Sea Level Rise and Urban Adaptation in Jakarta

Allan Hsiao
Princeton University

January 24, 2024


#CLIMATE NO JUSTICE

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 recommendations
    - Direct: partial commitment
    - Indirect: moving capital

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 <u>coast</u> or migrate <u>inland</u>
- **Dynamic:** incur costs <u>today</u> or damages <u>tomorrow</u>

- **Moral hazard** introduces a market failure
  - Even with one location, one period

Coastal development and defense

- **Development** d at cost $c(d)$ for $c'' > 0$ (agent)
- **Defense** g at cost $e(g)$ for $e'' > 0$ (principal)
- Residential value $r(d,g)$ for $r_{dg} > 0$

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

- Moral hazard: time inconsistency + uninternalized cost

Coastal development and defense

- **Development** d at cost $c(d)$ for $c'' > 0$ (agent)
- **Defense** g at cost $e(g)$ for $e'' > 0$ (principal)
- Residential value $r(d, g)$ for $r_{dg} > 0$

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

- Moral hazard: time inconsistency + uninternalized cost

Coastal development and defense

- **Development** d at cost $c(d)$ for $c'' > 0$ (agent)
- **Defense** g at cost $e(g)$ for $e'' > 0$ (principal)
- Residential value $r(d, g)$ for $r_{dg} > 0$

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

- Moral hazard: time inconsistency + uninternalized cost

Coastal development and defense

- **Development** d at cost $c(d)$ for $c'' > 0$ (agent)
- **Defense** g at cost $e(g)$ for $e'' > 0$ (principal)
- Residential value $r(d,g)$ for $r_{dg} > 0$

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

- Moral hazard: time inconsistency + uninternalized cost

Coastal development and defense

- **Development** d at cost $c(d)$ for $c'' > 0$ (agent)
- **Defense** g at cost $e(g)$ for $e'' > 0$ (principal)
- Residential value $r(d, g)$ for $r_{dg} > 0$

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

- Moral hazard: time inconsistency + uninternalized cost

Coastal development and defense

- **Development** d at cost $c(d)$ for $c'' > 0$ (agent)
- **Defense** g at cost $e(g)$ for $e'' > 0$ (principal)
- Residential value $r(d, g)$ for $r_{dg} > 0$

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

- Moral hazard: time inconsistency + uninternalized cost

Agent and principal

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

First best with commitment

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

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

- If g unconstrained via domestic or foreign ability

Over-development without commitment

1. Development d^n
2. Defense $g^n(d^n)$

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

- If g continuous via height, quality, maintenance, or expectation

But 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)
  - Worse with more periods, more locations
  - (Unless migration is not an option)

Equivalent 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 risk is aggregate for Jakarta

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*

Target Konstruksi

Tahap A

Konstruksi: 2014-2017
Flood safety: 2030

Tahap B

Konstruksi: 2018-2022
Flood Safety: 2030

Tahap C

Konstruksi: 2022

Empirics

Framework

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

- $\tilde{r}(d, f)$: **spatial model** of residential demand
- $f(g)$: **hydrological model** of flooding

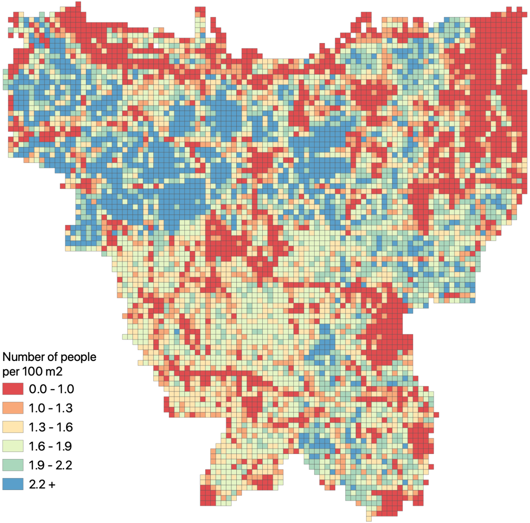
- $c(d)$: **dynamic model** of developer supply
- $e(g)$: **engineering model** of sea wall costs

Residential demand

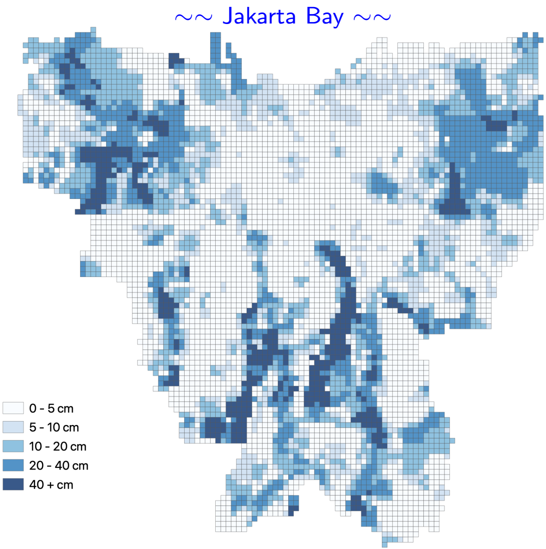
$$u_{ik} = \alpha r_k + \phi f_k + x_k \gamma + \varepsilon_k + \epsilon_{ik}$$

- **Spatial choice:** renter residents i, locations k
  - Private cost $\frac{\phi}{\alpha}$ of flooding f $(r_{dg} > 0)$
  - Moral hazard increasing in $\frac{\phi}{\alpha}$
- **Estimation:** linear IV with population data
  - Rent endogeneity from unobserved amenities
  - Ruggedness as supply shifter

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	

Developer supply

1. $$\tilde{V}_{kt}(D,L) = \max_{s\in\{0,1\}} \{V_{kt}(D,L),\ \alpha P_{kt}(D,L)\}$$
2. $$V_{kt}(D,L) = \alpha r_{kt}(D) + \mathbb{E}[\max_{d\in\{0,1\}} \{v^d_{kt}(D,L) + \epsilon^d_{ikt}\}]$$

- **Dynamic choice:** landlord developers i, time t, portfolios (D,L)
  - Private cost c of developing
  - Moral hazard increasing in α
- **Estimation:** linear IV with construction data
  - Rent endogeneity from unobserved costs
  - Residential amenities as demand shifter

Developer supply

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

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

- **Dynamic choice:** landlord developers i, time t, portfolios (D, L)
  - Private cost c of developing
  - Moral hazard increasing in α
- **Estimation:** linear IV with construction data
  - Rent endogeneity from unobserved costs
  - Residential amenities as demand shifter

Continuation values from data

1. $\tilde{V}_{kt}(D,L) = \max_{s\in\{0,1\}} \{V_{kt}(D,L),\ \alpha P_{kt}(D,L)\}$

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

- If real estate markets are efficient
  - P rises if $P < V$, P falls if $P > V$
  - Frictions as unobserved costs

Continuation values from data

1. $$\tilde{V}_{kt}(D,L) = \max_{s\in\{0,1\}} \{V_{kt}(D,L),\ \alpha P_{kt}(D,L)\}$$

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

- If real estate markets are efficient
  - P rises if $P < V$, P falls if $P > V$
  - Frictions as unobserved costs

Estimation without solving

2. $$V_{kt}(D,L) = \alpha r_{kt}(D) + \mathbb{E}[\max_{d\in\{0,1\}}\{v^d_{kt}(D,L) + \epsilon^d_{ikt}\}]$$

$$\begin{aligned}\ln p^1_{kt} - \ln p^0_{kt} &= v^1_{kt}(D,L) - v^0_{kt}(D,L)\\ &= -c_{kt}(x,\varepsilon) + \beta\mathbb{E}[V_{kt+1}(D+1,L-1) - V_{kt+1}(D,L)]\\ &= -c_{kt}(x,\varepsilon) + \alpha\beta\mathbb{E}[P^D_{kt+1} - P^L_{kt+1}]\\ &= -c_{kt}(x,\varepsilon) + \alpha\beta(P^D_{kt} - P^L_{kt})\end{aligned}$$

- Simple IV estimator (without finite dependence)
  - Market expectations capitalize into prices
  - Developers respond to prices as if statically

Estimation without solving

2. $$V_{kt}(D,L) = \alpha r_{kt}(D) + \mathbb{E}[\max_{d\in\{0,1\}}\{v^d_{kt}(D,L) + \epsilon^d_{ikt}\}]$$

$$\begin{aligned}\ln p^1_{kt} - \ln p^0_{kt} &= v^1_{kt}(D,L) - v^0_{kt}(D,L)\\ &= -c_{kt}(x,\varepsilon) + \beta\mathbb{E}[V_{kt+1}(D+1,L-1) - V_{kt+1}(D,L)]\\ &= -c_{kt}(x,\varepsilon) + \alpha\beta\mathbb{E}[P^D_{kt+1} - P^L_{kt+1}]\\ &= -c_{kt}(x,\varepsilon) + \alpha\beta(P^D_{kt} - P^L_{kt})\end{aligned}$$

- Simple IV estimator (without finite dependence)
  - Market expectations capitalize into prices
  - Developers respond to prices as if statically

Estimation without solving

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

$$\begin{aligned}
\ln p^1_{kt} - \ln p^0_{kt} &= v^1_{kt}(D,L) - v^0_{kt}(D,L) \\
&= -c_{kt}(x,\varepsilon) + \beta\mathbb{E}[V_{kt+1}(D+1,L-1) - V_{kt+1}(D,L)] \\
&= -c_{kt}(x,\varepsilon) + \alpha\beta\mathbb{E}[P^D_{kt+1} - P^L_{kt+1}] \\
&= -c_{kt}(x,\varepsilon) + \alpha\beta(P^D_{kt} - P^L_{kt})
\end{aligned}$$

- Simple IV estimator (without finite dependence)
  - Market expectations capitalize into prices
  - Developers respond to prices as if statically

Estimation without solving

$$\text{②}\quad V_{kt}(D,L) = \alpha r_{kt}(D) + \mathbb{E}[\max_{d\in\{0,1\}}\{v^d_{kt}(D,L) + \epsilon^d_{ikt}\}]$$

$$\begin{aligned}
\ln p^1_{kt} - \ln p^0_{kt} &= v^1_{kt}(D,L) - v^0_{kt}(D,L)\\
&= -c_{kt}(x,\varepsilon) + \beta\mathbb{E}[V_{kt+1}(D+1,L-1) - V_{kt+1}(D,L)]\\
&= -c_{kt}(x,\varepsilon) + \alpha\beta\mathbb{E}[P^D_{kt+1} - P^L_{kt+1}]\\
&= -c_{kt}(x,\varepsilon) + \alpha\beta(P^D_{kt} - P^L_{kt})
\end{aligned}$$

- Simple IV estimator (without finite dependence)
  - Market expectations capitalize into prices
  - Developers respond to prices as if statically

Estimation without solving

$$❷ \quad V_{kt}(D,L) = \alpha r_{kt}(D) + \mathbb{E}[\max_{d\in\{0,1\}}\{v^d_{kt}(D,L) + \epsilon^d_{ikt}\}]$$

$$\begin{aligned}
\ln p^1_{kt} - \ln p^0_{kt} &= v^1_{kt}(D,L) - v^0_{kt}(D,L) \\
&= -c_{kt}(x,\varepsilon) + \beta\mathbb{E}[V_{kt+1}(D+1,L-1) - V_{kt+1}(D,L)] \\
&= -c_{kt}(x,\varepsilon) + \alpha\beta\mathbb{E}[P^D_{kt+1} - P^L_{kt+1}] \\
&= -c_{kt}(x,\varepsilon) + \alpha\beta(P^D_{kt} - P^L_{kt})
\end{aligned}$$

- Simple IV estimator (without finite dependence)
  - Market expectations capitalize into prices
  - Developers respond to prices as if statically

Estimation without solving

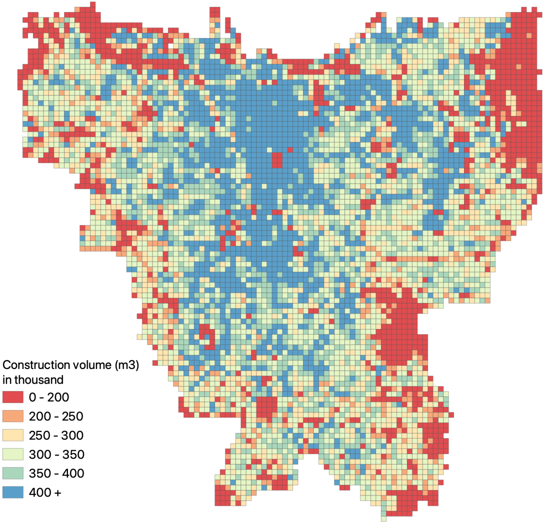
2. $$V_{kt}(D,L) = \alpha r_{kt}(D) + \mathbb{E}[\max_{d\in\{0,1\}}\{v^d_{kt}(D,L) + \epsilon^d_{ikt}\}]$$

$$\begin{aligned} \ln p^1_{kt} - \ln p^0_{kt} &= v^1_{kt}(D,L) - v^0_{kt}(D,L) \\ &= -c_{kt}(x,\varepsilon) + \beta\mathbb{E}[V_{kt+1}(D+1,L-1) - V_{kt+1}(D,L)] \\ &= -c_{kt}(x,\varepsilon) + \alpha\beta\mathbb{E}[P^D_{kt+1} - P^L_{kt+1}] \end{aligned}$$

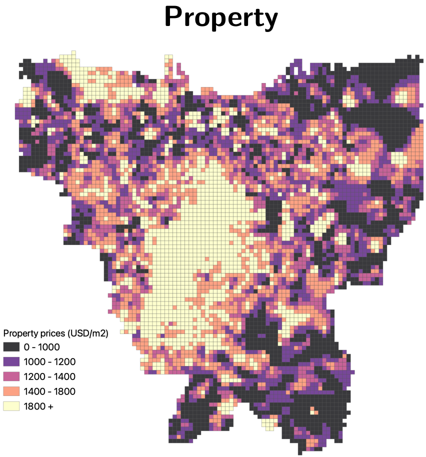
$$\ln p^1_{kt} - \ln p^0_{kt} = -c_{kt}(x,\varepsilon) + \alpha\beta(P^D_{kt} - P^L_{kt})$$

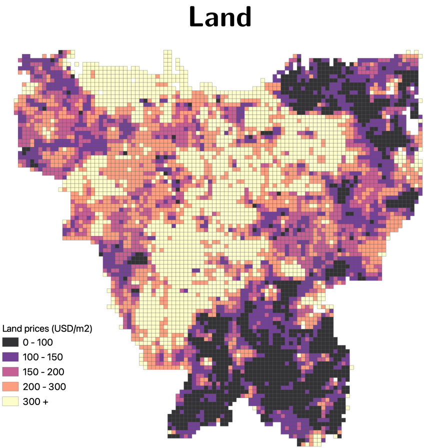
- Simple IV estimator (without finite dependence)
  - Market expectations capitalize into prices
  - Developers respond to prices as if statically

Building construction (global data)



Real estate prices (urban data)

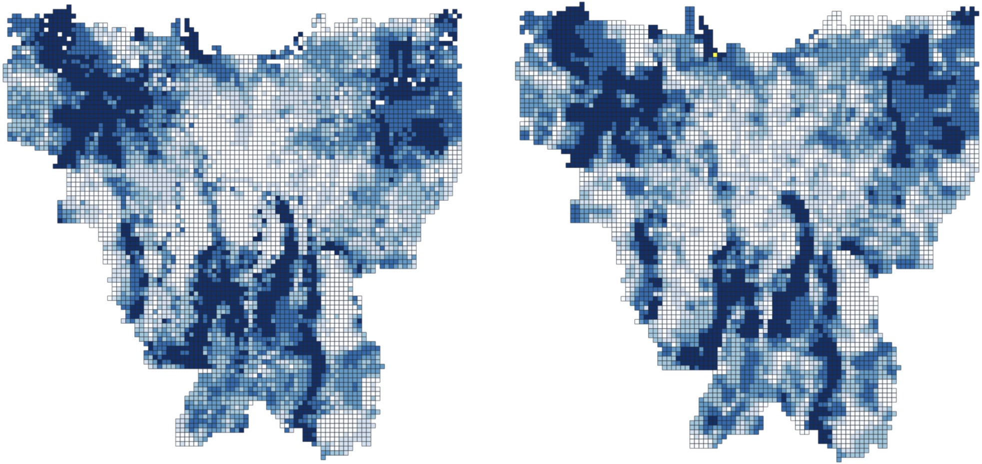




Supply estimates

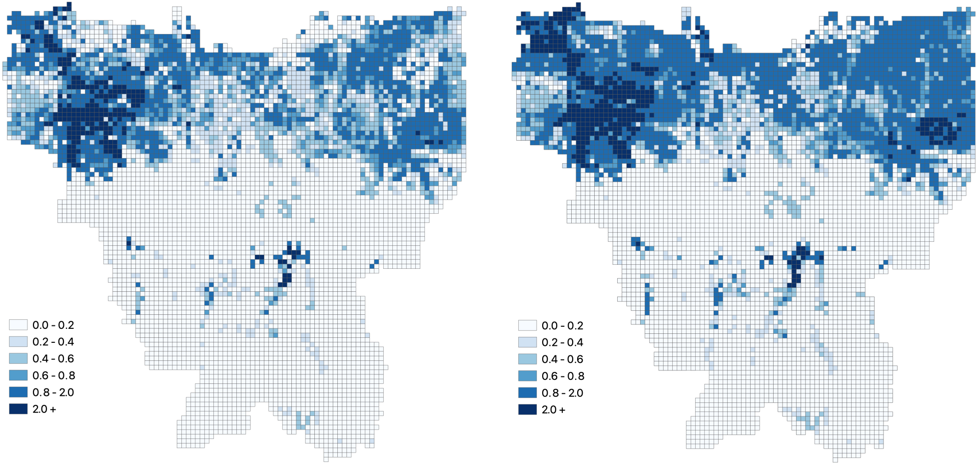
	IV		First stage	
	Estimate	SE	Estimate	SE
Prices	0.171***	(0.041)		
Residential amenities			0.182***	(0.043)
Flooding	0.064	(0.044)	-0.842***	(0.216)
Ruggedness	-0.143***	(0.054)	1.268***	(0.103)
District FE	x		x	
Observations	5,780		5,780	
F-statistic			18.14	

Flooding



Predicted vs. observed monthly flooding (2013-2020)

Flooding



3m vs. 5m sea wall

Sea wall costs

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

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

Counterfactuals

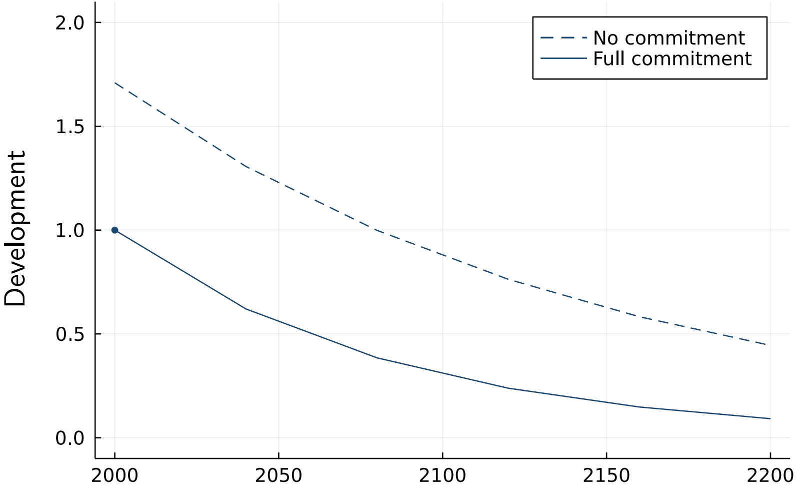
Equilibrium given $r(d,g)$, $c(d)$, and $e(g)$

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

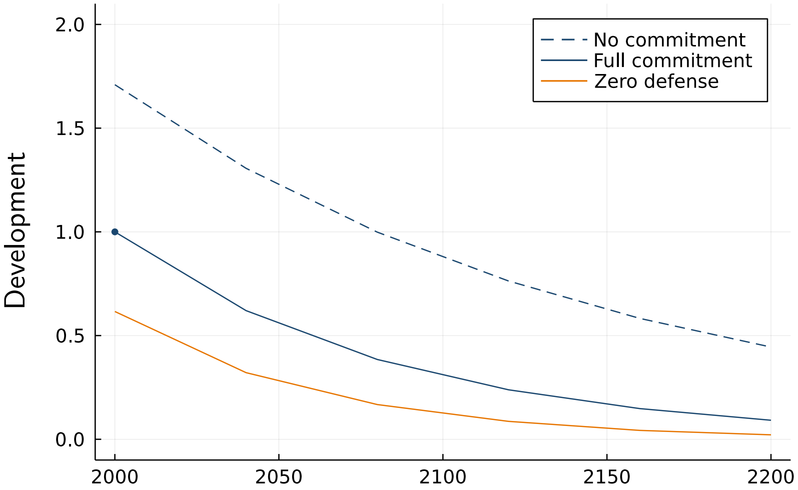
$$P^{\text{res}}(d,g) = P^{\text{dev}}(d,g)$$

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

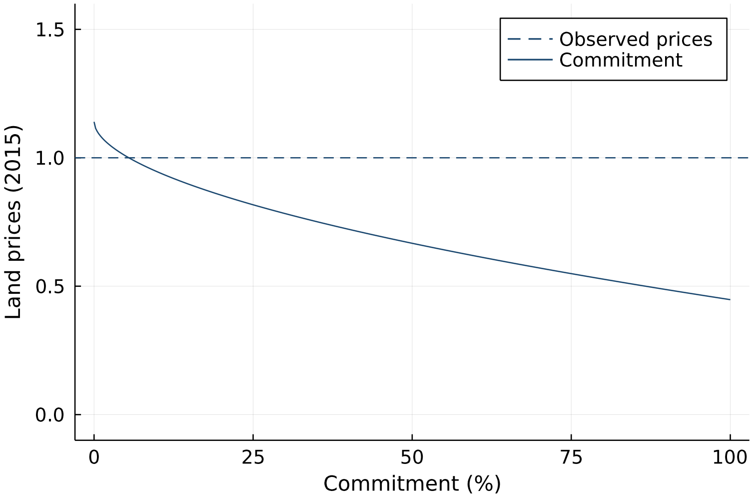
Moral hazard delays adaptation



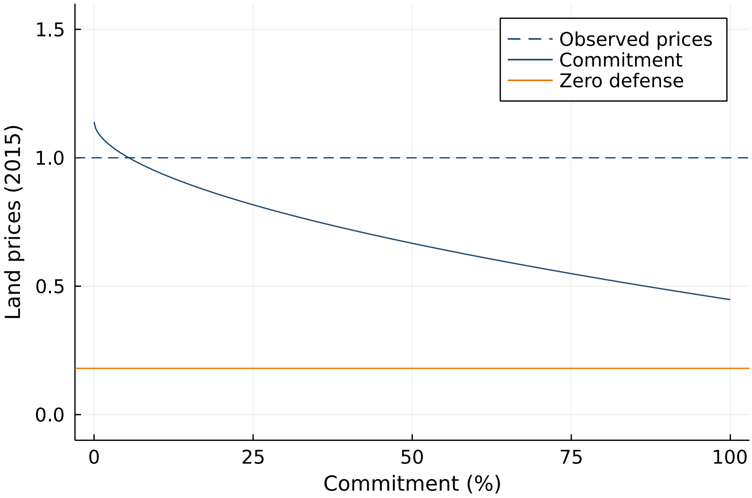
Moral hazard delays adaptation



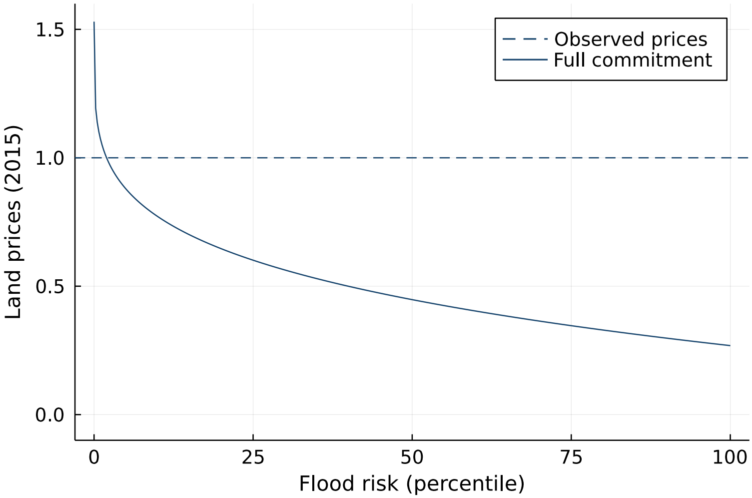
Moral hazard can rationalize observed prices



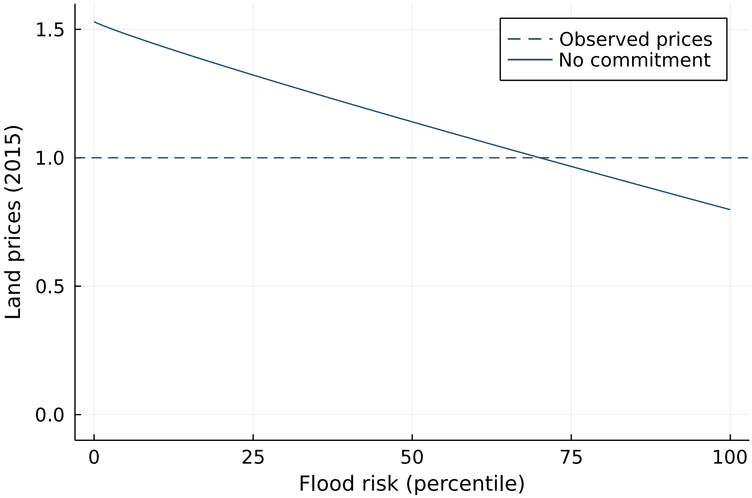
Moral hazard can rationalize observed prices



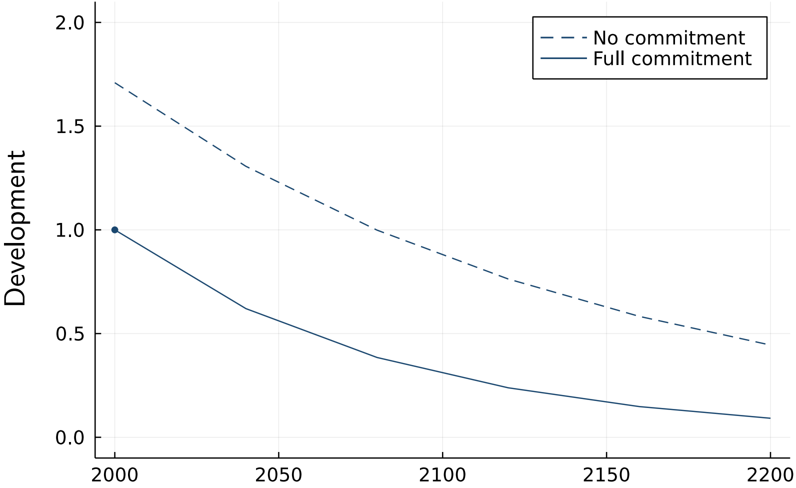
Flood risk cannot rationalize observed prices



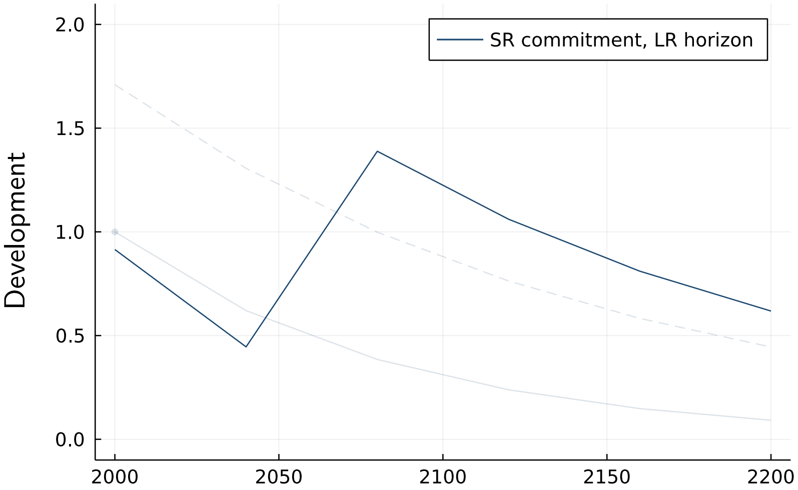
Flood risk cannot rationalize observed prices



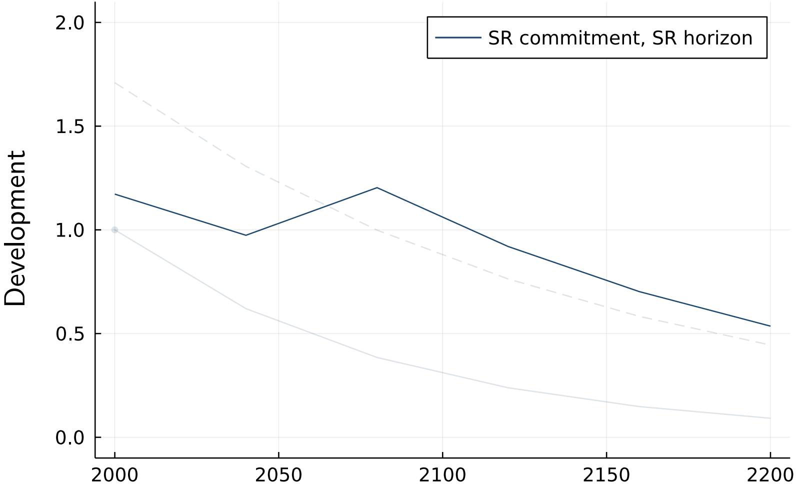
Partial commitment helps, subject to politics



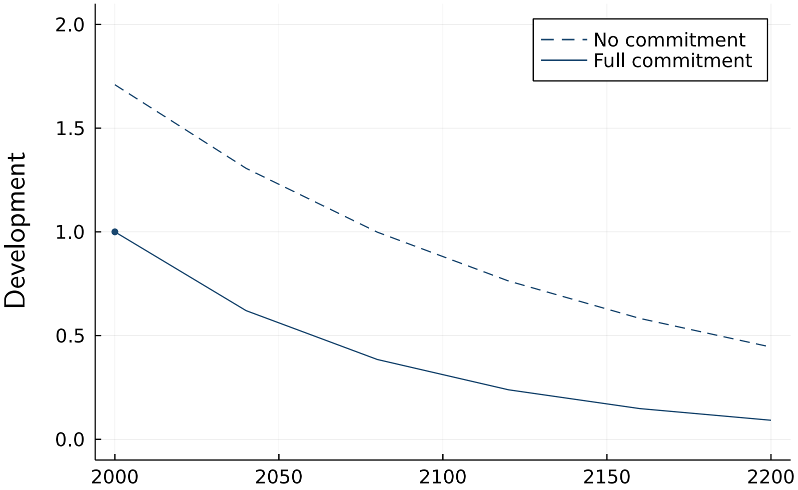
Partial commitment helps, subject to politics



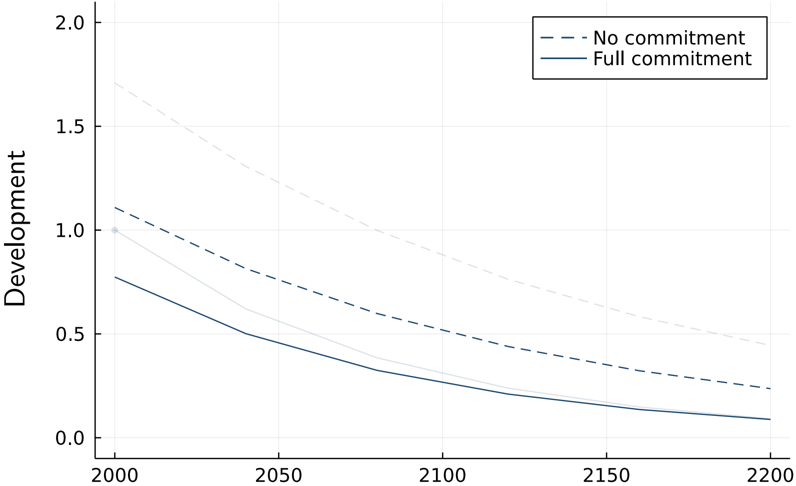
Partial commitment helps, subject to politics



Moving the capital reduces moral hazard



Moving the capital reduces moral hazard



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)