Sea Level Rise

Clare Balboni
LSE

Allan Hsiao
Princeton

BREAD-IGC PhD Course
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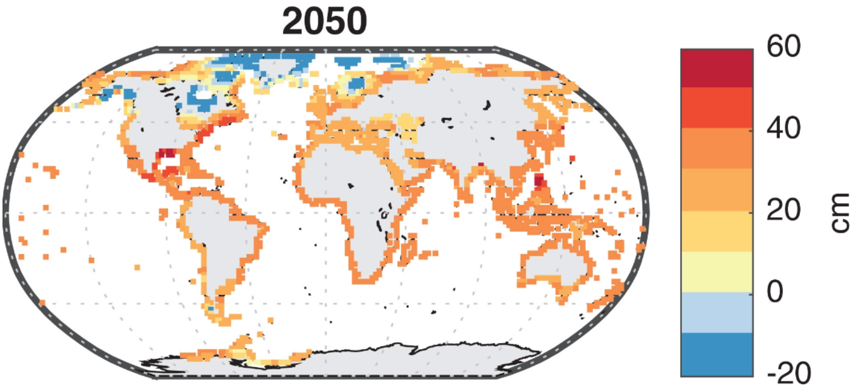
Projections

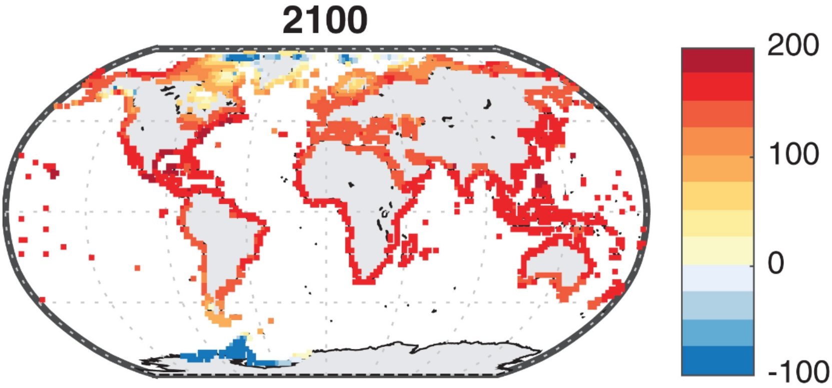
- Global mean sea level (GMSL)
  - 0.40-0.69 m higher for 2°C warming by 2100 (Depsky et al. 2023)
  - Possibly much higher via land subsidence, ice-sheet instability
- Wide-ranging consequences for coastal areas
  - Permanent inundation
  - More frequent flooding
  - Saline intrusion
  - Ecosystem degradation

Kopp et al. (2017)



High-emission scenario (RCP 8.5)

Kopp et al. (2017)



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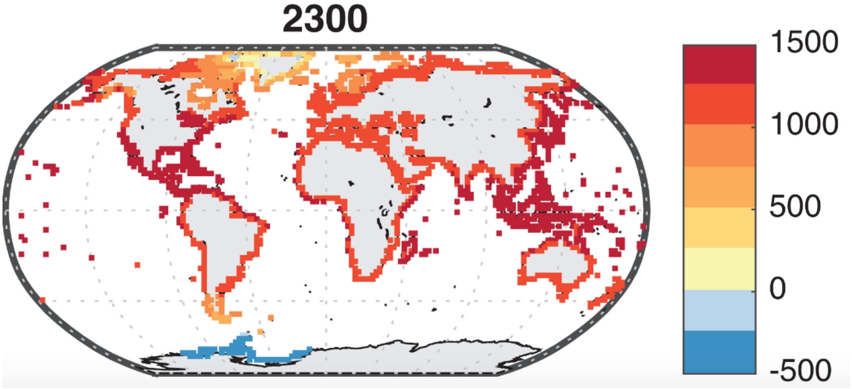


High-emission scenario (RCP 8.5)

IPCC (2021)

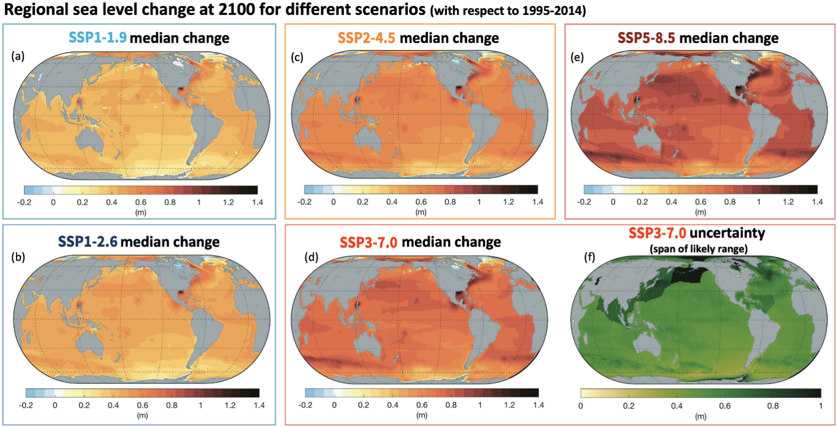


Figure 9.28 | Regional sea level change at 2100 for different scenarios (with respect to 1995–2014). Median regional relative sea level change from 1995–2014 up to 2100 for: **(a)** SSP1-1.9; **(b)** SSP1-2.6; **(c)** SSP2-4.5; **(d)** SSP3-7.0; **(e)** SSP5-8.5; and **(f)** width of the likely range for SSP3-7.0. The high uncertainty in projections around Alaska and the Aleutian Islands arises from the tectonic contribution to vertical land motion, which varies greatly over short distances in this region. Further details on data sources and processing are available in the chapter data table (Table 9.SM.9).

Scope for adaptation

- Sea level rise realized gradually with large predictable component
- Populations may therefore adapt to changes
  - Relocating to safer areas
  - Property-level adaptative investments
  - New agricultural technologies and practices
  - Government investment in risk-reducing public goods
  - Disaster insurance
- Feasibility depends on natural, economic, political, institutional barriers

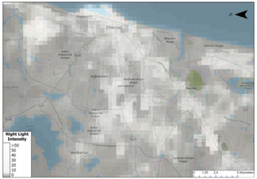
Quantifying current damages

Damages from coastal disasters

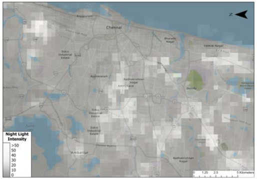
- Affect large share of global population
  - Floods caused 31,000 deaths, affected 330 mn, $240 bn damages from 2012-2018 (Guha-Sapir et al. 2016)
  - 35% population affected by tropical cyclones (Hsiang & Jina 2014)
- Several studies examine short- and medium-run impacts
  - Many focus on US disasters, more recent evidence from developing countries (Vigdor 2008, Indaco et al. 2021, De Mel et al. 2012, Rentschler et al. 2021)
  - Recent studies leverage high resolution global datasets (Kocornik-Mina et al. 2020, Gandhi et al. 2022)

Damages from coastal disasters

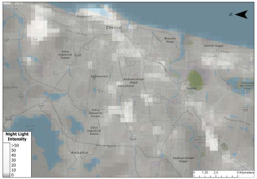
Figure 3: Night Lights Before and After Floods in Chennai: 2015-16



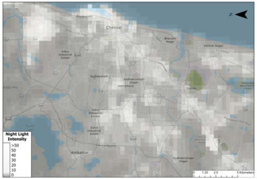
(a) October 2015



(b) November 2015



(c) December 2015



(d) January 2016

Notes: Average monthly night light intensity in Chennai, capital of Tamil Nadu state, India. Chennai suffered from major floods between November-December 2015, with economic losses estimated to be US$1bn. Figure 3a and 3b show the light intensity in October and November of 2015, respectively, whereas Figure 3c and 3d show the light intensity in December 2015 and January 2016, respectively.

Gandhi et al. (2022)

Adaptation to coastal disasters

- Micro-level evidence on adaptation
  - Flood-tolerant rice varieties (Dar et al. 2013, Emerick et al. 2016)
  - Bridges reduce market access costs of floods (Brooks & Donovan 2020)
- Adaptation with experience
  - Countries with more cyclones suffer lower marginal losses (Hsiang & Narita 2012)
  - Cities with more flooding suffer less (Gandhi et al. 2022)
- Natural disasters may induce adaptation
  - Larger, persistent declines in newly populated areas (Kocornik-Mina et al. 2020)
  - Flooded firms relocate to other neighborhoods (Indaco et al. 2021)
  - Flood-affected firms shift towards less flood-prone suppliers (Balboni et al. 2023)

Projecting future damages

Accounting for dynamic spatial adjustment

- Future damages depend on **dynamic spatial** interactions and constraints
- Recent literature uses dynamic spatial general equilibrium models
  - Inter-temporal decisions + spatial linkages across locations
- Permits estimation of
  - Losses from future sea level rise in equilibrium
  - Importance of different adaptive responses
  - Impacts of counterfactual policies

Desmet et al. (2021)

- Estimate impacts of global sea level rise allowing for adjustment via
  - Migration of people
  - Trade in goods
  - Investment in local technology

- As land is inundated, distribution of economic activity shifts inland
  - Static cost of relocation, impact on agglomeration economies
  - Dynamic agglomeration economies influence productivity, innovation, and growth

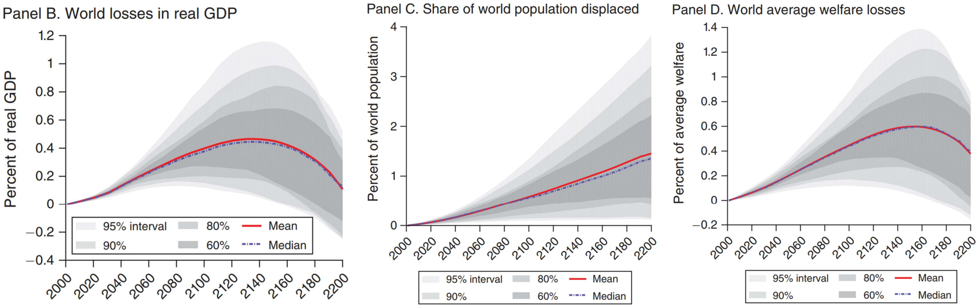
- So losses in flooded regions partly offset by gains elsewhere

Model estimation

- Simulate model of world economy at 1° resolution from 2000 to 2200
  - Probabilistic sea level rise projections for GHG emission scenarios
  - Yields average predicted costs of flooding + confidence bands

- Under intermediate emissions scenario, sea level rise $\Rightarrow$
  - 0.19% decline in global real GDP in PDV terms
  - 0.24% decline in welfare
  - Displacement of 1.46% of world population by 2200
  - Significant spatial heterogeneity in effects

Counterfactual simulations



Heterogeneous local impacts

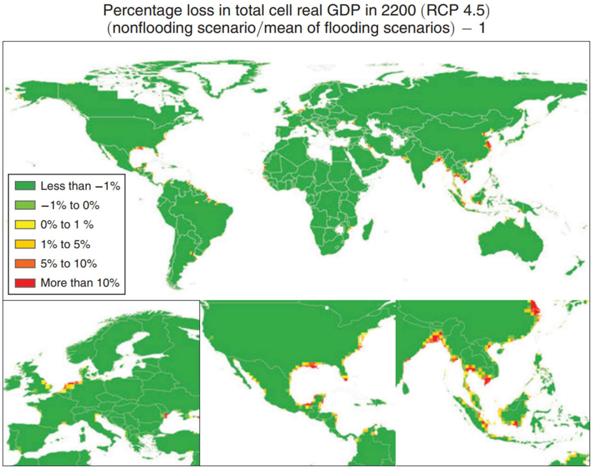
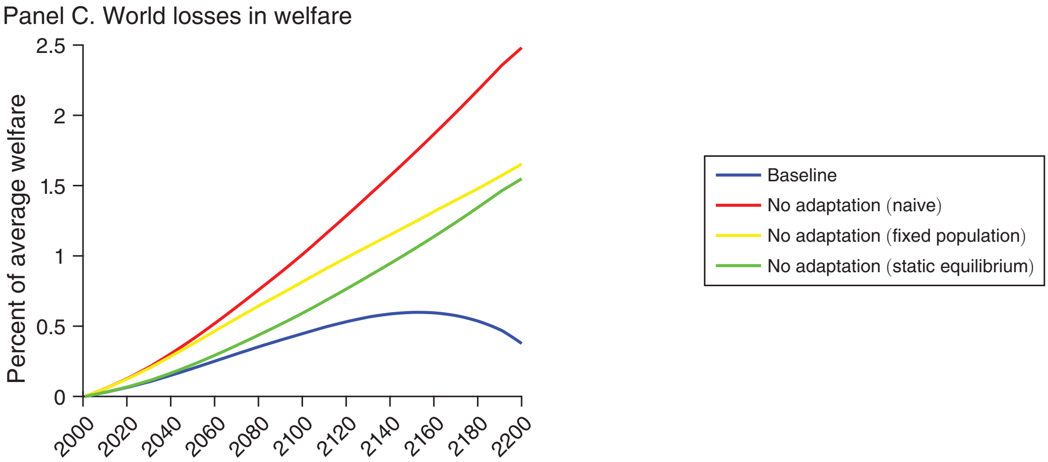


FIGURE 4. PERCENTAGE MEAN LOSS IN TOTAL CELL REAL GDP IN 2200 UNDER RCP 4.5

Importance of dynamic spatial adjustment

- In benchmark model, sea level rise $\Rightarrow \downarrow 0.11\%$ global real GDP in 2200
- Much larger losses when ignoring dynamic spatial adjustment
  - If people cannot migrate, damages are $\downarrow 4.5\%$
  - If people can migrate but firms cannot innovate, damages are $\downarrow 1.5\%$
- Damages depend crucially on magnitude of migration restrictions
  - Losses may be substantially mitigated by freer mobility

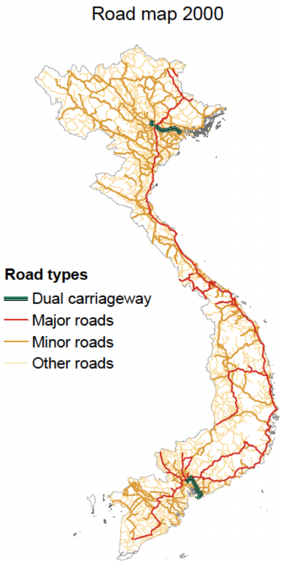
Importance of dynamic spatial adjustment

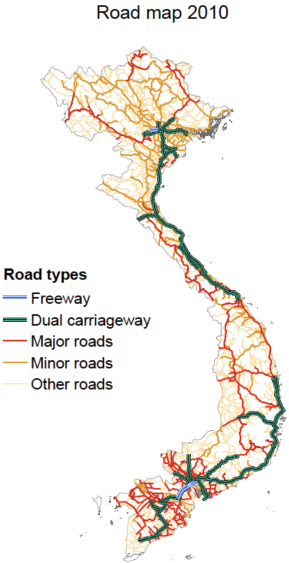


Balboni (2023)

- Considers how accounting for future sea level rise alters returns to infrastructure investments and assessments of where they should be allocated today
- Populations have historically favored coasts but coastal advantage changing
- Should infrastructure investments continue to favor coastal regions?
    - Still attract large, often growing share, e.g. road density

Road investments in Vietnam (2000-2010)





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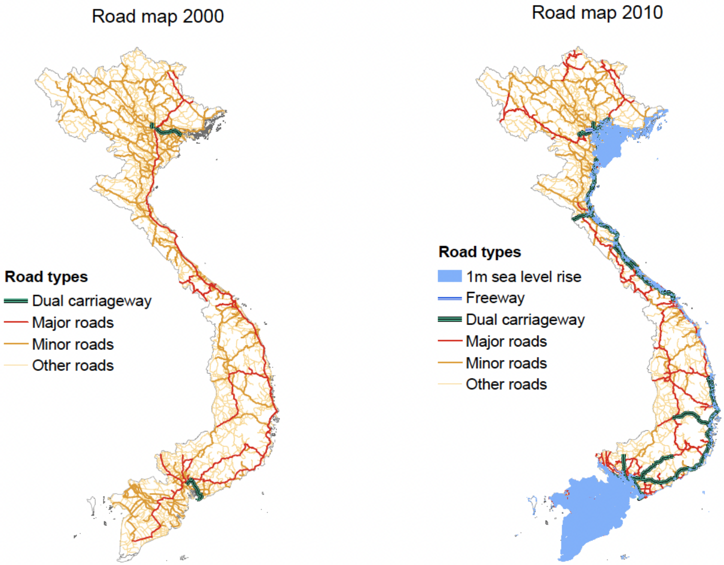
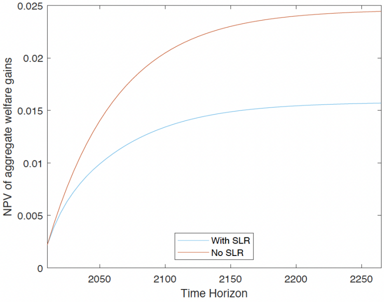


Model estimation

- General equilibrium model of impacts of road investments
  - Locations differ in productivity, amenities, trade links
  - Road investments durable, affected by future sea level rise
  - Costly trade and migration adjustments
- Future sea level rise alters estimates of returns to realized road investments



Counterfactual simulations

- Estimate whether reallocating upgrades could have achieved higher gains
  - Comparable counterfactual networks vary in coastal concentration
- Two scenarios
  - Gradual 1m sea level rise over 100 years
  - No future sea level rise
- Sea level rise meaningfully changes assessment of where to allocate infrastructure
  - Forward looking investments $>$ otherwise comparable allocations
  - Dynamics matter: long-run gains / short-run costs

Government policy

Government policy

- Will fundamentally shape damages and adaptation
- Margins of adaptation
  - **Dynamic:** short- vs. long-run
  - **Spatial:** migration vs. in-place
- Policy faces trade-offs on both margins
  - And distortions from moral hazard

Hsiao (2023)

- **Jakarta** is world's second largest city at 32M (first by 2030)
  - By 2050, 35% below sea level
  - Proposed sea wall at up to $40B
- **How does government intervention complicate adaptation?**
  - Dynamic spatial model of development and defense
  - Estimated with granular data for Jakarta


#CLIMATE NO JUSTICE

Model

$$w^t = \sum_{t'=t}^{T} \beta^{t'-t} \left(\sum_i r_i(D_{t'}, g_{t'}) - \sum_i c(d_{it'}) - \sum_i e(g_{it'}) \right)$$

- Development d_{it}, defense g_{it} for locations i, periods t
    - Welfare w^t from residential value r_{it} $\left(\frac{\partial r}{\partial D}, \frac{\partial r}{\partial g}, \frac{\partial^2 r}{\partial D \partial g} > 0\right)$
    - At private cost c_{it}, public cost e_{it} $\left(\frac{\partial c}{\partial d}, \frac{\partial e}{\partial g} > 0\right)$

- **Spatial** via vectors $D_t = \{D_{it}\}_i$, $g_t = \{g_{it}\}_i$
- **Dynamic** via stocks $D_{it} = \sum_{t'=1}^{t} d_{it'}$ for durable d_{it}
    - Non-durable g_{it} captures continued sea level rise (or maintenance)

Two locations, two periods

- Locations $i \in \{\text{coast}, \text{inland}\}$, periods $t \in \{1, 2\}$
  - Development $d_t = \{d_t^{\text{co}}, d_t^{\text{in}}\}$
  - Defense $g_t = \{g_t^{\text{co}}, 0\}$ $\left(\frac{\partial r}{\partial g^{\text{in}}} = 0 \text{ for } r = r^{\text{co}} + r^{\text{in}}\right)$

- Government chooses (d_1^*, g_1^*) anticipating (d_2^*, g_2^*)

$$d_1^*, g_1^* = \arg\max_{d_1, g_1} \{w_1(d_1, g_1) + \beta w_2(d_2^*, g_2^*; d_1)\}$$

$$d_2^*, g_2^* = \arg\max_{d_2, g_2} \{w_2(d_2, g_2; d_1)\}$$

Trade-offs

- **Spatial:** $g_1^{\text{co}} \uparrow$ induces $d_1^{\text{co}} \uparrow$, $d_1^{\text{in}} \downarrow$
  - Higher residential value $r_1 = r_1^{\text{co}} + r_1^{\text{in}}$ (coastal premium)
  - But higher public cost e_1^{co}
- **Dynamic:** $g_1^{\text{co}} \uparrow$ induces $D_2^{\text{co}} \uparrow$, $D_2^{\text{in}} \downarrow$, $g_2^{\text{co}} \uparrow$
  - Higher residential value $r_2 = r_2^{\text{co}} + r_2^{\text{in}}$
  - But higher public cost $e_2^{\text{co}} > e_1^{\text{co}}$
- As coastal population grows, higher losses and moving costs if g^{co} fails
  - Optimal policy depends on coastal (spatial), short-run (dynamic) preferences

Moral hazard

- Development can force defense $\left(\frac{\partial^2 r}{\partial D \partial g} > 0\right)$
  - Developers anticipate defense at public cost
  - After development, government forced to defend
- **Problem:** time-inconsistent defense + uninternalized costs
  - Leads to coastal lock-in with too much d_t^{co}, too little d_t^{in}
  - Solution is to commit or regulate, but not easy

Distortions

- **Spatial:** $d_1^{\text{co}} \uparrow$ induces $g_1^{\text{co}} \uparrow$, $d_1^{\text{in}} \downarrow$
  - Coastal residents can force local government
  - Local government can force national government

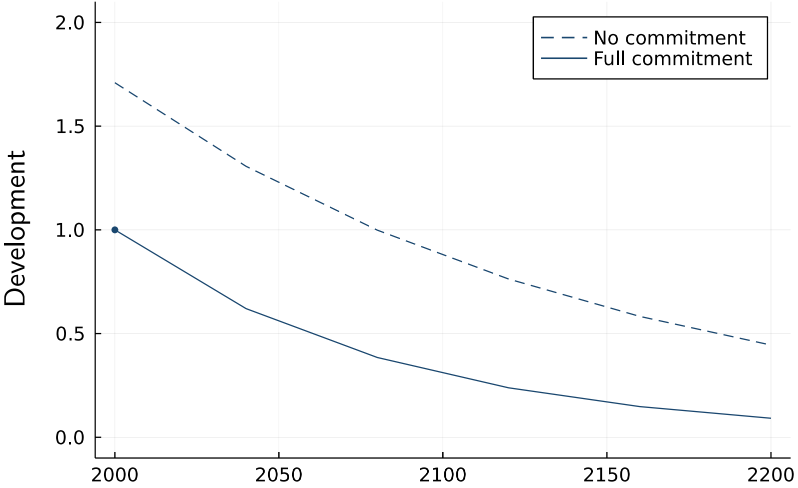
- **Dynamic:** $d_1^{\text{co}} \uparrow$ induces $g_2^{\text{co}} \uparrow$, $d_1^{\text{in}} \downarrow$, $d_2^{\text{in}} \downarrow$
  - Current government can force future government
  - Future government cannot regulate current government!

Empirical framework

$$W = r(d,g) - c(d) - e(g)$$

- $\tilde{r}(d,f)$: **spatial model** of residential demand
- $f(g)$: **hydrological model** of flood risk
- $c(d)$: **dynamic model** of developer supply
- $e(g)$: **engineering model** of sea wall costs

Moral hazard delays adaptation



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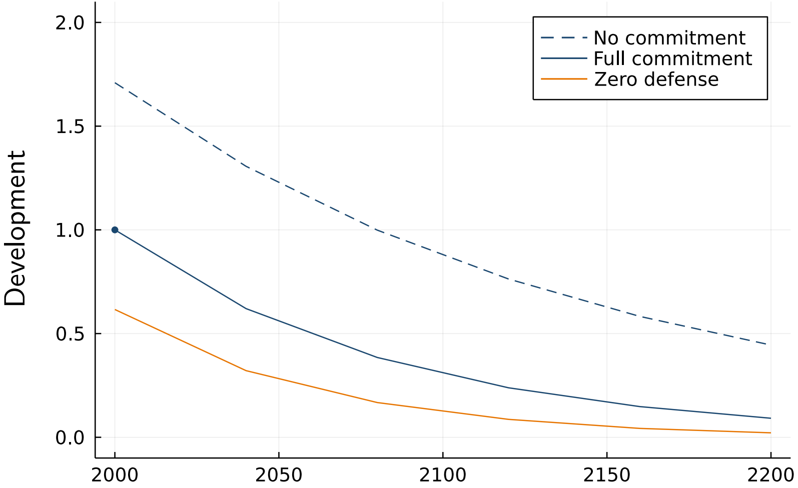
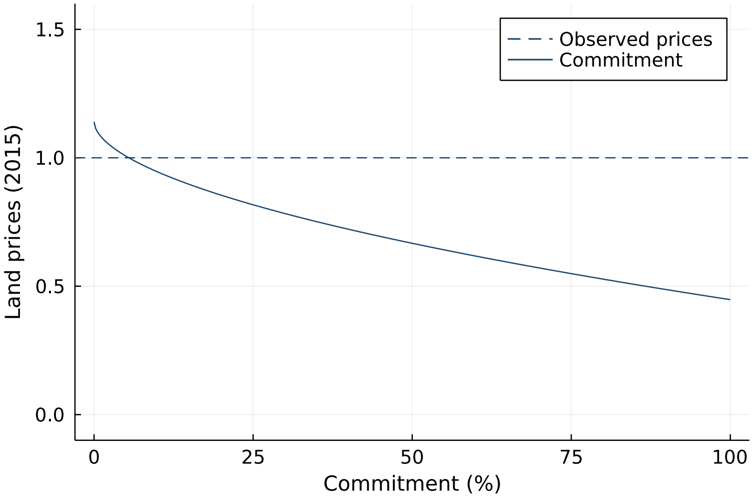


Moral hazard can rationalize observed prices



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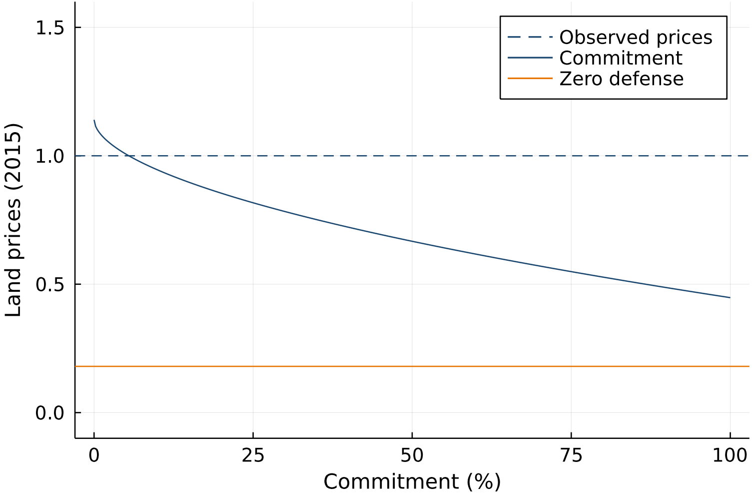
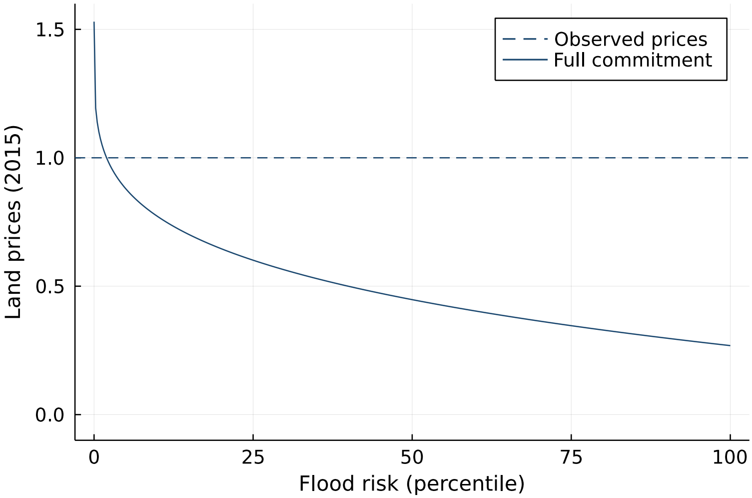


Flood risk cannot rationalize observed prices



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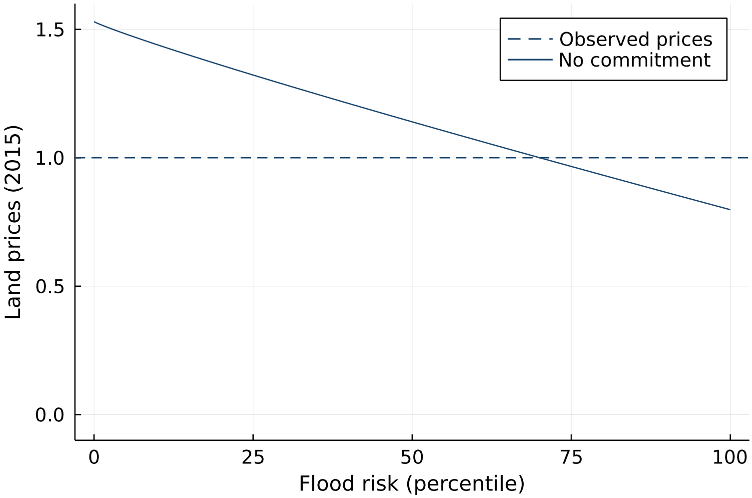

Conclusion

Sea level rise threatens 1B people by 2050

- Major implications for economic well-being
  - Damages and adaptation shaped by dynamic and spatial interactions
- Government policy will play a major role
  - But faces important trade-offs and distortions
- Opportunities for more work in this important area