

# Sea Level Rise and Urban Adaptation in Jakarta

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# Jakarta

- By 2050, 35% below sea level (Andreas et al. 2018)
  - Land subsidence + sea level rise
  - Proposed sea wall at up to \$40B
- **How does government intervention complicate adaptation?**

# This paper

- **Coastal moral hazard** as defense bails out development
  - If government is time-inconsistent
  - 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 options

- Direct: partial commitment, partial regulation
- Indirect: moving capital, slowing land subsidence

# Contributions

- **Adaptation frictions** under endogenous government action
  - 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-Vincenzi 2022, Fried 2022, Patel 2023
- **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. 2023, Bilal & Rossi-Hansberg 2023

# Outline

① Theory

② Empirics

③ Policy

# Theory

## Fundamental trade-offs

- **Spatial:** adapt in-place at coast or migrate inland
- **Dynamic:** incur costs today or damages tomorrow
- **Moral hazard** introduces a market failure
  - Even with one location, one period

## Coastal development and defense

- **Development**  $D$  at cost  $C(D)$  (agent)
- **Defense**  $G$  at cost  $E(G)$  (principal)
- Residential value  $R(D, G)$  for  $R_{DG} > 0$

$$\max_D \Pi = \max_D \{R(D, G) - C(D)\}$$

$$\max_G W = \max_G \{R(D, G) - C(D) - E(G)\}$$

- Moral hazard: time inconsistency + uninternalized cost

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# Agent and principal

- ① “Developers” vs. government
- ② Local vs. national government
- ③ Current vs. future government

## First best with commitment

- ① Defense  $G$
- ② Development  $D(G)$

$$[\Pi_D] \quad R_D = C_D$$

$$[W_G] \quad R_G = E_G$$

- Same as social planner, who chooses  $(D, G)$  directly

# Over-development without commitment

- ① Development  $D$
- ② Defense  $G(D)$

$$\begin{aligned} [\Pi_D] \quad R_D = C_D &\rightarrow \text{high } G, \text{ high } D \\ [W_G] \quad R_G = E_G &\rightarrow \text{high } D, \text{ high } G \end{aligned}$$

- Weak coordination on high  $(D, G)$ , given multiplicity ( $R_{DG} > 0$ )
  - If  $G$  unconstrained via domestic or foreign ability

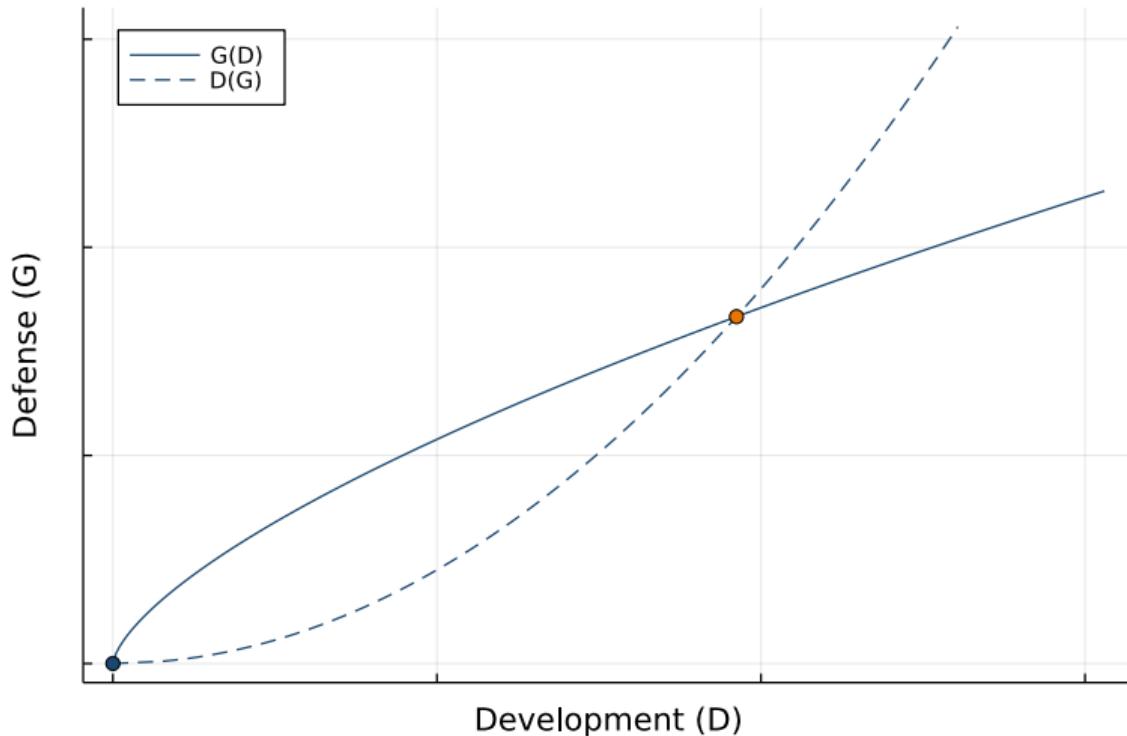
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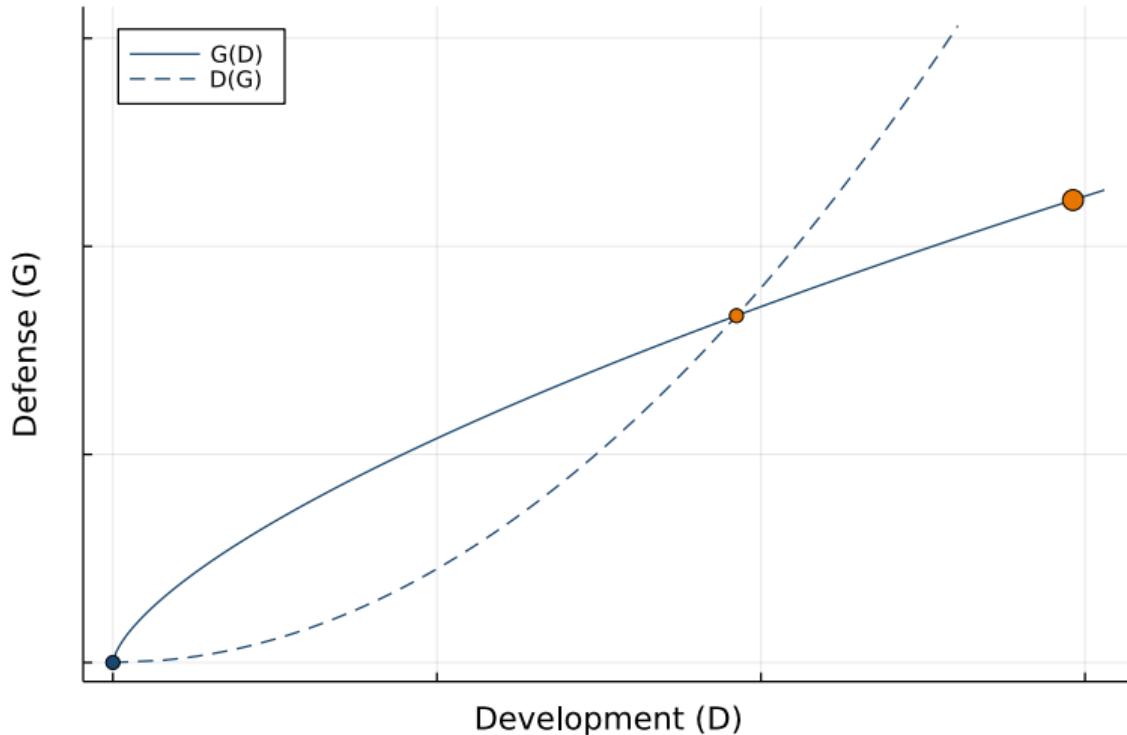
$$\begin{aligned} [\Pi_D] \quad R_D + R_G G_D &= C_D \\ [W_G] \quad R_G &= E_G \end{aligned}$$

- Strong coordination on high  $(D, G(D))$ , given  $G_D > 0$  ( $R_{DG} > 0$ )
  - If  $G$  continuous via height, quality, maintenance, or expectation

## Example



## Example



## Commitment is challenging

- Ex post, principal wants to defend (plus lobbying)
  - Time inconsistency magnifies moral hazard
  - Current government moves before future government
- Coastal defense crowds out inland migration (lock-in)
  - If inland migration is possible

## Alternative solutions

- Regulation with tax or quota
  - But still need commitment to costly enforcement
- Local financing rules
  - But even locally, inland taxes subsidize coast
- Mandated insurance
  - But local risk is aggregate, so usually subsidized in practice
- Coasian bargaining
  - But large transfers are challenging and still bad for principal

# JAKARTA GIANT SEA WALL



PIK 2 terlibat dalam Perencanaan JAKARTA GIANT SEA WALL  
Proyek Pemerintah dalam pengembangan daerah pesisir

# Profil Proyek NCICD

- Peletakan batu pertama: Oktober 2014
- Target rampung: 2022
- Tahapan pembangunan: 3 (Tahap A, B, dan C)
- Pelaksana: Kementerian PU dan Pemprov DKI
- Biaya investasi: Rp300 triliun
- Reklamasi lahan: 1.000 hektare

Sumber: Kementerian PU-Pera, berbagai sumber, diolah

Wing Park Neighbourhood Waterfront Neighbourhood

Maritime Communities

## Target Konstruksi

### Tahap A

Konstruksi: 2014-2017  
Flood safety: 2030

### Tahap B

Konstruksi: 2018-2022  
Flood Safety: 2030

### Tahap C

Konstruksi: 2022



# Empirics

# Framework

$$R(D, G), \quad C(D), \quad E(G)$$

- **Development:** spatial demand, dynamic supply
- **Defense:** hydrological model, engineering costs
- **Moral hazard** from model, not data
  - *Potential* impact on adaptation
  - But can rationalize price data

# Demand

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

- **Spatial choice:** renters  $i$ , locations  $k$ 
  - Private cost of flooding
  - Moral hazard increasing in flood disutility
  - Moving inland abandons amenities, incurs migration costs
- **Estimation:** linear IV with 2015 population data
  - Rent endogeneity from unobserved amenities
  - Ruggedness as supply shifter
- No dynamics, agglomeration, uncertainty

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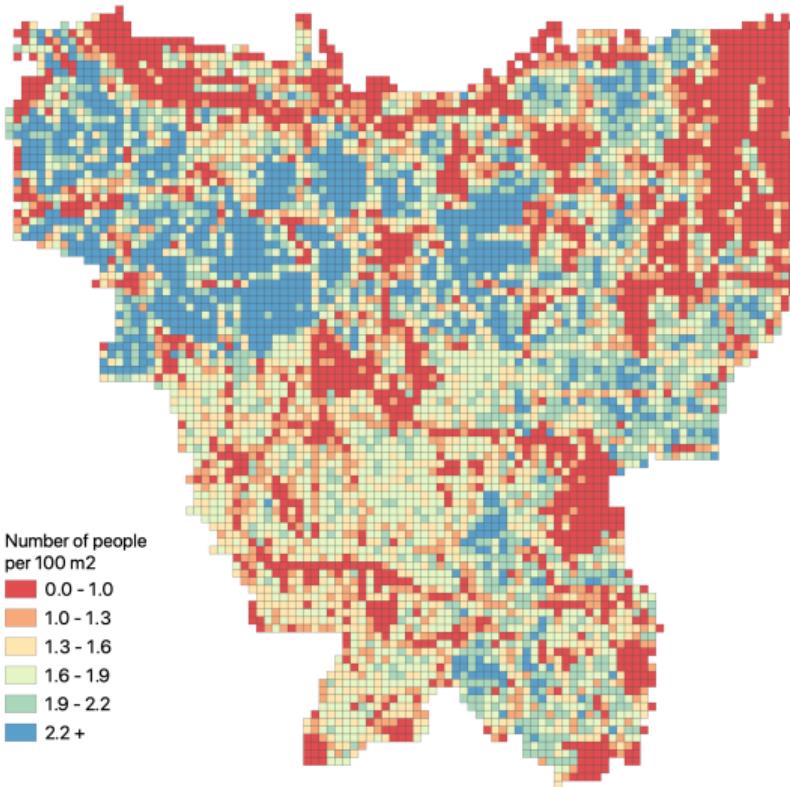
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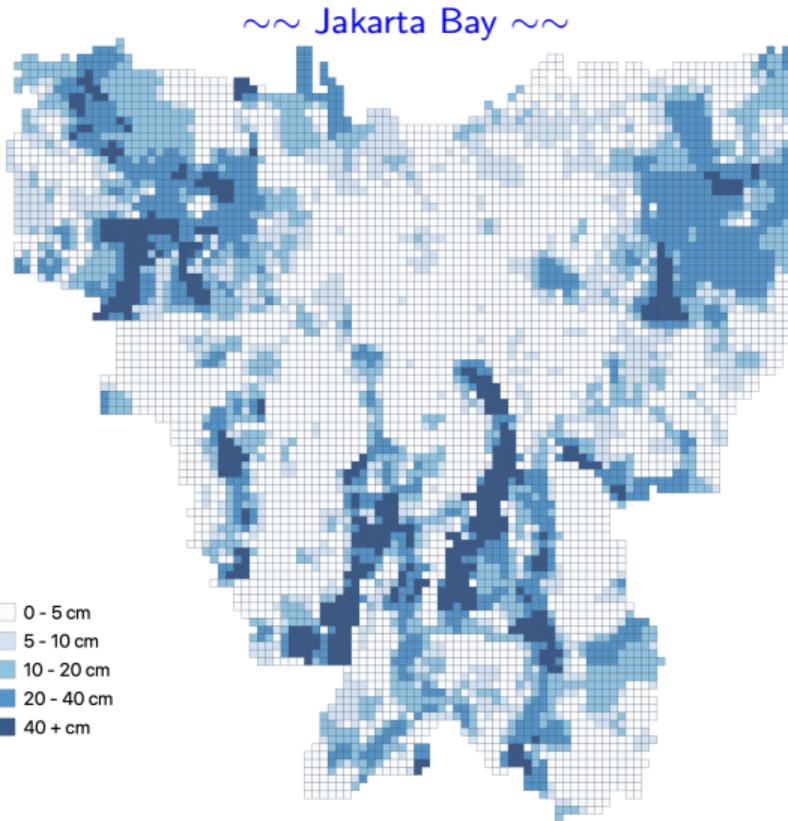
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## Population (global data)



# Flooding (2013-2020, past → future)



## Demand estimates (imply \$0.3B flood damages)

	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	

# Supply

$$c_{kt} \quad \text{vs.} \quad \alpha(r_{kt} + \beta r_{kt+1} + \beta^2 r_{kt+2} + \dots)$$

- **Dynamic choice:** landowners  $i$ , locations  $k$ , time  $t$ , state  $D_{ikt} \in \{0, 1\}$ 
  - Private cost of development
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## Small, homogeneous landowners

$$w_t = \{r_{kt}, c_{kt}, P_{kt}^1, P_{kt}^0\}_k$$

- Take aggregate state as given: rents, costs, and property prices
  - 14k developers in Jakarta, 1k with \$3.5M annual revenue
  - Constant returns to scale
- Local government coordinates, developers react competitively
  - Market power lessens development
  - But also facilitates coordination

# Choices

- **Developed plots:** sell or hold

$$① \quad V_{kt}^1 = \max\{\alpha P_{kt}^1, \tilde{V}_{kt}^1\}$$

$$② \quad \tilde{V}_{kt}^1 = \alpha r_{kt} + \beta \mathbb{E}[V_{kt+1}^1]$$

- **Empty plots:** sell, develop, or hold

$$③ \quad V_{kt}^0 = \max\{\alpha P_{kt}^0, \tilde{V}_{kt}^0\}$$

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# Equilibrium prices

- Rents clear rental markets:  $D_{kt}^{\text{res}}(r_t; f_t) = D_{kt}^{\text{dev}}(r_{kt}, r_{kt+1}, \dots)$
- REITs arbitrage property prices
  - Can buy assets and collect rents
  - Observed prices capture continuation values (Kalouptsidi 2014)

$$\begin{aligned} ① \quad V_{kt}^1 &= \max\{\alpha P_{kt}^1, \tilde{V}_{kt}^1\} & V_{kt}^1 &= \alpha P_{kt}^1 \\ ③ \quad V_{kt}^0 &= \max\{\alpha P_{kt}^0, \tilde{V}_{kt}^0\} & V_{kt}^0 &= \alpha P_{kt}^0 \end{aligned}$$

$$P_{kt}^1 = \sum_{t'=0}^{\infty} \beta^{t'} \mathbb{E}[r_{kt+t'}], \quad P_{kt}^0 = \frac{1}{\alpha} \log \left( \exp(\beta V_{kt+1}^1 - c_{kt}) + \exp(\beta V_{kt+1}^0) \right)$$

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## Logit inversion

$$④ \quad \tilde{V}_{kt}^0 = \mathbb{E}[\max\{\beta V_{kt+1}^1 - c_{kt} + \varepsilon_{ikt}^1, \beta V_{kt+1}^0 + \varepsilon_{ikt}^0\}]$$

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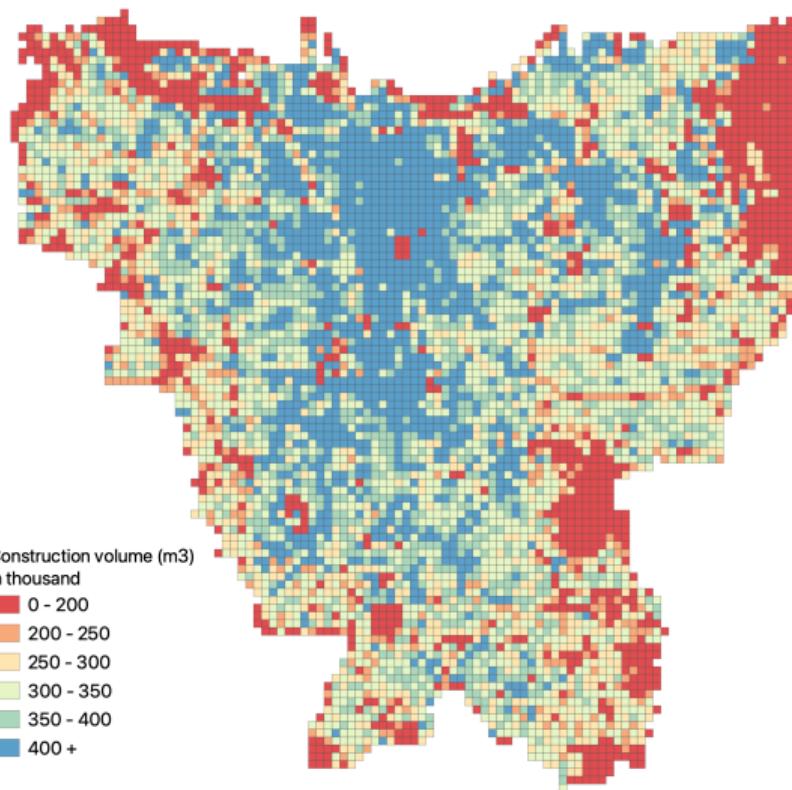
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# Estimation

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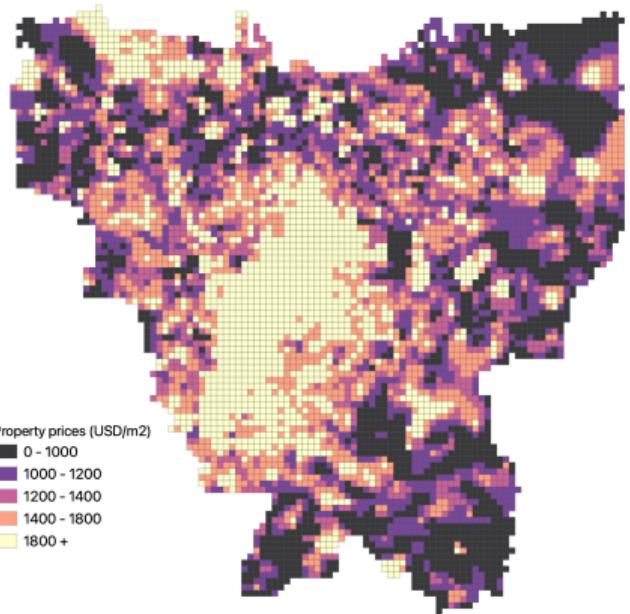
- **Estimation:** linear IV with 2015 construction data
  - Rent endogeneity from unobserved costs
  - Residential amenities as demand shifter
- **Policy-invariant:** can invert to infer policy
  - Market expectations capitalize into prices
  - Developers respond to prices as if statically
- Alternatives: full-solution, two-step, Euler CCP

## Building construction (global data)

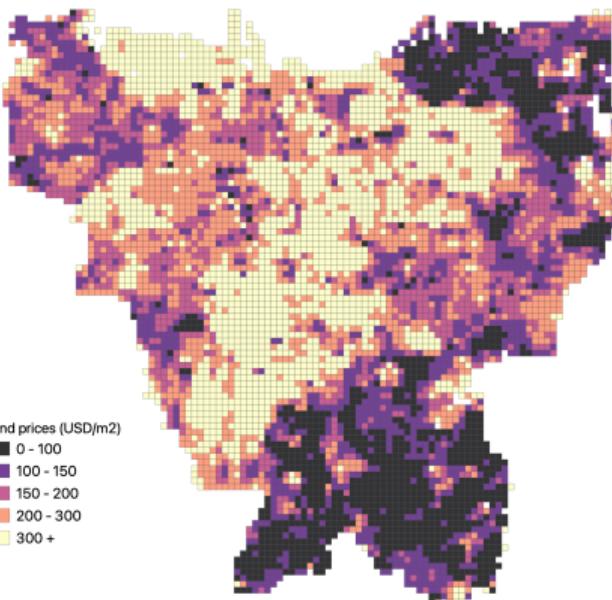


# Real estate prices (urban data)

Property



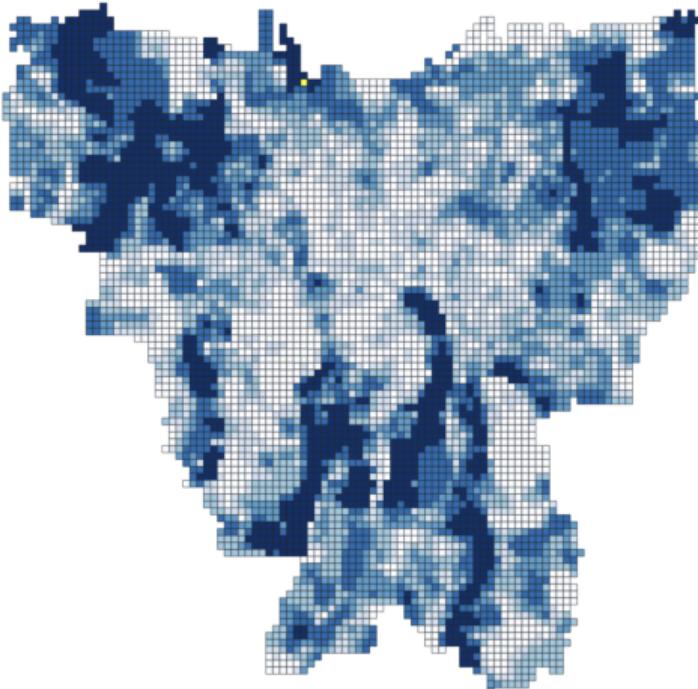
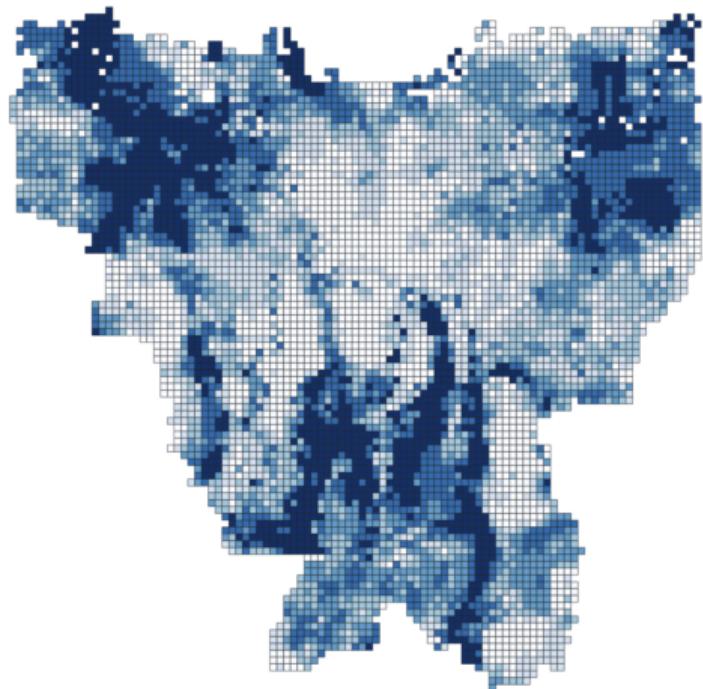
Land



## Supply estimates

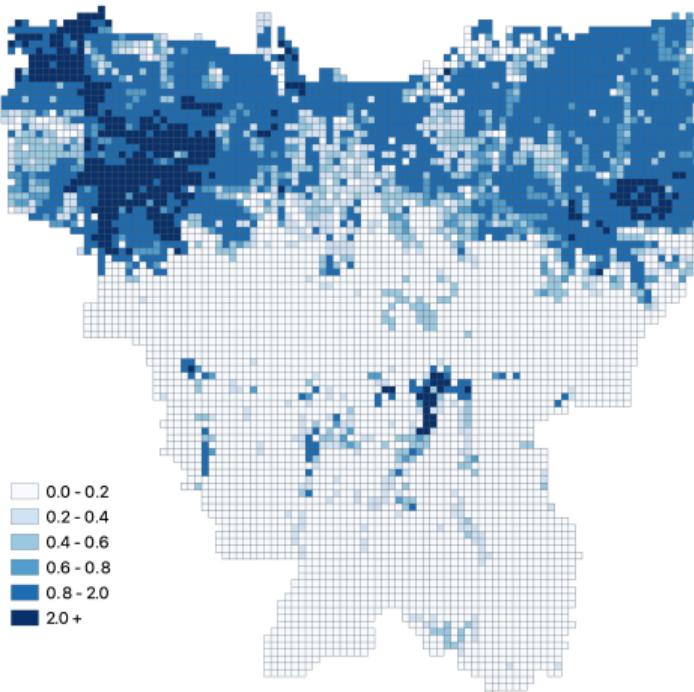
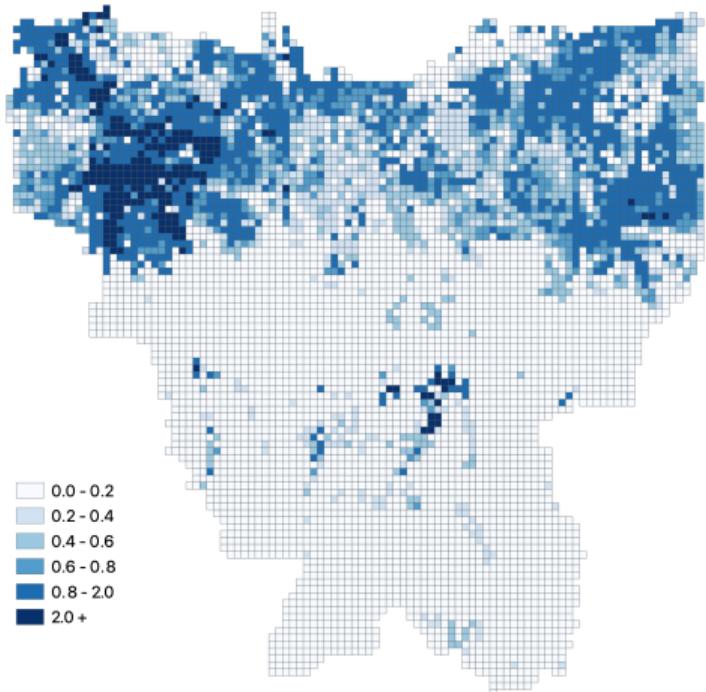
	IV		First stage	
	Estimate	SE	Estimate	SE
Prices	0.171***	(0.041)		
Residential amenities			0.182***	(0.043)
Flooding	0.064	(0.044)	-0.842***	(0.216)
Ruggedness	-0.143***	(0.054)	1.268***	(0.103)
District FE	x		x	
Observations	5,780		5,780	
F-statistic			18.14	

## Flooding (under SLR + subsidence)



Predicted vs. observed monthly flooding (2013-2020)

## Flooding (under SLR + subsidence)



3m vs. 5m sea wall

## Sea wall costs

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

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

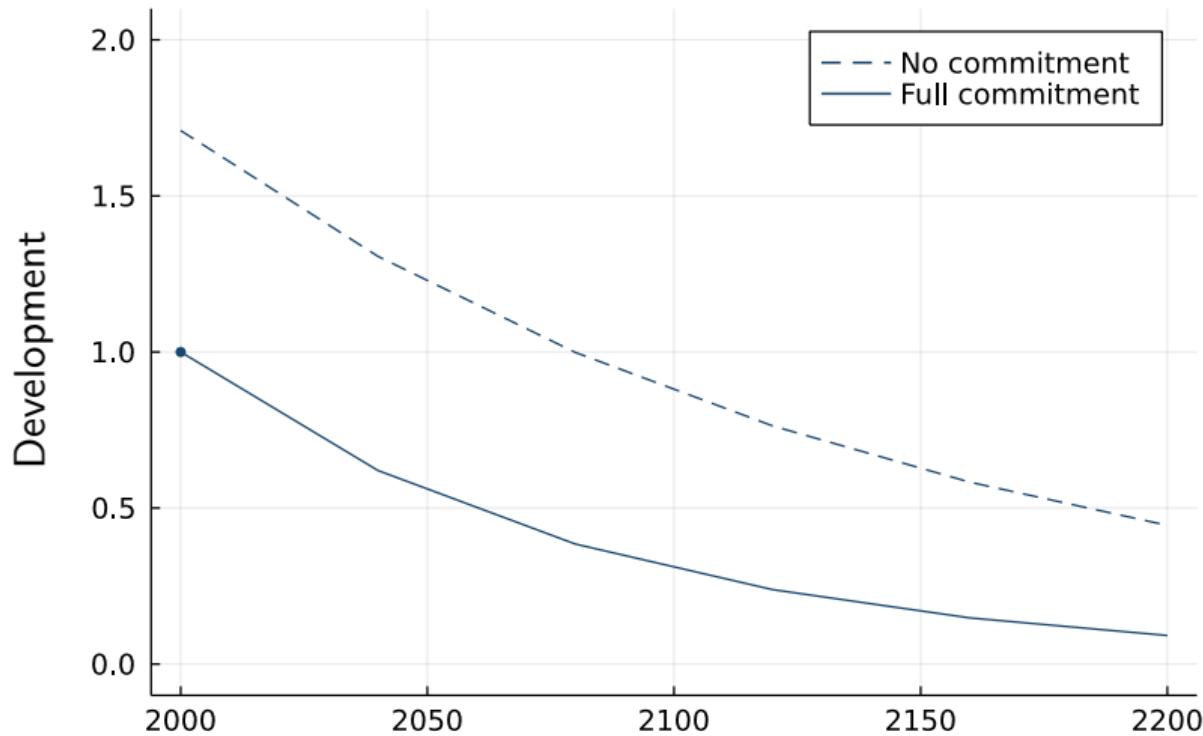
# Counterfactuals

## Solving the model

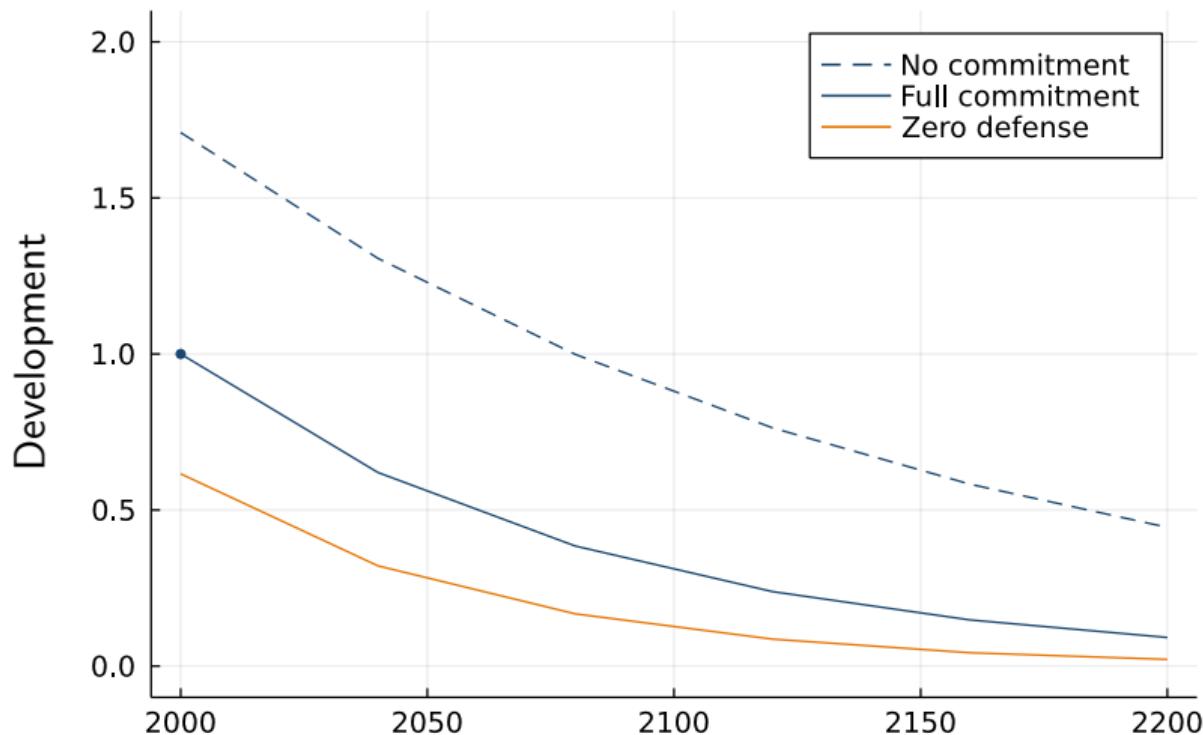
$$D^*(G) = \arg \max \Pi(D; G)$$
$$[G^*(D) = \arg \max W(G; D)]$$

- Solving across locations and periods
  - In spatial equilibrium, by backward induction
  - Need expectational assumptions
- Sea wall construction every 40 years
  - Typical lifespan of 30 to 50 years

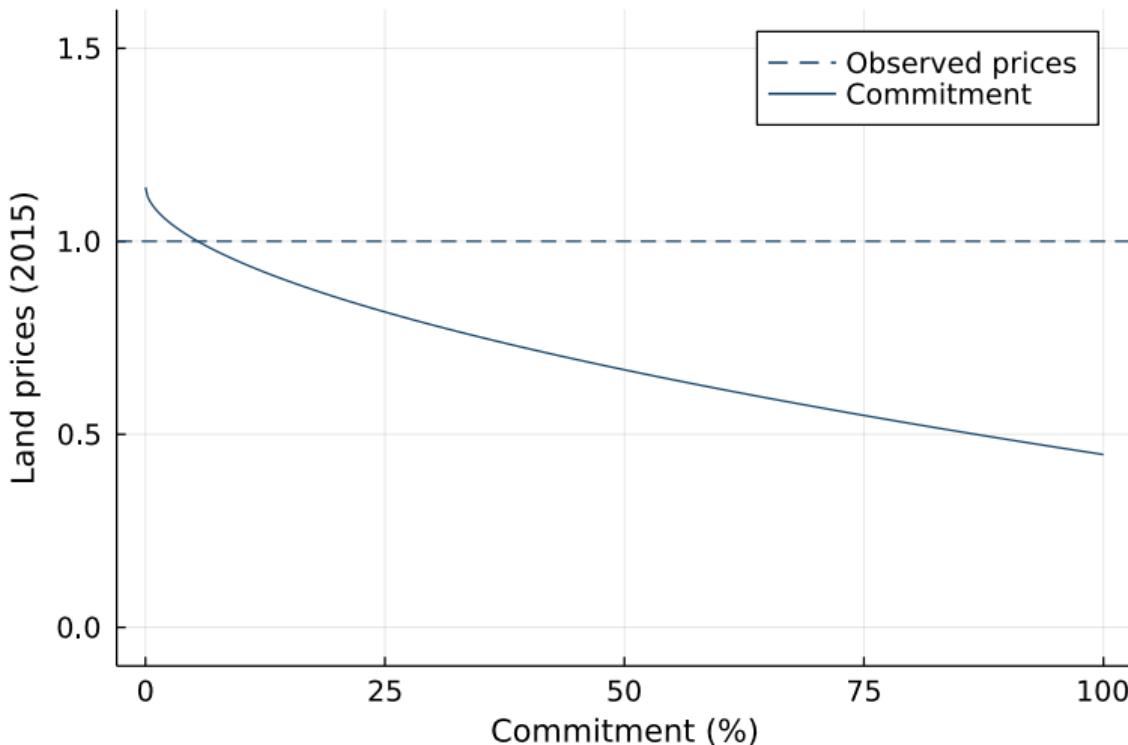
## Moral hazard delays adaptation



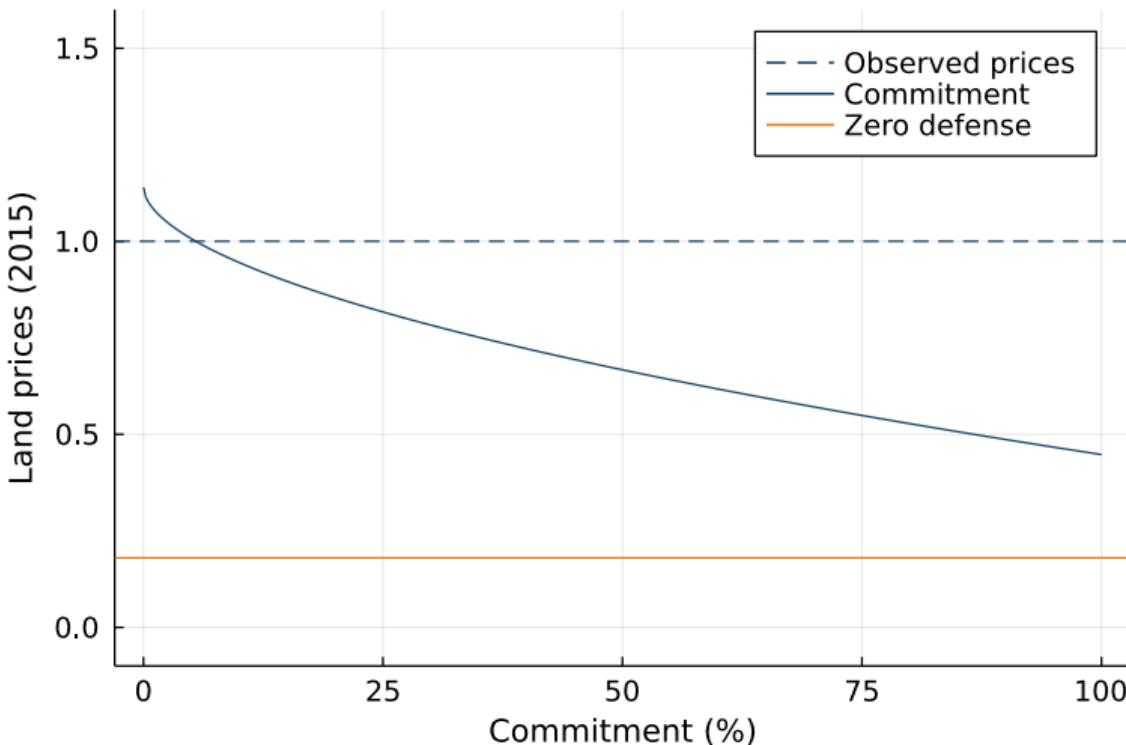
## Moral hazard delays adaptation (55% loss)



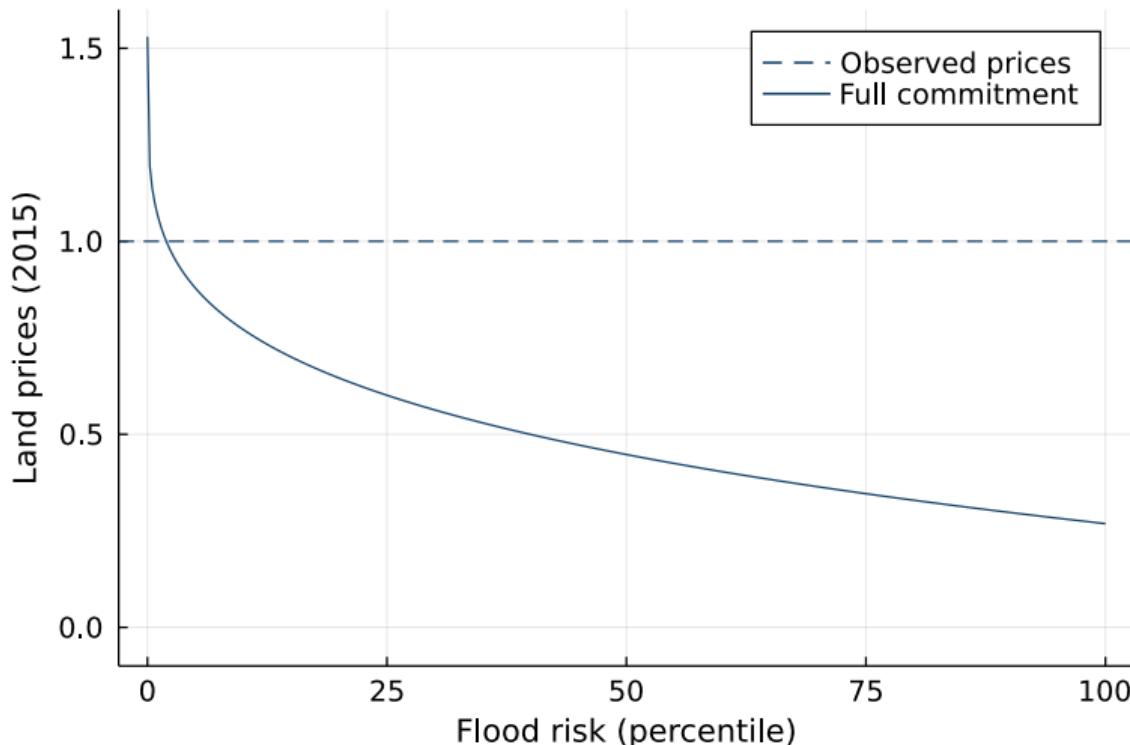
## Moral hazard can rationalize observed prices



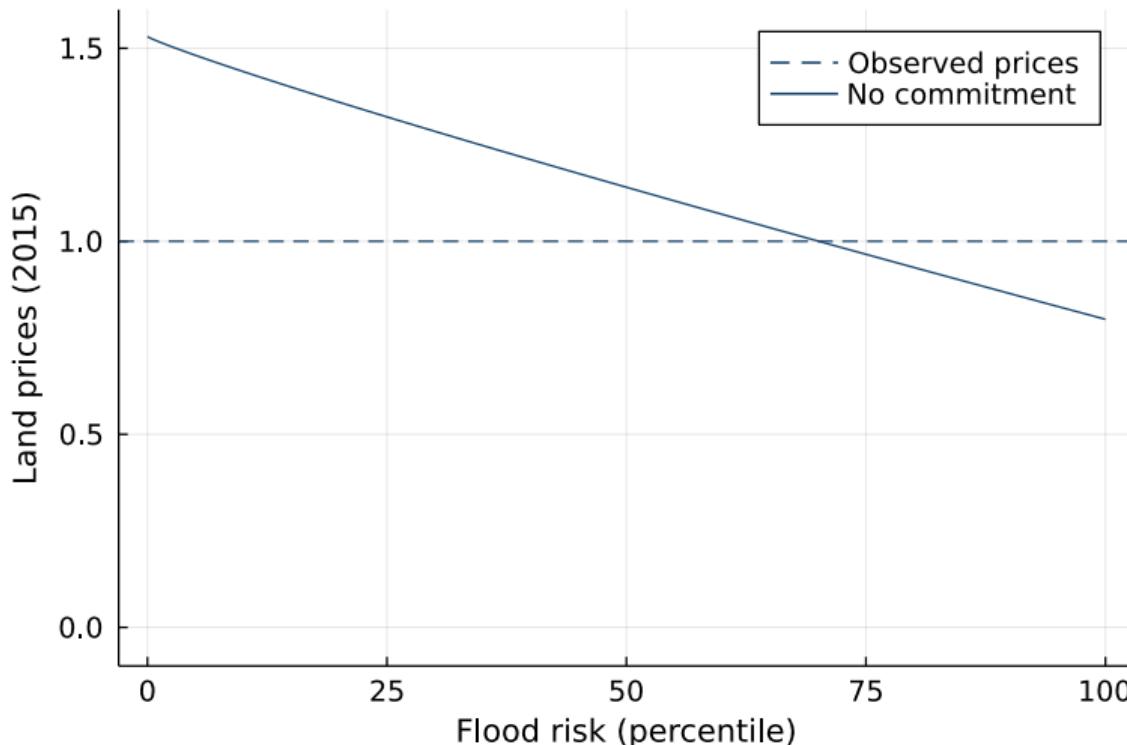
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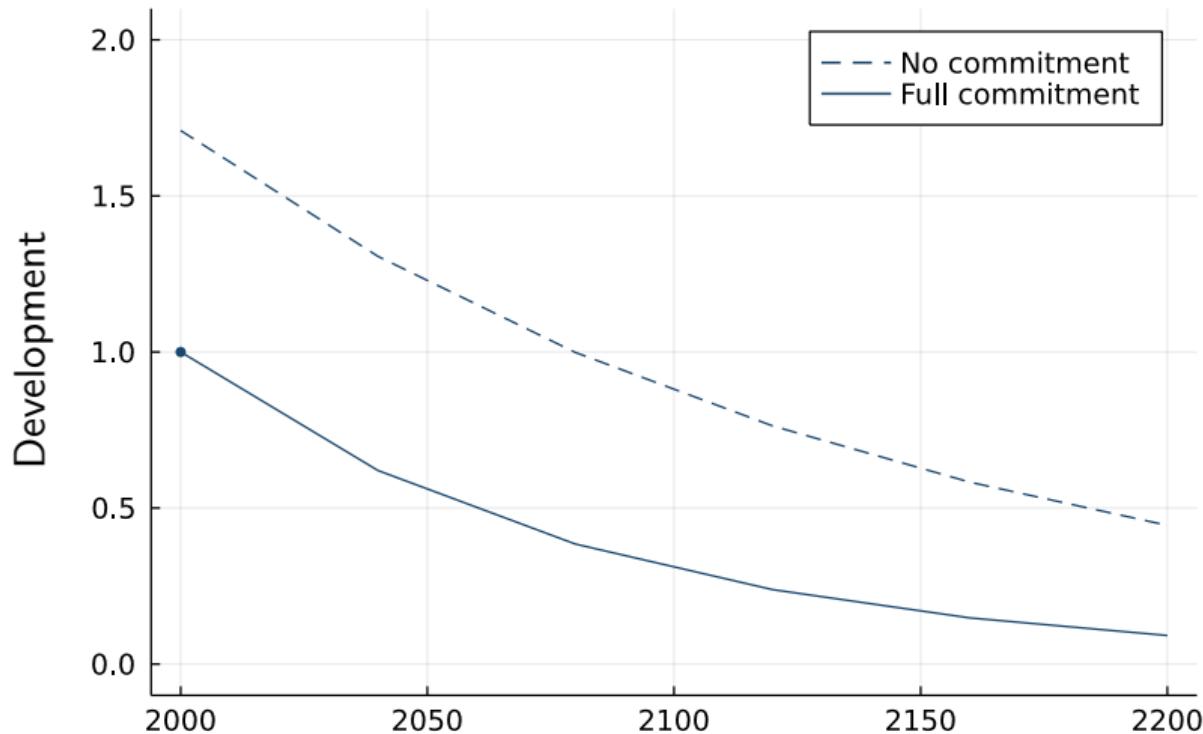
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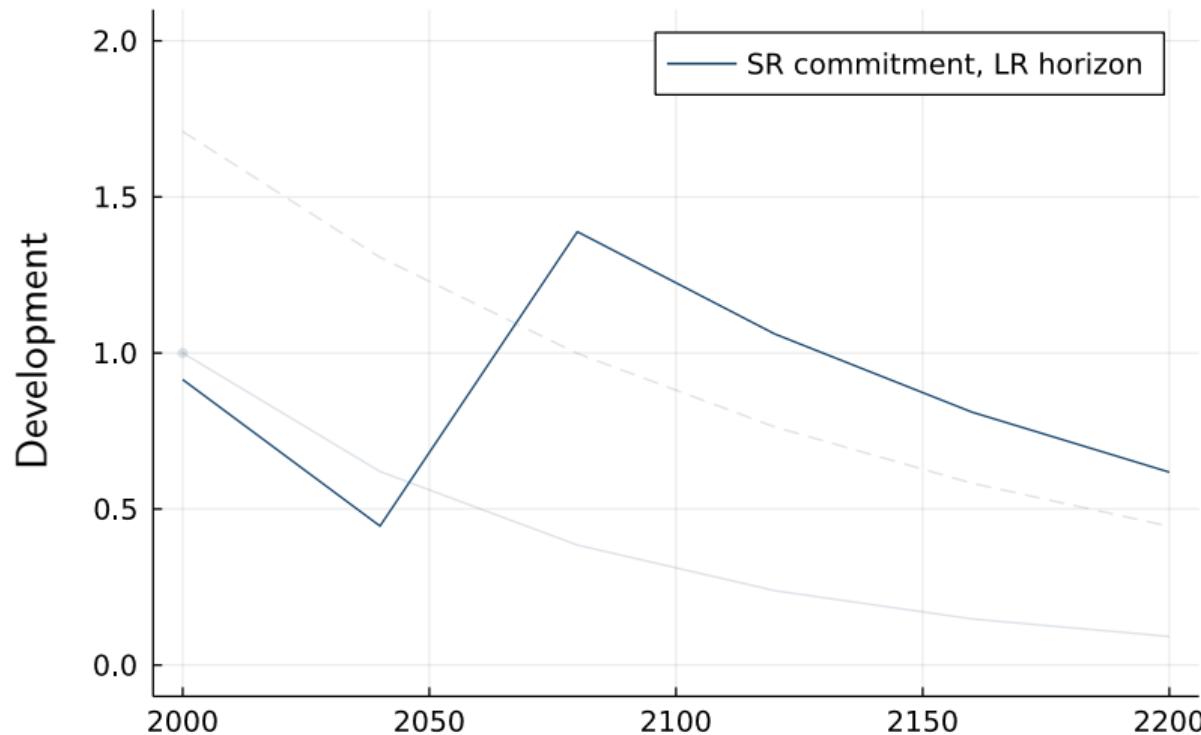
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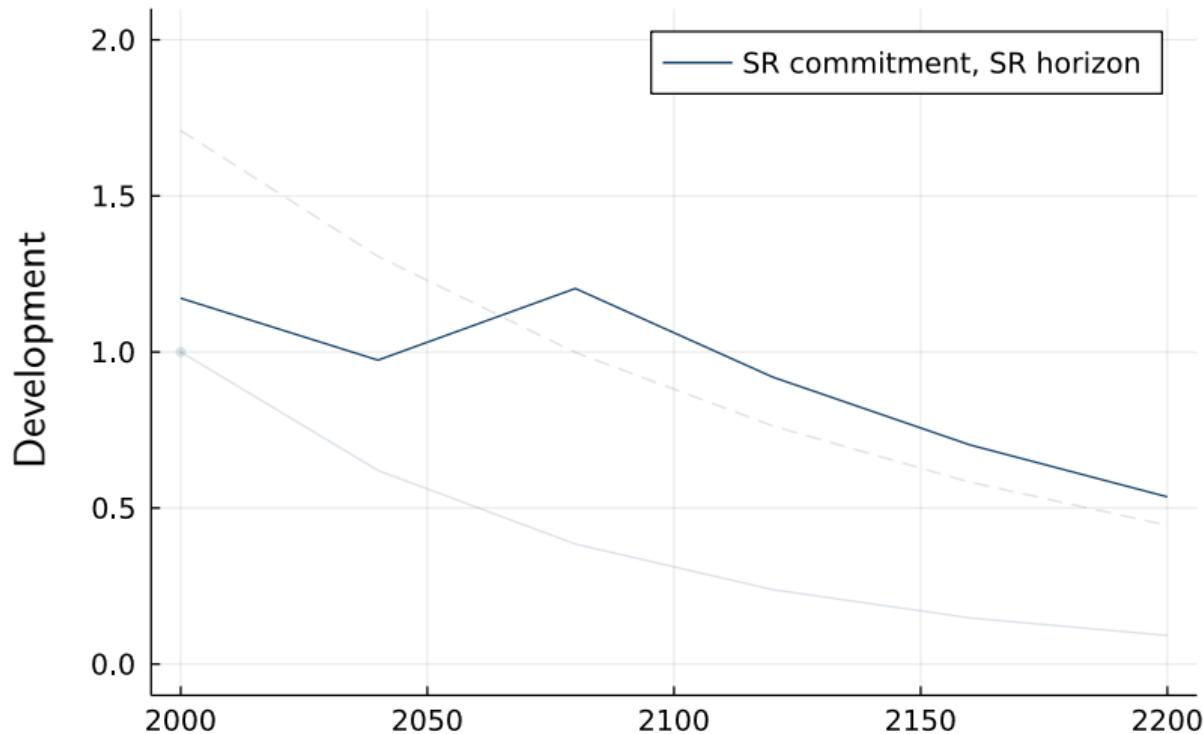
## Partial commitment helps, subject to politics (53% vs. 63% loss)



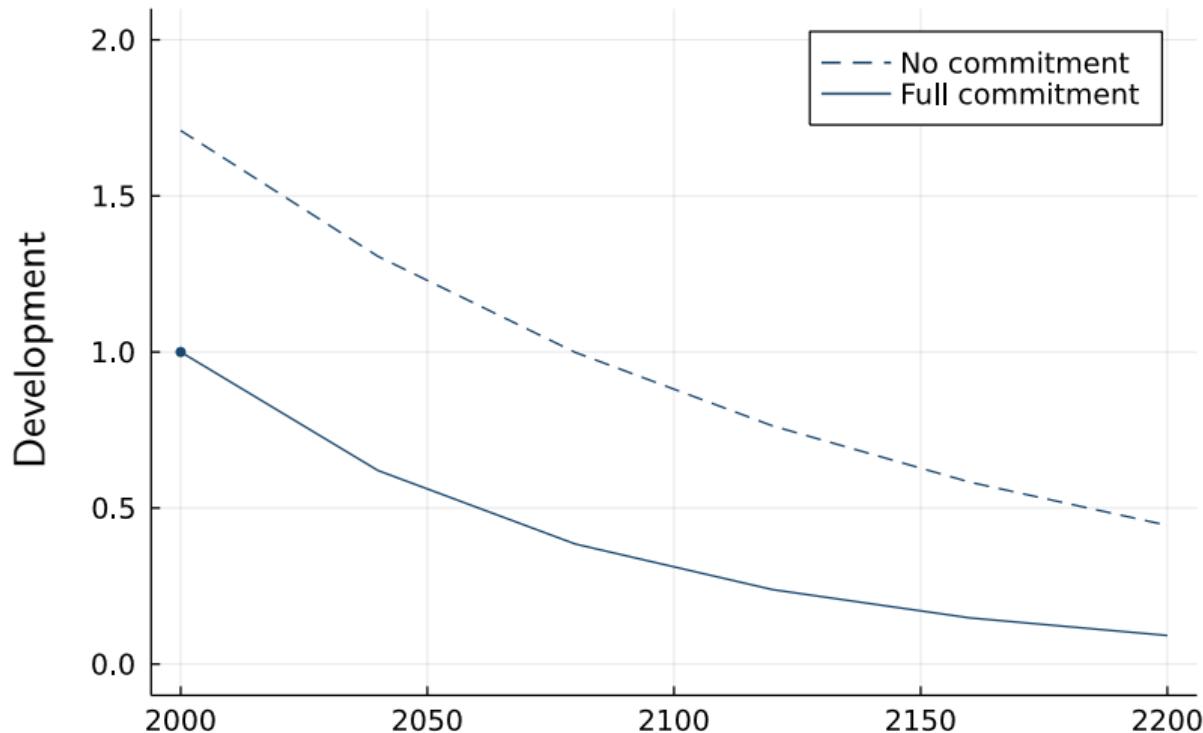
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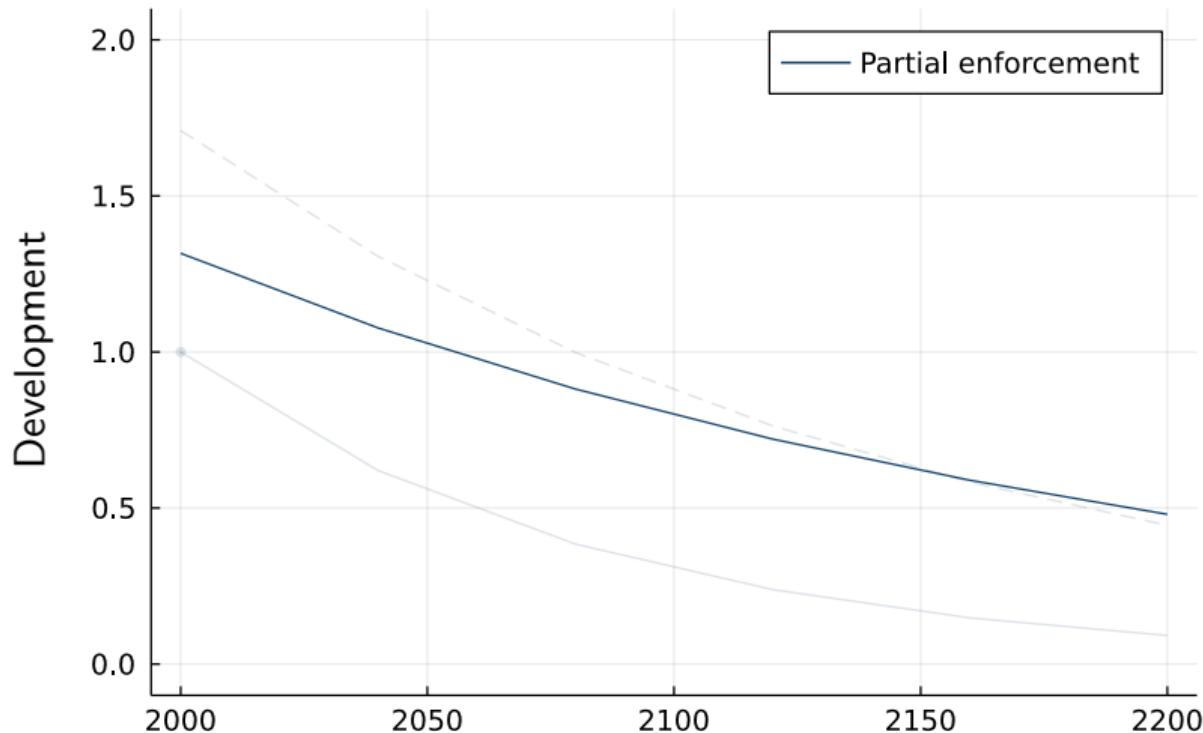
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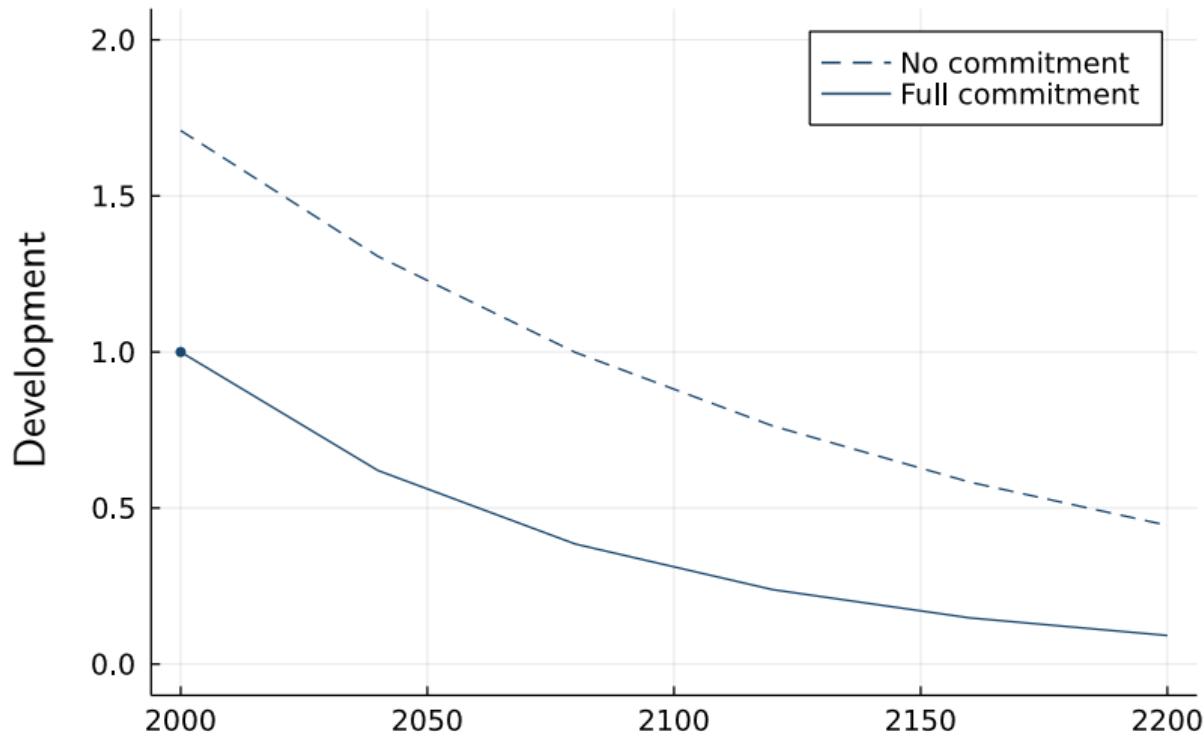
## Partial enforcement helps, if consistent (79% loss)



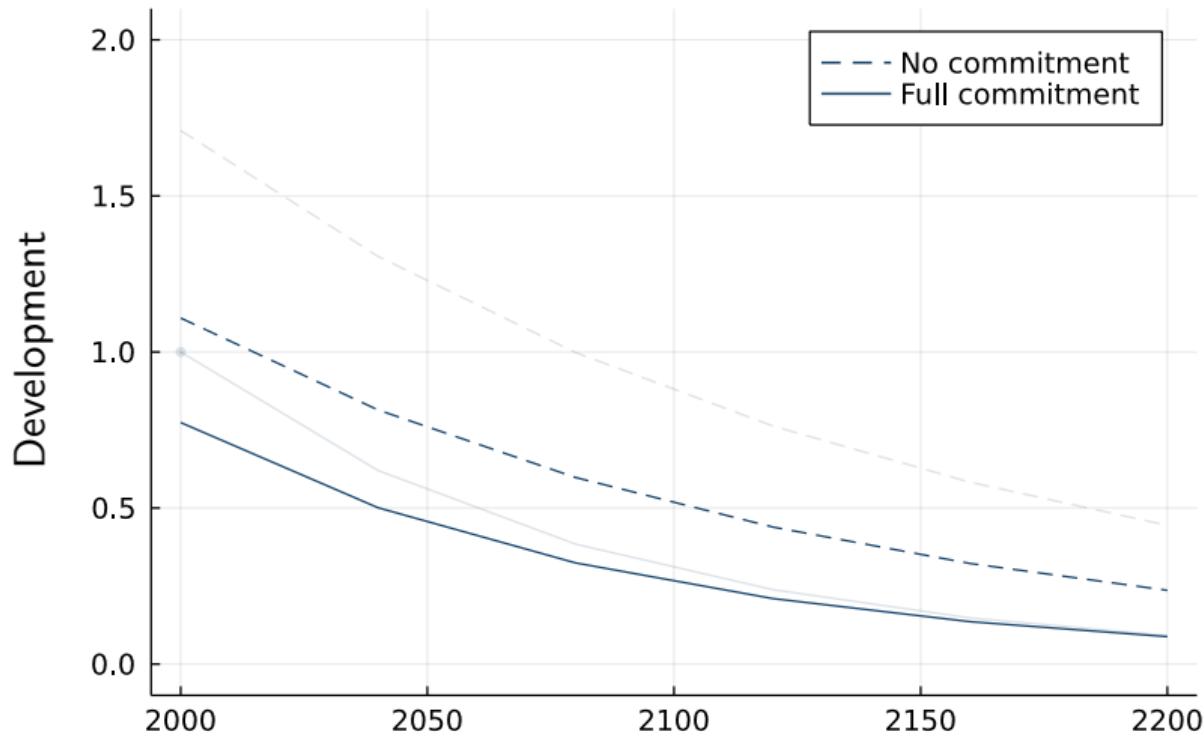
## Partial enforcement helps, if consistent (79% loss)



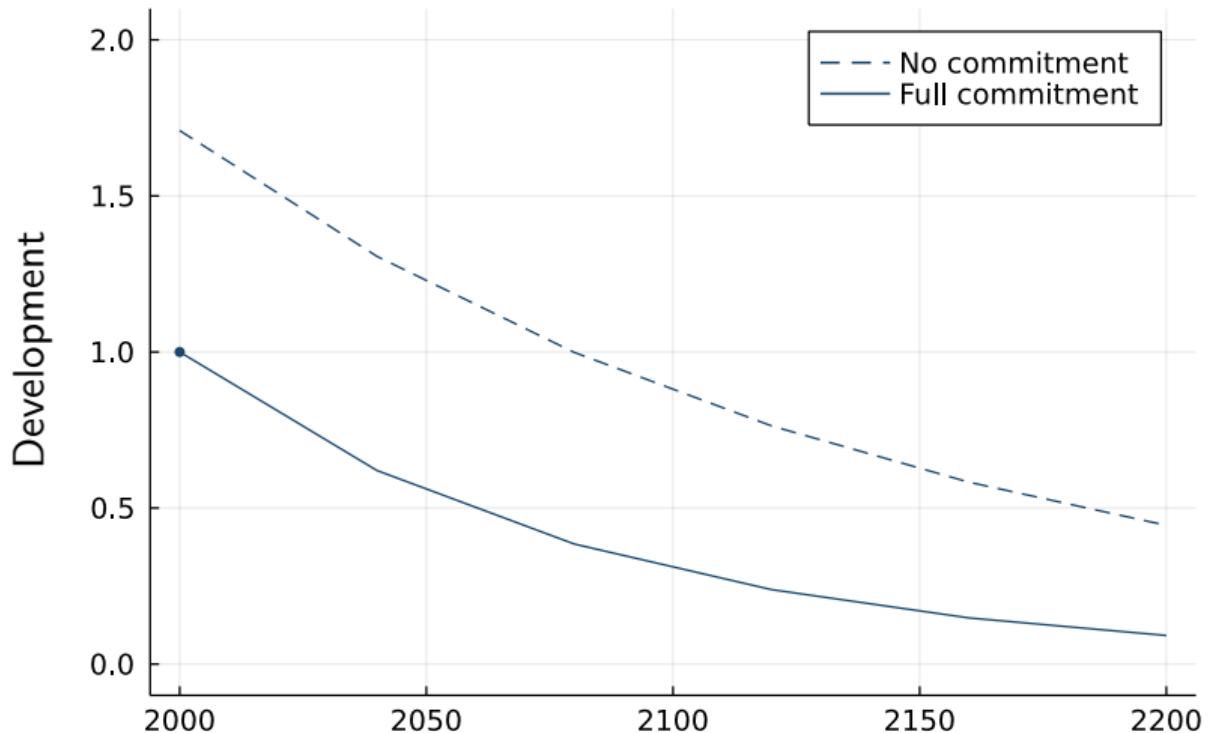
## Moving the capital reduces moral hazard (26% loss)



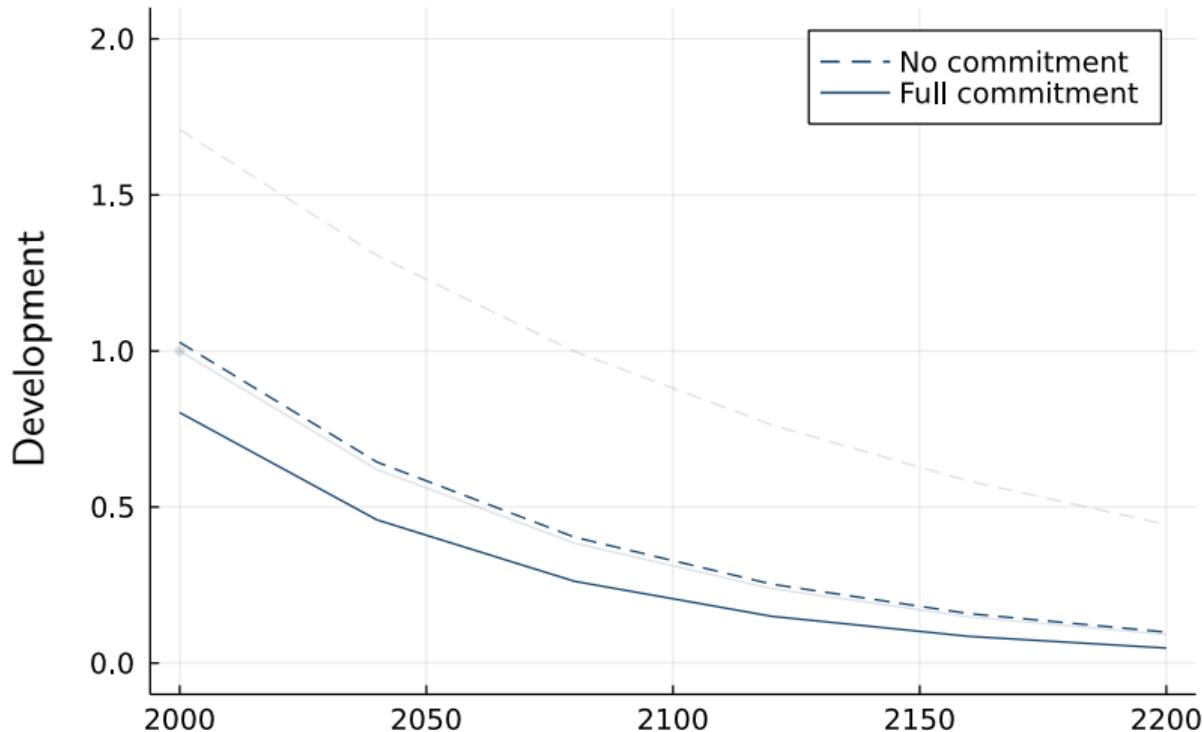
## Moving the capital reduces moral hazard (26% loss)



## Slowing subsidence reduces moral hazard (6% loss)



## Slowing subsidence reduces moral hazard (6% loss)



# Policy recommendations

## ① Partial commitment

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

## ② Indirect policy

- Moving capital, as is already happening
- Less efficient, but more politically feasible

# Conclusion

# Summary

- **Moral hazard can impede climate adaptation**
- Jakarta foreshadows the future for other coastal cities

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)