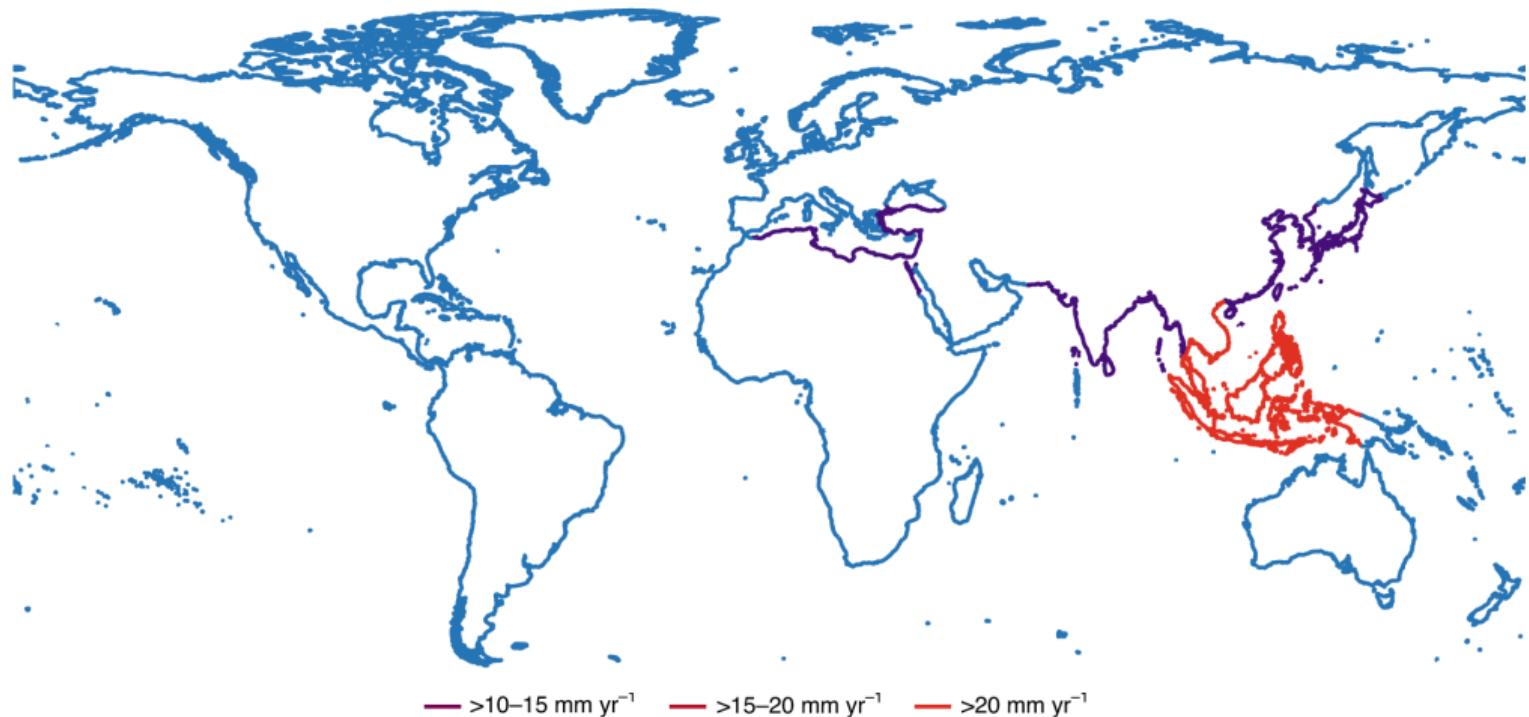


# Sea Level Rise and Urban Adaptation in Jakarta

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



(Nicholls et al. 2021)



# 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

<b>Commitment</b>	$g'_1(d_1)$	$g'_2(d_1)$	$g'_2(d_2)$
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

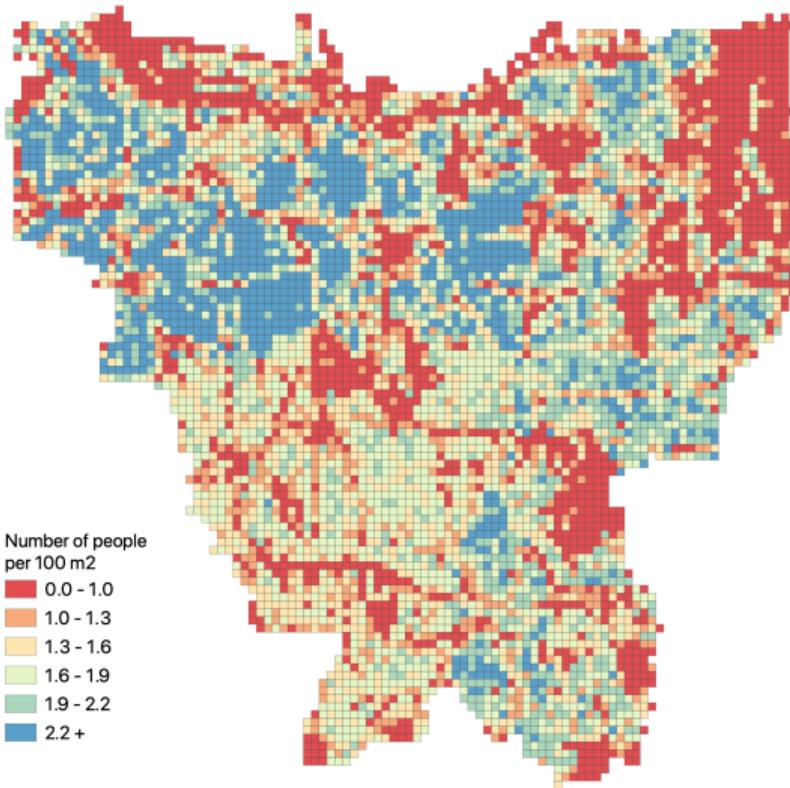
## Residential demand

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

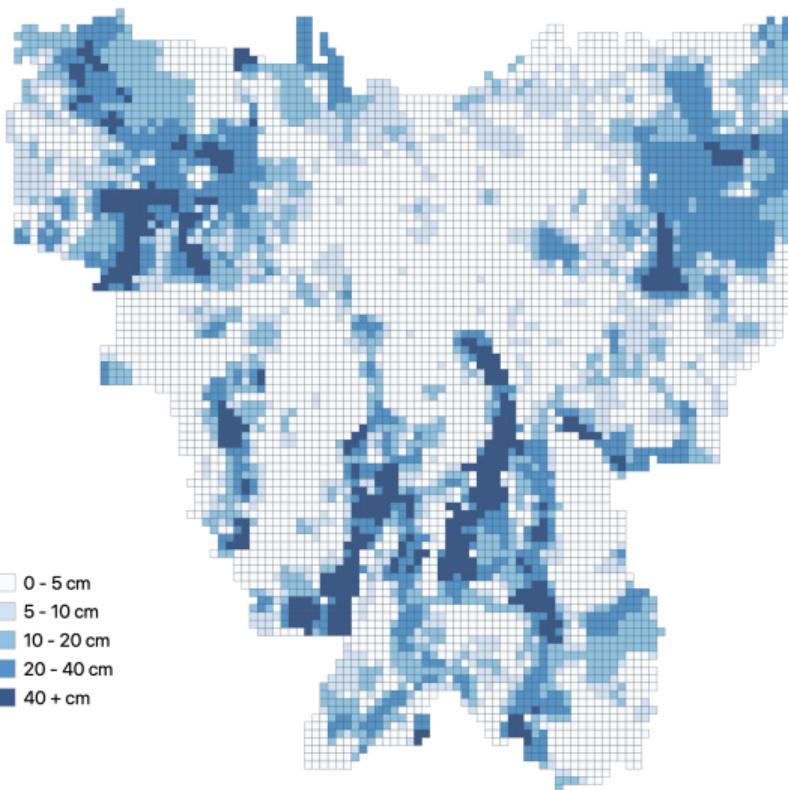
- **Spatial model** of residential choice (individual  $i$ , origin  $j$ , destination  $k$ )
  - Resident renters consider rents, flooding, amenities, distances, logit shocks
  - Moving inland abandons high-amenity places and incurs migration costs
- **Estimation** with 2020 population shares and instruments (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  $\varepsilon$ )
  - Flexible expectations without finite dependence ( $P$  as market offer)

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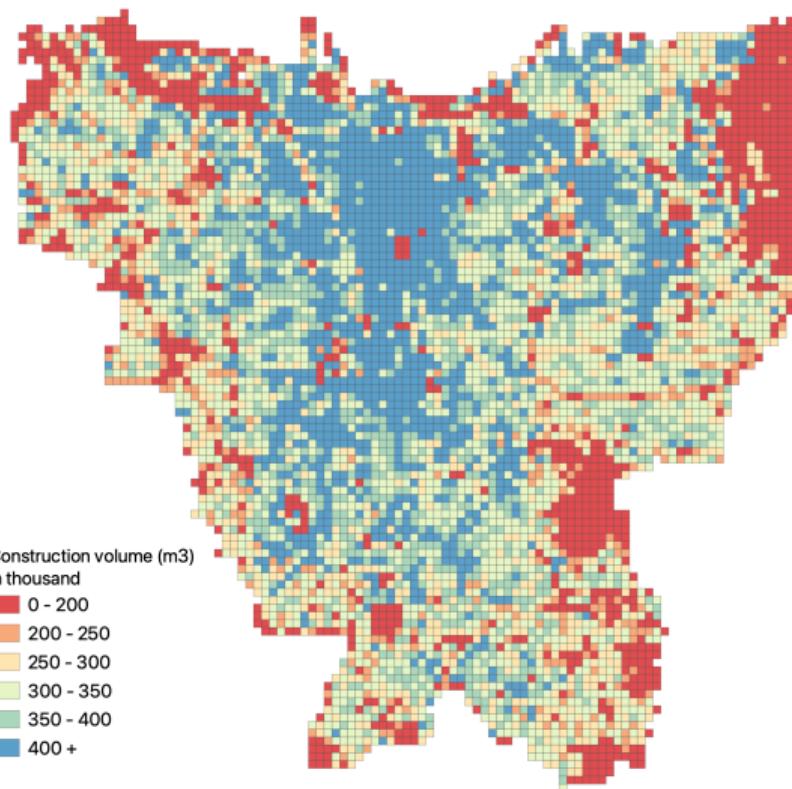
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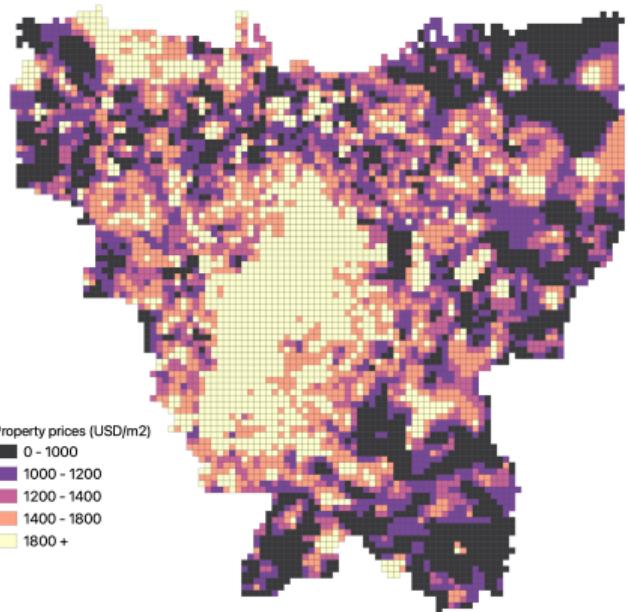
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## Building construction (global data)

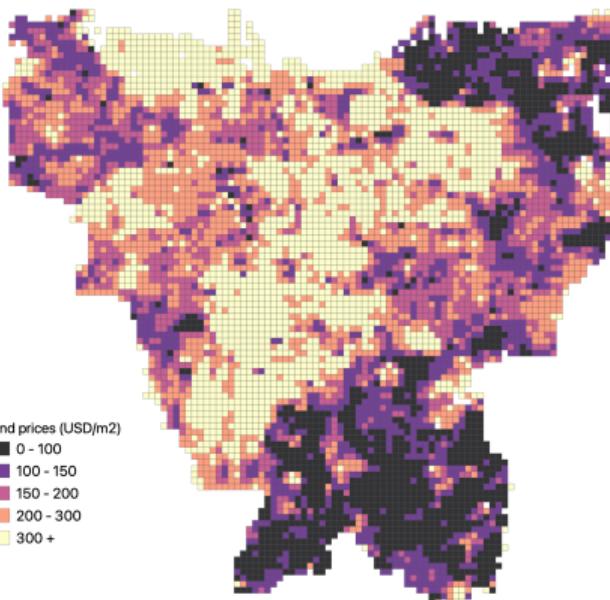


# Real estate prices (urban data)

Property



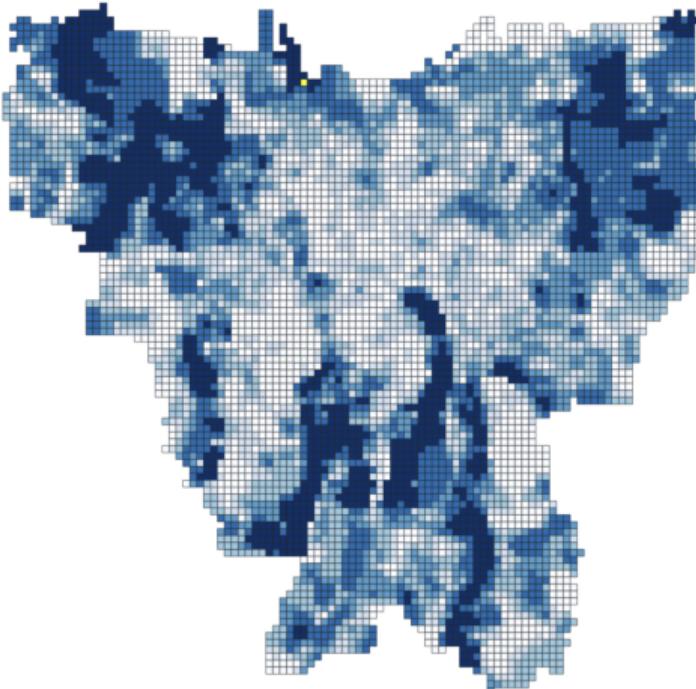
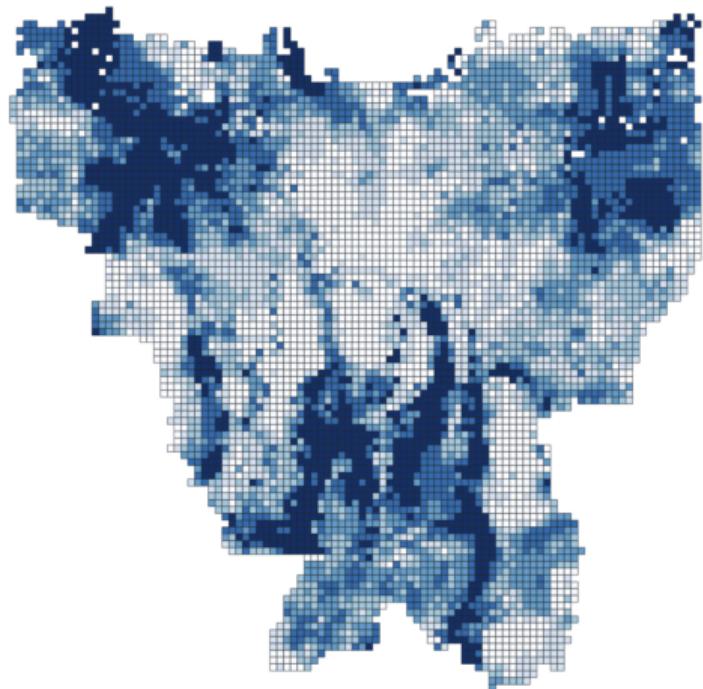
Land



## Supply estimates

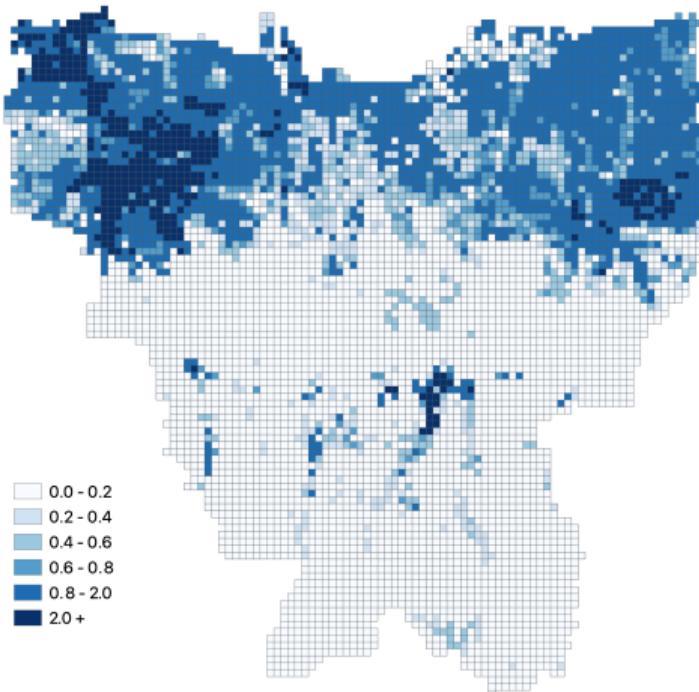
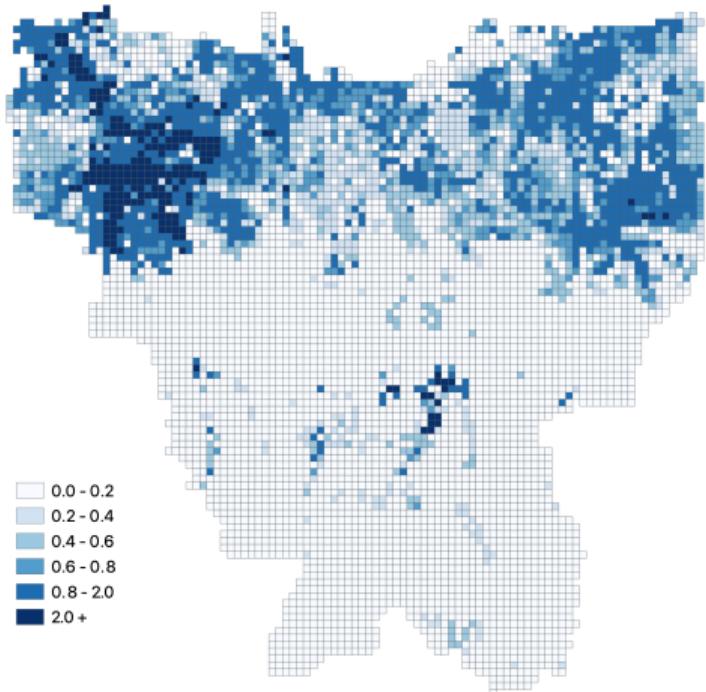
	IV		First stage	
	Estimate	SE	Estimate	SE
Prices	0.171***	(0.041)		
Residential amenities			0.182***	(0.043)
Flooding	0.064	(0.044)	-0.842***	(0.216)
Ruggedness	-0.143***	(0.054)	1.268***	(0.103)
District FE	x		x	
Observations	5,780		5,780	
F-statistic			18.14	

## 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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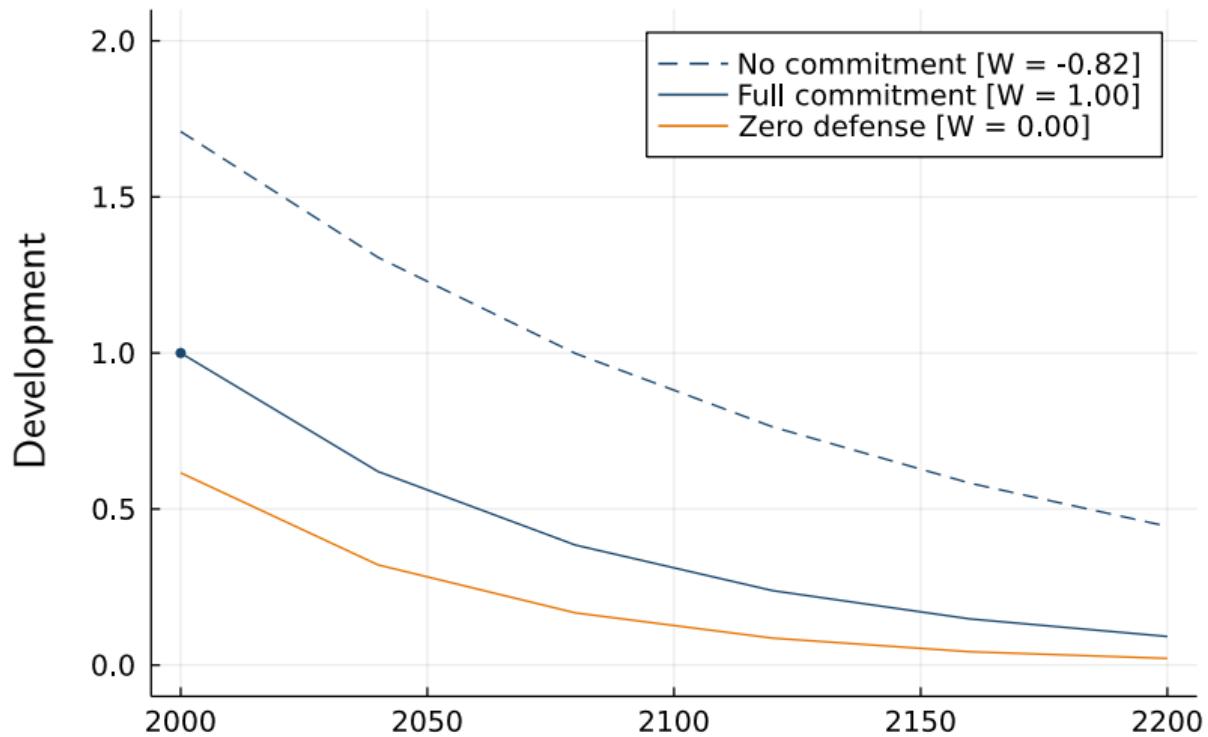
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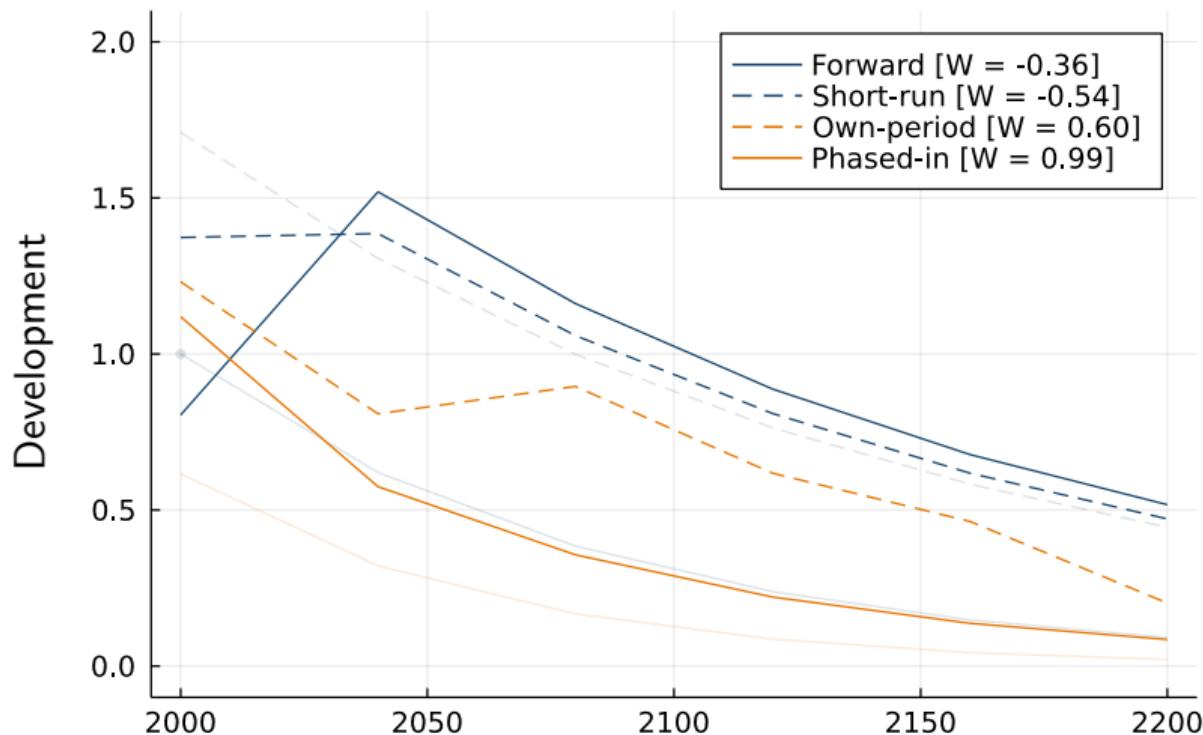
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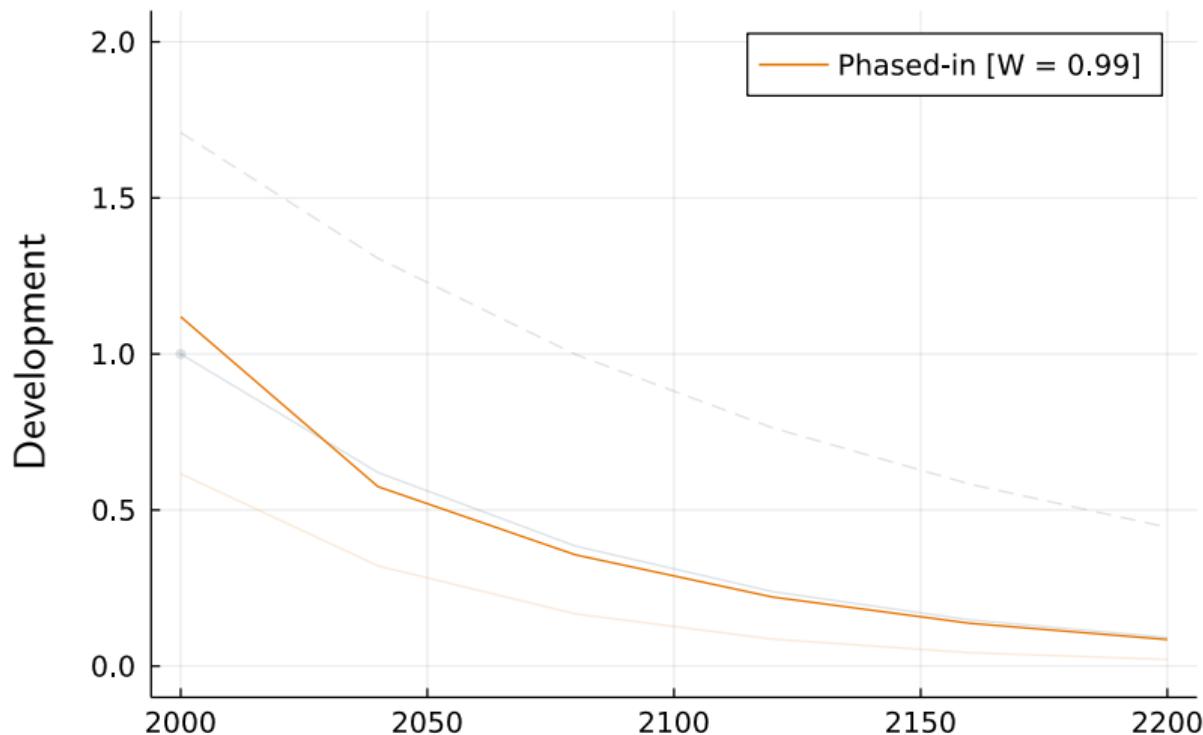
# Commitment



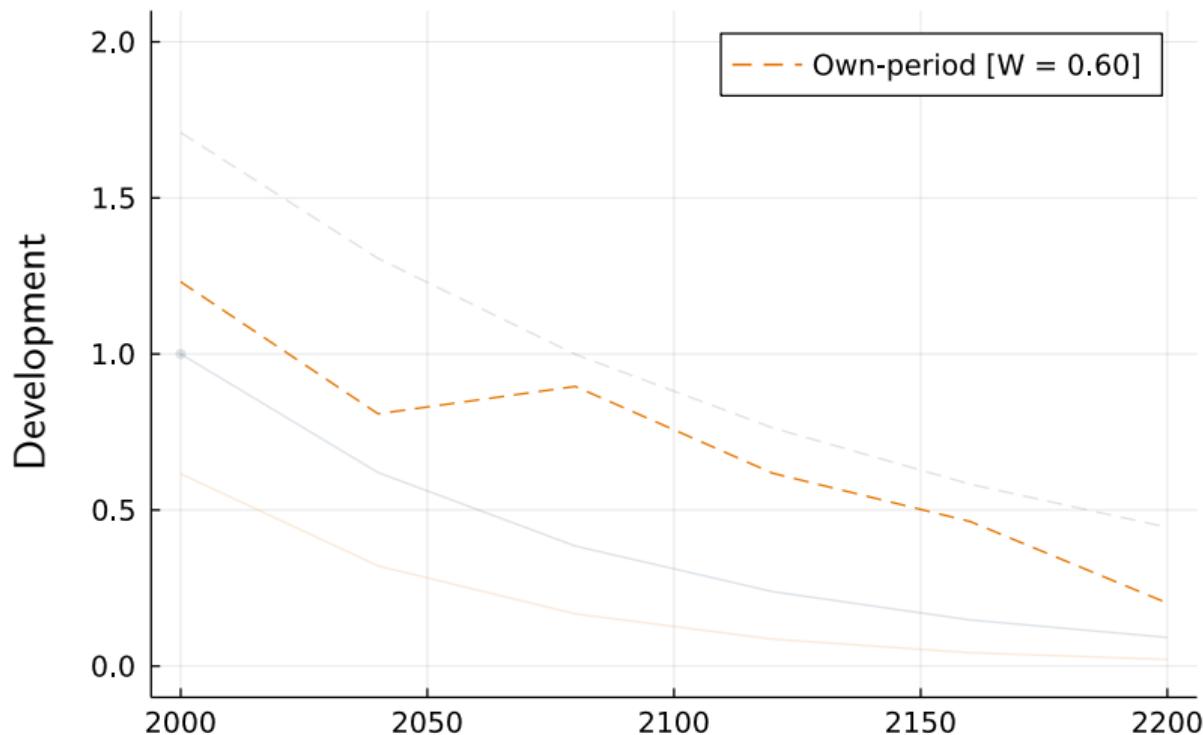
## Partial commitment: one period



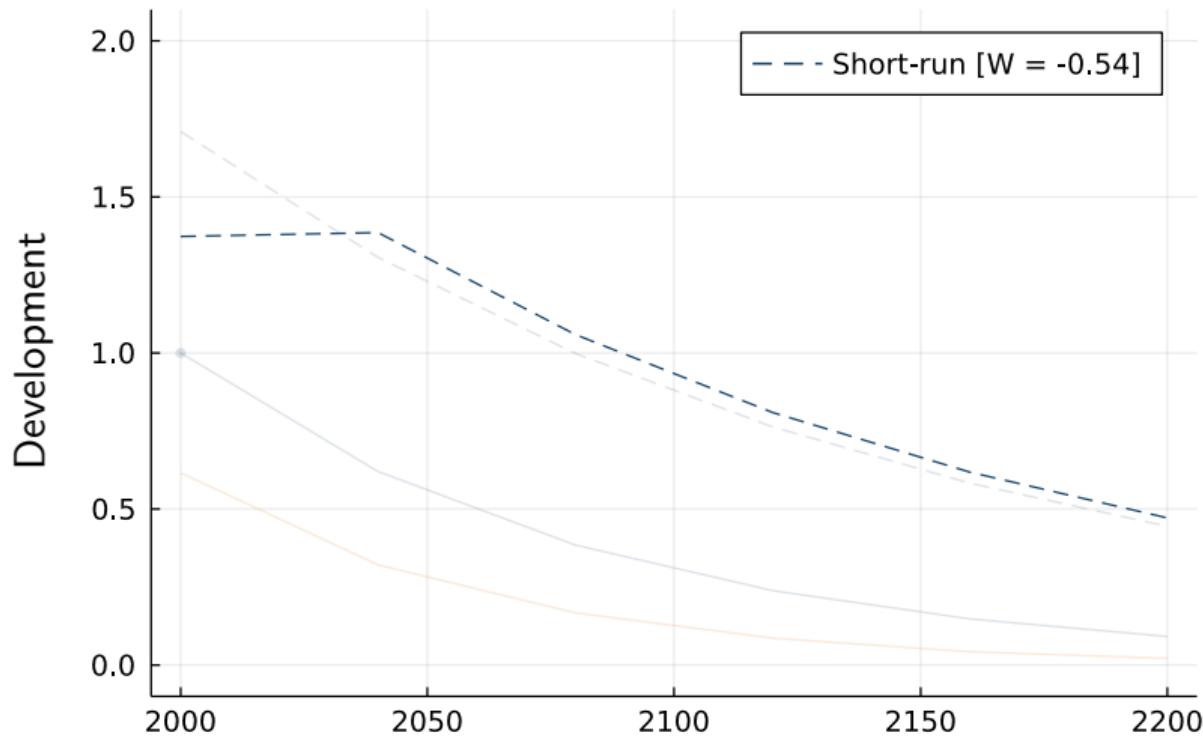
## Partial commitment: one period



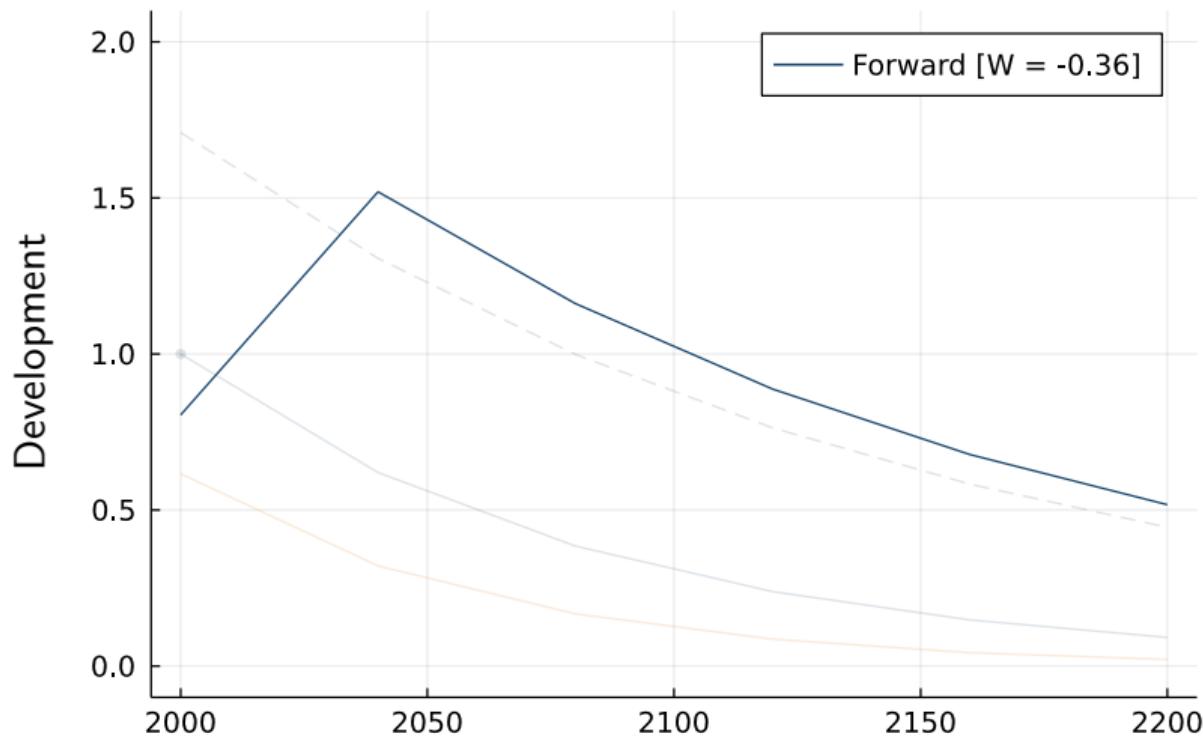
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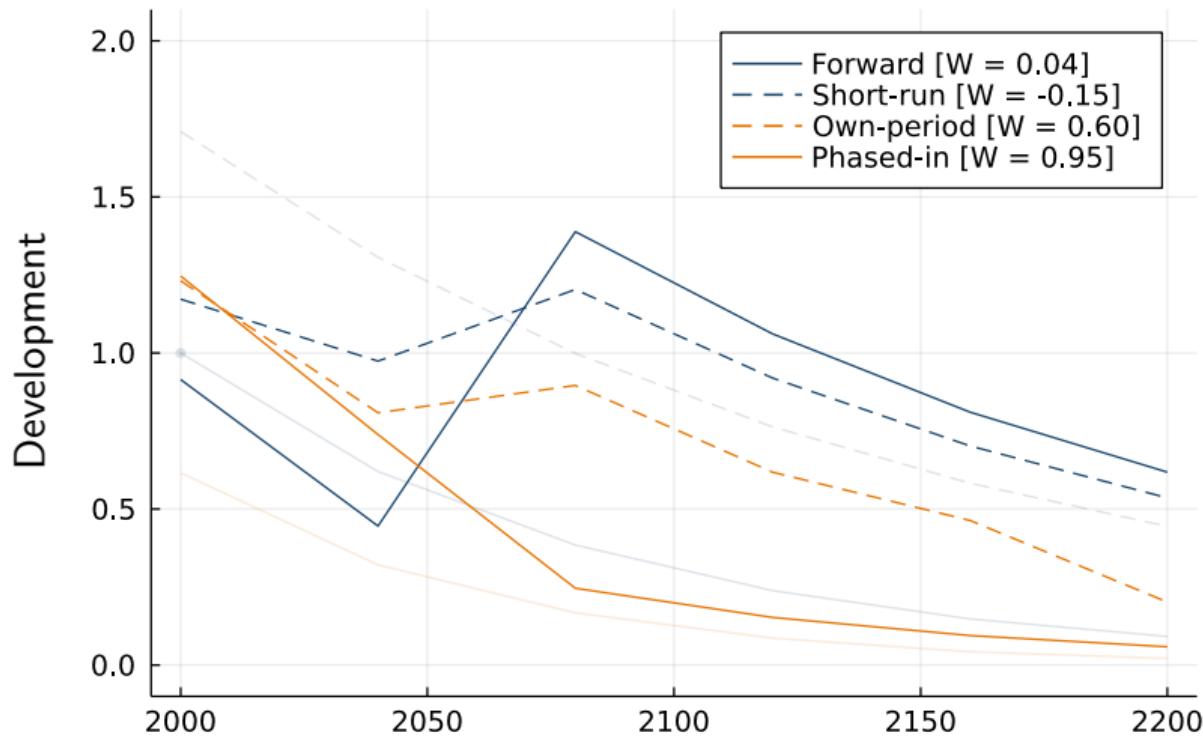
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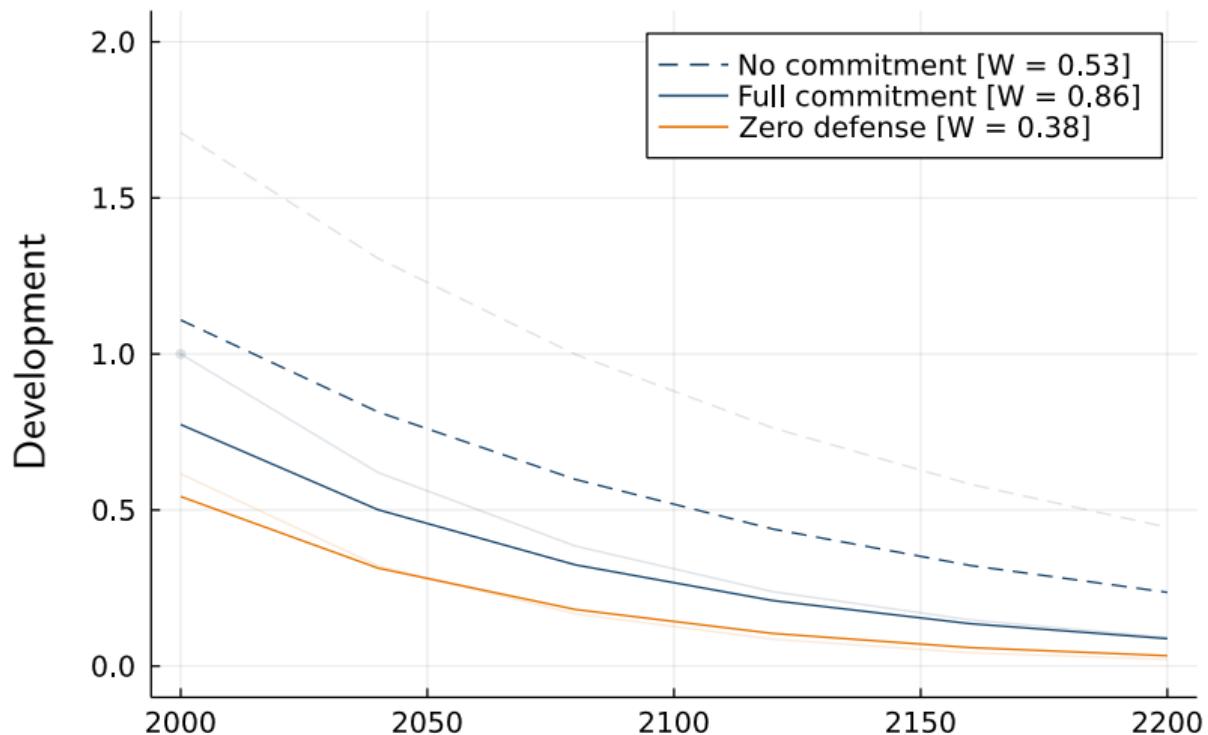
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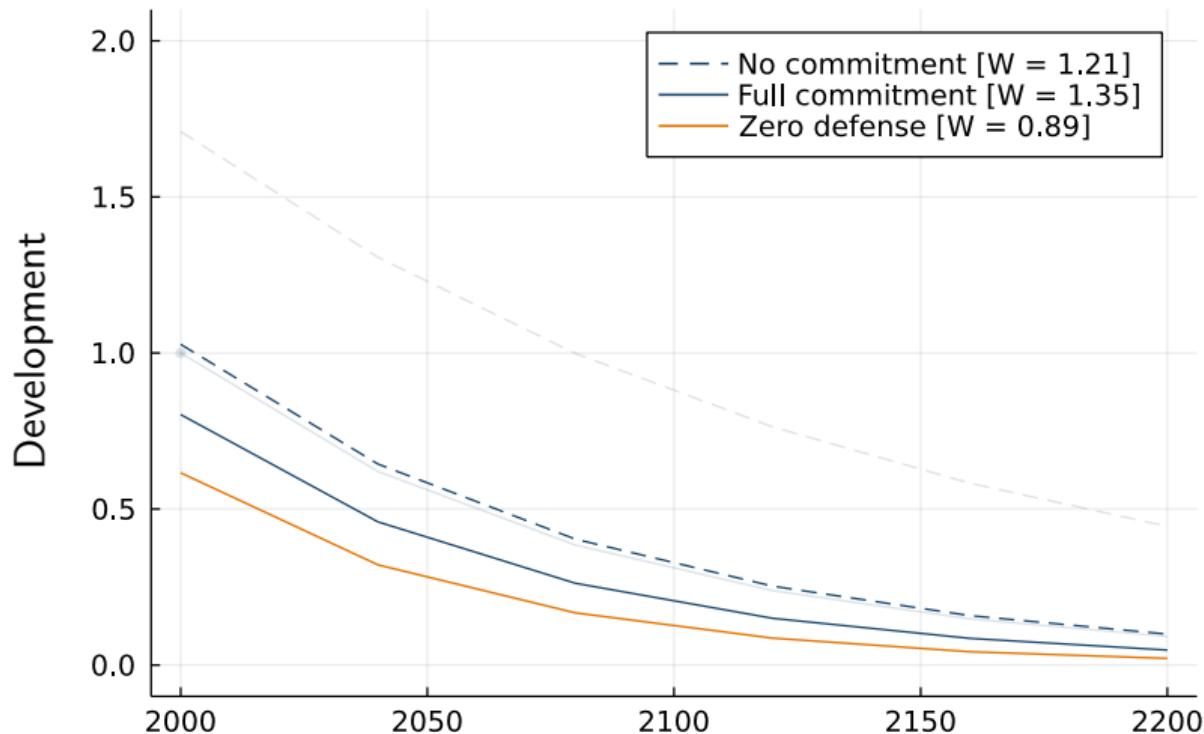
## Partial commitment: two periods



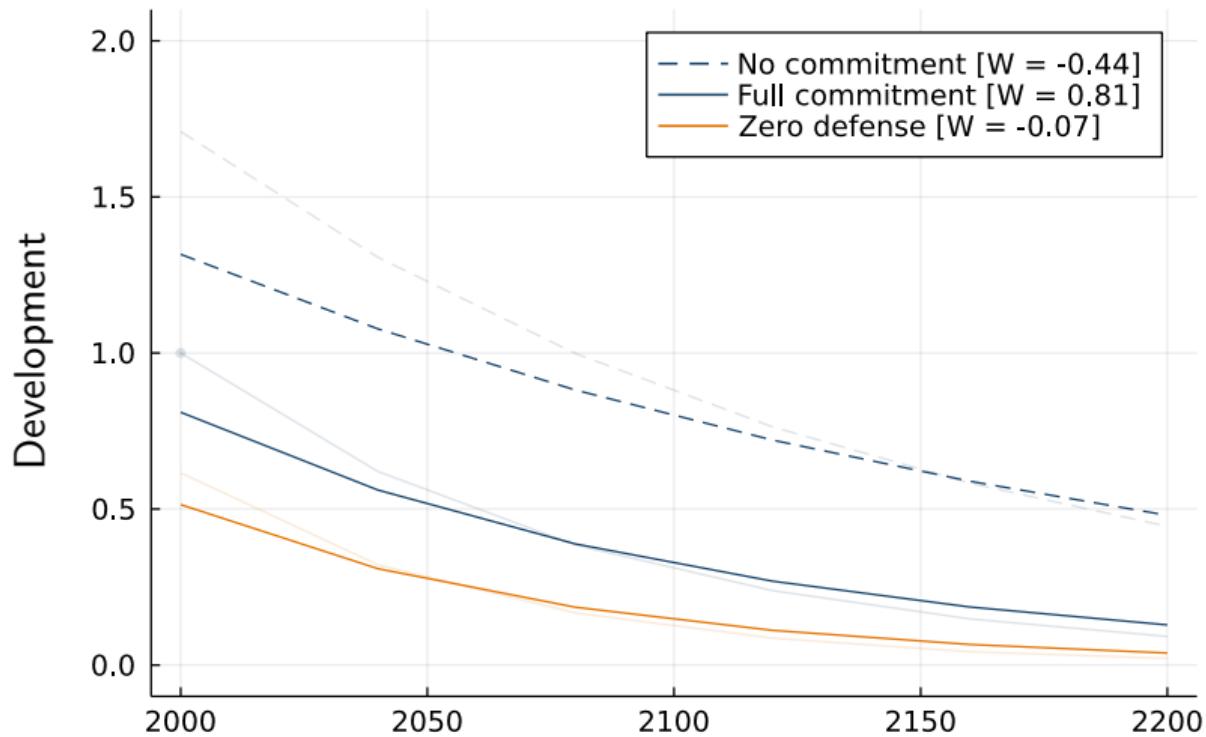
## Integrated policy: inland incentives



## 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)