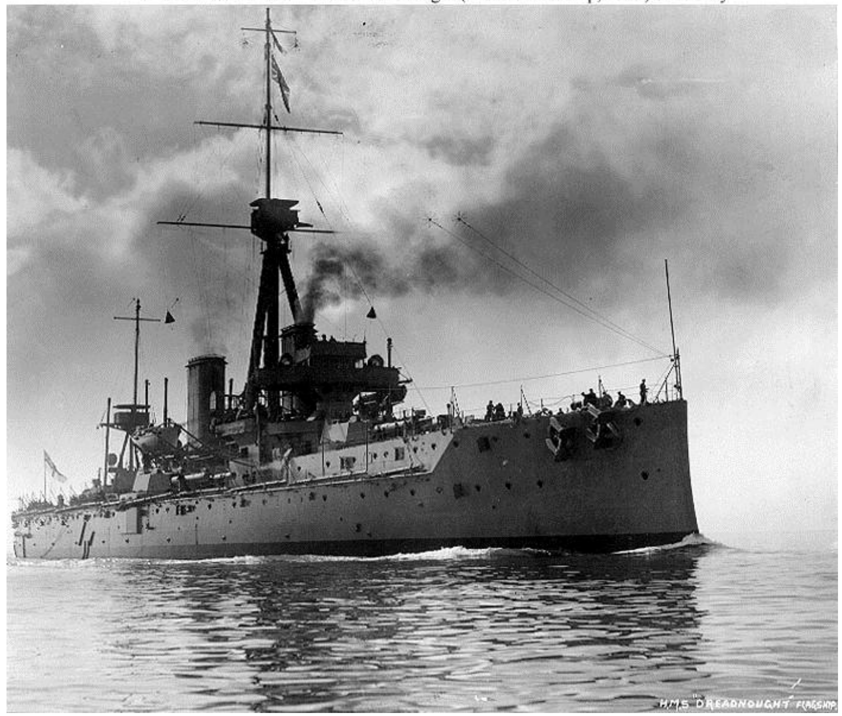
Photo # NH 61005 HMS Dreadnought (British battleship, 1906) underway



Climate Change Impacts: Connecting Science with IAMs

Ian Sue Wing

Boston University

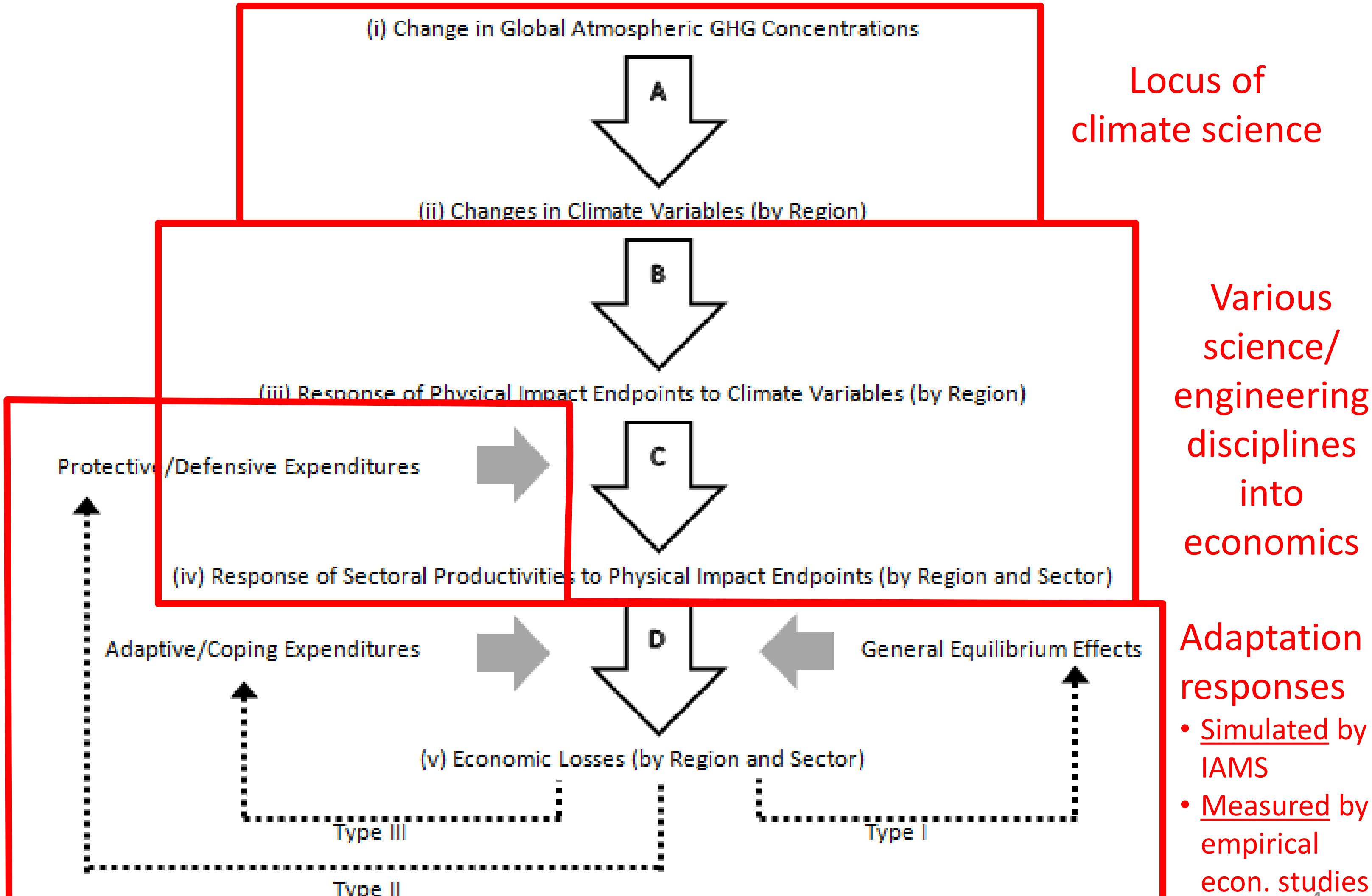
Plan of Talk

- Goals
- A conceptual model of climate impacts and damages
- Modeling impacts as shocks within IAMs: approaches and implications
- The role and value of emulators in translational research
- Screening of impact categories, endpoints and potentially affected sectors

Overarching Goals of Analysis (Tony Redux)

- What are the likely welfare costs of specific categories of climate impacts, both individually and when combined?
- How can we assess these costs in a manner which effectively leverages the current generation of IAMs?
  - Key issue: computational efficiency
- How can we flexibly incorporate current and evolving knowledge on impacts in ways that adequately capture the considerable sectoral, geographic and temporal heterogeneity of climatic variable shifts, and consequent changes in key biophysical endpoints?

Economic Damages from Climate Impacts: A Bottom-Up Framework



Source: Sue Wing & Fisher-Vanden (2013)

Definitions

(Sue Wing & Fisher-Vanden, 2013; Fisher-Vanden et al, 2013)

- What do I mean by impacts?
  - (iii) Response of biophysical impact endpoints to changes in climatic variables
    - e.g., changes in crop productivity driven by temperature/precipitation shifts
  - (iv) Endpoint-driven shocks to sectors in the economy to changes in endpoints, ***without any subsequent responses of economic actors***
    - e.g., changes in agricultural output driven by productivity changes, ***without any adjustments in agricultural management practices***
- What do I mean by adaptation?
  - Response of economic actors to shocks defined above, classified into 3 types
    - (I) Passive market responses and general equilibrium effects (e.g., increases in electricity use, generation and prices as a consequence of increased summer cooling demands)
    - (II) Deliberate investments designed to reduce the magnitude of shocks by shielding natural and human systems from endpoint changes (e.g., sea walls)
    - (III) Deliberate investments designed to lower costs of adjustments to residual shocks that do end up occurring (e.g., redundant production capacity, disaster preparedness/response capacity)

Modeling (Adverse) Impacts: A Production Function Approach

IP: Intermediate input productivity shock (> 1)

IS: Intermediate input supply shock (<1)

LS: Labor supply shock (<1)

RP: Resource productivity shock (>1)

LP: Labor productivity shock (>1)

RS: Resource supply shock (<1)

$$Q_Y = \eta_Y \cdot F\left[\eta_L Q_L, \eta_K Q_K, \eta_{I_1} Q_{I_1}, \dots, \eta_{I_N} Q_{I_N}, \eta_{R_1} Q_{R_1}, \dots, \eta_{R_Z} Q_{R_Z}\right]$$

YP: Output productivity shock (< 1)

KS: Capital supply shock (>1)

KP: Capital productivity shock (>1)

Q_Y = output, Q_L = labor input, Q_K = capital input, Q_{I_i} = type-j intermediate input ($j = \{1, \dots, N\}$), Q_{R_z} = type-z resource input ($z = \{1, \dots, Z\}$)

η_Y = total factor productivity, η_L = labor productivity, η_K = capital productivity, η_{R_i} = intermediate input productivity, η_{R_z} = resource productivity

Implications for Measurement

- **<u>Con:</u>** IAMs have a limited ability to value impacts in a way that disentangles confounding effects of passive (Type I) adaptations
  - Unless we are using production/cost functions where shocks are neutral and essentially scale output—in which case $Impact = (1 - \eta_Y)Q_Y$—the influence of shocks on <u>inputs</u> to production can only be realized by calculating output using the production relationship, with all the substitution responses that entails!
- **<u>Pro(-ish):</u>** Frees us to concentrate squarely on the relationships between the shocks (ηs) and climate-related changes in endpoints
  - Often difficult to distinguish between changes in specific endpoints and changes in ηs for different region x sector combinations
  - Practical implication: expedient to assume a one-to-one relationship between key endpoints deemed to be representative indicators of particular shocks of interest
- <u>Better articulation of the relationships between endpoints and shocks is a key science need!</u>
  - Requires translational research at the interface between various science/engineering disciplines and economics
  - Example 1: In IAM studies, response of yields to climate change is assumed to be equivalent to technological shocks to crop production functions that are either neutral (η_Y) or biased toward land ($\eta_{R_{Land}}$)
  - Example 2: while substantial progress has been made in characterizing response of ecosystem structure and functions to climate change, still rudimentary understanding of how these attributes map into ecosystem services that influence the productivity of various sectors, or directly consumed

Implications for IAMs

- No model capable of simulating entire pathway A-D can hope to capture all of the relevant feedbacks and interactions
  - Straightforward to compute GHG concentrations, global mean temperature, difficult to accurately represent linkages to impacts at scales that matter
  - Changes in climatic variables such as temperature and precipitation in response to global radiative forcing are subject to substantial fine-scale regional and temporal heterogeneity
  - Responses of many impact endpoints to climate variables manifest themselves at spatial and temporal scales much finer than models are capable of representing
- Historical analogue: obsolescence of dreadnoughts/battleships post-WWI/II
  - Too costly to construct and maintain in the face of feasible technological alternatives for achieving the same strategic objectives
- Alternative: use multiple models, deal with causal chain asynchronously
  - Don't attempt to simulate the processes by which the economy generates emissions, and then GHGs affect global mean temperature
  - Instead use GCMs to generate (A), however the downside of this approach is inflexibility: "lock-in" of any subsequent analyses to the climate warming scenarios used for force the GCM
  - Key option for stages (B) and (C): process simulations of the future vs. empirically-derived climate-response functions (CRFs)
    - Many science needs in process model improvement, others can elaborate on this better than I
    - Downside of process modeling is computational expense: runs needed for every scenario
    - Reduced-form empirical CRFs a hot topic in economics literature, can be flexibly used in conjunction with different climate scenarios/IAMs, but regional coverage often severely limited

Return of the Dreadnoughts

- The holy grail of emulation: what might it look like?
  A. Changes in climate variables (region, time)
  = *f* [GHG concentrations(time, time-1, ...)]
  B. Changes in endpoints (category, region, time)
  = *g* [Changes in climate variables (region, time); ...]
  C. Changes in productivity (sector, region, time)
  = *h* [Changes in endpoints (category, region, time); ...]
- Key science (and economics) needs
  - What are the response functions *f*, *g*, and *h*?
  - How do they vary across regions of the world?
  - Identifying gaps, and remedying them with basic data collection
    - B. is a particular problem in many sectors/regions
  - Characterization of shocks generated by response functions when forced by climate extremes
- Under-appreciated benefits of this approach
  - A single set of response surfaces can be utilized by a wide variety of models
  - For areas of the world/endpoints where hard data aren't forthcoming, but estimates can be generated using process simulations, emulators can be constructed from econometric estimates
  - Affords validation/comparison: head-to-head comparisons of CRFs where the dependent variable is historical data vs. generated by process models, using the same climatic inputs

Digression: the SCC and Its Usefulness in Framing Impacts Uncertainties

$$SCC^T_{l',0} =$$

$$\sum_{t=0}^{T} \beta^t \left[\begin{array}{c} \left.\frac{\partial Q_0}{\partial q_{l',0}}\right|_{\boldsymbol{q}_0} \cdot \left.\frac{\partial G_t}{\partial Q_0}\right|_{\widetilde{\boldsymbol{G}}_{\tau\leq t},\widetilde{\boldsymbol{Q}}_{\tau\leq t},?} \\ \cdot \sum_i \left[\sum_l \left[\begin{array}{c} \left.\frac{\partial V_{i,l,t}}{\partial G_t}\right|_{\widetilde{\boldsymbol{V}}_{\tau\leq t},\widetilde{\boldsymbol{G}}_{\tau\leq t},?} \\ \cdot \sum_j \left[\left.\frac{\partial E_{j,l,t}}{\partial V_{i,l,t}}\right|_{\widetilde{\boldsymbol{E}}_{\tau\leq t},\widetilde{\boldsymbol{V}}_{l,t}?} \cdot \left[\sum_k \left.\frac{\partial Y_{k,l,t}}{\partial E_{j,l,t}}\right|_{\widetilde{\boldsymbol{Y}}_t,\widetilde{\boldsymbol{E}}_{l,t},?} \right] \right] \end{array} \right] \right] \end{array} \right]$$

Adapted from Sue Wing & Fisher-Vanden (2013)

Digression: the SCC and Its Usefulness in Framing Impacts Uncertainties

Contemporaneous leakage
(target region l')

$$SCC_{l',0}^{T} =$$

$$\sum_{t=0}^{T} \beta^t \left[\left. \frac{\partial Q_0}{\partial q_{l',0}} \right|_{\boldsymbol{q}_0} \cdot \left. \frac{\partial G_t}{\partial Q_0} \right|_{\widetilde{\boldsymbol{G}}_{\tau \le t}, \widetilde{\boldsymbol{Q}}_{\tau \le t}, ?} \cdot \sum_i \left[\sum_l \left[\left. \frac{\partial V_{i,l,t}}{\partial G_t} \right|_{\widetilde{\boldsymbol{V}}_{\tau \le t}, \widetilde{\boldsymbol{G}}_{\tau \le t}, ?} \cdot \sum_j \left[\left. \frac{\partial E_{j,l,t}}{\partial V_{i,l,t}} \right|_{\widetilde{\boldsymbol{E}}_{\tau \le t}, \widetilde{\boldsymbol{V}}_{l,t} ?} \cdot \left[\sum_k \left. \frac{\partial Y_{k,l,t}}{\partial E_{j,l,t}} \right|_{\widetilde{\boldsymbol{Y}}_t, \widetilde{\boldsymbol{E}}_{l,t}, ?} \right] \right] \right] \right] \right]$$

Adapted from Sue Wing & Fisher-Vanden (2013)

Digression: the SCC and Its Usefulness in Framing Impacts Uncertainties

Effect of current global emissions on future concentration path
(future periods t to horizon T)

$$SCC^{T}_{l',0} =$$

$$\sum_{t=0}^{T} \beta^t \left[\left.\frac{\partial Q_0}{\partial q_{l',0}}\right|_{\boldsymbol{q}_0} \cdot \left.\frac{\partial G_t}{\partial Q_0}\right|_{\widetilde{\boldsymbol{G}}_{\tau\le t},\widetilde{\boldsymbol{Q}}_{\tau\le t},?} \cdot \sum_i \left[\sum_l \left[\left.\frac{\partial V_{i,l,t}}{\partial G_t}\right|_{\widetilde{\boldsymbol{V}}_{\tau\le t},\widetilde{\boldsymbol{G}}_{\tau\le t},?} \cdot \sum_j \left[\left.\frac{\partial E_{j,l,t}}{\partial V_{i,l,t}}\right|_{\widetilde{\boldsymbol{E}}_{\tau\le t},\widetilde{\boldsymbol{V}}_{l,t}?} \cdot \left[\sum_k \left.\frac{\partial Y_{k,l,t}}{\partial E_{j,l,t}}\right|_{\widetilde{\boldsymbol{Y}}_{t},\widetilde{\boldsymbol{E}}_{l,t},?} \right]\right]\right]\right]\right]$$

Adapted from Sue Wing & Fisher-Vanden (2013)

Digression: the SCC and Its Usefulness in Framing Impacts Uncertainties

Effect of future concentrations on future climatic variables (variables i, regions l)

$$SCC_{l',0}^{T} =$$

$$\sum_{t=0}^{T} \beta^t \left[\left.\frac{\partial Q_0}{\partial q_{l',0}}\right|_{\boldsymbol{q}_0} \cdot \left.\frac{\partial G_t}{\partial Q_0}\right|_{\widetilde{\boldsymbol{G}}_{\tau\le t},\widetilde{\boldsymbol{Q}}_{\tau\le t},?} \cdot \sum_i \left[\sum_l \left[\left.\frac{\partial V_{i,l,t}}{\partial G_t}\right|_{\widetilde{\boldsymbol{V}}_{\tau\le t},\widetilde{\boldsymbol{G}}_{\tau\le t},?} \cdot \sum_j \left[\left.\frac{\partial E_{j,l,t}}{\partial V_{i,l,t}}\right|_{\widetilde{\boldsymbol{E}}_{\tau\le t},\widetilde{\boldsymbol{V}}_{l,t}?} \cdot \left[\sum_k \left.\frac{\partial Y_{k,l,t}}{\partial E_{j,l,t}}\right|_{\widetilde{\boldsymbol{Y}}_{t},\widetilde{\boldsymbol{E}}_{l,t},?} \right]\right]\right]\right]\right]$$

Adapted from Sue Wing & Fisher-Vanden (2013)

Digression: the SCC and Its Usefulness in Framing Impacts Uncertainties

Effect of future climatic variables on future impact endpoints (endpoints j, regions l)

$$SCC_{l',0}^{T} =$$

$$\sum_{t=0}^{T} \beta^t \left[\left. \frac{\partial Q_0}{\partial q_{l',0}} \right|_{\boldsymbol{q}_0} \cdot \left. \frac{\partial G_t}{\partial Q_0} \right|_{\widetilde{\boldsymbol{G}}_{\tau \le t}, \widetilde{\boldsymbol{Q}}_{\tau \le t}, ?} \cdot \sum_i \left[\sum_l \left[\left. \frac{\partial V_{i,l,t}}{\partial G_t} \right|_{\widetilde{\boldsymbol{V}}_{\tau \le t}, \widetilde{\boldsymbol{G}}_{\tau \le t}, ?} \cdot \sum_j \left[\left. \frac{\partial E_{j,l,t}}{\partial V_{i,l,t}} \right|_{\widetilde{\boldsymbol{E}}_{\tau \le t}, \widetilde{\boldsymbol{V}}_{l,t} ?} \cdot \left[\sum_k \left. \frac{\partial Y_{k,l,t}}{\partial E_{j,l,t}} \right|_{\widetilde{\boldsymbol{Y}}_t, \widetilde{\boldsymbol{E}}_{l,t}, ?} \right] \right] \right] \right] \right]$$

Adapted from Sue Wing & Fisher-Vanden (2013)

Digression: the SCC and Its Usefulness in Framing Impacts Uncertainties

Effect of future endpoints on future sectoral output (economic sectors k, regions l)

$$SCC_{l',0}^{T} =$$

$$\sum_{t=0}^{T} \beta^t \left[\left.\frac{\partial Q_0}{\partial q_{l',0}}\right|_{\boldsymbol{q}_0} \cdot \left.\frac{\partial G_t}{\partial Q_0}\right|_{\widetilde{\boldsymbol{G}}_{\tau\le t},\widetilde{\boldsymbol{Q}}_{\tau\le t},?} \cdot \sum_i \left[\sum_l \left[\left.\frac{\partial V_{i,l,t}}{\partial G_t}\right|_{\widetilde{\boldsymbol{V}}_{\tau\le t},\widetilde{\boldsymbol{G}}_{\tau\le t},?} \cdot \sum_j \left[\left.\frac{\partial E_{j,l,t}}{\partial V_{i,l,t}}\right|_{\widetilde{\boldsymbol{E}}_{\tau\le t},\widetilde{\boldsymbol{V}}_{l,t}?} \cdot \left[\sum_k \left.\frac{\partial Y_{k,l,t}}{\partial E_{j,l,t}}\right|_{\widetilde{\boldsymbol{Y}}_{t},\widetilde{\boldsymbol{E}}_{l,t},?} \right] \right] \right] \right] \right]$$

Adapted from Sue Wing & Fisher-Vanden (2013)

Very Preliminary Screening Study

- 2013 National Climate Assessment "impact sectors"
  - Agriculture, fisheries, energy supply, energy use, water resources, human health, transportation, forestry, land use and land cover change, sea level rise, extreme events, and ecosystems and biodiversity
- Procedure
  - Identify specific biophysical impact endpoints associated with these categories
  - Identify sectors and activities within the economy which each of these endpoints potentially affects
  - Outline options for modeling within PF framework
  - Next steps: expand dimensions to consider data gaps by region

Endpoints, Sectors, Modeling Strategies (1)

"Impact Sector"	Sectors/ Activities	Impact Endpoints	Economic Manifestation	Modeling Strategies and Options
Agriculture	Crop sectors	Drought Heat stress Shift in crop suitability zones	Reduced crop productivity/yields	Simple: Neutral productivity shock to crop sector cost functions **[YP]** Nuanced: Biased productivity shock to land or land-water fixed-factor resource input to agriculture sector **[RP]**
	Livestock sector	Heat stress	Reduced productivity	Neutral productivity shock to sectoral cost function **[YP]**
Fisheries	Fisheries sectors	Shift in marine habitat	Reduced yields	Simple: Neutral productivity shock to fishery sector cost function **[YP]** Nuanced: Biased productivity shock to habitat fixed-factor resource input to fisheries sector **[RP]**
Energy Supply	Primary energy supply sectors	Fresh water scarcity	Reduction in cooling water withdrawals Reduction in hydroelectric generation	Simple: Neutral productivity shock to energy supply sector cost functions **[YP]** Nuanced: Biased productivity shock to fixed-factor input to energy supply sectors **[RP]**
		Increased ambient temperatures	Reduction in thermoelectric generation efficiency	Simple: Neutral productivity shock to electric power sector cost function **[YP]** Nuanced: Biased productivity shock to fuel inputs to electric power **[IP]**
Energy Use	Non-energy sectors Household sector	Increased cooling demands Decreased heating demands	Secular increase in overall demand for energy	Secular shifts in energy demand functions and energy productivity in sectors' cost/households' expenditure functions **[IP]**

Endpoints, Sectors, Modeling Strategies (2)

"Impact Sector"	Sectors/ Activities	Impact Endpoints	Economic Manifestation	Modeling Strategies and Options
Water Resources	Marketed water sector	Drought	Reduction in output	Simple: Neutral productivity shock to water supply sector cost function **[YP]** Nuanced: Biased productivity shock to endowment of fixed-factor resource input to water supply sector **[RP]**
	Agriculture	Drought	Reduction in non-marketed water inputs Reduction in irrigation	Simple: Neutral productivity shock to agriculture sector cost function **[YP]** Nuanced: Neutral productivity shock to irrigation subsector **[YP]**
Human Health	Aggregate labor supply	Increased morbidity/ mortality due to disease, heat stress	Reduction in labor supply/productivity	Reduction in baseline rate of labor productivity increase **[LP]**
	Household sector		Secular increase in healthcare demand	Secular shifts in healthcare demand functions and productivity of healthcare input to households' expenditure functions **[IP]**
Forestry/ Land Use/ Land Cover Change	Forestry sectors	Fires	Reduction in output Capital stock destruction	Best modeled under **Extreme Events**
		CO_2 fertilization/ woody encroachment	Increase in output	Simple: Neutral productivity shock to forestry sector cost function **[YP]** Nuanced: Biased productivity shock to fixed-factor or land input to forestry sector **[RP]**
		Shift in crop suitability zones	Reduction in productivity	

Endpoints, Sectors, Modeling Strategies (3)

"Impact Sector"	Sectors/ Activities	Impact Endpoints	Economic Manifestation	Modeling Strategies and Options
Transportation	Marketed transport services	Damage to infrastructure from sea level rise and extreme events	Reduction in output Capital stock destruction	Best modeled under **Extreme Events** and **Sea Level Rise**
Sea Level Rise	All sectors	Inundation Abandonment/defense of coastal lowland areas	Reduced land/capital endowment Increase in coastal protection expenditure	Simple: Neutral productivity shocks in all sectors, differentiated according to potential for exposure **[YP]** Nuanced: Reduction in supply of land, mandated increase in non-productive defensive investments in exposed sectors **[RS, KS]**
Extreme Events	All sectors	Floods Hurricanes Forest fires	Capital stock destruction Business interruption	Simple: Neutral productivity shocks in all sectors, differentiated according to severity of impact and potential for exposure **[YP]** Nuanced: Reduction in endowments of labor and sector-specific capital **[LS, KS]**

Endpoints, Sectors, Modeling Strategies (4)

"Impact Sector"	Sectors/ Activities	Impact Endpoints	Economic Manifestation	Modeling Strategies and Options
Ecosystems/ Biodiversity/ Ecosystem Services	Fisheries sector	Marine habitat loss/ ecosystem disruption	Reduction in yields	Best modeled under **Fisheries**
	Agriculture/ Forestry sectors	Increasing virulence of pathogenic species	Reduction in yields	Best modeled under **Agriculture and Forestry**
	Tourism/ Household sectors	Nature-based recreation and tourism	Reduction in supply of non-market amenities	Simple: Neutral productivity shock in tourism sector **[YP]** Nuanced: Biased productivity shock to "natural capital" fixed-factor input to tourism sector **[RP]** Reduction in endowment of "natural amenity" fixed-factor consumed by household **[RS]**
	All sectors	Coastal hazard reduction	Capital stock protection	Best modeled under **Extreme Events** (Hurricanes, Floods)
	Marketed water sector	Reduced water supply/quality	Reduction in output	Best modeled under **Water Resources**