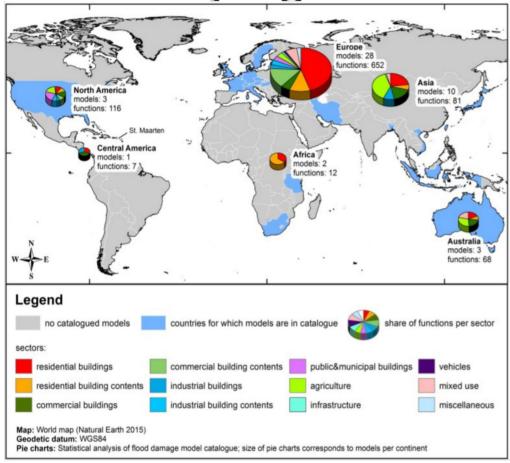
Focus: rich characterization of economic consequences of singular extreme weather events occurring on relatively short time-scales over a limited geographic domain Key prototype: USGS ARkStorm scenario

- 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)

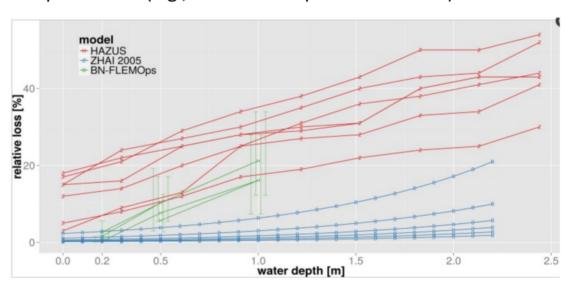
Dettinger et al (2012). Design and quantification of an extreme winter storm scenario for emergency preparedness and planning exercises in California, Natural Hazards 60:1085-1111; Warner et al (2015). Changes in winter atmospheric rivers along the North American west coast in CMIP5 climate models, J. 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
 - $\uparrow \Delta T$ migration \uparrow migration from agriculture-dependent countries to OECD countries
 - Likely impact of $\uparrow \Delta T$ is \uparrow migration from middle-income to nearby destinations (mostly non-OECD!), \downarrow migration from poor countries

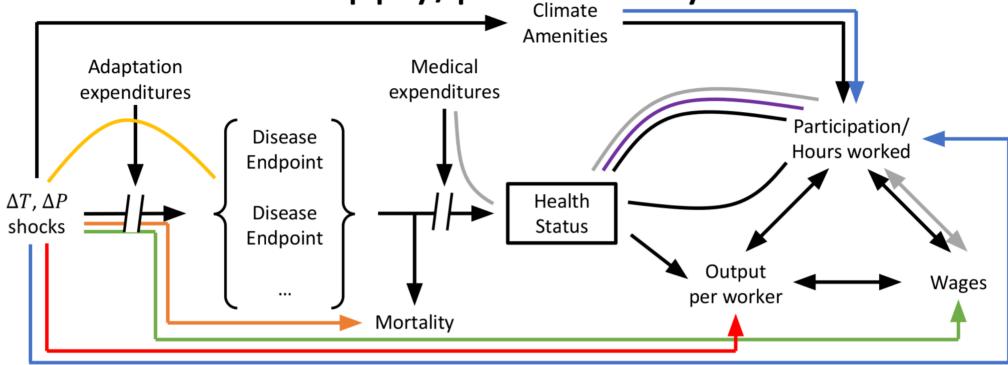
Baez et al (2017). Heat Exposure and Youth Migration in Central America and the Caribbean AER 107: 446-450. Bohra-Mishra et al (2014). Nonlinear permanent migration response to climatic variations but minimal response to disasters, PNAS 111: 9780-9785. Cai et al (2016). Climate variability and international 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



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)

Halvaran C and I Tiliak (2014) Health Human Capital and Life Cycle Labor Symply AED 104: 127-121 (LIS)

Climate and the shape of ecosystems:

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Extend ideas of Tschirhart, Mullon. Red: potential impact pathways of ΔT , other variables.

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

Parameters: θ = 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 \Leftrightarrow 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 \Rightarrow comparative static bioenergetic CGE model in a complementarity format:

Zero profit biomass addition:
$$p_{j} \leq \beta_{j} + \begin{cases} \left(\Sigma_{r} \theta_{r,j}^{\sigma_{j}} w_{r}^{1-\sigma_{j}} \right)^{1/(1-\sigma_{j})} & \text{primary producers} \\ \left(\Sigma_{i} \theta_{i,j}^{\sigma_{j}} p_{i}^{1-\sigma_{j}} \right)^{1/(1-\sigma_{j})} & \text{predators} \end{cases}$$

$$\text{Market clearance total biomass:} \quad s_{i}(1-\mu_{i}) + a_{i} - \Sigma_{j} \theta_{i,j}^{\sigma_{j}} p_{i}^{-\sigma_{j}} p_{j}^{\sigma_{j}} \left(s_{j} \left(1-\mu_{j} \right) + a_{j} \right) \geq e_{i}[a_{i}, p_{i}] \qquad 1 \neq i$$

Market clearance total biomass: (2)

 $Z_r \geq \Sigma_j \theta_{r,j}^{\sigma_j} w_r^{-\sigma_j} p_i^{\sigma_j}$ Market clearance resources: (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 landwater 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.