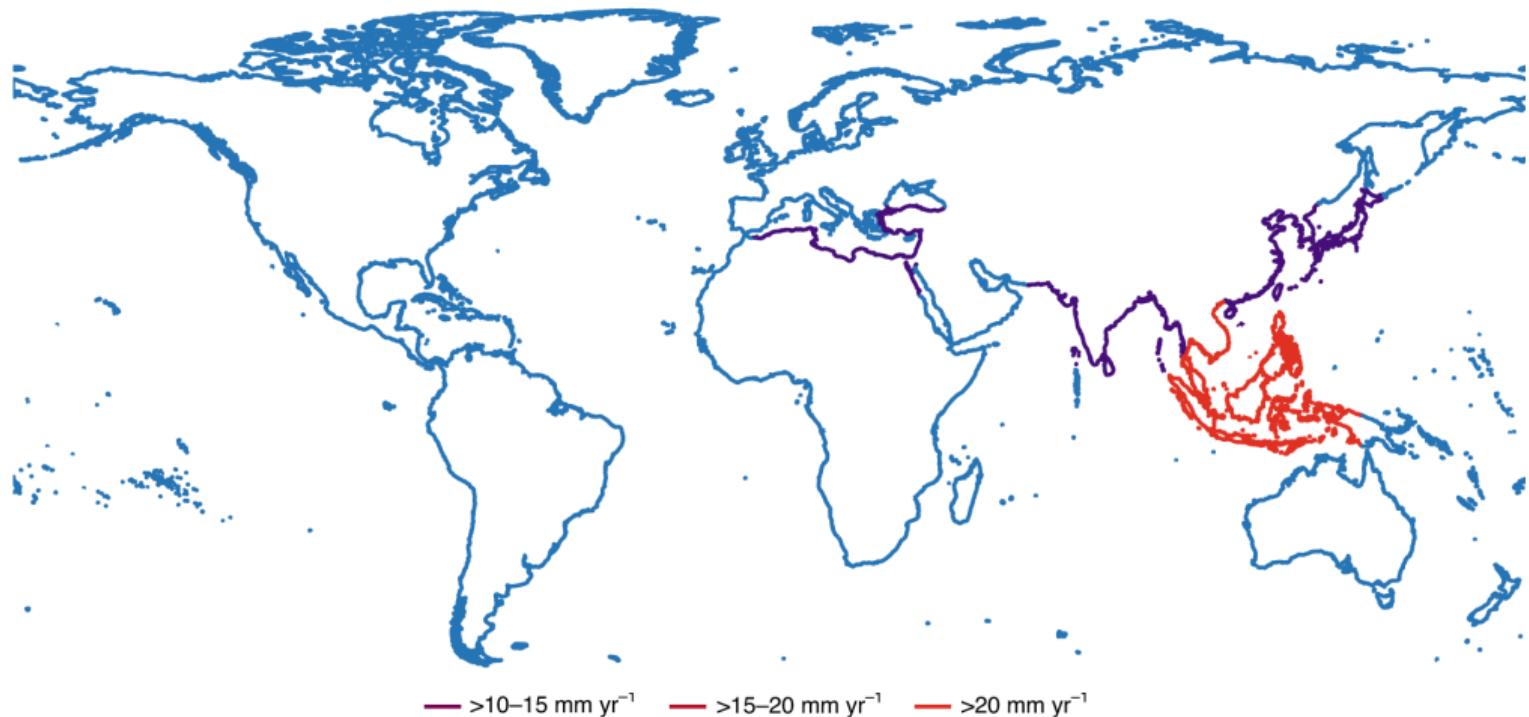


Sea Level Rise and Urban Adaptation in Jakarta

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Princeton University

October 20, 2023

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



(Nicholls et al. 2021)



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** as coastal development forces defense
 - If government cannot commit or regulate
 - Delays inland migration at high social cost
- **Dynamic spatial model** of development and defense
 - 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
 - Desmet et al. 2021, Barreca et al. 2016, Costinot et al. 2016
 - 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
 - Kalouptsidi 2014, Hotz & Miller 1993, Arcidiacono & Miller 2011, Murphy 2018
 - 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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Agent and principal

- ① Developers vs. government
- ② Coastal vs. local government
- ③ Local vs. national government
- ④ Current vs. future government

Commitment: first best

- ① Defense g^* or tax $e(g)$
- ② Development $d^*(g^*)$

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

- But ex post, principal wants to defend (plus lobbying)
- And tax can be costly to enforce (or impossible)

No commitment: coastal over-development

- 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: uninternalized cost + time inconsistency (as magnifier)
- Coastal defense crowds out inland migration (lock-in)

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

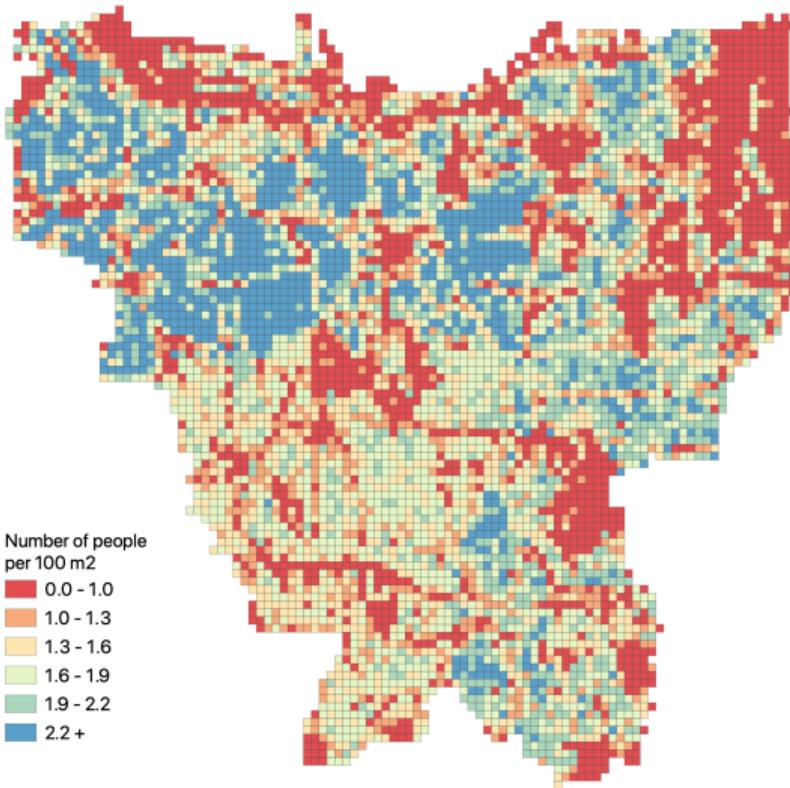
Residential demand

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

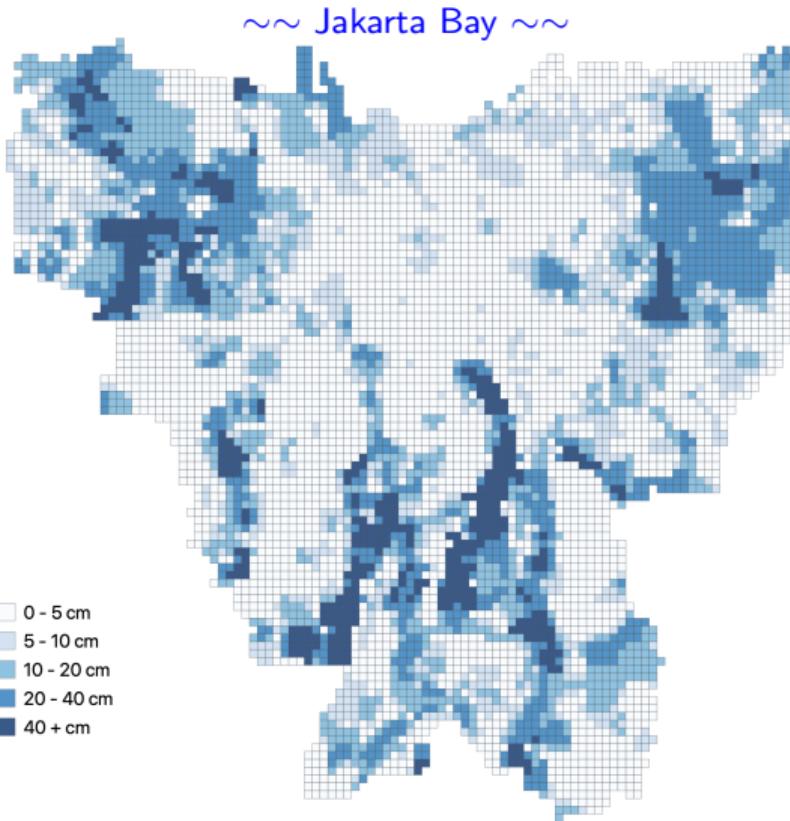
- **Spatial model** of residential choice (individual i , origin j , destination k)
 - Resident renters consider rents, flooding, amenities, distances, logit shocks
 - Moral hazard increasing in $\frac{\phi}{\alpha}$
- **Estimation:** match population shares (BLP 1995)
 - Rent endogeneity from unobserved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

Details

Population (global data)



Flooding (2013-2020, past → future)



Demand estimates (implied flood damages: \$0.3B → \$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

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

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

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

- **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
- **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

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

$$\begin{aligned}\ln p_{kt}^1 - \ln p_{kt}^0 &= v_{kt}^1(D, L) - v_{kt}^0(D, L) \\ &= -c_{kt}(x, \varepsilon) + \beta \mathbb{E}[V_{kt+1}(D+1, L-1) - V_{kt+1}(D, L)] \\ &= -c_{kt}(x, \varepsilon) + \alpha \beta \mathbb{E}[P_{kt+1}^D - P_{kt+1}^L] \\ &= -c_{kt}(x, \varepsilon) + \alpha \beta (P_{kt}^D - P_{kt}^L)\end{aligned}$$

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

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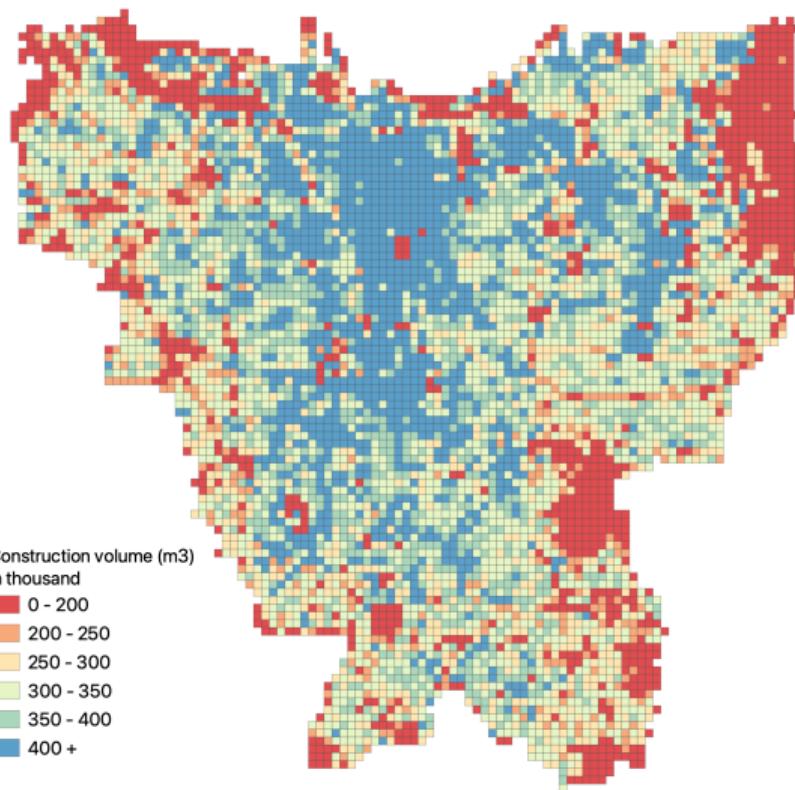
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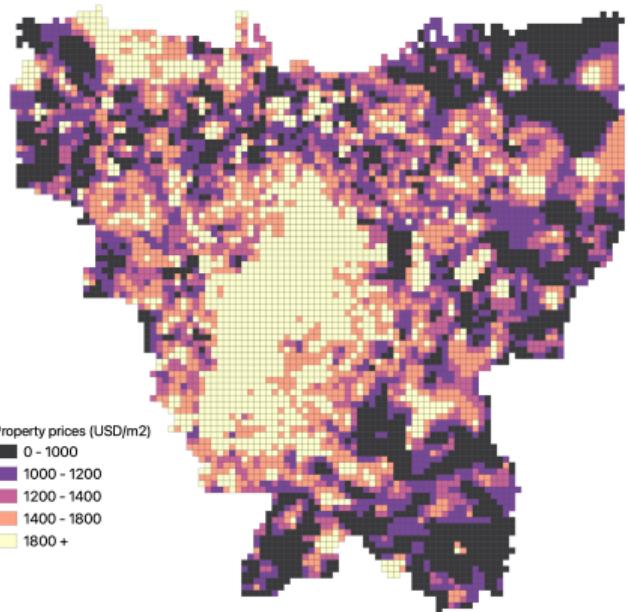
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Building construction (global data)

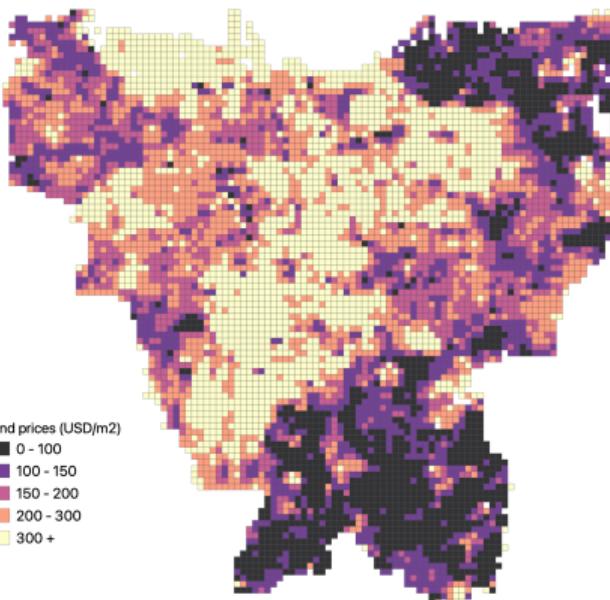


Real estate prices (urban data)

Property



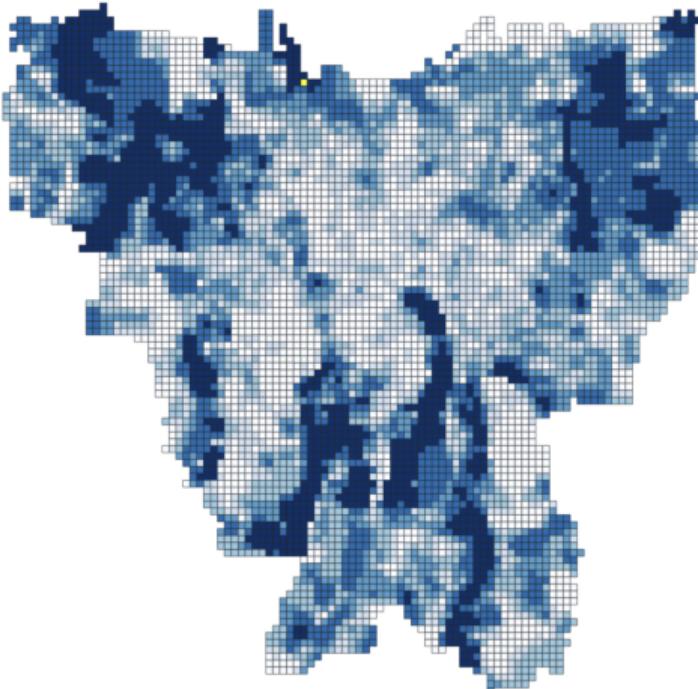
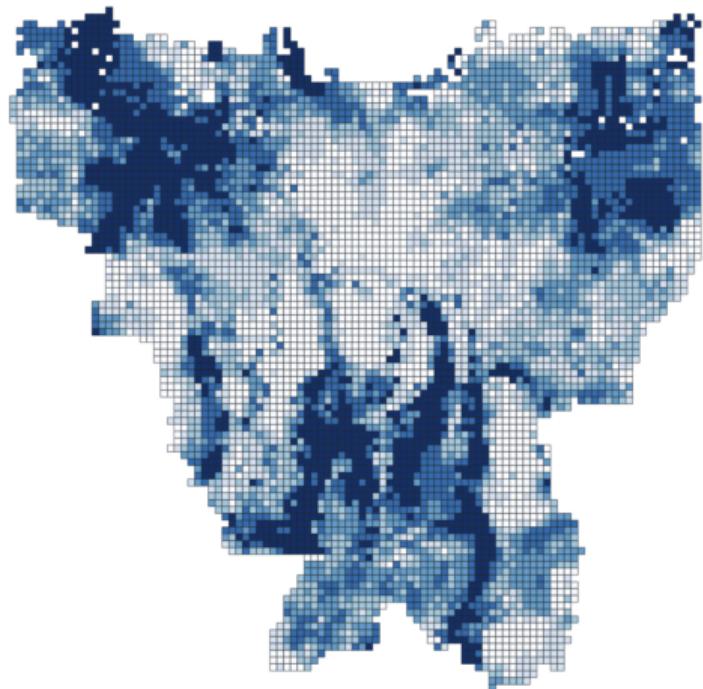
Land



Supply estimates

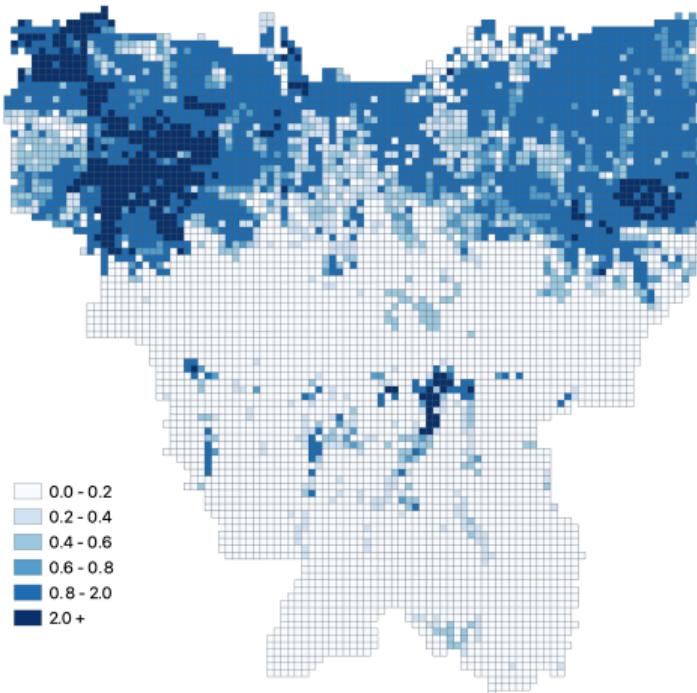
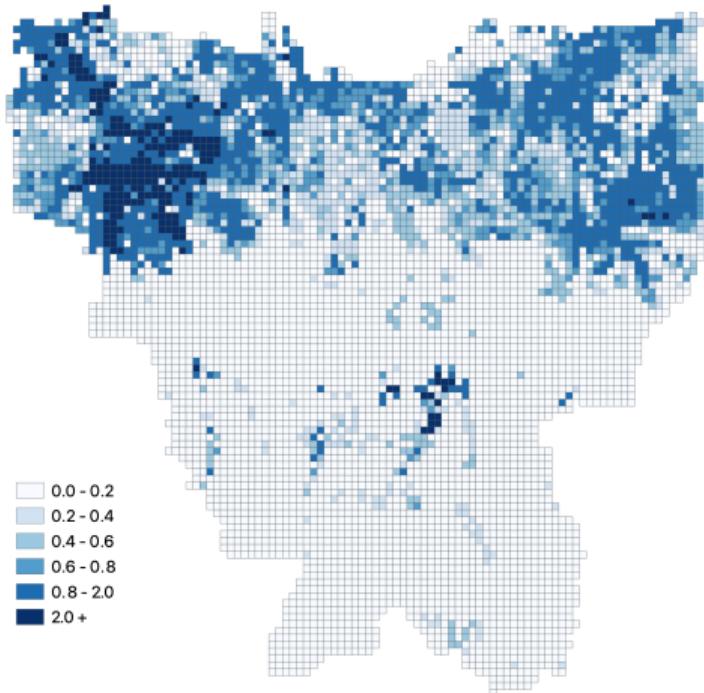
	IV		First stage	
	Estimate	SE	Estimate	SE
Prices	0.171***	(0.041)		
Residential amenities			0.182***	(0.043)
Flooding	0.064	(0.044)	-0.842***	(0.216)
Ruggedness	-0.143***	(0.054)	1.268***	(0.103)
District FE	x		x	
Observations	5,780		5,780	
F-statistic			18.14	

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)

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

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

Counterfactuals

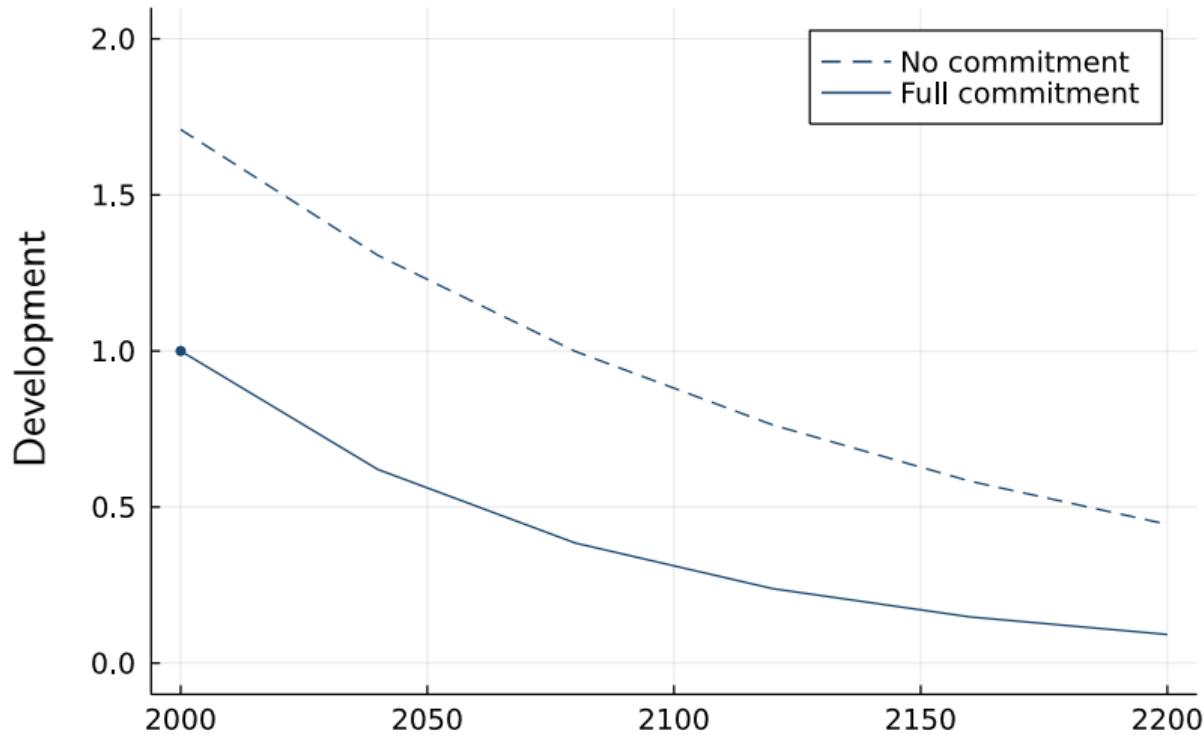
Equilibrium given $r(d, g)$, $c(d)$, and $e(g)$

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

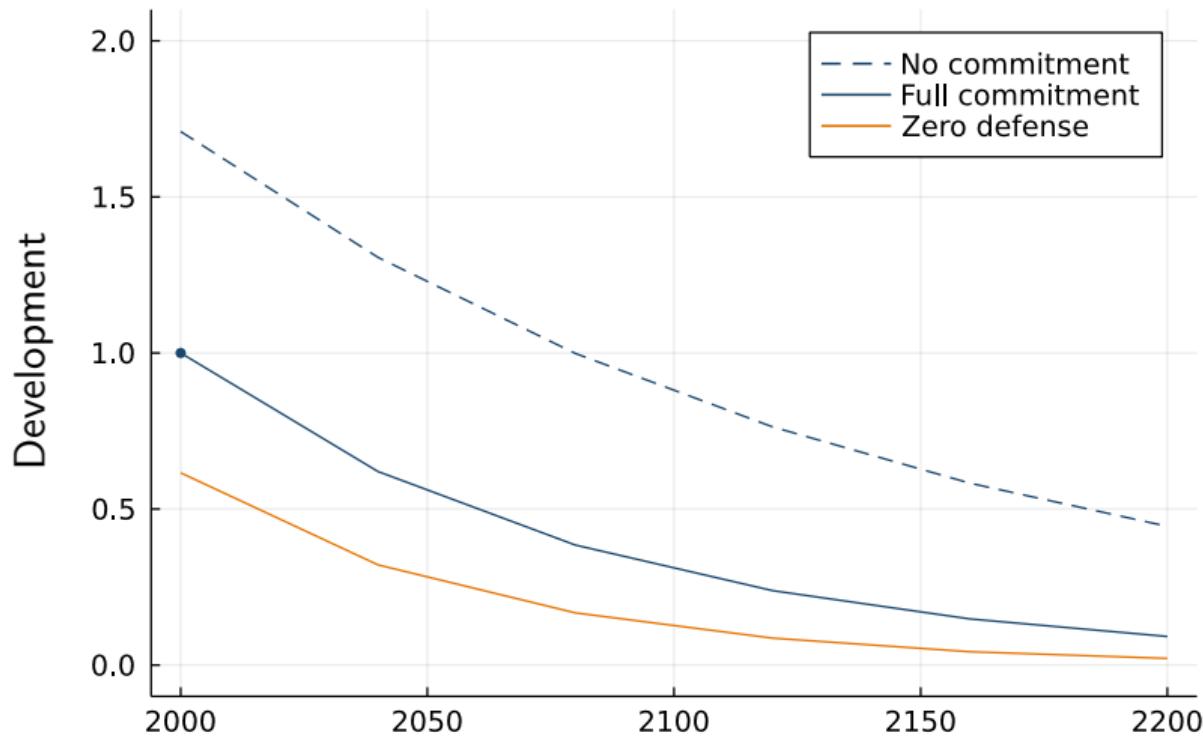
$$P^{\text{res}}(d, g) = P^{\text{dev}}(d, g)$$

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

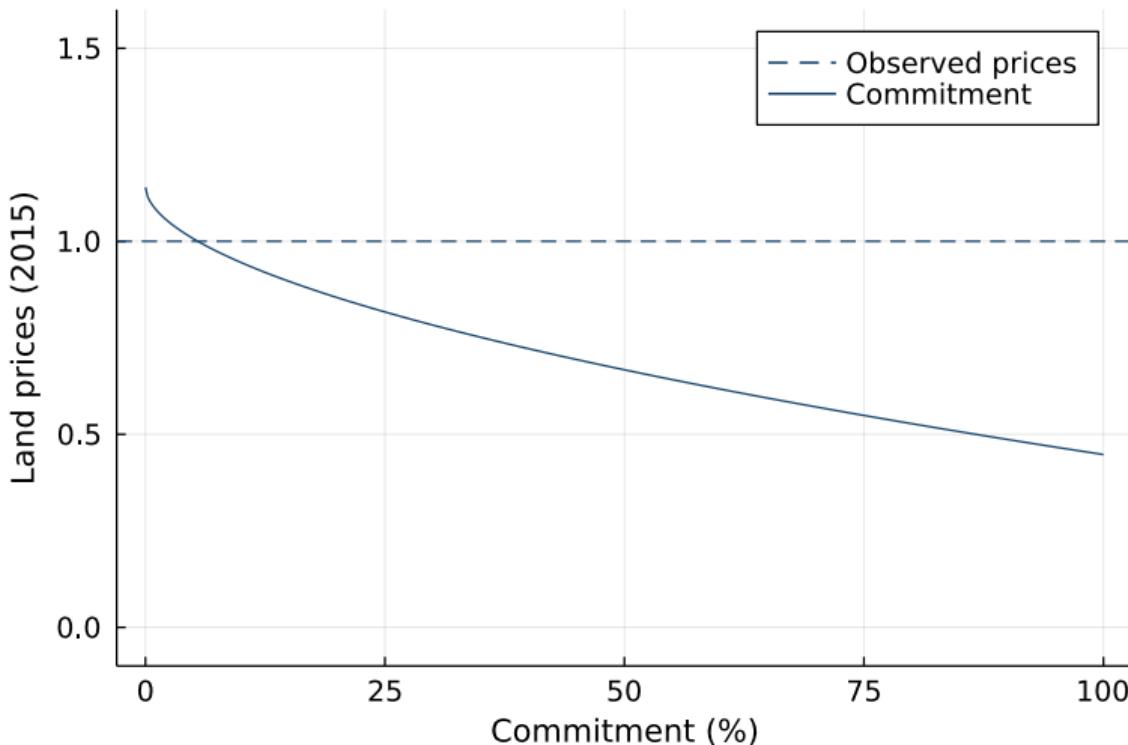
Moral hazard delays adaptation



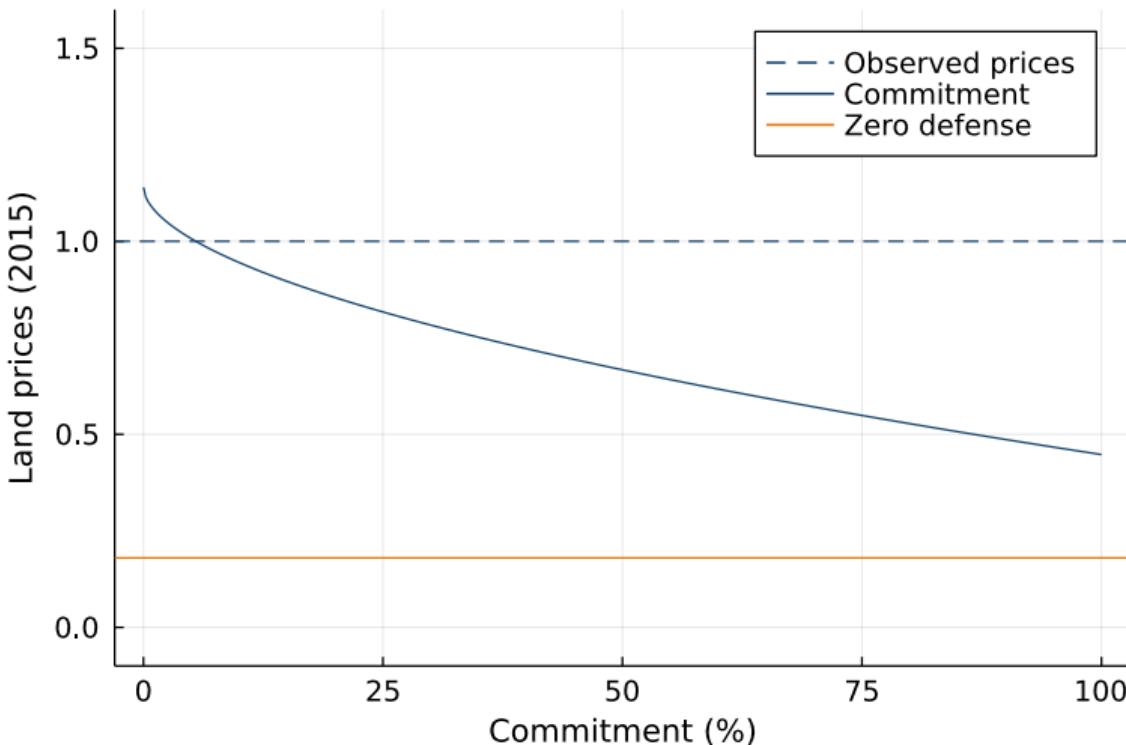
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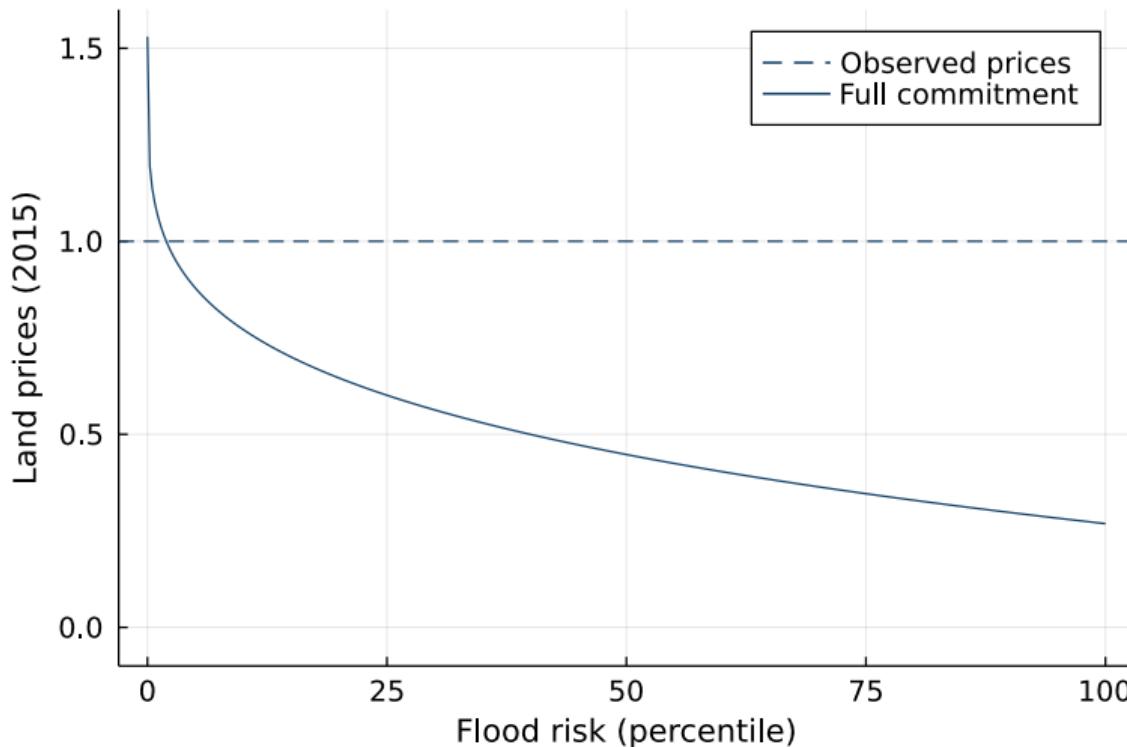
Moral hazard can rationalize observed prices



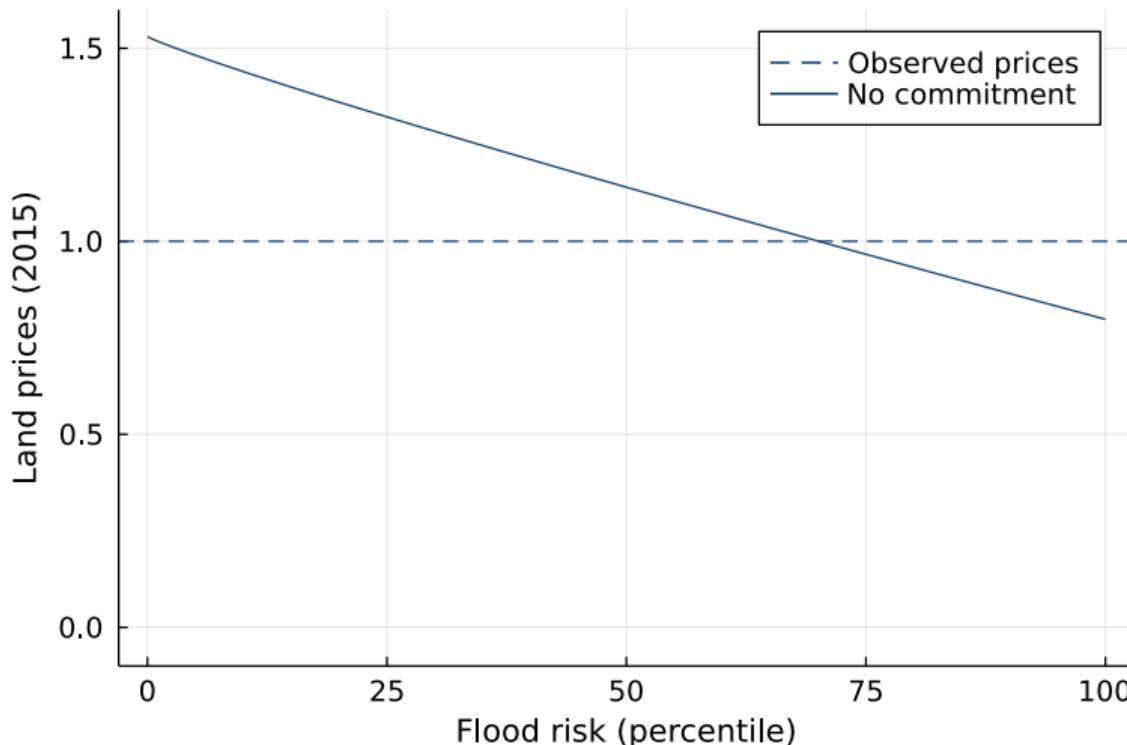
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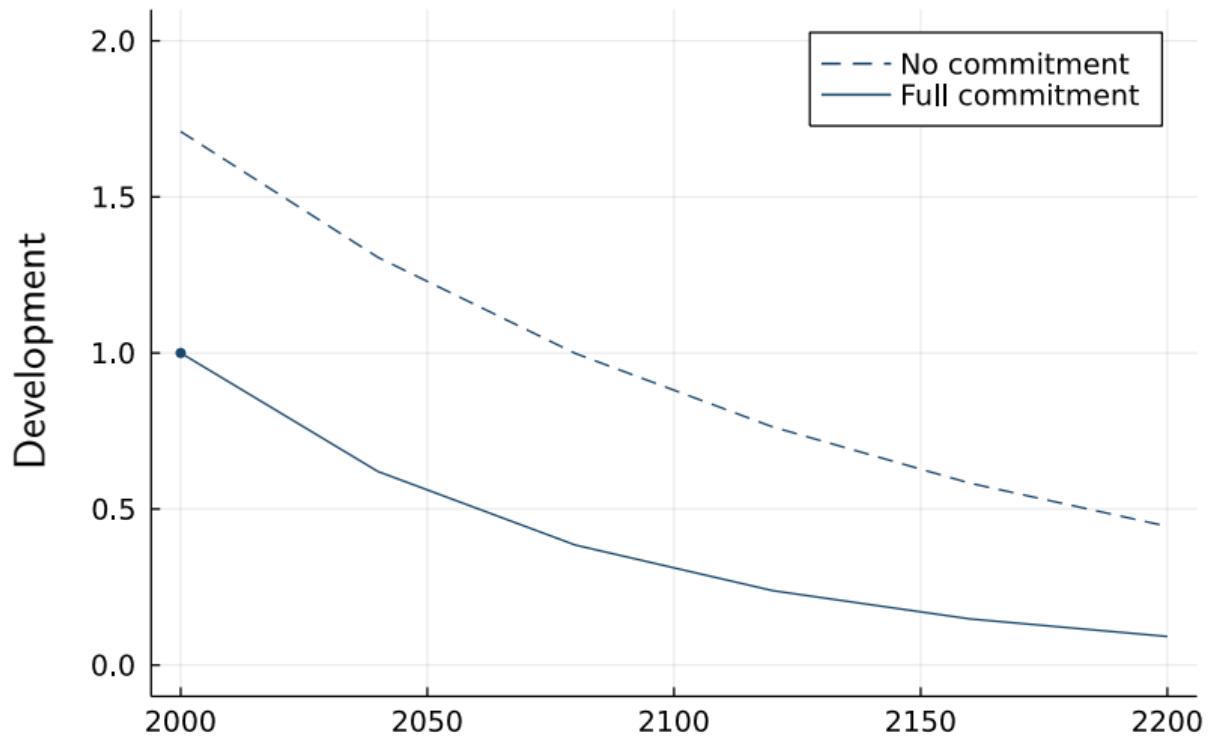
Flood risk cannot rationalize observed prices



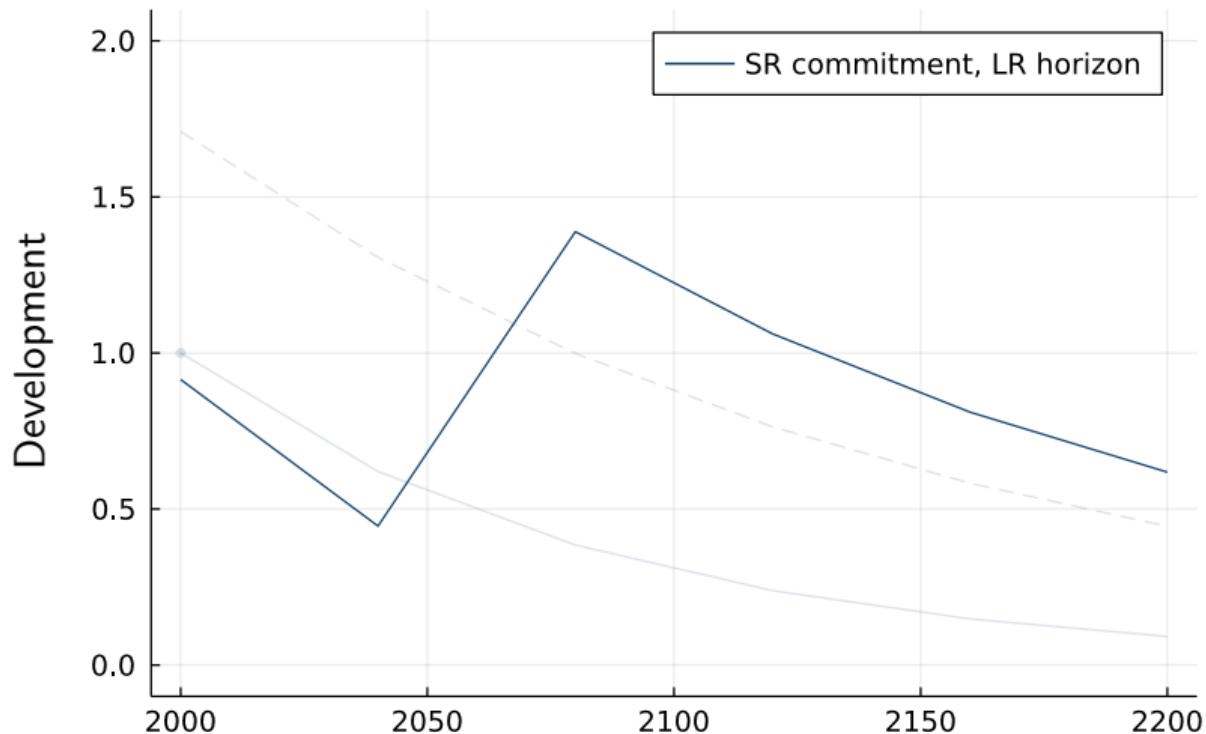
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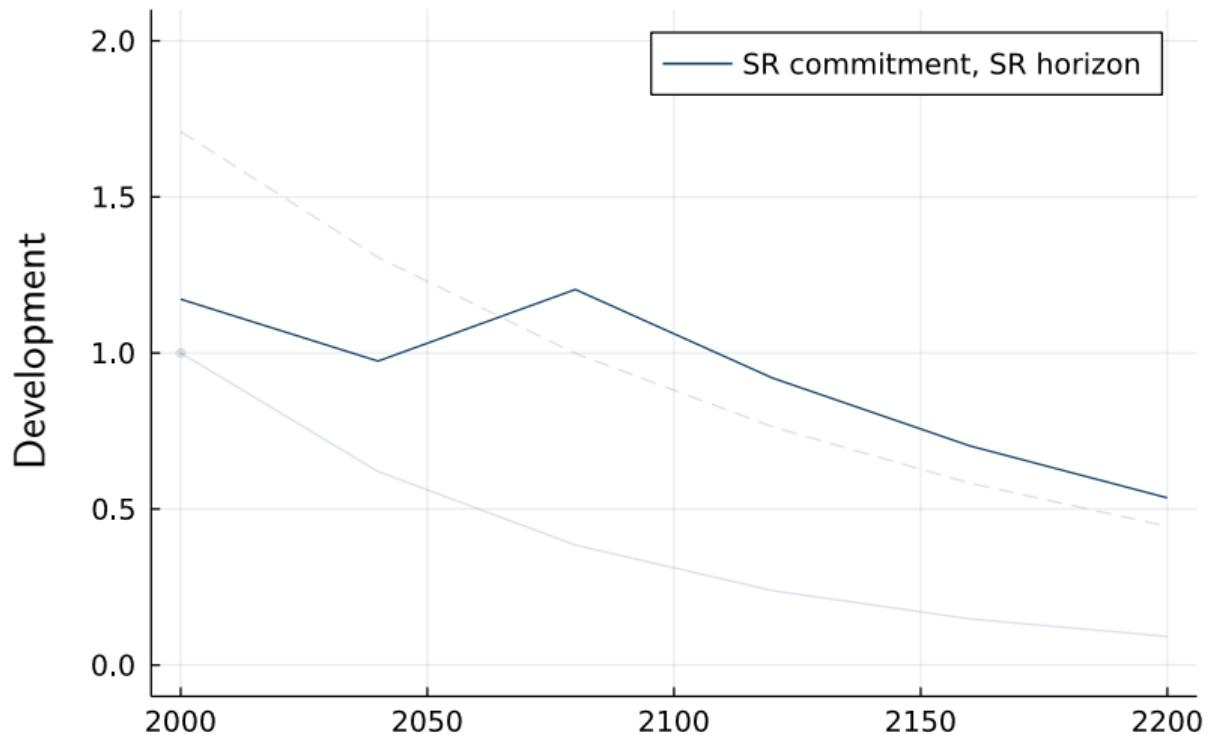
Partial commitment helps, subject to politics



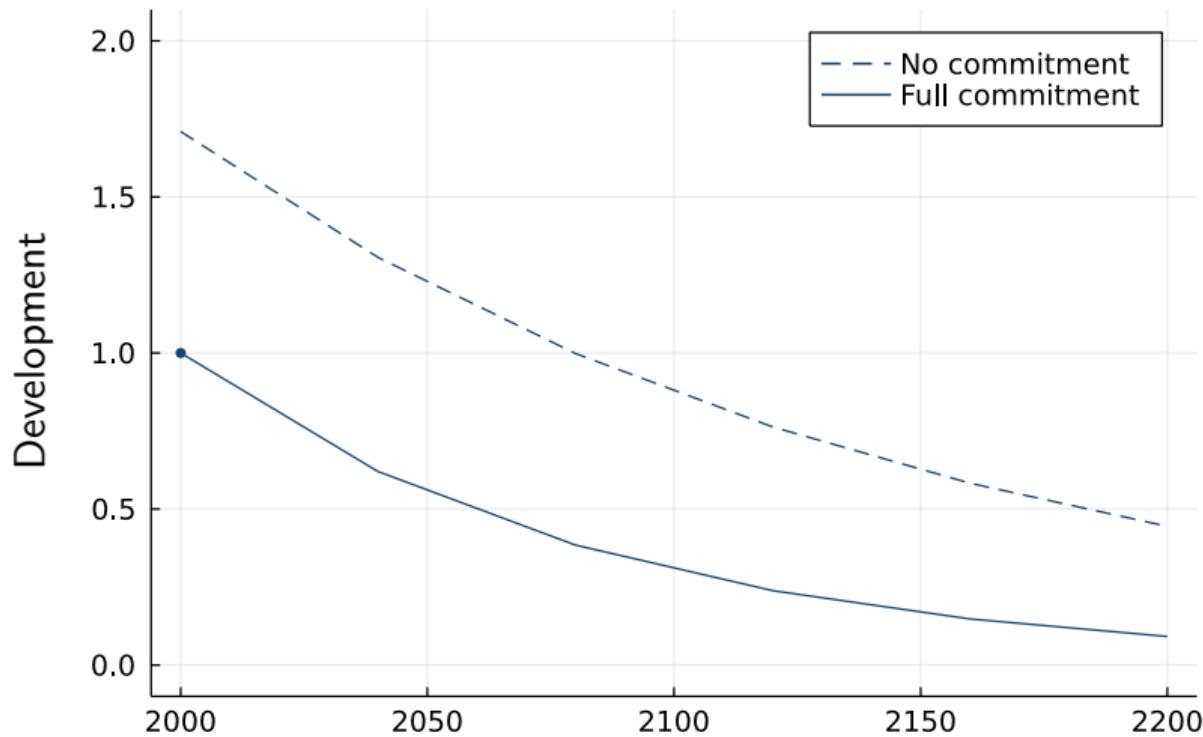
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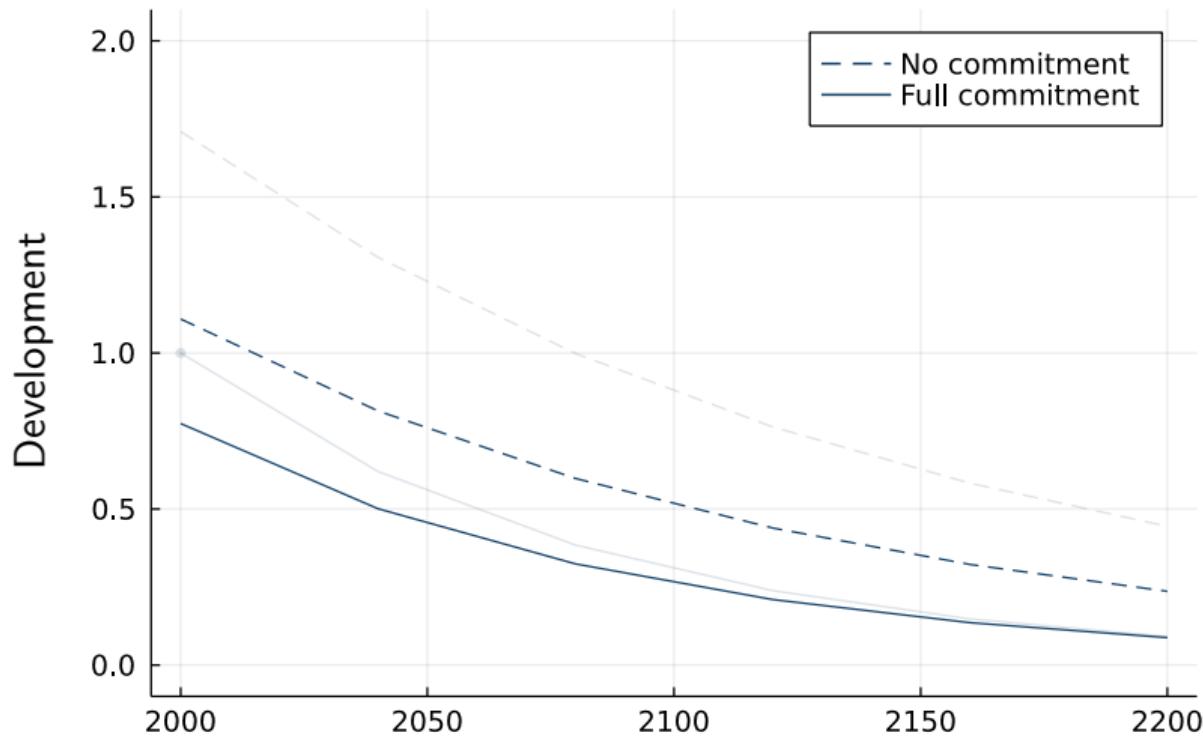
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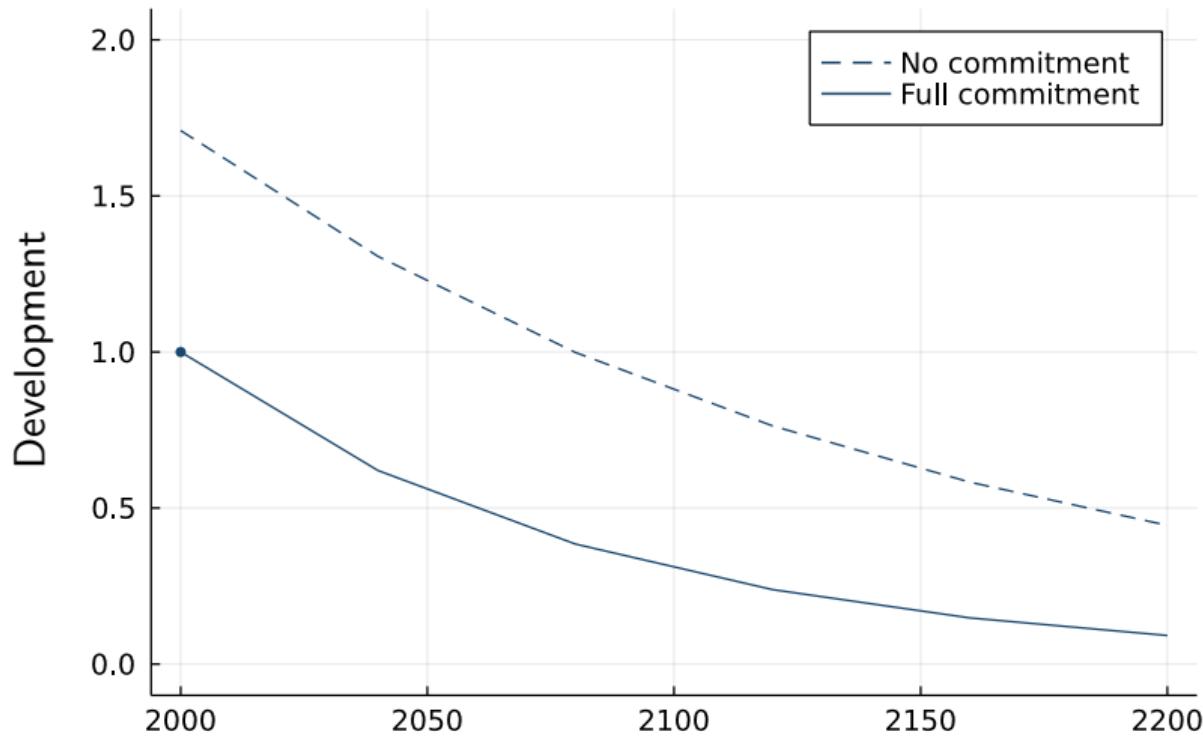
Moving the capital reduces moral hazard



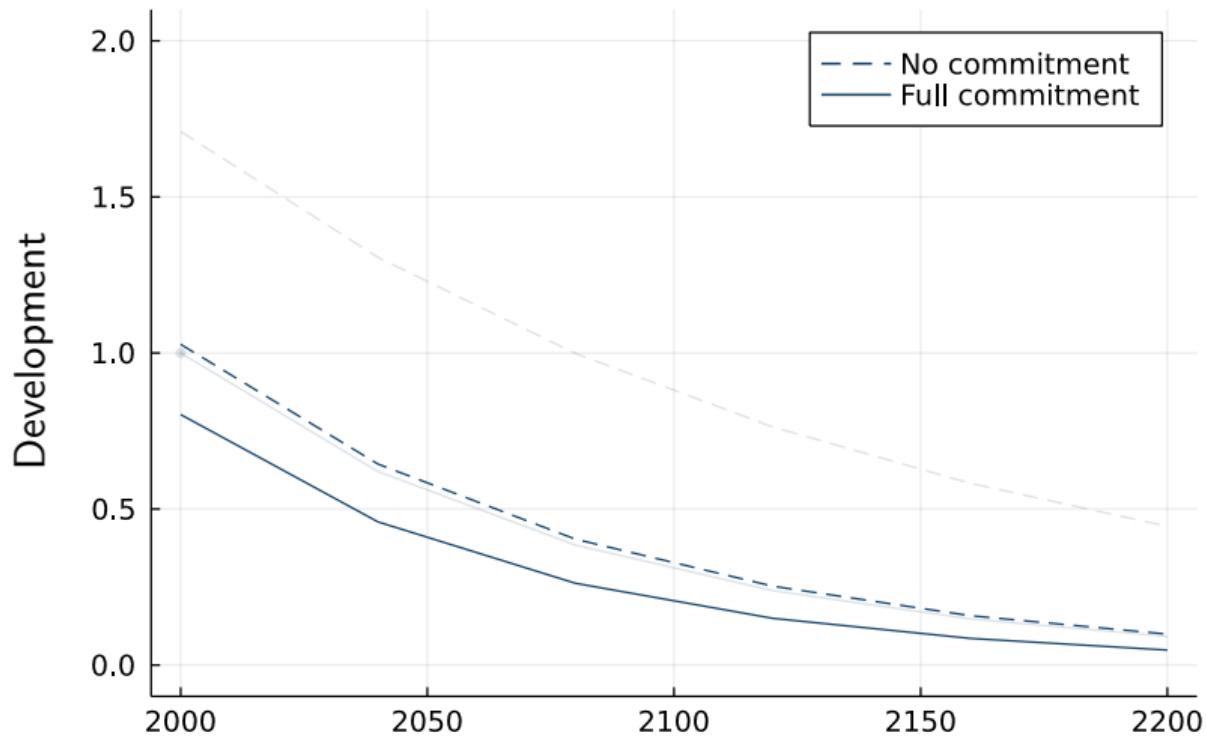
Moving the capital reduces moral hazard



Slowing subsidence reduces moral hazard



Slowing subsidence reduces moral hazard



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)