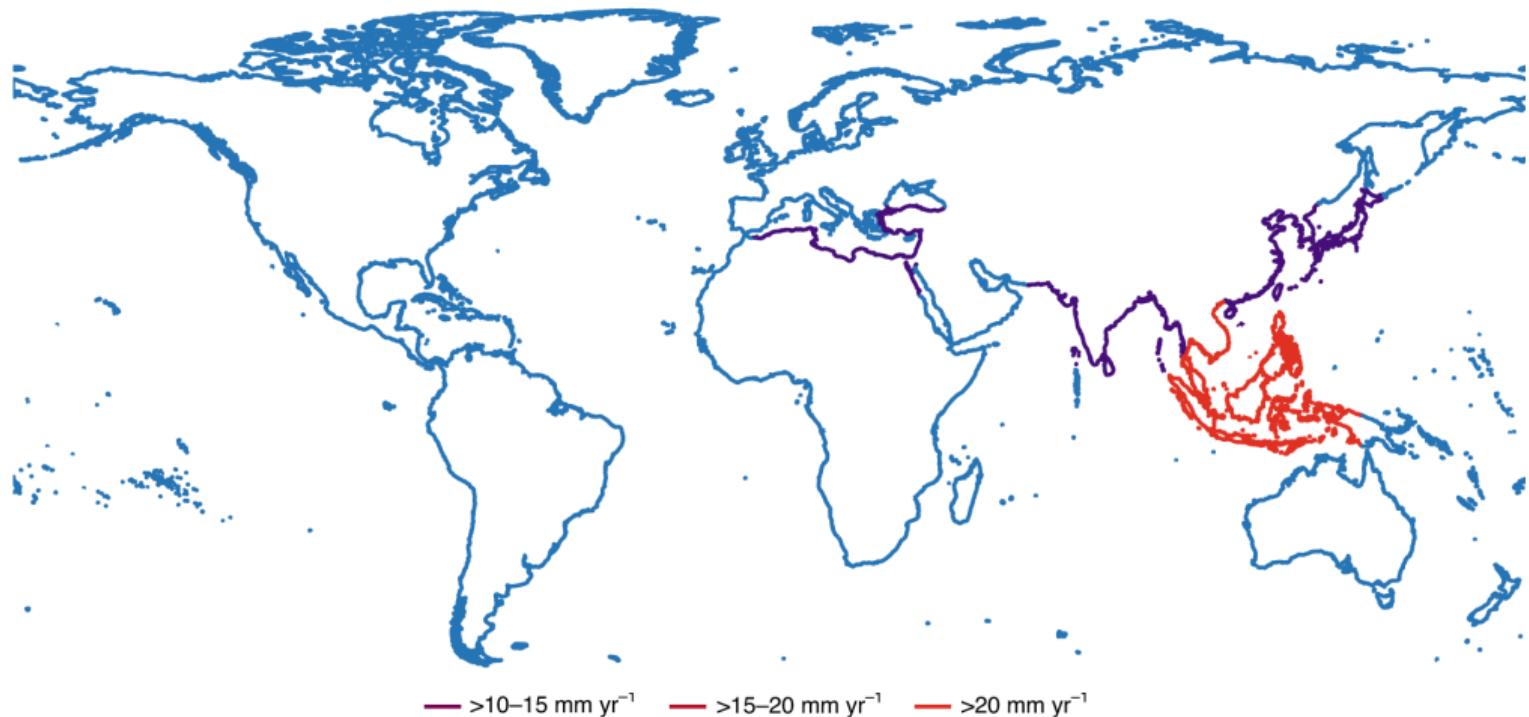


Sea Level Rise and Urban Adaptation in Jakarta

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Princeton University

June 6, 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 (95% for north)
 - 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

- Full commitment: gradual managed retreat
- No commitment: coastal lock-in (5x in 2200)
- Zero defense can dominate

② Policy prescriptions

- Partial commitment: short-run or phased-in
- Integrated approach: sea wall + inland incentives

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

- Current vs. future government
- Local vs. national government
- Coastal residents/developers vs. government

Commitment (first best)

- ① Defense $g^* > 0$
- ② Response $d^*(g^*) > 0$

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

- But ex post, defense optimal + lobbying (rezoning)
- Equivalent: tax $e(g)$, but costly to enforce

No commitment

- ① Development $d^n > d^*$
- ② Response $g^n(d^n) > g^*$ at uninternalized cost ($r'(g) > 0$)

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

- Time inconsistency: static gain, dynamic cost ($g'(d) > 0$)
- **Moral hazard:** coastal lock-in, delayed adaptation ($g'(d)$ magnifier)

Over time: two periods + durability

Commitment	$g'_1(d_1)$	$g'_2(d_1)$	$g'_2(d_2)$
Full (difficult)	-	-	-
Partial			
Short-run	-	x	x
Phased-in	x	-	-
Own-period	-	x	-
None	x	x	x

Empirics

Empirical framework

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

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

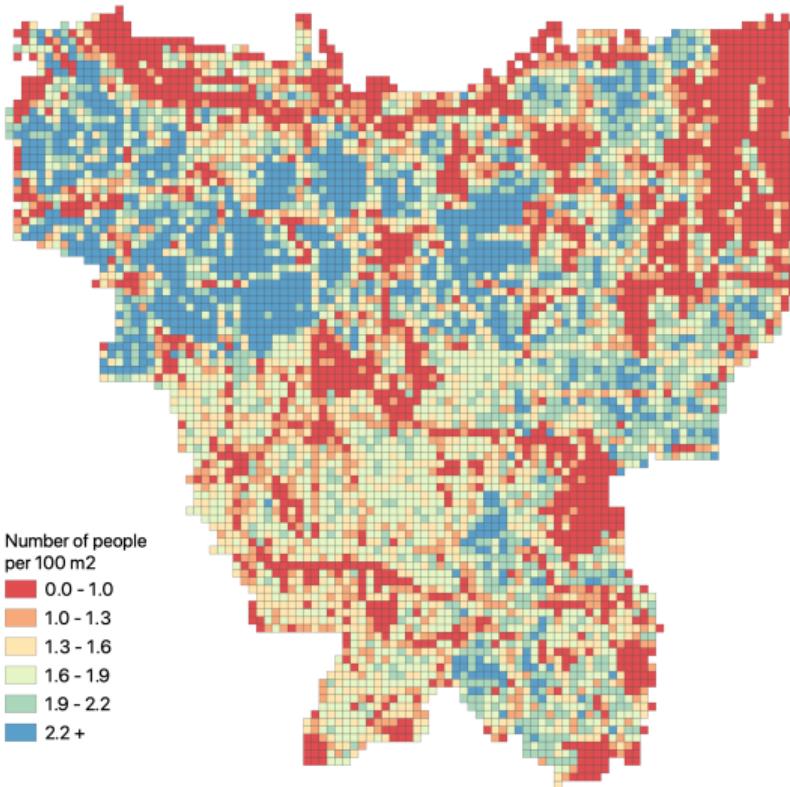
Residential demand

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

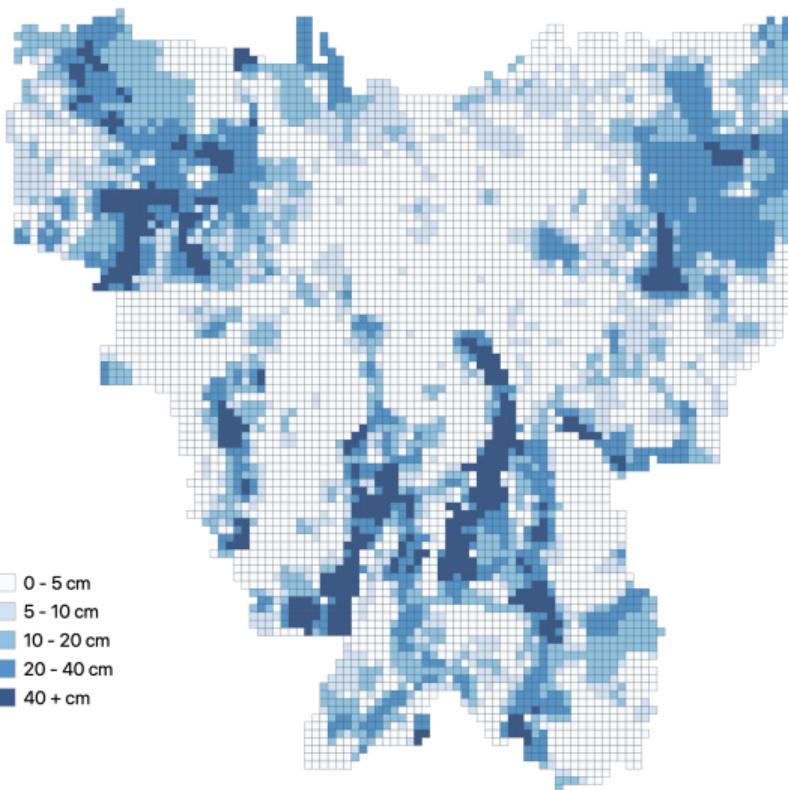
- **Spatial model** of residential choice (individual i , origin j , destination k)
 - Resident renters consider rents, flooding, amenities, distances, logit shocks
 - Moving inland abandons high-amenity places and incurs migration costs
- **Estimation** with 2020 population shares and instruments (BLP 1995)
 - Price endogeneity from correlation of rents and 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

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

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

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

- **Dynamic model** of developer choice (individual i , location k , time t)
 - Developer landlords consider rents, costs, logit shocks (development D , land L)
 - Moving inland abandons high-rent places and incurs construction costs
- **Estimation:** data as continuation values (Kalouptsidi 2014)
 - Price endogeneity from correlation of rents and unobserved costs
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Data as continuation values

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

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

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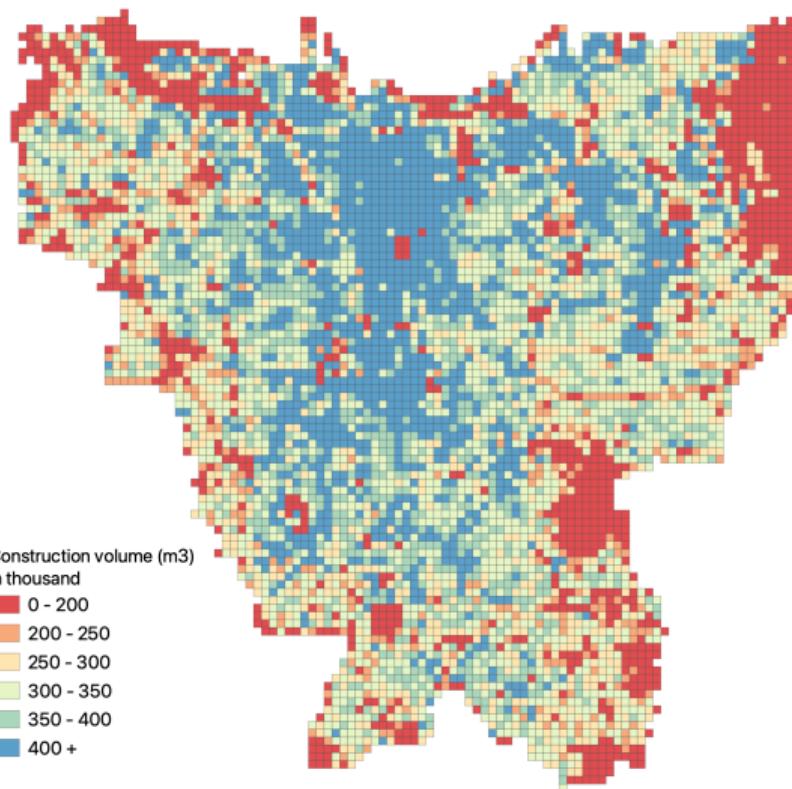
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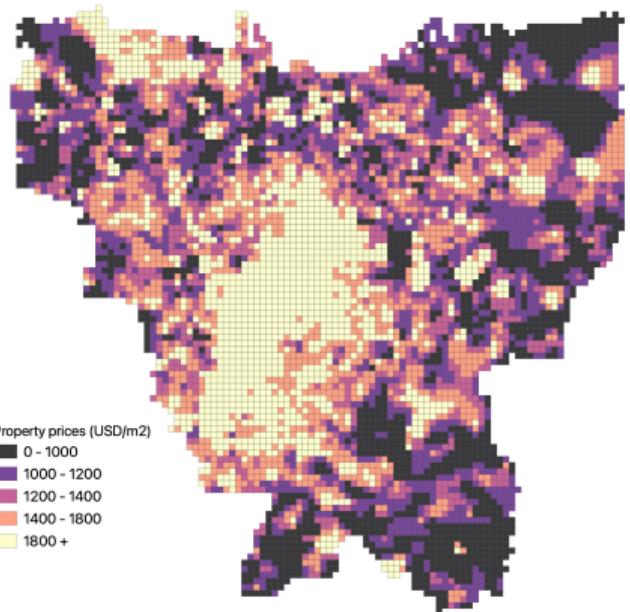
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Building construction (global data)

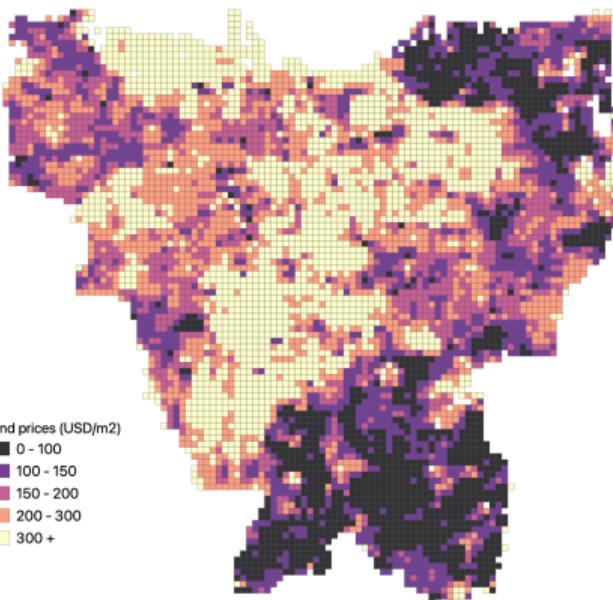


Real estate prices (urban data)

Property



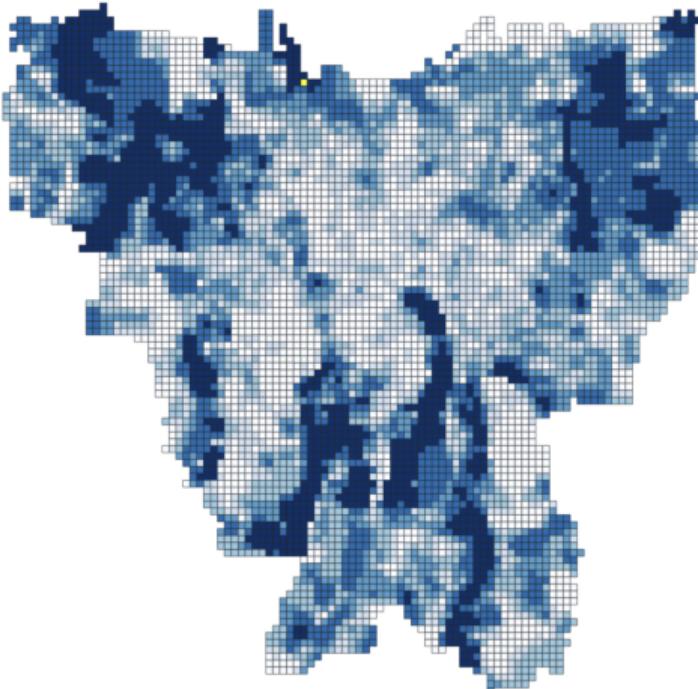
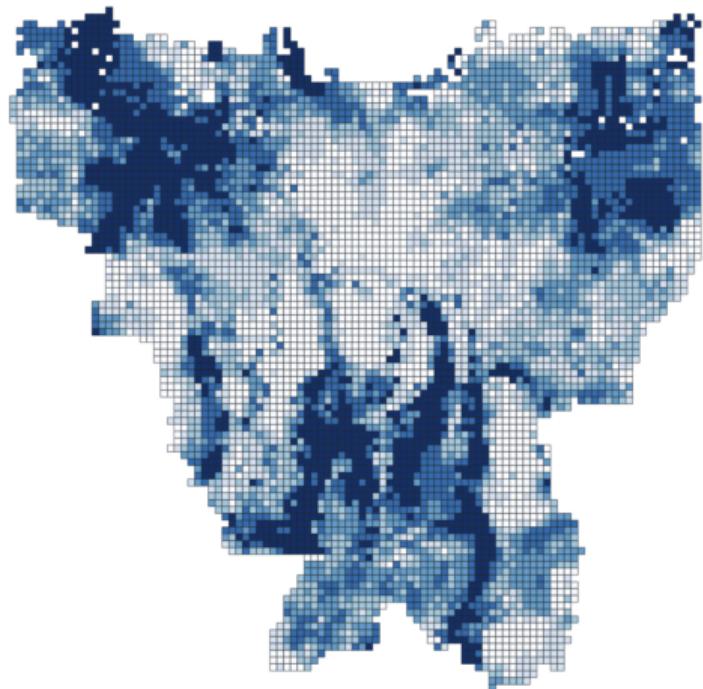
Land



Supply estimates

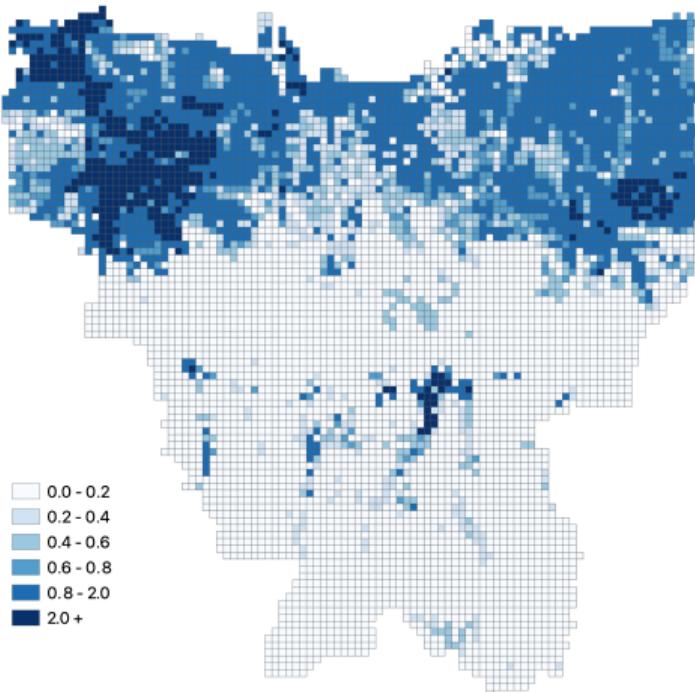
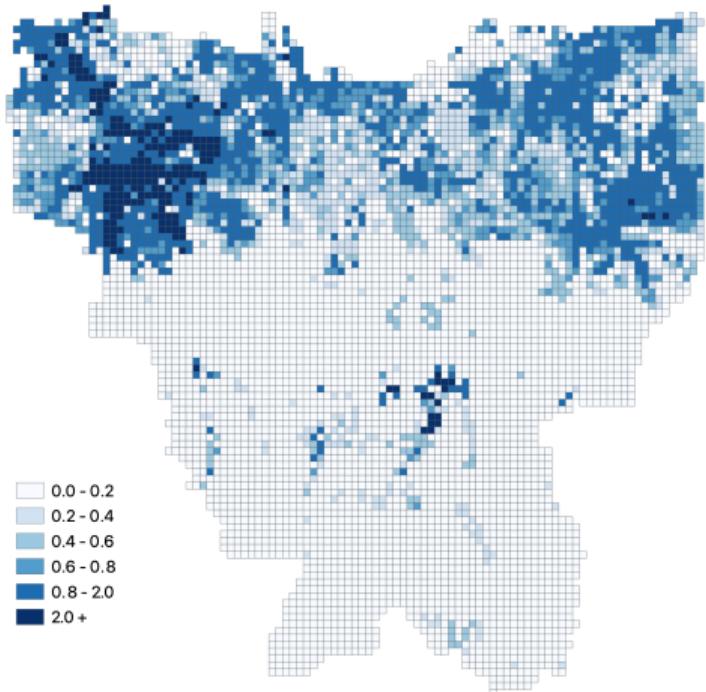
	IV		First stage	
	Estimate	SE	Estimate	SE
Prices	0.171***	(0.041)		
Residential amenities			0.182***	(0.043)
Flooding	0.064	(0.044)	-0.842***	(0.216)
Ruggedness	-0.143***	(0.054)	1.268***	(0.103)
District FE	x		x	
Observations	5,780		5,780	
F-statistic			18.14	

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 $e(g)$

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

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

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

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

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

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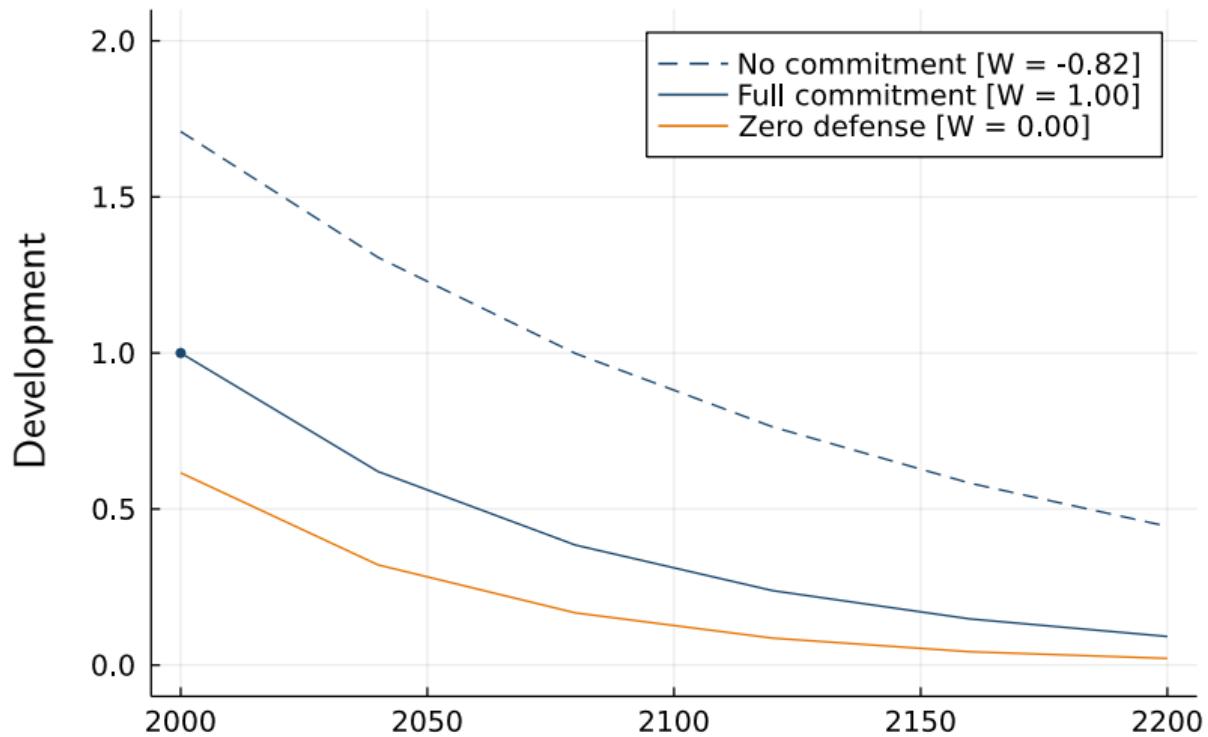
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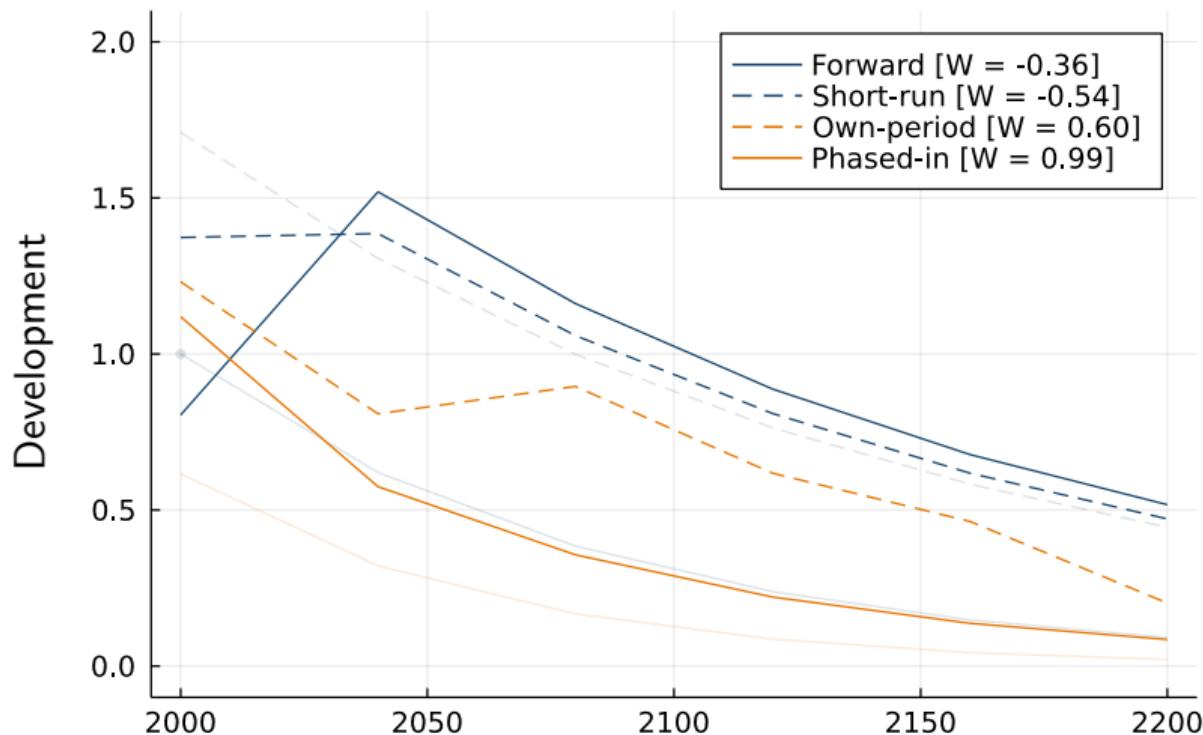
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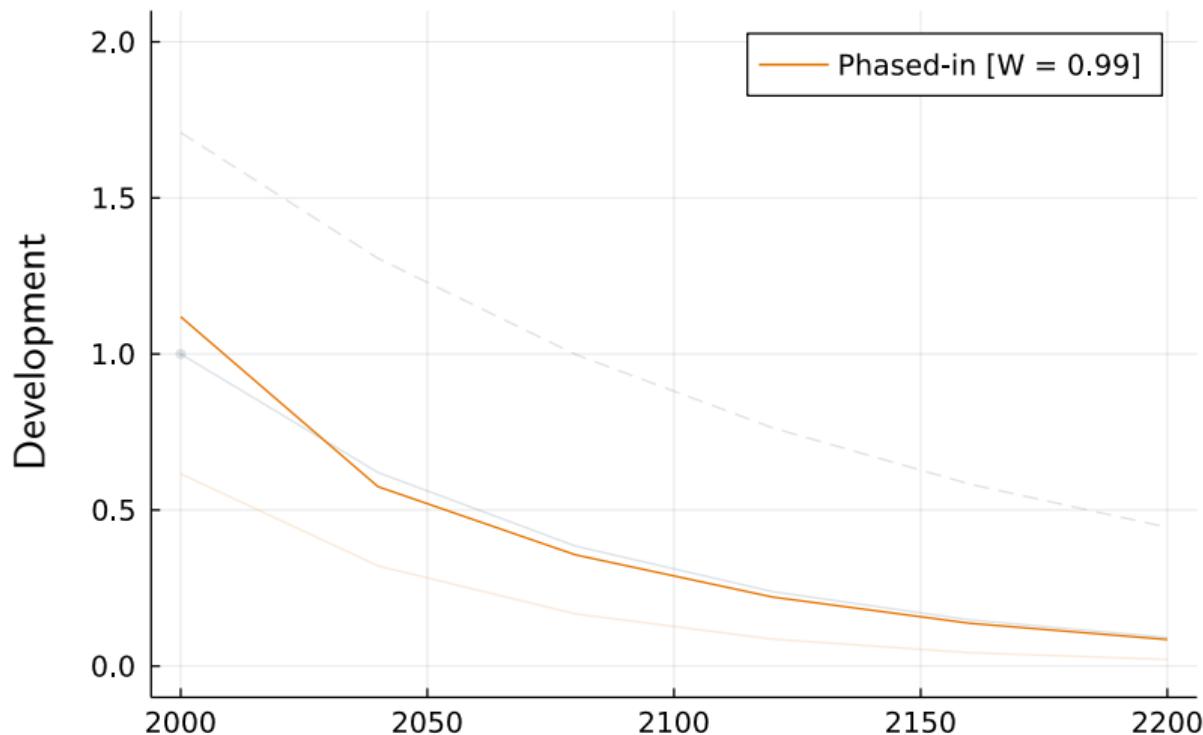
Commitment



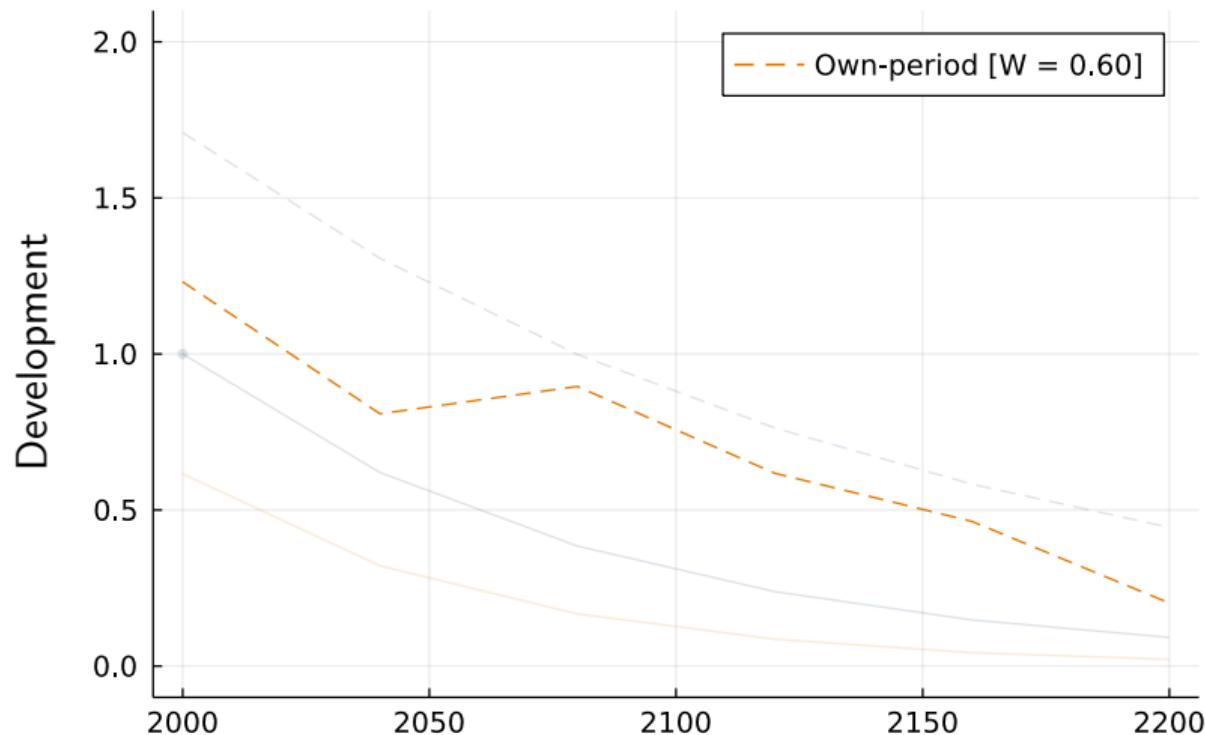
Partial commitment: one period



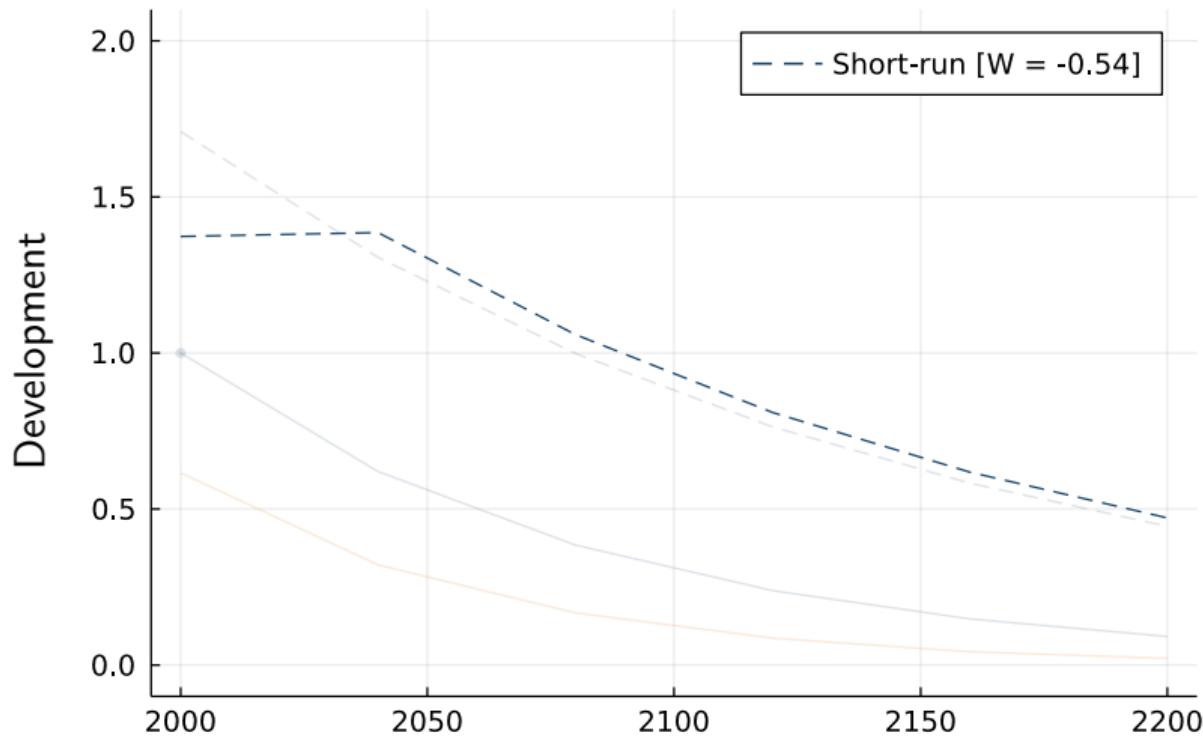
Partial commitment: one period



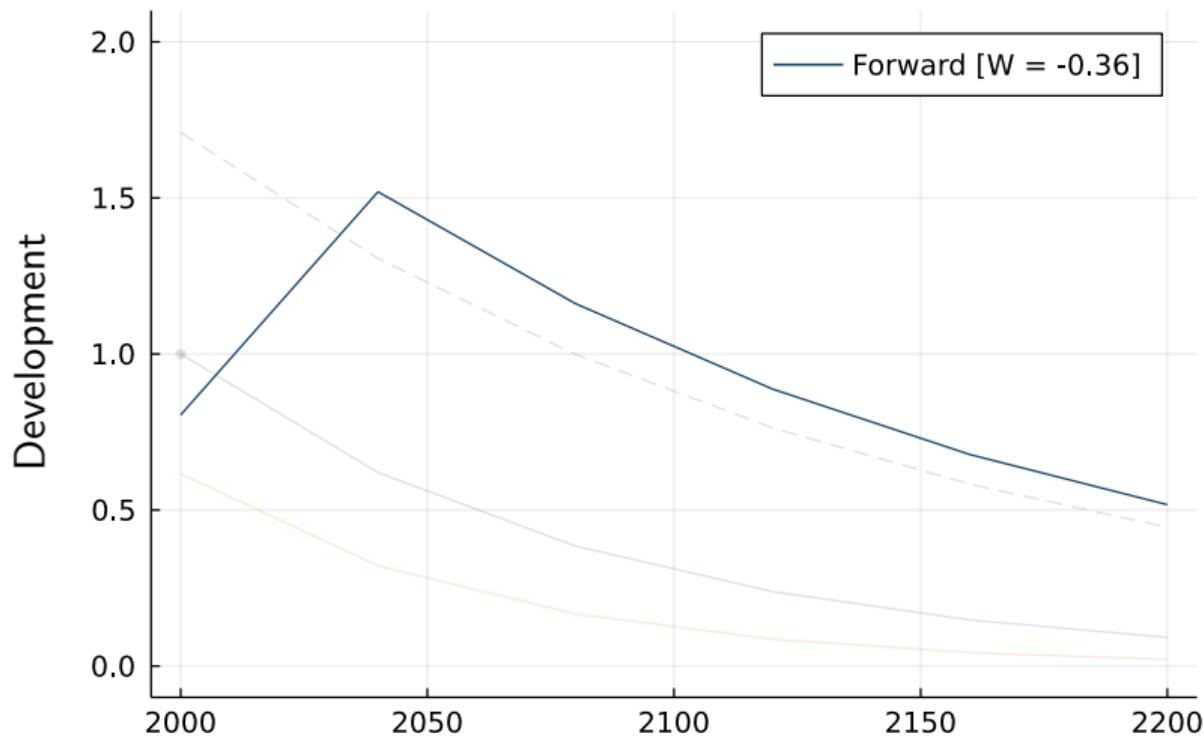
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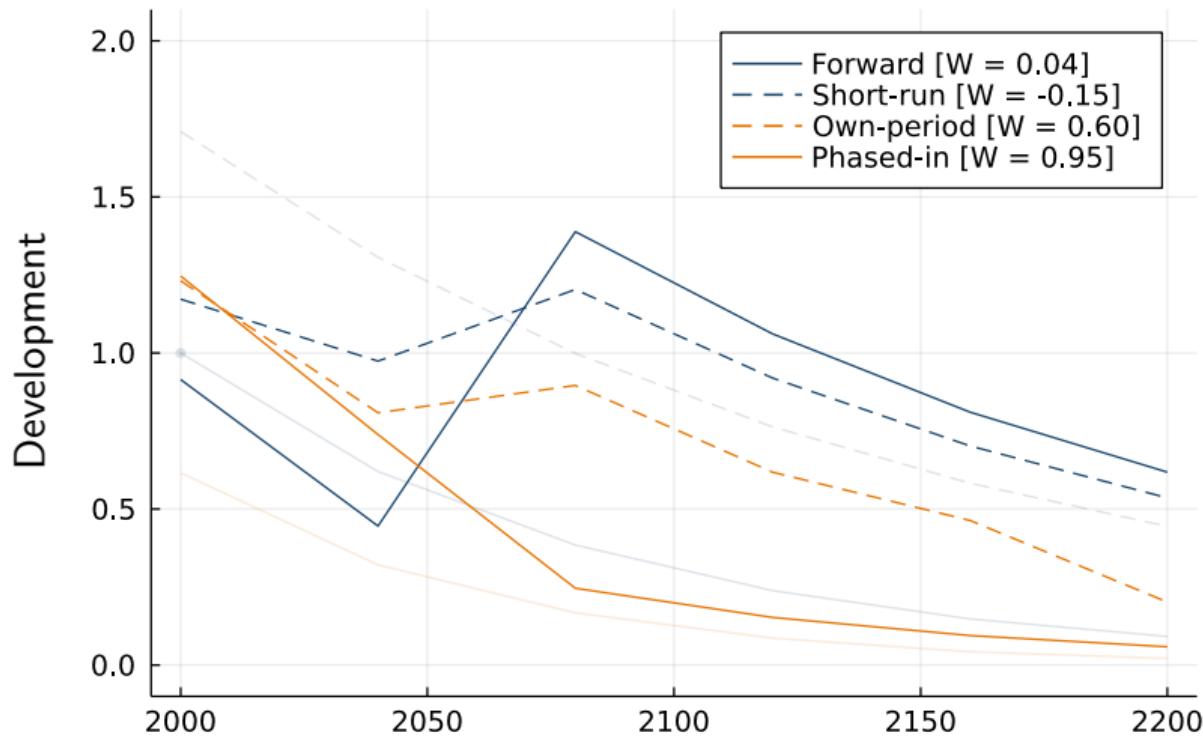
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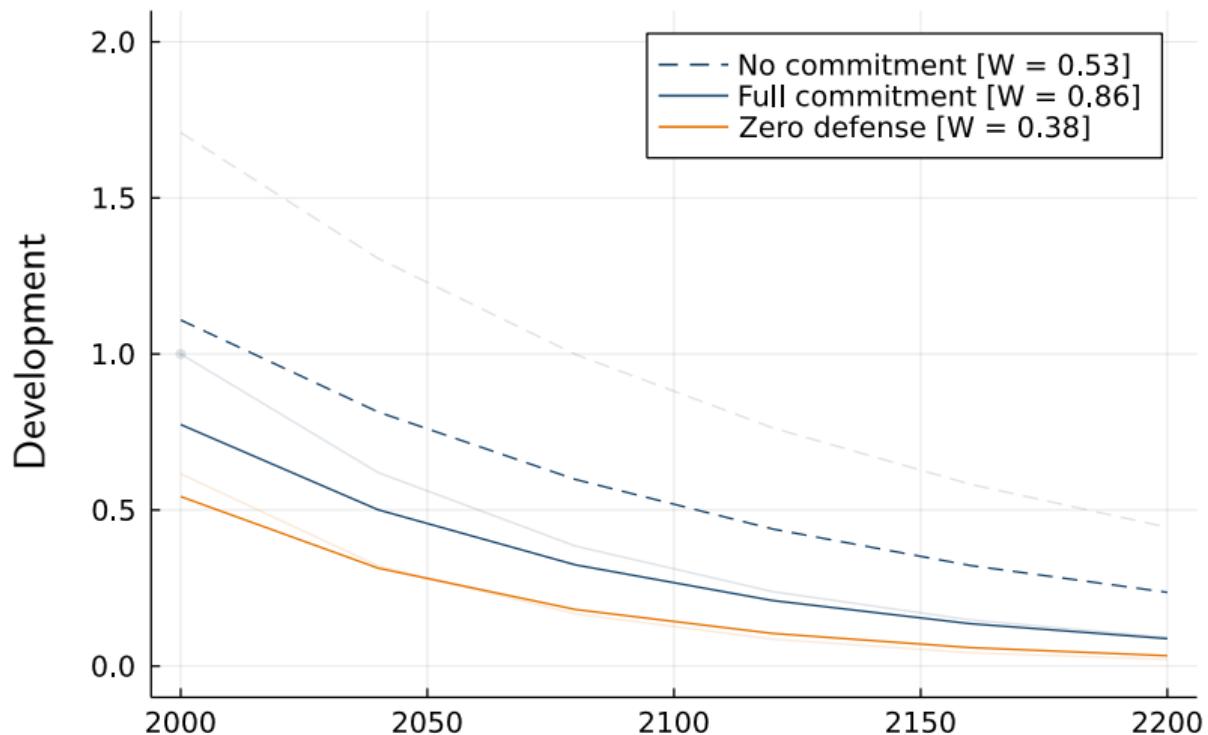
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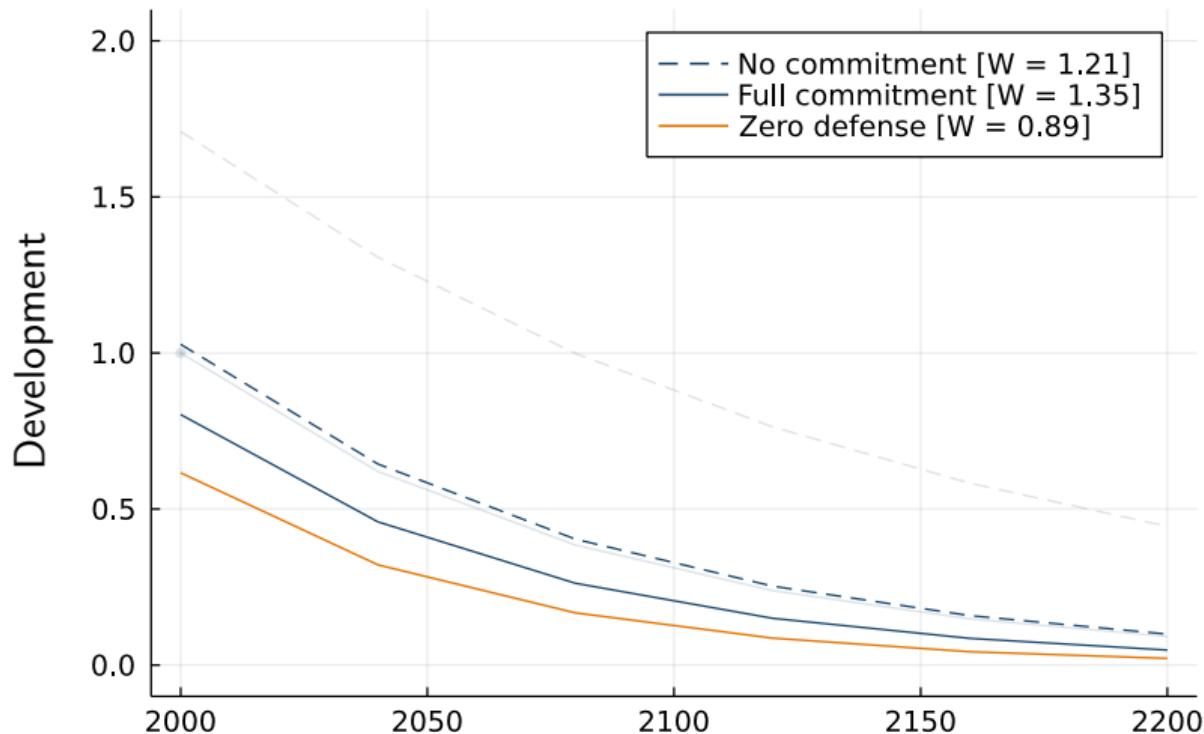
Partial commitment: two periods



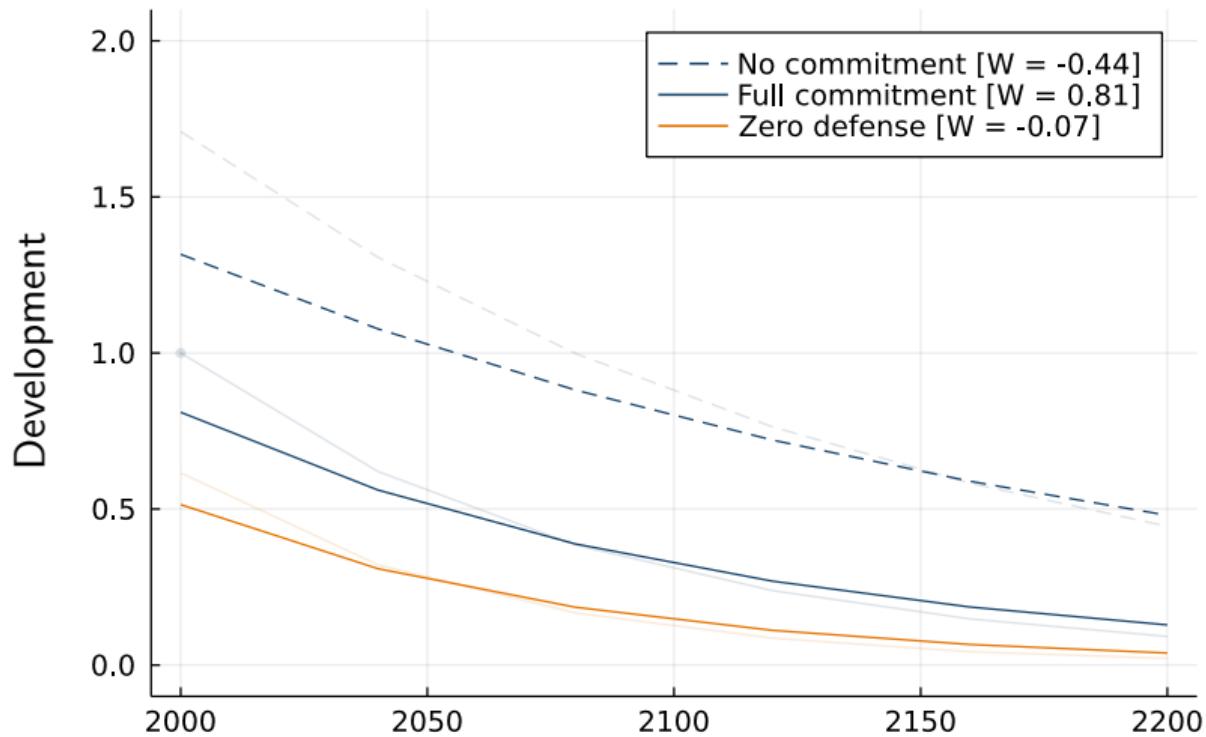
Integrated policy: inland incentives



Integrated policy: (some) subsidence control



Integrated policy: (some) coastal regulation



Policy recommendations (long-run commitment is difficult)

① Partial commitment

- Persistence: benefits of short-run policy
- Anticipation: benefits of phased-in policy

② Integrated policy (current efforts to move political capital)

- Pairing sea wall with inland incentives that reduce moral hazard
- Indirect approach is less efficient but more politically feasible

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)