Sea Level Rise and Urban Adaptation in Jakarta

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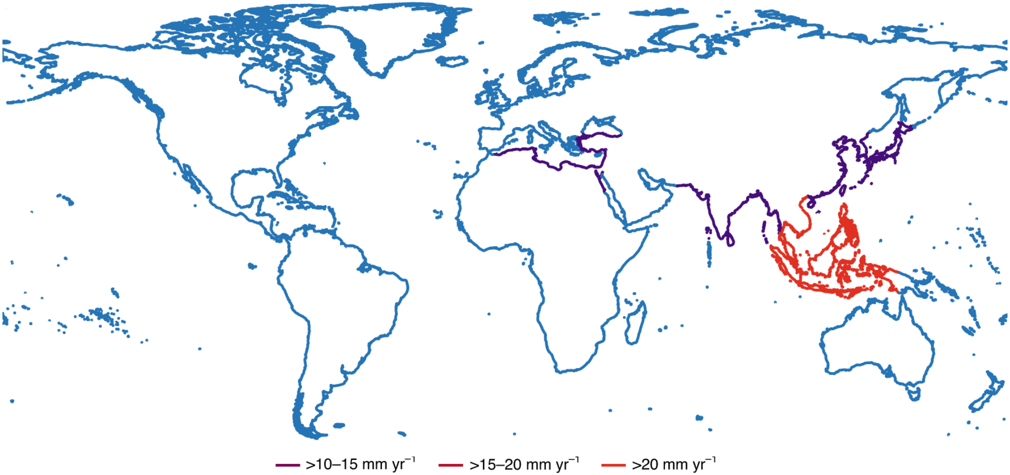
Sea level rise threatens 1B people by 2050 (IPCC 2019)



(Nicholls et al. 2021)


#CLIMATE NO JUSTICE

Jakarta

- World's second largest city at 31M (first by 2030)
  - By 2050, 35% below sea level (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

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

Commitment (first best)

1. Defense $g^* > 0$
2. Development $d^*(g^*) > 0$

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

- But ex post, want to defend (lobbying)
- Equivalent: tax $e(g)$, but costly to enforce

No commitment

1. Development $d^n > d^*$
2. Defense $g^n(d^n) > g^*$ at uninternalized cost

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

- Time inconsistency: static gain, dynamic cost $(r'(g), g'(d) > 0)$
- 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

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

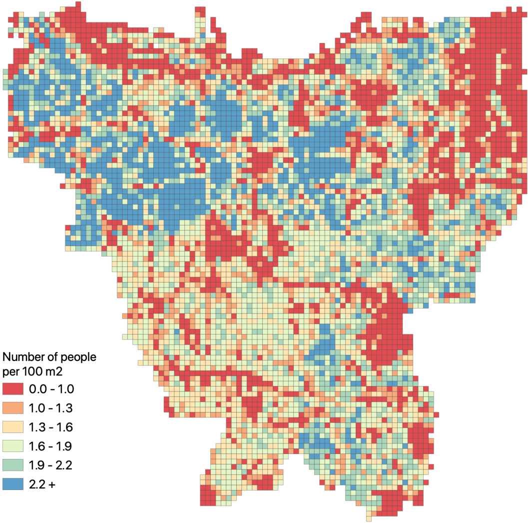
- $\tilde{r}(d, f)$: **spatial model** of residential demand
- $c(d)$: **dynamic model** of developer supply
- $f(g)$: **hydrological model** of flood risk
- $e(g)$: **engineering model** of sea wall costs

Residential demand

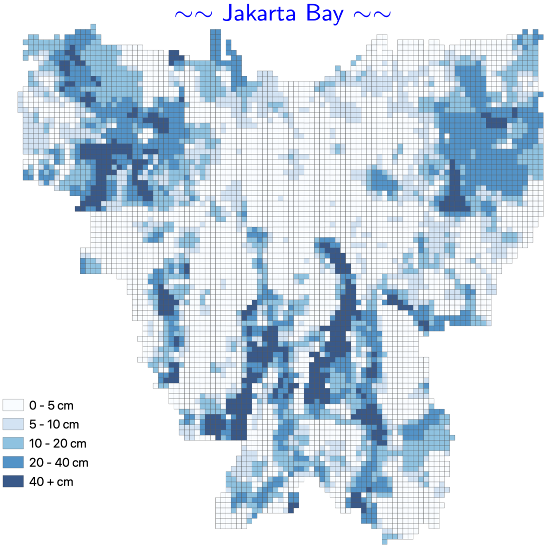
$$U_{ijk} = \underbrace{\alpha r_k + \phi f_k + x_k \gamma + \varepsilon_k}_{\delta_k} + \tau m_{jk} + \epsilon_{ijk}$$

- **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) Details
  - Price endogeneity from correlation of rents and unobserved amenities
  - IV with ruggedness as supply shifter

Population (global data)



Flooding (2013-2020, past $\rightarrow$ 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
  - IV with residential amenities as demand shifters

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Data as continuation values

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

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&= -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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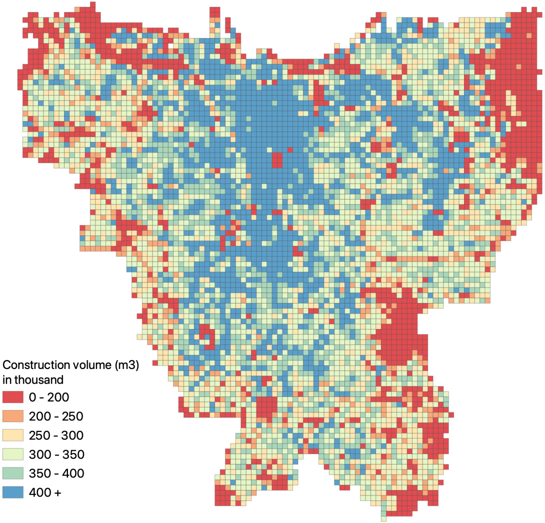
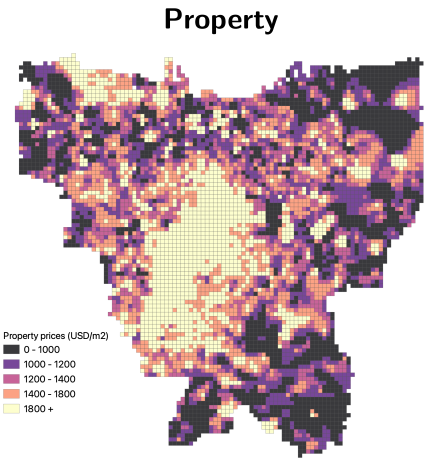
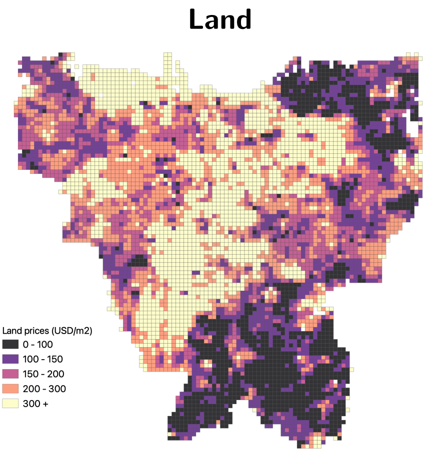
Building construction (global data)



Real estate prices (urban data)

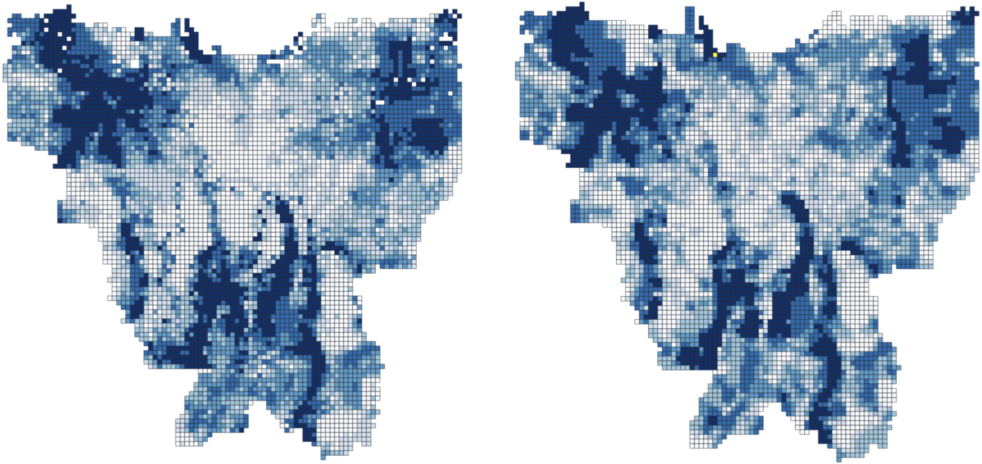




Supply estimates

	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)

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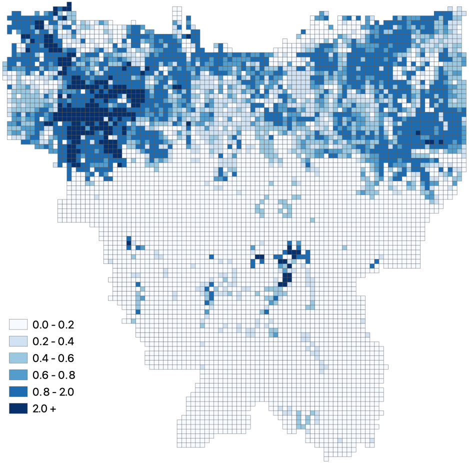

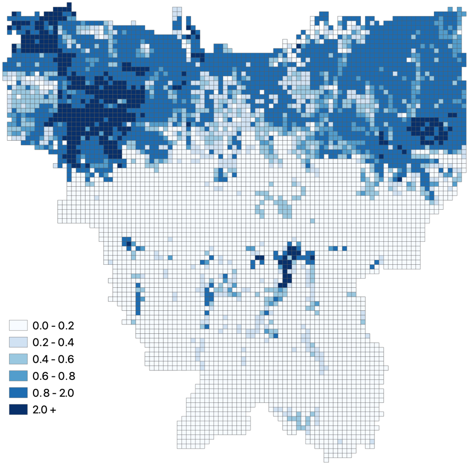

3m vs. 5m sea wall

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 $e(g)$

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

$$d^n = \arg\max \{r(d, g^*(d)) - c(d)\}$$
$$d = \{d \mid P^{\text{res}}(d, g) = P^{\text{dev}}(d)\}$$

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

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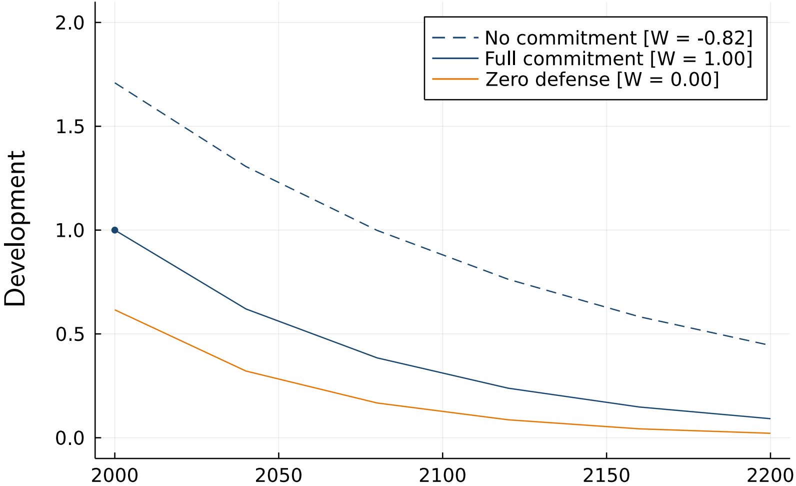
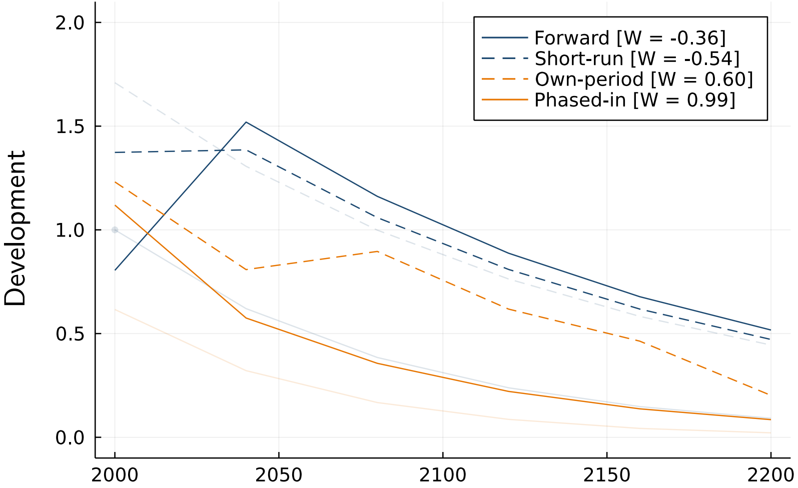
Commitment: first-best taxation



Partial commitment: one period



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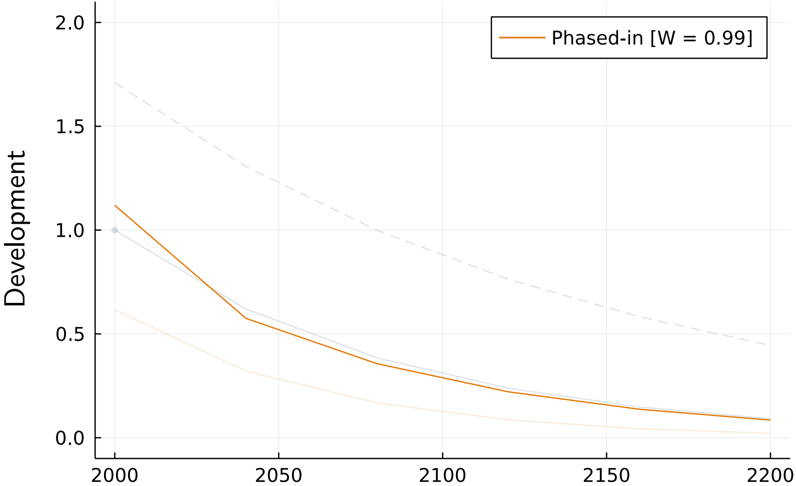

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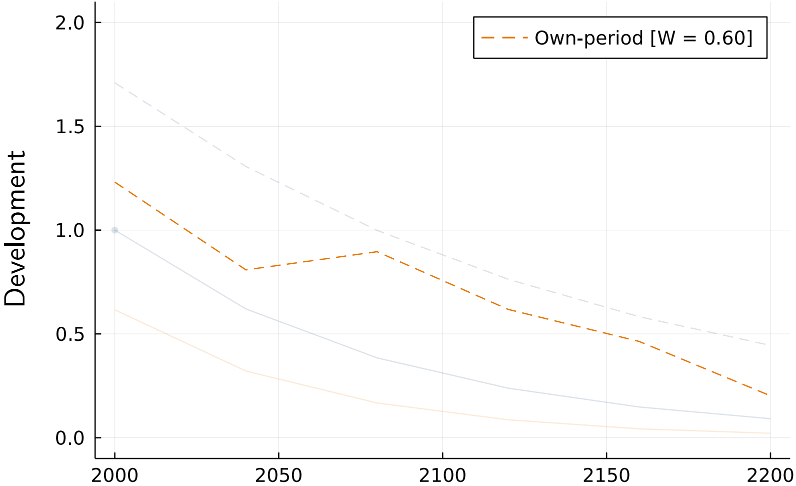

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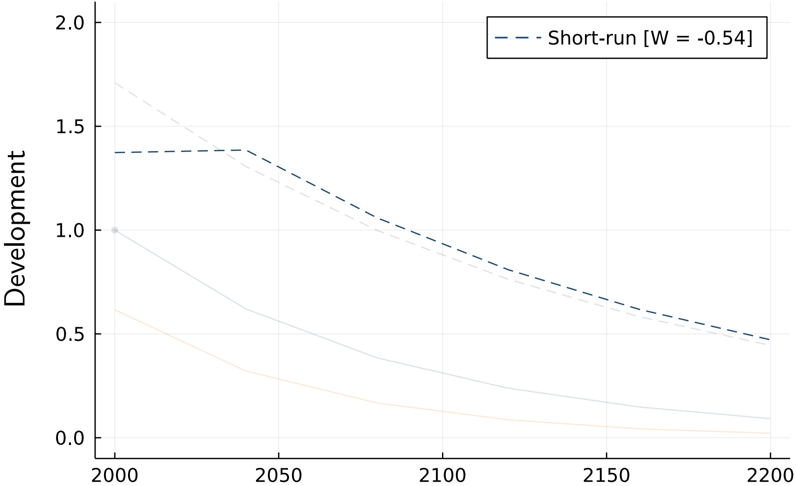

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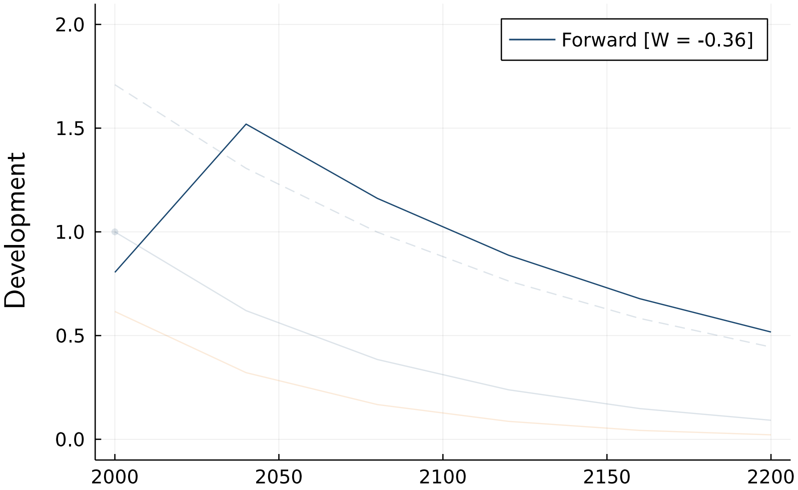
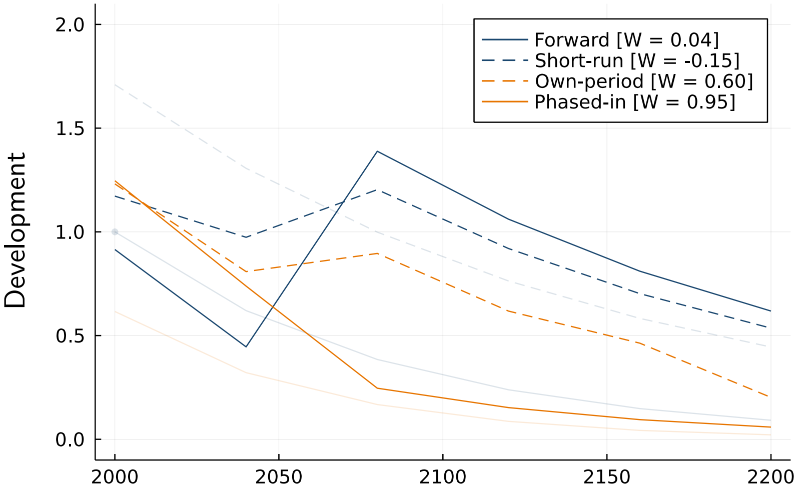
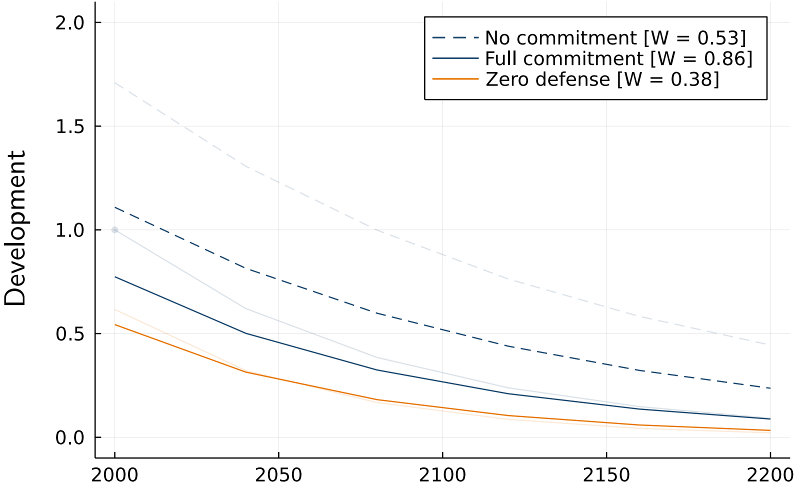


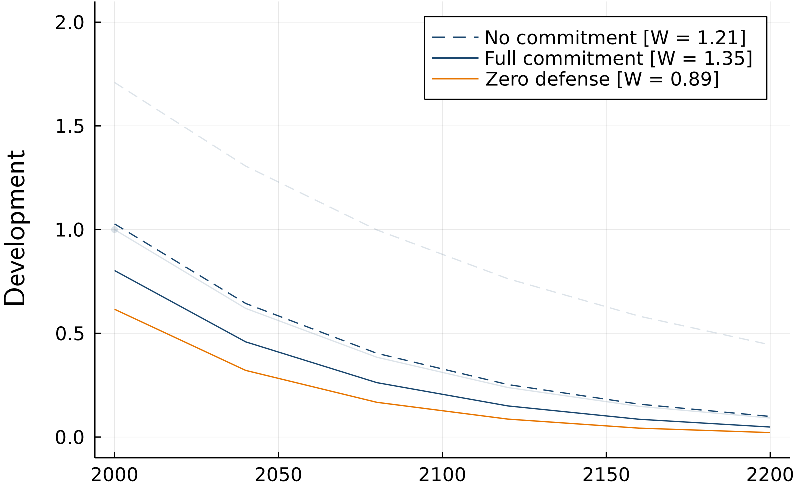
Partial commitment: two periods



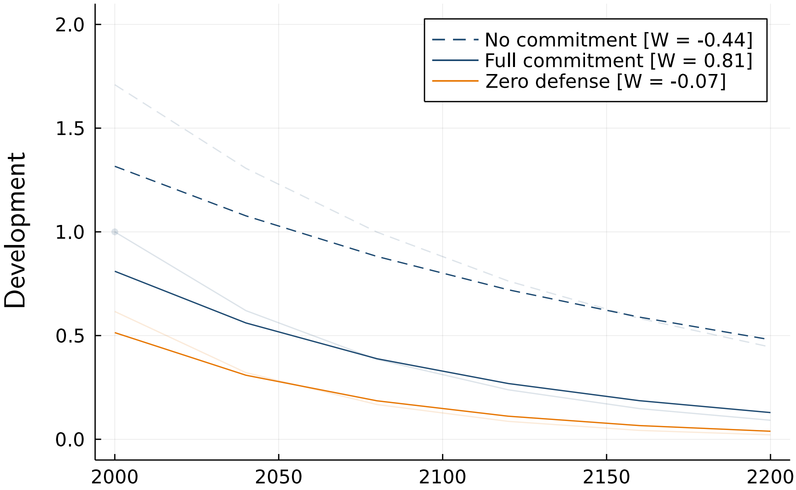
Integrated policy: inland incentives



Integrated policy: (some) subsidence control



Integrated policy: (some) coastal regulation



Policy recommendations

1. **Partial commitment** (full commitment is difficult)
   - 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)