Sea Level Rise and Urban Adaptation in Jakarta

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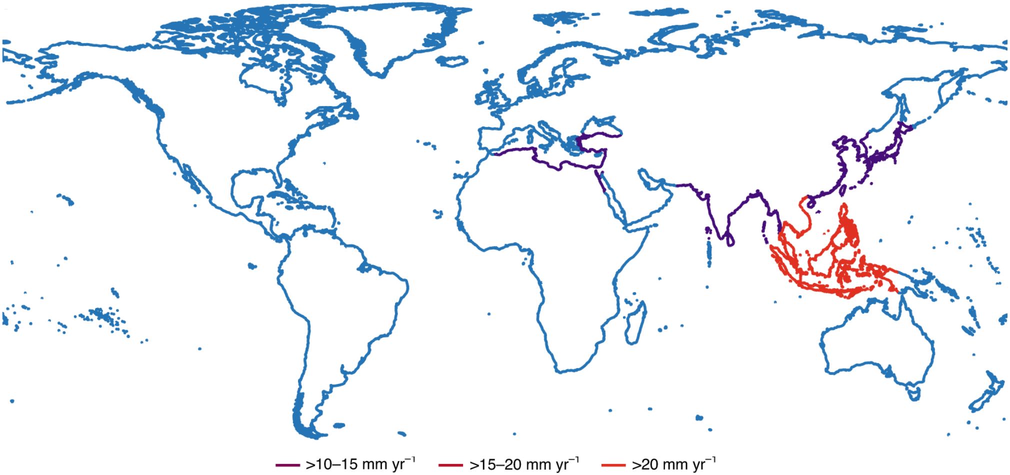
Sea level rise threatens 1B people by 2050 (IPCC 2019)



(Nicholls et al. 2021)


#CLIMATE NO JUSTICE

Jakarta

- World's second largest city at 31M (first by 2030)
    - By 2050, 35% below sea level
    - Proposed sea wall at up to $40B

- **How does government intervention complicate adaptation?**

This paper

- **Moral hazard** from time-inconsistent defense
  - Continued development at high social cost
- **Dynamic spatial model** of development and defense at the coast
  - Estimated with granular data for Jakarta

Results

1. Severe moral hazard
   - Coastal persistence without commitment (5x in 2200)
   - Rationalizes high land prices despite future flood risk
2. Policy prescriptions
   - Direct: partial commitment or regulation
   - Indirect: moving capital, slowing subsidence

Contributions

- **Adaptation frictions** under endogenous government intervention
  - Barreca et al. 2016, Costinot et al. 2016, Desmet et al. 2021
  - Moral hazard: Kydland & Prescott 1977, Kousky et al. 2006, Boustan et al. 2012
- **Sea level rise** damages and policies
  - Kocornik-Mina et al. 2020, Balboni 2021, Castro-Vicenzi 2022, Fried 2022, Lin et al. 2022
- **Dynamic spatial model** of urban development
  - Hotz & Miller 1993, Arcidiacono & Miller 2011, Scott 2013, Kalouptsidi 2014, Murphy 2018
  - Alternative: Desmet et al. 2018, Caliendo et al. 2019, Kleinman et al. 2022

Outline

1. **Theory**
2. **Empirics**
3. **Counterfactuals**

Theory

Coastal development and defense

1. **Development** d at cost $c(d)$ for $c'' > 0$ (agent)
2. **Defense** g at cost $e(g)$ for $e'' > 0$ (principal)
3. Residential value $r(d,g)$ for $r_{dg} > 0$

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

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Interpretation: agent and principal

1. Coastal developers/residents vs. government
2. Local vs. national government
3. Current vs. future government

Commitment: first best

1. Defense g^*
2. Development $d^*(g^*)$

$$\begin{aligned} [d^*] \quad & r'(d) = c'(d) \\ [g^*] \quad & r'(g) = e'(g) \end{aligned}$$

- But want to defend ex post (plus lobbying)
- Equivalent: tax $e(g)$ or quota d^*, but costly to enforce (or impossible)

No commitment: coastal lock-in

1. Development d^n
2. Defense $g^n(d^n)$

$$\begin{aligned} &[d^n] \quad r'(d) + r'(g)\,g'(d) = c'(d) \\ &[g^n] \quad r'(g) = e'(g) \end{aligned}$$

- Moral hazard: time inconsistency + uninternalized cost ($g'(d)$ as magnifier)
- Coastal defense crowds out inland migration

Moral hazard over time

Commitment	$g_1'(d_1)$	$g_2'(d_1)$	$g_2'(d_2)$
Full (difficult)	-	-	-
None	x	x	x
Partial, short-run	-	x	x
Partial, phased-in	x	-	-

Empirics

Empirical framework

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

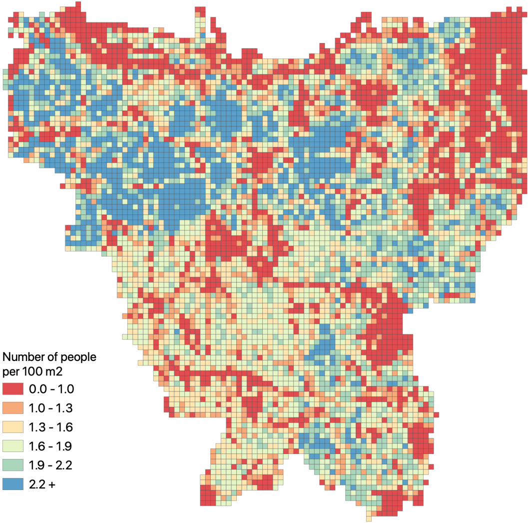
- $\tilde{r}(d, f)$: **spatial model** of residential demand
- $f(g)$: **hydrological model** of flood risk
- $c(d)$: **dynamic model** of developer supply
- $e(g)$: **engineering model** of sea wall costs

Residential demand

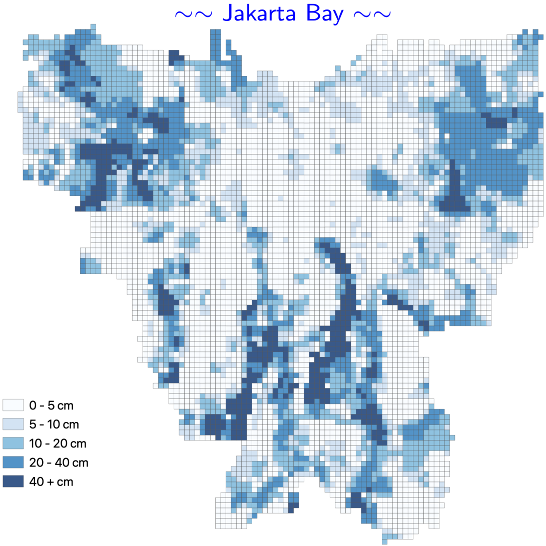
$$U_{ijk} = \alpha r_k + \phi f_k + x_k\gamma + \varepsilon_k + \tau m_{jk} + \epsilon_{ijk}$$

- **Spatial model** of residential choice (individual i, origin j, destination k)
  - Resident renters consider rents, flooding, amenities, distances, logit shocks
  - Moral hazard increasing in $\frac{\phi}{\alpha}$ via $r'(g)$
- **Estimation:** match population shares (BLP 1995) Details
  - Rent endogeneity from unobserved amenities
  - IV with ruggedness as supply shifter

Population (global data)



Flooding (2013-2020, past $\longrightarrow$ future)



Demand estimates (implied flood damages: \$0.3B $\rightarrow$ \$2.2B)

	IV		First stage	
	Estimate	SE	Estimate	SE
Rents	-0.032***	(0.004)		
Ruggedness			12.20***	(1.176)
Flooding	-0.490***	(0.097)	-15.53***	(2.485)
Residential amenities	0.110***	(0.018)	1.540***	(0.469)
District FE	x		x	
Observations	5,780		5,780	
F-statistic			108	

Developer supply

$$V_{kt}(D,L) = \alpha r_{kt}(D) + \mathbb{E}[\max_{d\in\{0,1\}} \{v^d_{kt}(D,L) + \epsilon^d_{ikt}\}]$$

$$v^1_{kt}(D,L) = -c_{kt}(x,\varepsilon) + \beta\mathbb{E}[V_{kt+1}(D+1,L-1)]$$

$$v^0_{kt}(D,L) = \beta\mathbb{E}[V_{kt+1}(D,L)]$$

- **Dynamic model** of developer choice (individual i, location k, time t)
  - Developer landlords consider rents, costs, logit shocks (development D, land L)
  - Moral hazard increasing in α via $r'(g)$
- **Estimation:** data as continuation values (Kalouptsidi 2014)
  - Rent endogeneity from unobserved costs
  - IV with residential amenities as demand shifter

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Data as continuation values

$$V_{kt}(D,L) = \alpha(P^D_{kt}D + P^L_{kt}L) \quad (*)$$

$$\begin{aligned}\ln p^1_{kt} - \ln p^0_{kt} &= v^1_{kt}(D,L) - v^0_{kt}(D,L)\\ &= -c_{kt}(x,\varepsilon) + \beta\mathbb{E}[V_{kt+1}(D+1,L-1) - V_{kt+1}(D,L)]\\ &= -c_{kt}(x,\varepsilon) + \alpha\beta\mathbb{E}[P^D_{kt+1} - P^L_{kt+1}]\\ &= -c_{kt}(x,\varepsilon) + \alpha\beta(P^D_{kt} - P^L_{kt})\end{aligned}$$

- Simple IV estimation (fast, transparent)
  - Need efficient real estate market ($P \to V$, frictions as ε)
  - Flexible expectations without finite dependence (P as market offer)

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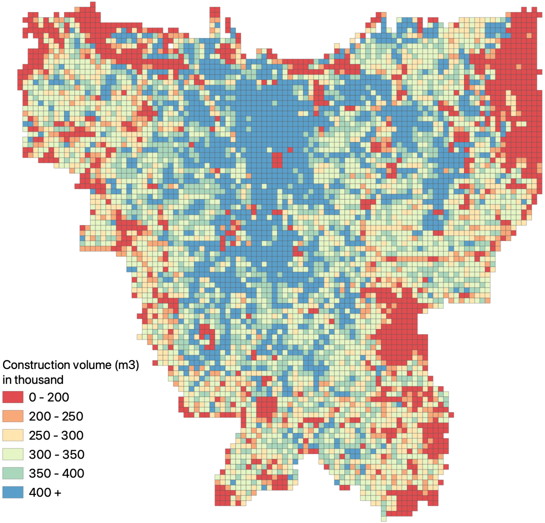
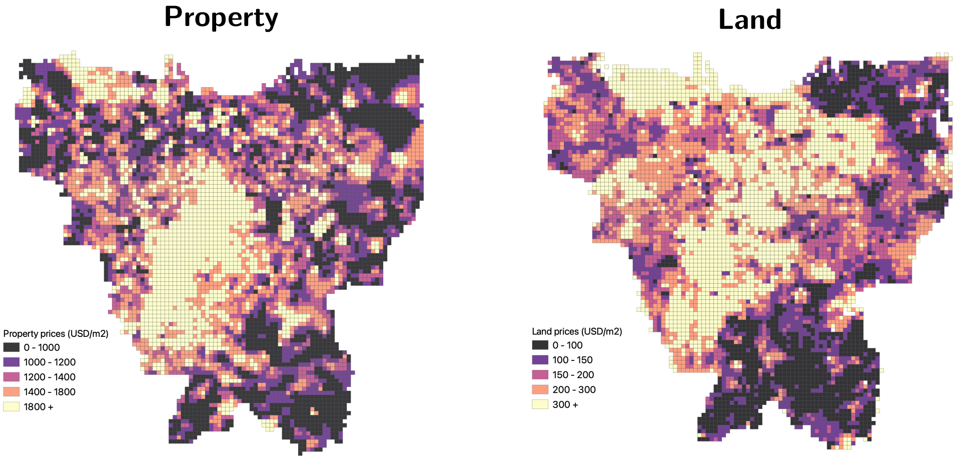
Building construction (global data)



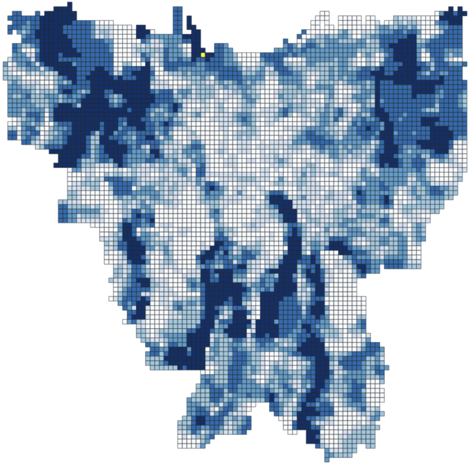
Real estate prices (urban data)



Supply estimates

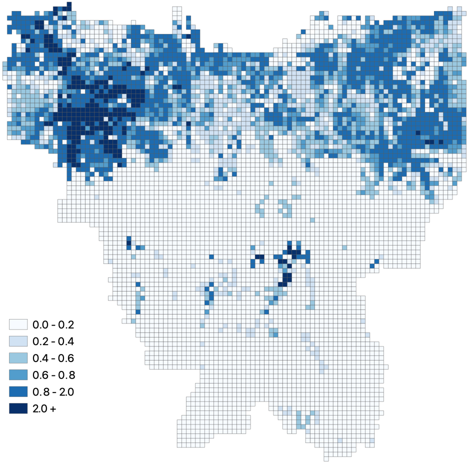
	IV		First stage	
	Estimate	SE	Estimate	SE
Prices	0.171***	(0.041)		
Residential amenities			0.182***	(0.043)
Flooding	0.064	(0.044)	-0.842***	(0.216)
Ruggedness	-0.143***	(0.054)	1.268***	(0.103)
District FE	x		x	
Observations	5,780		5,780	
F-statistic			18.14	

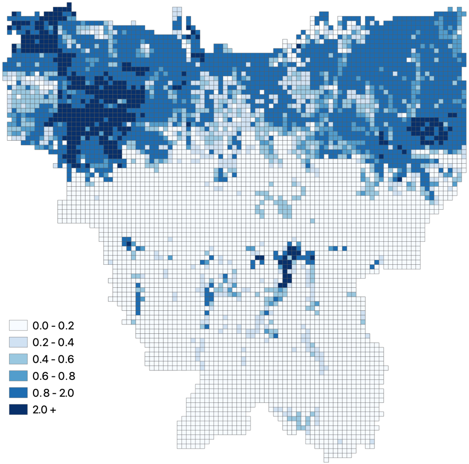
Flood risk (ML model)



Predicted vs. observed monthly flooding (2013-2020)

Flood risk (ML model)





3m vs. 5m sea wall

Sea wall costs (engineering model)

$$e(g) = \underbrace{10.67 * g * 60}_{\text{onshore}} + \underbrace{10.78 * (2g + 16) * 32}_{\text{offshore}} \quad (\$1\text{M})$$

- $9.5B for 3m wall, $12B for 5m wall
  - Matches official estimates from 2014 and 2020
  - Simple linear model (Lenk et al. 2017)

Counterfactuals

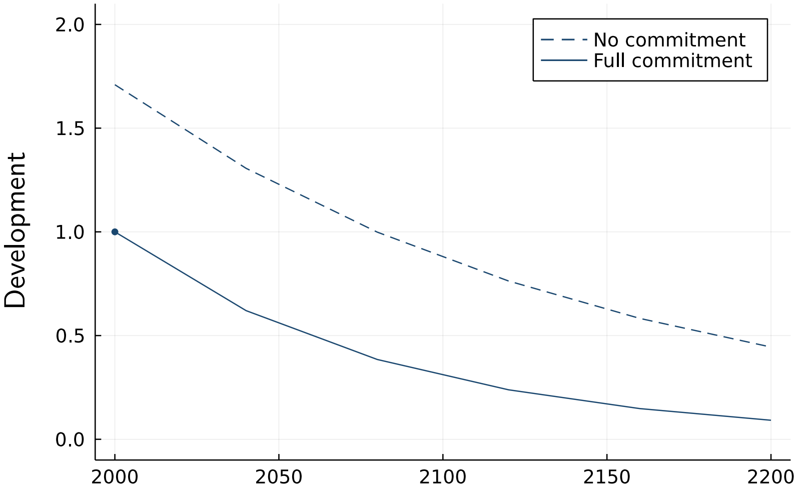
Equilibrium given $r(d,g)$, $c(d)$, and $e(g)$

$$g^*(d) = \arg\max\left\{r(g;d) - c(d) - e(g)\right\}$$
$$d^*(g) = \arg\max\left\{r(d;g) - c(d)\right\}$$

$$P^{\text{res}}(d,g) = P^{\text{dev}}(d,g)$$

- Solving full model (more assumptions)
    - Across locations in spatial equilibrium
    - Across periods by backward induction

Moral hazard delays adaptation



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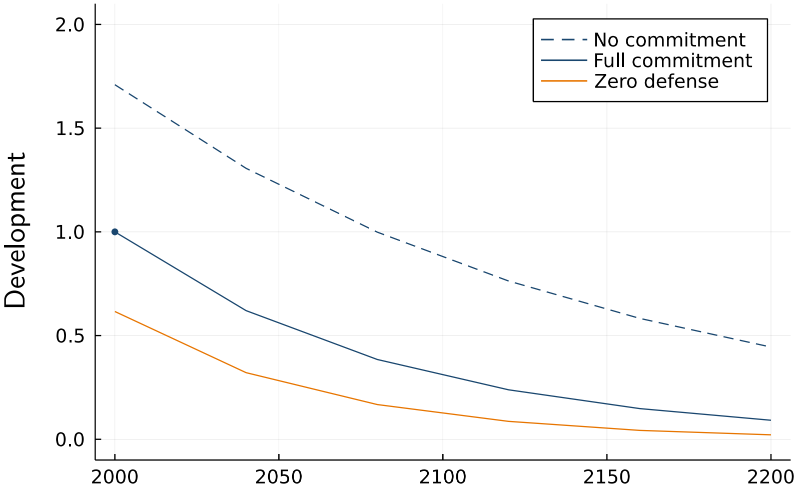
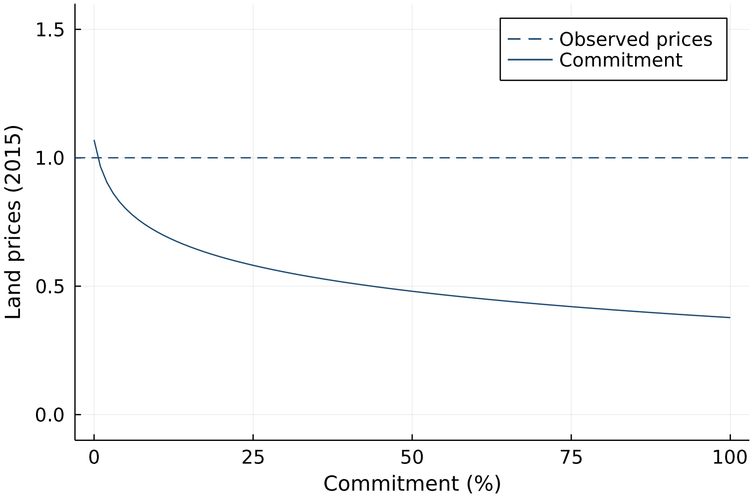


Moral hazard can rationalize observed prices



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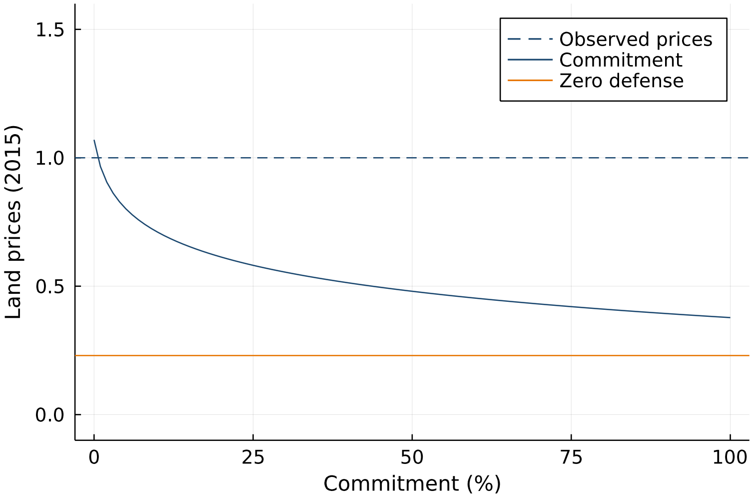
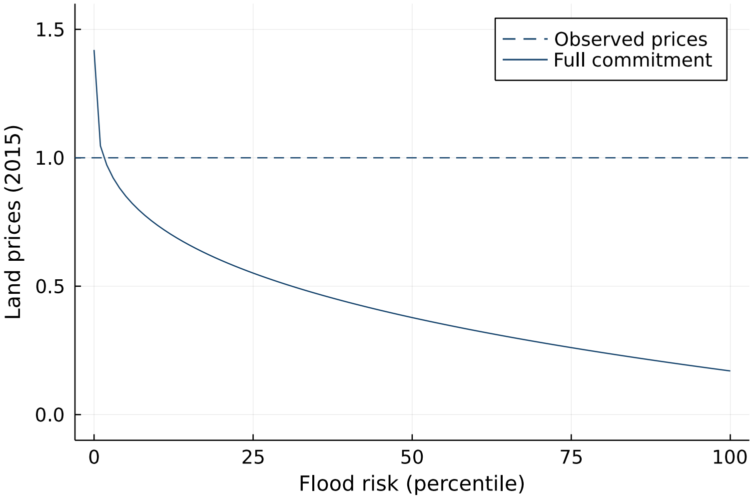


Flood risk cannot rationalize observed prices



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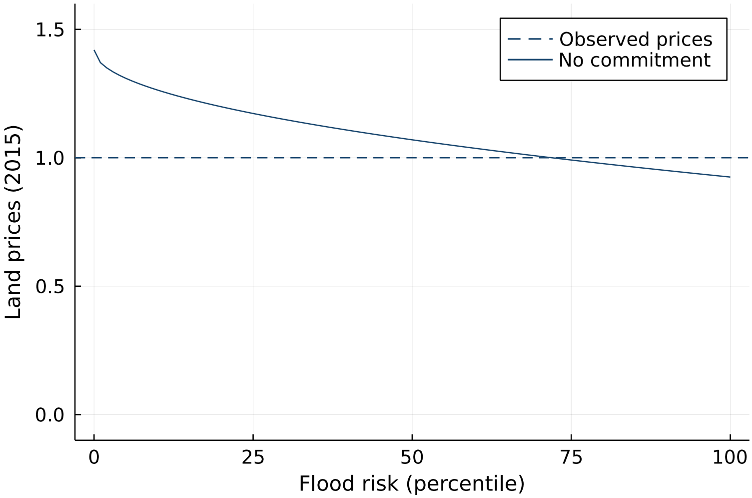
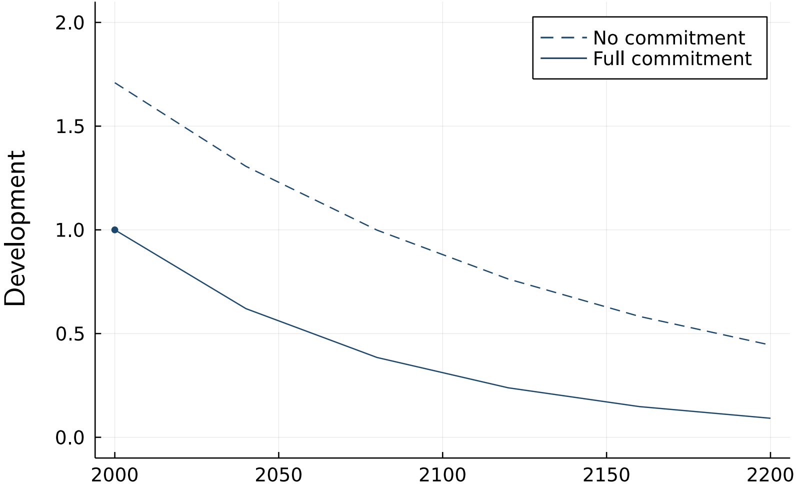


Partial commitment helps, subject to politics



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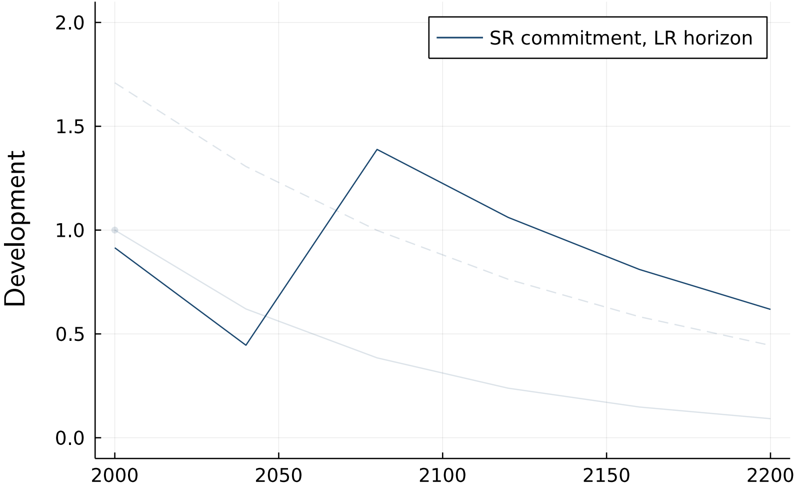

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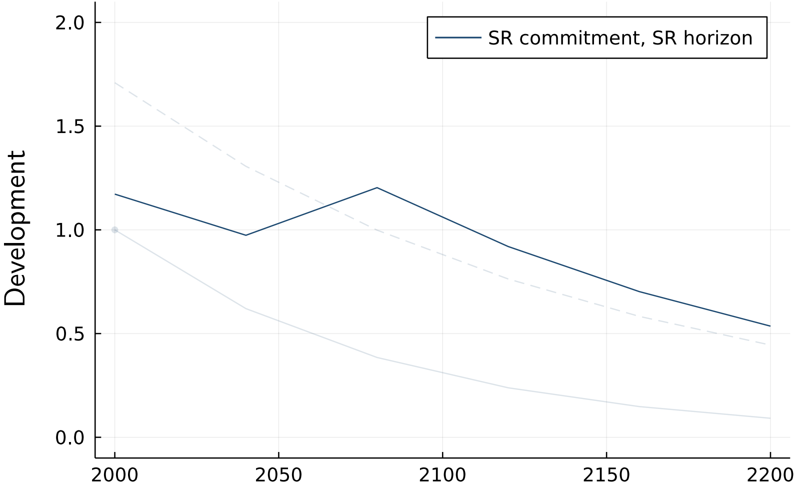
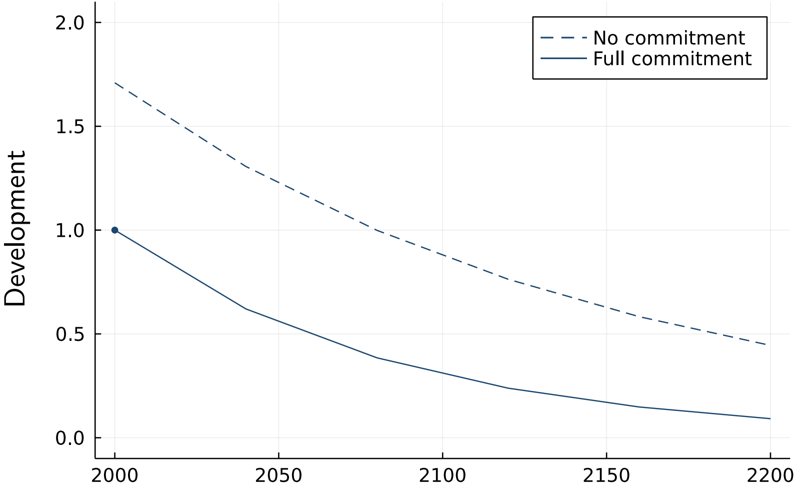


Moving the capital reduces moral hazard



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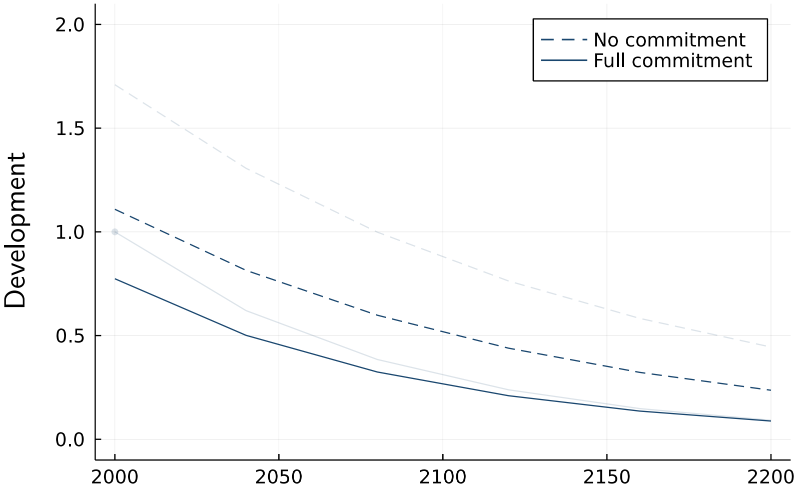
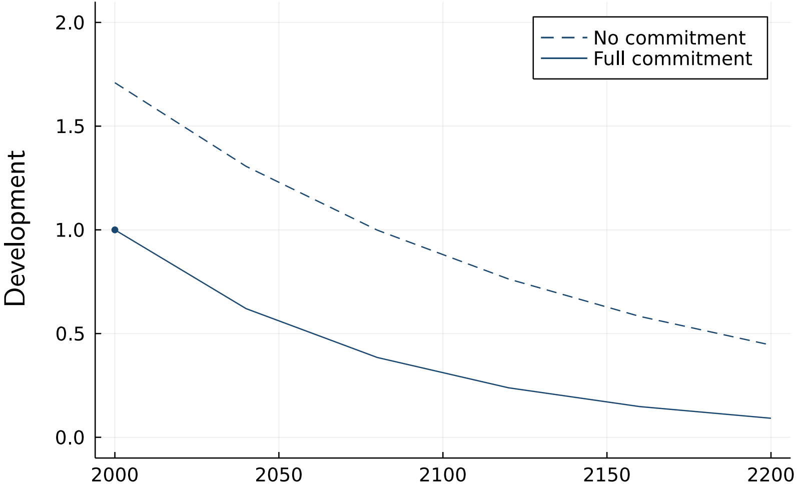


Slowing subsidence reduces moral hazard



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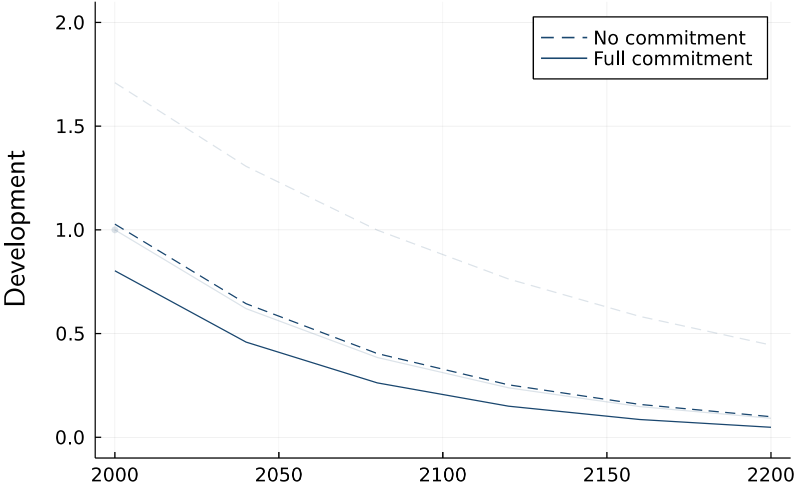

Policy recommendations

1. **Partial commitment**
    - Persistence: benefits of short-run policy
    - Anticipation: benefits of phased-in policy
2. **Integrated policy**
    - Moving capital or slowing subsidence
    - Less efficient, but more politically feasible
    - Moral hazard in other direction?

Conclusion

Summary

- **Moral hazard impedes adaptation** to climate change
- **Jakarta** foreshadows sea level rise that threatens 1B people by 2050

1	Miami	6	Mumbai
2	Guangzhou	7	Tianjin
3	New York City	8	Tokyo
4	Kolkata	9	Hong Kong
5	Shanghai	10	Bangkok

Hanson et al. (2011)