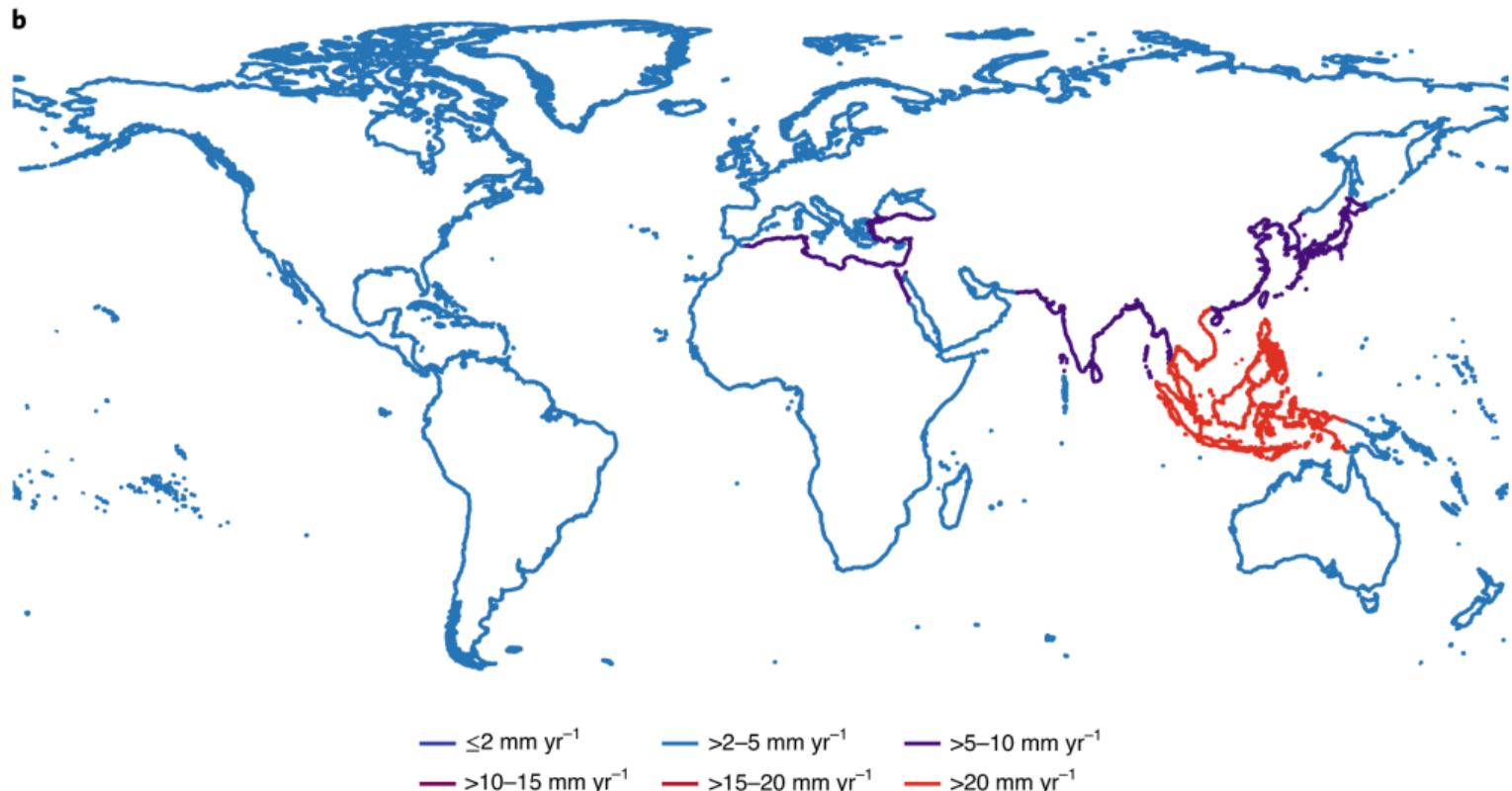


Sea Level Rise and Urban Adaptation in Jakarta

Allan Hsiao
Princeton University

November 10, 2022

Sea levels are rising globally (Nicholls et al. 2021)





Motivation

- **Sea level rise threatens 1B people by 2050** (IPCC 2019)
 - 680M people in low-elevation coastal zones today
- Jakarta will be 35% below sea level by 2050 (Andreas et al. 2018)
 - World's second largest city at 31M (first by 2030)
 - In response, \$40B in proposed infrastructure investments
- **How does government intervention affect long-run adaptation?**
 - How does public adaptation affect private adaptation?

This paper

- **Dynamic spatial model** of coastal development and government defense
 - Estimated with granular spatial data for Jakarta
- Long-run adaptation requires moving inland, but
 - ① Moral hazard from government intervention
 - ② Persistence from durable capital
- **Result:** limited adaptation without government commitment

Contributions

- **Adaptation frictions** under endogenous government intervention
 - Kydland & Prescott 1977, Glaeser & Gyourko 2005, Vigdor 2008, Boustan et al. 2012, Balboni 2021, Desmet et al. 2021, Baylis & Boomhower 2022, Fried 2022, Mulder 2022, Wagner 2022
- **Dynamic spatial model** of urban development
 - Hopenhayn 1992, Ericson & Pakes 1995, Hotz & Miller 1993, Arcidiacono & Miller 2011, Scott 2013, Kalouptsidi 2014, Desmet et al. 2018, Caliendo et al. 2019, Kleinman et al. 2022
- **Sea level rise damages** for Jakarta
 - Budiyono et al. 2015, Takagi et al. 2016, Wijayanti et al. 2017, Andreas et al. 2018

Outline

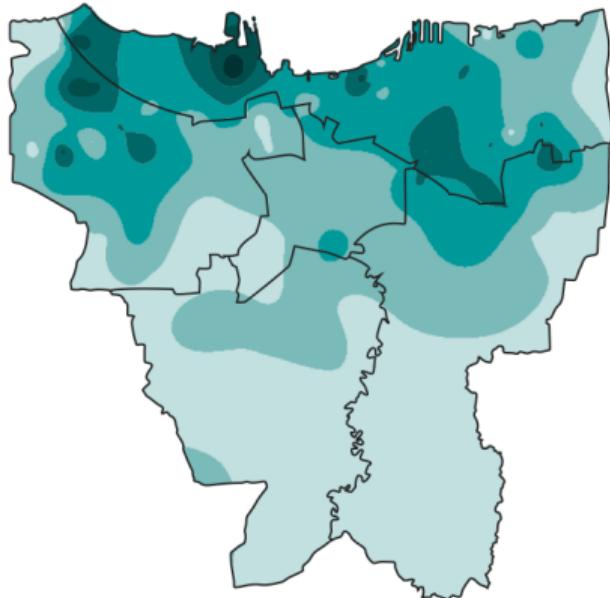
- ① Setting
- ② Theory
- ③ Empirics
- ④ Simulations

Setting

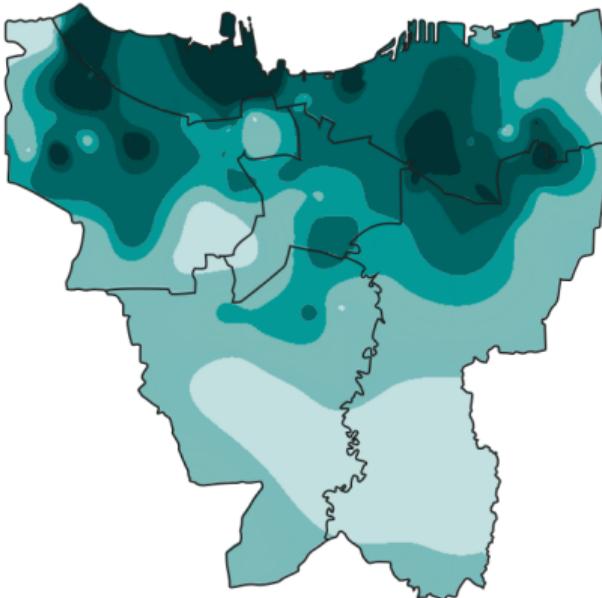




Future land subsidence (SLR 1m by 2100)



2025

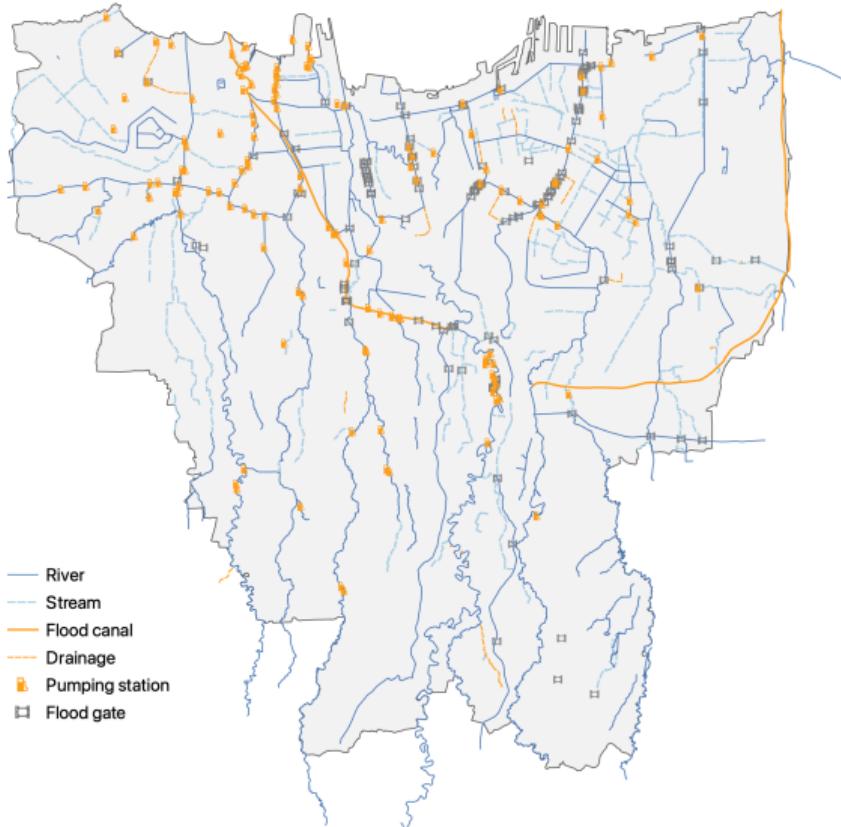


2050



Flood infrastructure

- 1918: West flood canal
- 1960: dams/reservoirs
- 1978: drainage canals
- 2002: East flood canal
- 2011: **sea wall plans**
- 2019: **Nusantara plans**



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

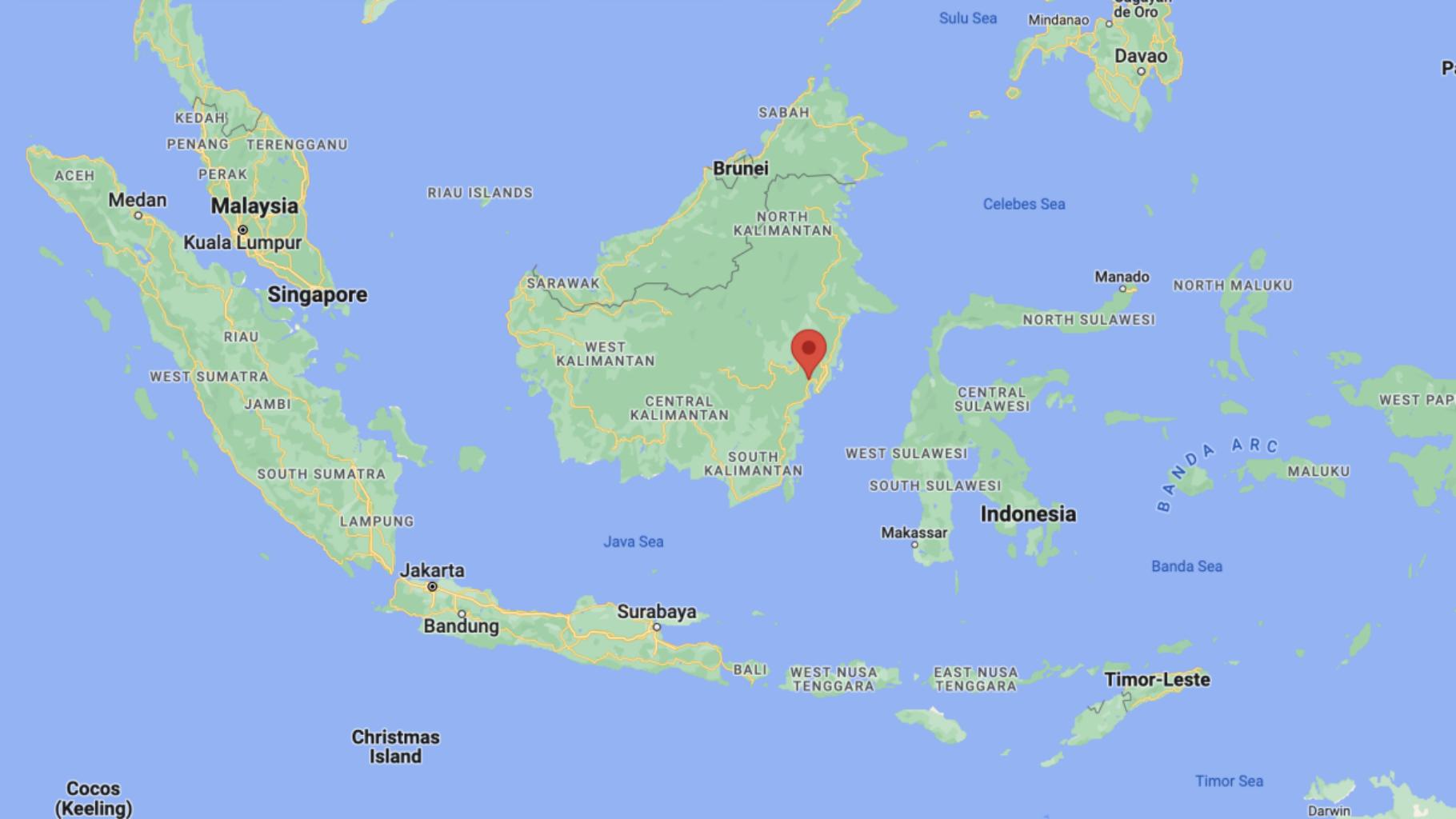
Konstruksi: 2014-2017
Flood safety: 2030

Tahap B

Konstruksi: 2018-2022
Flood Safety: 2030

Tahap C

Konstruksi: 2022



Cocos
(Keeling)

Theory

Coastal development and defense

- ① **Developers** develop d at cost $c(d)$ for $c'' > 0$ (atomistically)
 - ② **Government** defends g at cost $f(g)$ for $f'' > 0$ (wall or otherwise)
 - ③ **Residents** receive $r(d, g)$ for $r_{dg} > 0$ (demand $r'(d; g)$, shifter g)
-
- **Welfare** $W(d, g) = r(d, g) - c(d) - f(g)$
 - **Profits** $\pi(d) = r'(d) - c'(d) + r'(g)g'(d)$ (competed away)

Coastal development and defense

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Moral hazard

- The **social planner** maximizes $W(d, g) = r(d, g) - c(d) - f(g)$

$$[d^*] \quad r'(d) = c'(d)$$

$$[g^*] \quad r'(g) = f'(g)$$

- Developers consider $\pi(d)$, and government $W(g; d)$

$$[d^n] \quad r'(d) + r'(g) g'(d) = c'(d)$$

$$[g^n] \quad r'(g) = f'(g)$$

- Moral hazard when $g'(d) > 0$ implies $d^n > d^*$, $g^n > g^*$

Moral hazard

- The **social planner** maximizes $W(d, g) = r(d, g) - c(d) - f(g)$

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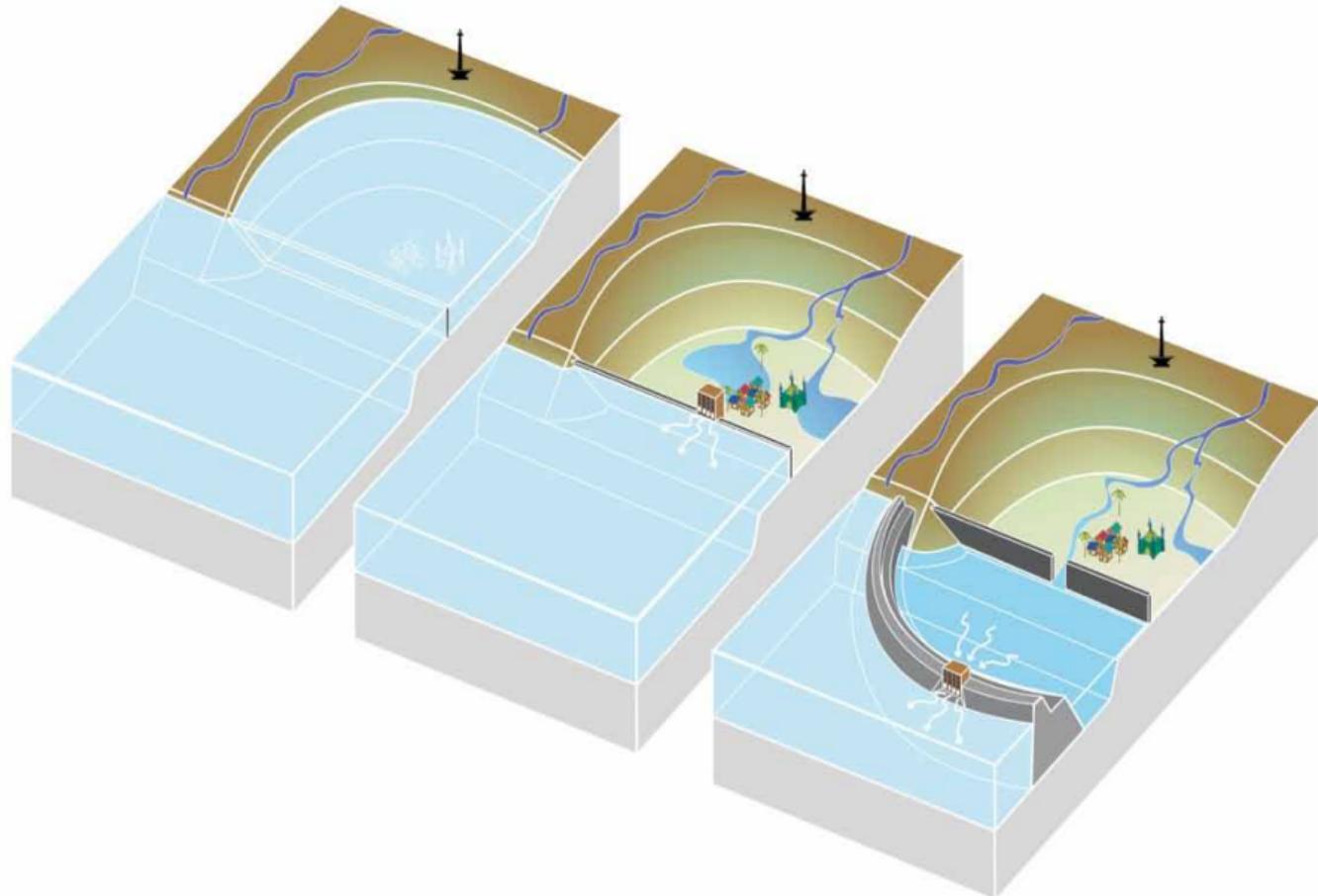
$$[d^n] \quad r'(d) + r'(g) g'(d) = c'(d)$$

$$[g^n] \quad r'(g) = f'(g)$$

- Moral hazard** when $g'(d) > 0$ implies $d^n > d^*$, $g^n > g^*$

Commitment + challenges

- Solution 1: **commit** to g^*
 - $g'(d) = 0$ implies $r'(g) g'(d) = 0$
 - But optimal for government to protect over-development ex post
- Solution 2: **commit** to d^*
 - By taxing or restricting development
 - But developers will lobby against enforcement ex post
- In Jakarta, political pressures demand action
 - In the US, lobbying for zoning expansions and against NFIP re-rating



Dynamics: $r(D_t, G_t)$ for $D_t = D_{t-1} + d_t$

① Moral hazard arises across periods

- Developers exploit both current and future governments (commitment issues)
- Current governments may exploit future governments (political myopia)

② Development has persistent effects

- Current governments can help future governments
- Over-development today raises development tomorrow

Details

Empirics

Empirical framework

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

- $r(d, s(g))$: **spatial model** of residential demand
- $s(g)$: **hydrologic model** of flood risk
- $c(d)$: **dynamic model** of developer supply
- $f(g)$: **engineering estimates**

High-resolution spatial data (2015/2020)

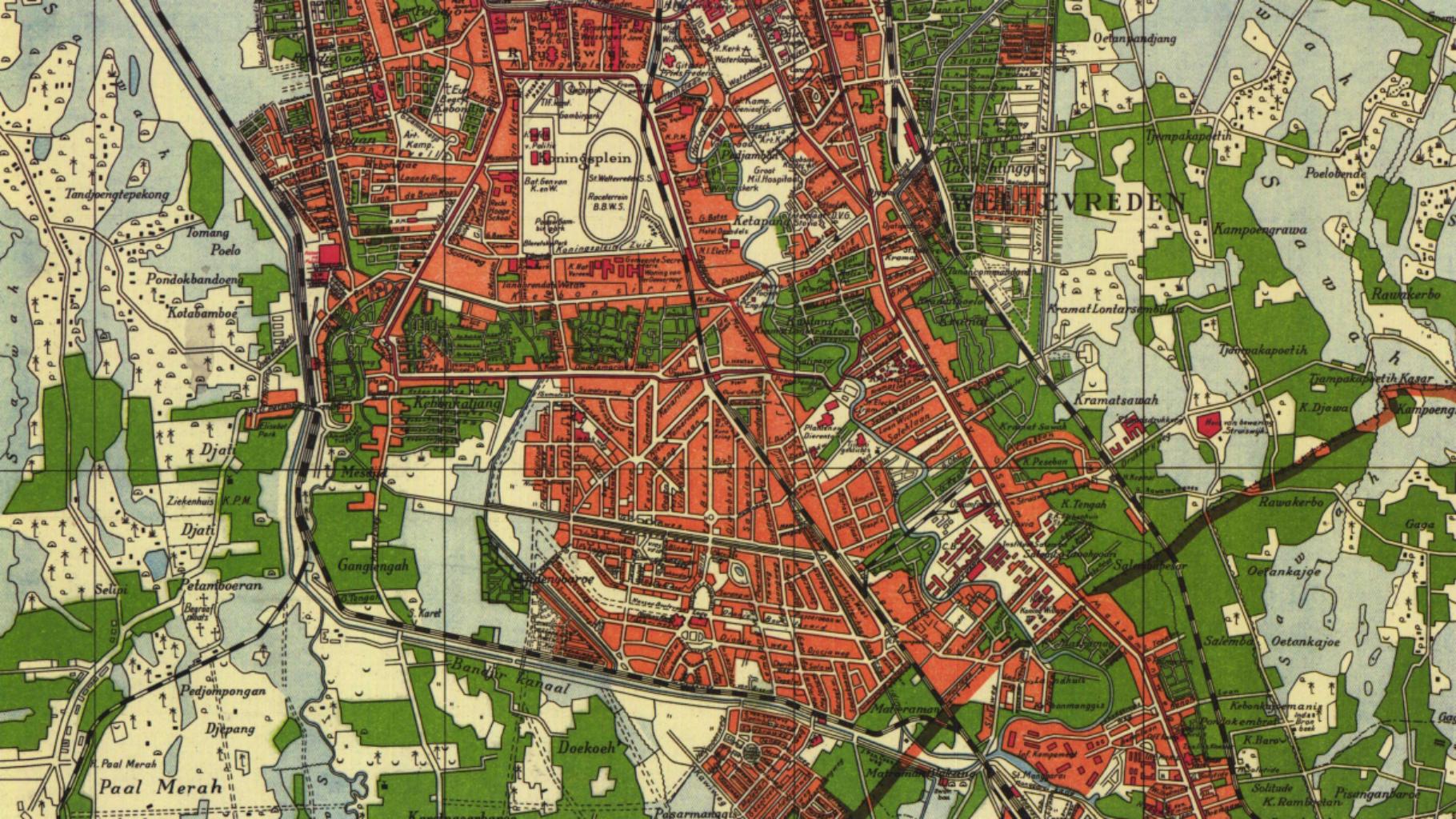
Variable	Source	Map
Building construction	GHSL	Map
Populations	GHSL	Map
Property values	99.co, brickz.id	Map
Land values	Jakarta Smart City	Map
Flood risk	(Hydrological model)	Map

Flooding ↓ ⇒ value ↑ ⇒ construction ↑

	Land value (\$/m ²)			
Flood risk (m/yr)	-2.31*** (3.00)	-1.29*** (3.12)	-0.59** (2.15)	-0.93*** (2.78)
District FE		x		
Sub-district FE			x	
Neighborhood FE				x
Observations	2,722	2,722	2,722	2,722

Flooding ↓ ⇒ value ↑ ⇒ construction ↑

Building construction (m ³)				
Land value (\$/m ²)	0.21*** (0.03)	0.27*** (0.03)	0.37*** (0.05)	0.30*** (0.05)
District FE		x		
Sub-district FE			x	
Neighborhood FE				x
Observations	2,722	2,722	2,722	2,722



Demand from residents

$$U_{ijk} = \underbrace{-\alpha r_k + \rho s_k + \xi_k}_{\delta_k} - \tau m_{jk} + \epsilon_{ijk}$$

- **Spatial model** of residential choice (individual i , origin j , destination k)
 - Static renters consider rents, flood safety, amenities, distances, logit shocks
 - Moving inland abandons high-amenity places and incurs migration costs
 - Will add firms to endogenize (some) amenities
- **Estimation** with 2020 population shares and instruments (BLP 1995)
 - Price endogeneity from correlation of rents and unobserved amenities
 - IV with soil quality and ruggedness as supply shifters

Details

Demand estimates

First stage	Rents	IV	Population
Ruggedness	0.010*** (0.001)	Rents	-0.113*** (0.019)
Flood safety	7.888** (4.018)	Flood safety	1.031** (0.507)
Coastal distance	-0.630*** (0.082)	Coastal distance	-0.072*** (0.016)
District FE	x	District FE	x
Observations	2,181	Observations	2,181
F-stat	76.38		

Supply from developers

$$V_k(w_t) = r_k(w_t)D_{kt} + \mathbb{E}_{kt}[\max\{v_k^1(w_t) + \epsilon_{kt}^1, v_k^0(w_t) + \epsilon_{kt}^0\}]$$

$$v_k^1(w_t) = -c(x_{kt}, \zeta_{kt}) + \beta \mathbb{E}_{kt}[V_k(w_{t+1}^1)]$$

$$v_k^0(w_t) = \beta \mathbb{E}_{kt}[V_k(w_{t+1}^0)]$$

- **Dynamic model** of developer choice (tract k , time t , $\mathbb{E}_{kt} = \mathbb{E}_k[\cdot | w_t]$)
 - Developer-landlords consider state $w_t = (\{D_{kt}\}, \{G_{kt}\})$, rents, costs, logit shocks
 - Moving inland abandons high-rent places and incurs construction costs
- **Estimation:** data as continuation values (Kalouptsidi 2014) [vs. Scott 2013]
 - Price endogeneity from correlation of rents and unobserved costs
 - IV with resident demographics as demand shifters

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Data as continuation values

$$\ln p_{kt}^1 - \ln p_{kt}^0 = v_k^1(w_t) - v_k^0(w_t)$$

$$v_k^1(w_t) = -c_{kt} + \beta \mathbb{E}_{kt}[V_k(w_{t+1}^1)]$$

$$v_k^0(w_t) = \beta \mathbb{E}_{kt}[V_k(w_{t+1}^0)]$$

- Estimation by linear IV: property vs. land values as (V^1, V^0)
 - Assuming competitive real estate markets with rational expectations
 - And atomistic developers

Data as continuation values

$$\ln p_{kt}^1 - \ln p_{kt}^0 = -c(x_{kt}, \zeta_{kt}; \theta) + P_{kt}^1 - P_{kt}^0 + \eta_{kt}$$

$$v_k^1(w_t) = -c_{kt} + \beta \mathbb{E}_{kt}[V_k(w_{t+1}^1)]$$

$$v_k^0(w_t) = \beta \mathbb{E}_{kt}[V_k(w_{t+1}^0)]$$

- Estimation by linear IV: property vs. land values as (V^1, V^0)
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Euler CCPs

$$\ln p_{kt}^1 - \ln p_{kt}^0 = v_k^1(w_t) - v_k^0(w_t)$$

$$v_k^1(w_t) = -c_{kt} + \beta \mathbb{E}_{kt}[r_k(w_{t+1}) + \beta V_k(w_{t+2}^{10}) - \ln p_{kt+1}^0]$$

$$v_k^0(w_t) = \beta \mathbb{E}_{kt}[-c_{kt+1} + \beta V_k(w_{t+2}^{01}) - \ln p_{kt+1}^1]$$

- Estimation by linear IV: today vs. tomorrow perturbation ($\Delta X_{kt} = X_{kt} - \beta X_{kt+1}$)
 - Assuming atomistic, long-lived developers with rational expectations
 - Also need $t+1$ data, rent data, and no depreciation

Euler CCPs

$$\Delta \ln p_{kt}^1 - \Delta \ln p_{kt}^0 = -\Delta c(x_{kt}, \zeta_{kt}; \theta) + \beta r_k(w_{t+1}) + \tilde{\eta}_{kt}$$

$$v_k^1(w_t) = -c_{kt} + \beta \mathbb{E}_{kt}[r_k(w_{t+1}) + \beta V_k(w_{t+2}^{10}) - \ln p_{kt+1}^0]$$
$$v_k^0(w_t) = \beta \mathbb{E}_{kt}[-c_{kt+1} + \beta V_k(w_{t+2}^{01}) - \ln p_{kt+1}^1]$$

- Estimation by linear IV: today vs. tomorrow perturbation ($\Delta X_{kt} = X_{kt} - \beta X_{kt+1}$)
 - Assuming atomistic, long-lived developers with rational expectations
 - Also need $t+1$ data, rent data, and no depreciation

Comparing approaches

Estimation	Speed	Expectations
Full-solution (NFP)	Slow	Specified
Two-step (BLP)	Fast	Specified
Euler CCPs	Fast	Rational agents
Baseline	Fast	Rational market

Rents

$$D_{kt}^{\text{res}} = D_{kt}^{\text{dev}}$$

[Residents] $D_{kt}^{\text{res}} = \sum_j n_{jt} \left[\frac{\exp\{U_{jk}(r_{kt})\}}{\sum_{\hat{k}} \exp\{U_{j\hat{k}}(r_{\hat{k}t})\}} \right] \phi$

[Developers] $D_{kt+1}^{\text{dev}} = D_{kt} + \frac{\exp\{v_k^1(r_k)\}}{\exp\{v_k^1(r_k)\} + \exp\{v_k^0(r_k)\}}$

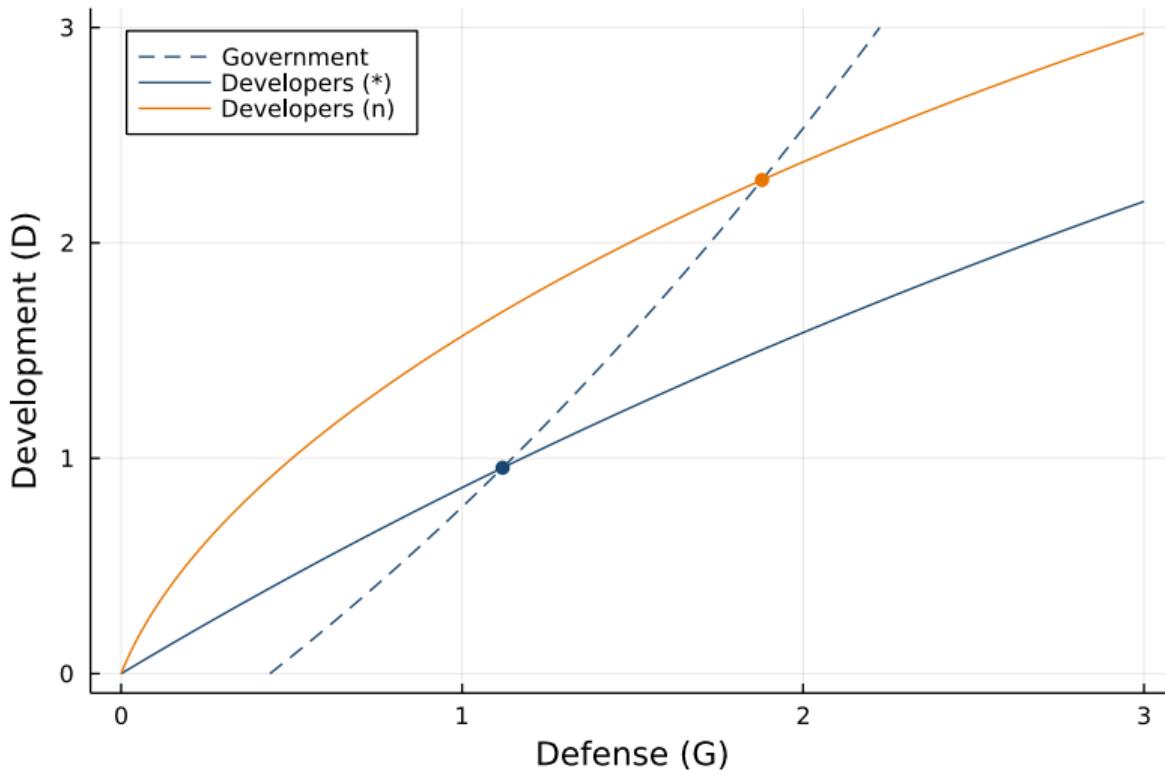
Government

- Commitment level and political turnover by assumption
 - Hydrological model of flood risk $s_k(G)$
 - Engineering estimates of costs $f(G)$
- Counterfactuals

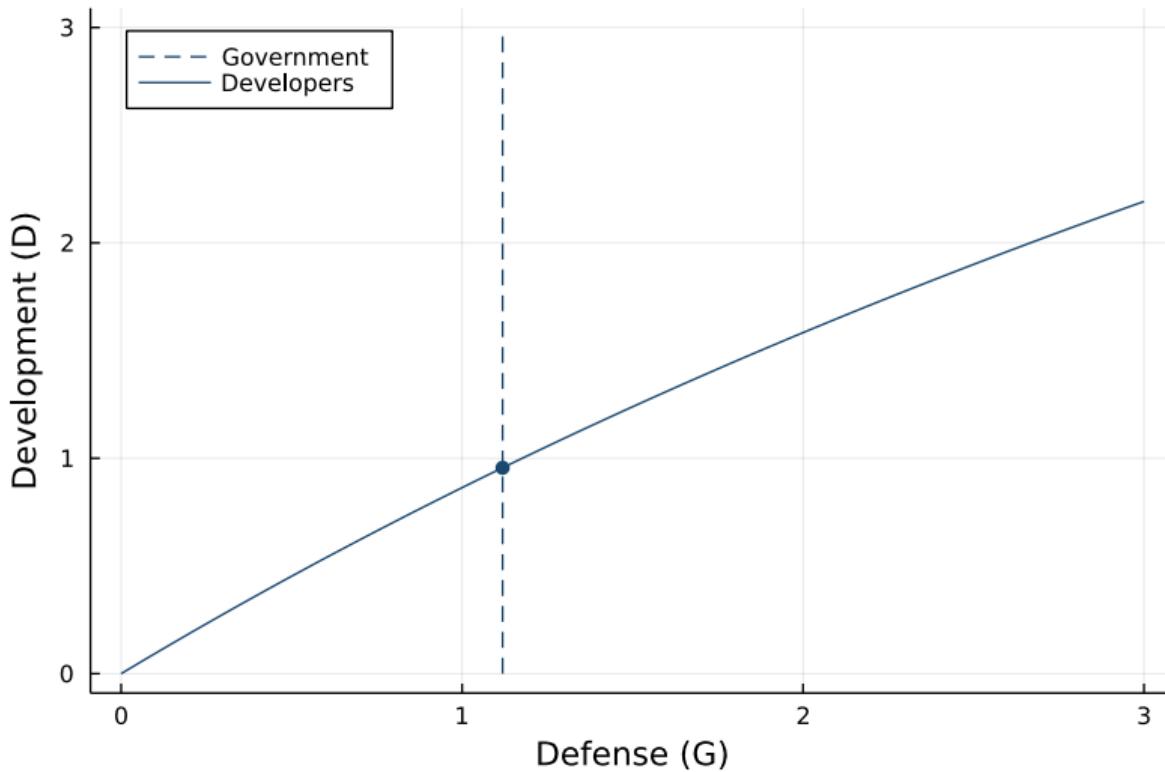
Defense $g \rightarrow$ flooding s by **hydrological** model
 \rightarrow rents r by **demand** model
 \rightarrow development d by **supply** model

Simulations

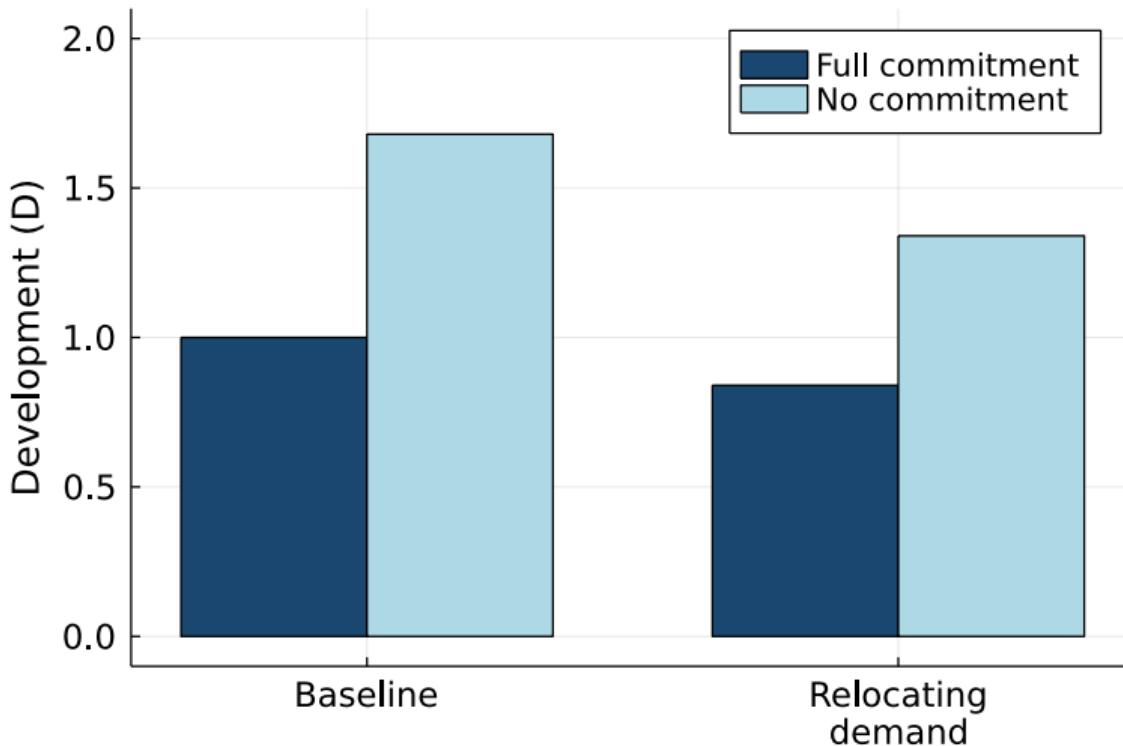
Over-development and over-defense



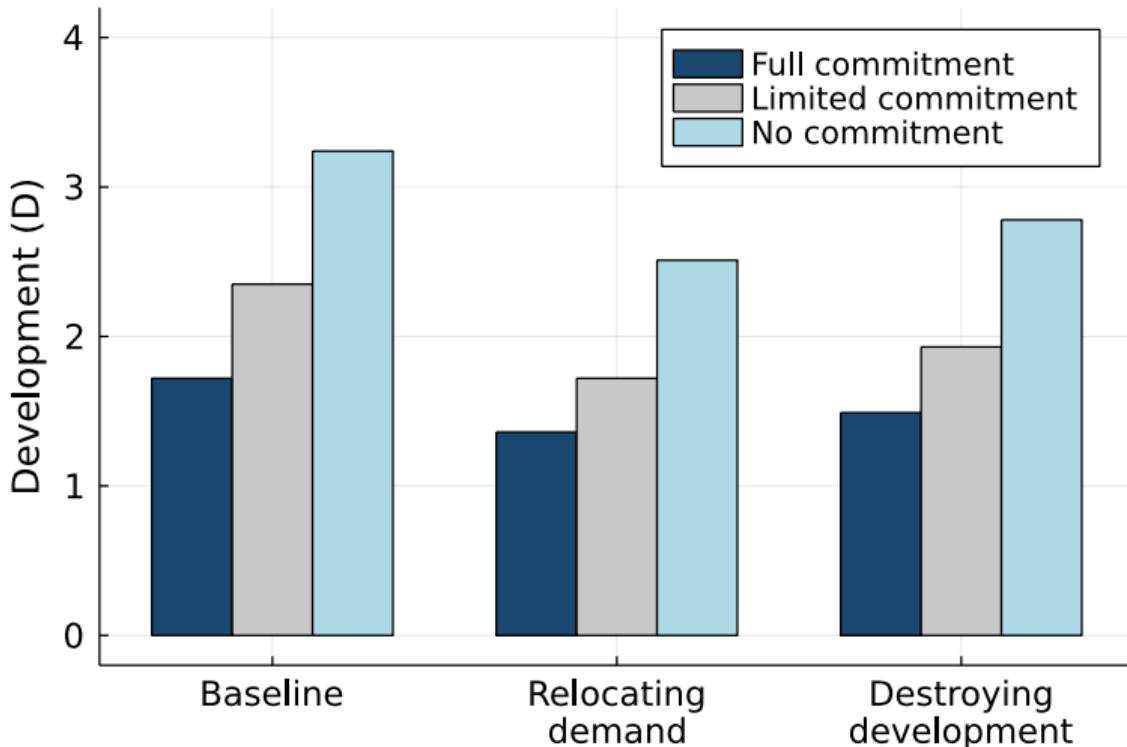
Over-development and over-defense



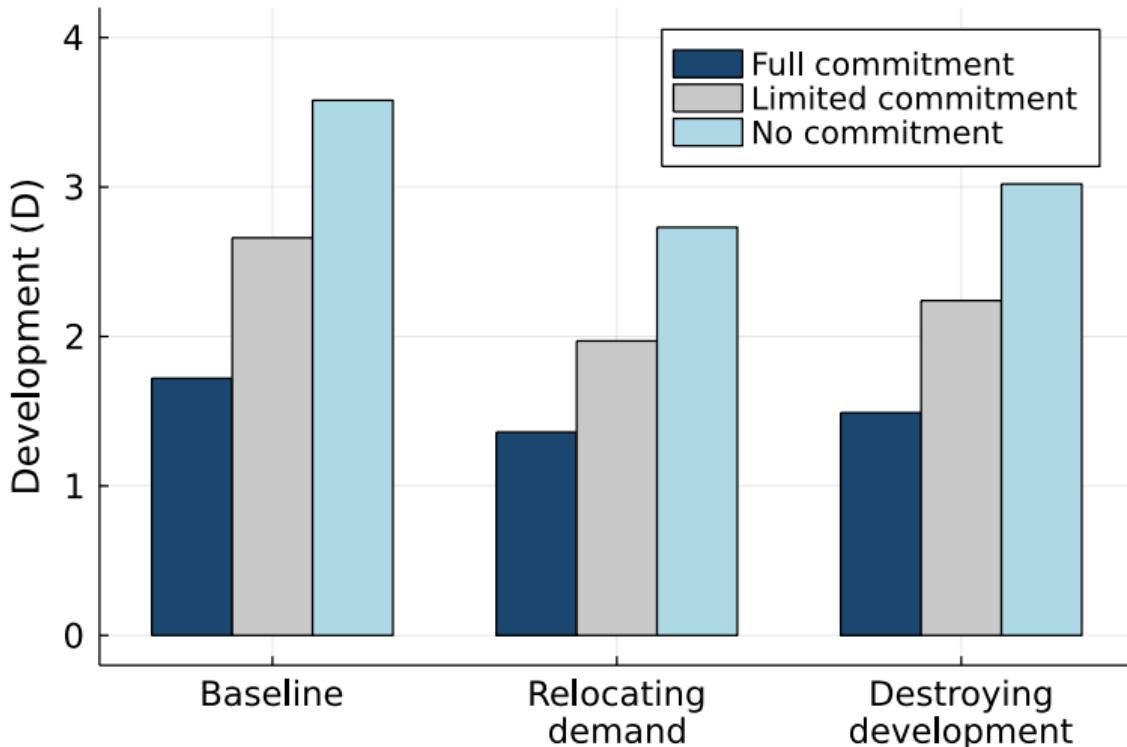
Short-run development



Long-run development (forward-looking)



Long-run development (political myopia)



Conclusion

Summary

- **Major frictions impede adaptation** to climate change
 - Government intervention induces moral hazard and lock-in
 - Commitment helps but faces political challenges
- **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)





Appendix

Commitment over time

Consider two periods. Welfare and profits for $\bar{D}_1 = 0$ are

$$W_1 = [r(G_1) + \beta r(G_2)]D_1 - c(D_1) - f(G_1),$$
$$\pi_1 = [r(G_1) + \beta r(G_2)]D_1 - c(D_1),$$

The **social planner** chooses (D_1, G_1, D_2, G_2) to maximize $W_1 + \beta W_2$.

Otherwise, **moral hazard**. Period two same as before; period one worse.

- ① D_1 does not internalize $f(G_1)$ or $f(G_2)$
- ② G_1 may not internalize $f(G_2)$

Commitment over time

Consider two periods. Welfare and profits for $\bar{D}_1 = 0$ are

$$W_2 = r(G_2)D_2 - c(D_2) - f(G_2),$$
$$\pi_2 = r(G_2)D_2 - c(D_2).$$

The **social planner** chooses (D_1, G_1, D_2, G_2) to maximize $W_1 + \beta W_2$.

Otherwise, **moral hazard**. Period two same as before; period one worse.

- ① D_1 does not internalize $f(G_1)$ or $f(G_2)$
- ② G_1 may not internalize $f(G_2)$

Commitment over time (2)

Commitment for $t = 1, 2$: choose (D_1, G_1, D_2, G_2) to max $W_1 + \beta W_2$.

$$[D_1^*] \quad \tilde{r}(G_1, G_2) = c'(D_1)$$

$$[G_1^*] \quad r'(G_1)D_1 = f'(G_1)$$

$$[\tilde{r}(G_1, G_2) = r(G_1) + \beta r(G_2)]$$

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Commitment for $t = 1, 2$: choose (D_1, G_1, D_2, G_2) to max $W_1 + \beta W_2$.

$$[D_1^*] \quad \tilde{r}(G_1, G_2) = c'(D_1)$$

$$[G_1^*] \quad r'(G_1)D_1 = f'(G_1)$$

Commitment for $t = 1$: choose (D_1, G_1) to max $W_1 + \beta W_2$, then G_2 to max W_2 .

$$[D_1] \quad \tilde{r}(G_1, G_2) = c'(D_1) + \beta r'(G_2)D_2G'_2$$

$$[G_1] \quad r'(G_1)D_1 = f'(G_1) + \beta r'(G_2)D_2G'_2$$

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Commitment for $t = 1, 2$: choose (D_1, G_1, D_2, G_2) to max $W_1 + \beta W_2$.

$$[D_1^*] \quad \tilde{r}(G_1, G_2) = c'(D_1)$$

$$[G_1^*] \quad r'(G_1)D_1 = f'(G_1)$$

No commitment: choose G_1 to max $W_1 + \beta W_2$, then G_2 to max W_2 .

$$[D_1] \quad \tilde{r}(G_1, G_2) + r'(G_1)D_1G'_1 + \beta r'(G_2)D_1G'_2 = c'(D_1)$$

$$[G_1] \quad r'(G_1)D_1 = f'(G_1) + \beta r'(G_2)D_2G'_2$$

Commitment over time (2)

Commitment for $t = 1, 2$: choose (D_1, G_1, D_2, G_2) to max $W_1 + \beta W_2$.

$$[D_1^*] \quad \tilde{r}(G_1, G_2) = c'(D_1)$$

$$[G_1^*] \quad r'(G_1)D_1 = f'(G_1)$$

No commitment + political myopia: choose G_1 to max W_1 , then G_2 to max W_2 .

$$[D_1] \quad \tilde{r}(G_1, G_2) + r'(G_1)D_1G'_1 + \beta r'(G_2)D_1G'_2 = c'(D_1)$$

$$[G_1] \quad r'(G_1)D_1 + \beta r'(G_2)D_1G'_2 = f'(G_1)$$

Commitment over time (3)

Lock in: over-development today raises development tomorrow.

$$\begin{aligned}[D_2] \quad & r(G_2) + r'(G_2)D_2 G'_2 = c'(D_2), \\ [G_2] \quad & r'(G_2)(D_1 + D_2) = f'(G_2),\end{aligned}$$

$D_1 \uparrow$ implies $G_2 \uparrow$ given more to defend.

Then $D_2 \uparrow$ implies $G_2 \uparrow\uparrow$ given strategic complementarity $\left(\frac{\partial D_2}{\partial G_2}, \frac{\partial G_2}{\partial D_2} > 0\right)$.

Back

Commitment over time (3)

Lock in: over-development today raises development tomorrow.

$$[D_2^*] \quad r(G_2) = c'(D_2),$$

$$[G_2^*] \quad r'(G_2)(D_1 + D_2) = f'(G_2),$$

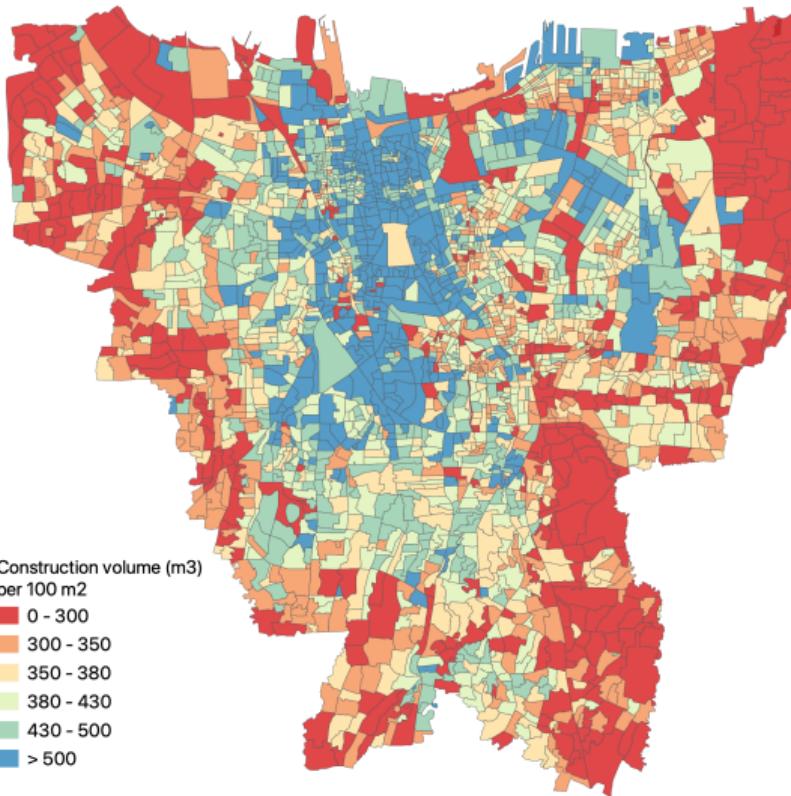
$D_1 \uparrow$ implies $G_2 \uparrow$ given more to defend.

Then $D_2 \uparrow$ implies $G_2 \uparrow\uparrow$ given strategic complementarity $\left(\frac{\partial D_2}{\partial G_2}, \frac{\partial G_2}{\partial D_2} > 0\right)$.

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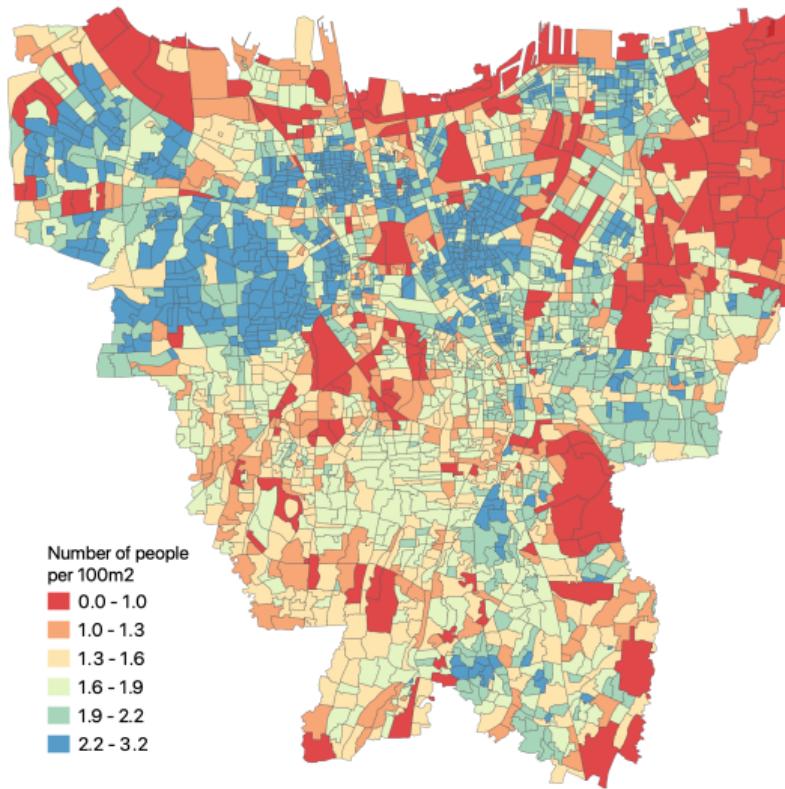
Building construction

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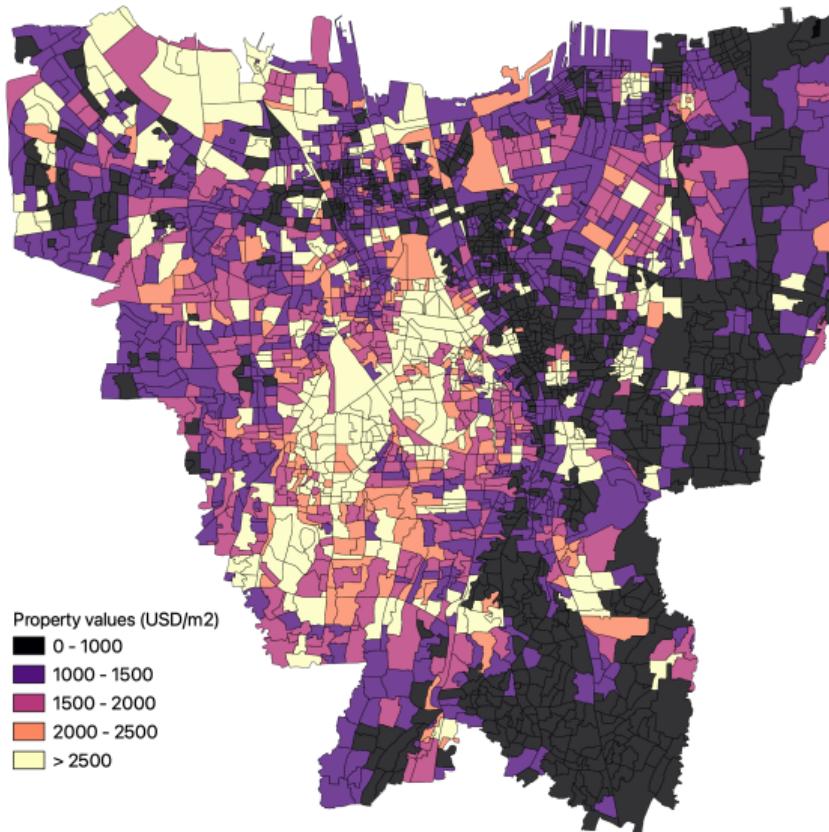
Populations

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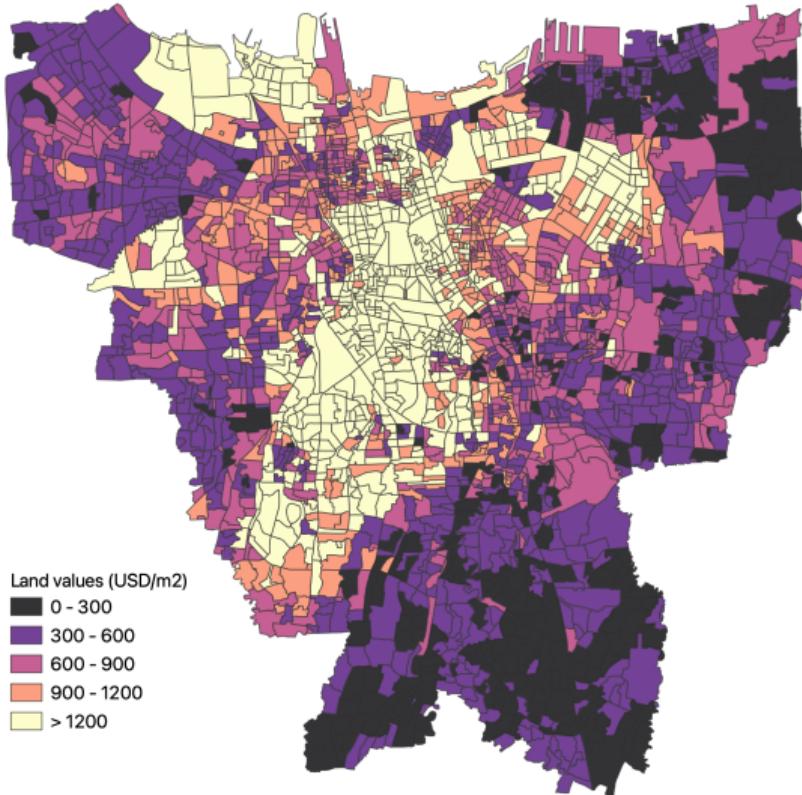
Property values

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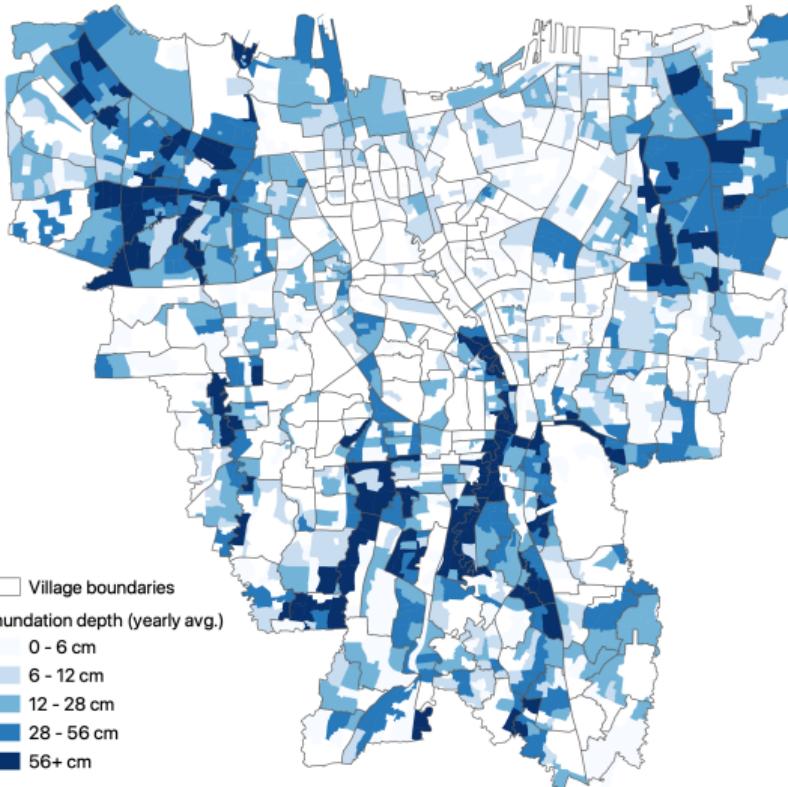
Land values

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Flood risk

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Estimating demand

- Origin populations with 2015 data, destination populations with 2020 data
- Focus on core, but allow one choice aggregating over periphery

① Given $\theta_2 = \tau$, estimate δ by contraction mapping

$$\text{population}_k = \frac{1}{\phi} D_k^{\text{res}}(\delta, \theta_2)$$

② Estimate $\theta_1 = (\alpha, \rho)$ and ξ by regression

$$\xi_k = \delta_k + \alpha r_k - \rho s_k$$

③ Estimate θ_2 by minimizing GMM objective function

$$Q(\theta) = g(\xi(\theta))' W g(\xi(\theta)) \quad \text{for} \quad \mathbb{E}[Z\xi(\theta)] = 0$$