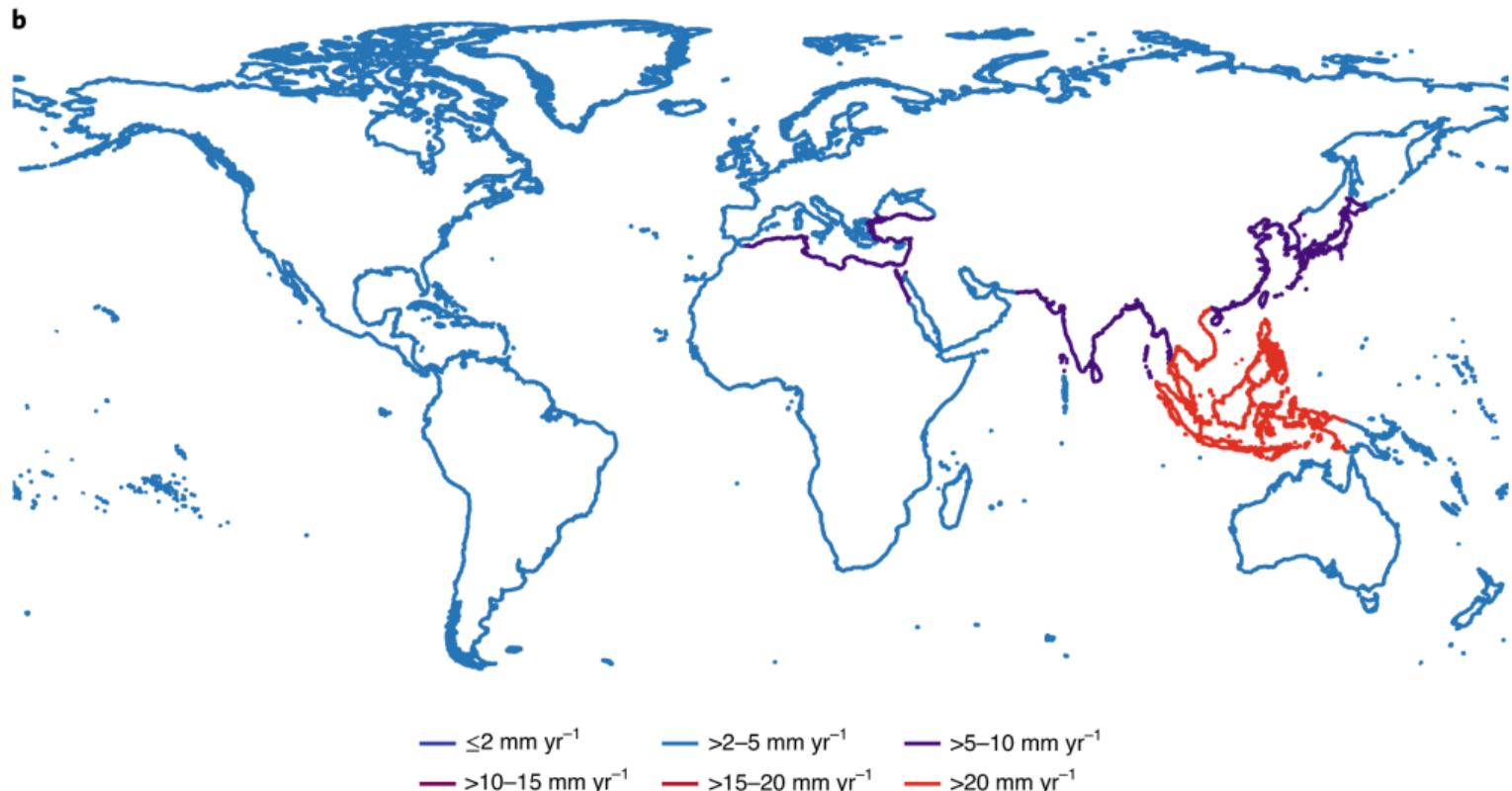


# Sea Level Rise and Urban Adaptation in Jakarta

Allan Hsiao  
Princeton University

November 15, 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

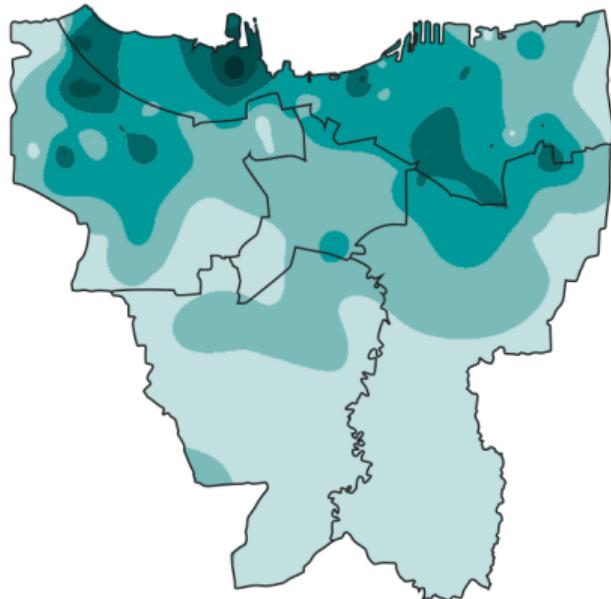
- ① Setting
- ② Theory
- ③ Empirics
- ④ Simulations

Setting

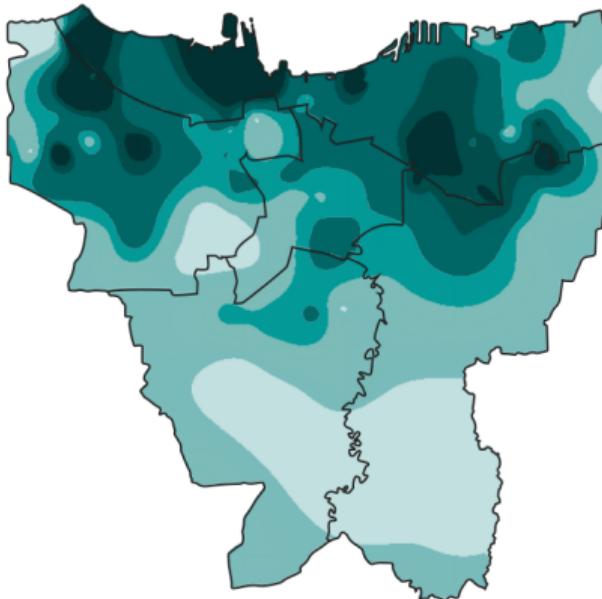




## Future land subsidence (SLR 1m by 2100)



2025

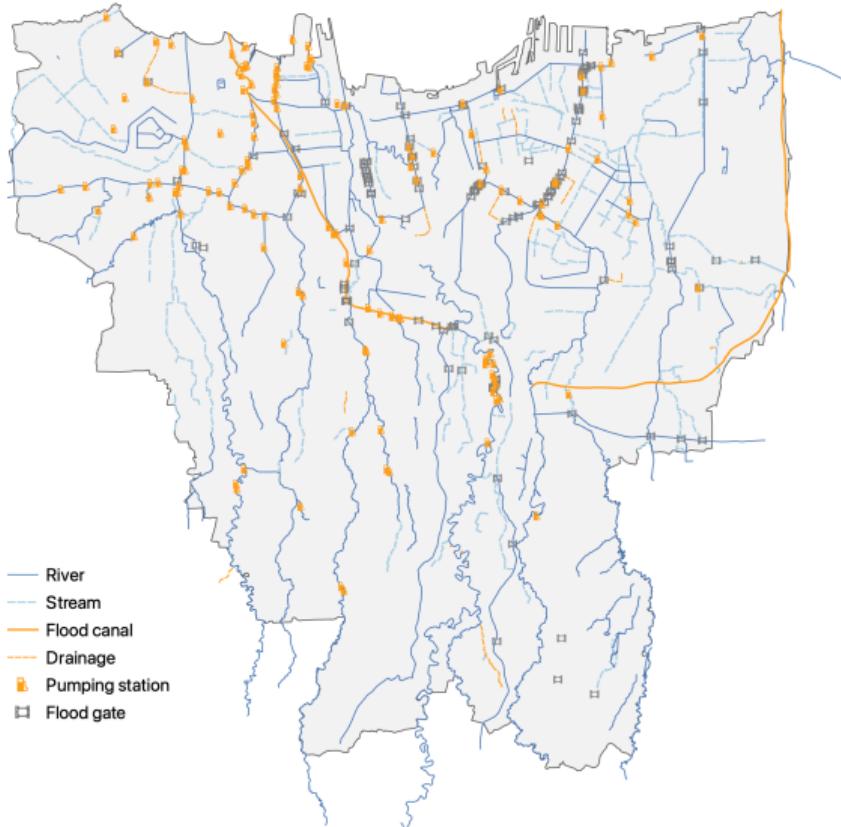


2050



# 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

Wing Park Neighbourhood Waterfront Neighbourhood

Head of Garuda

Wing Park Neighbourhood

Maritime Communities

Core Area

Creative HQ and Research

Tail Area

Creative Living Park

Maritime Communities

## Target Konstruksi

### Tahap A

Konstruksi: 2014-2017  
Flood safety: 2030

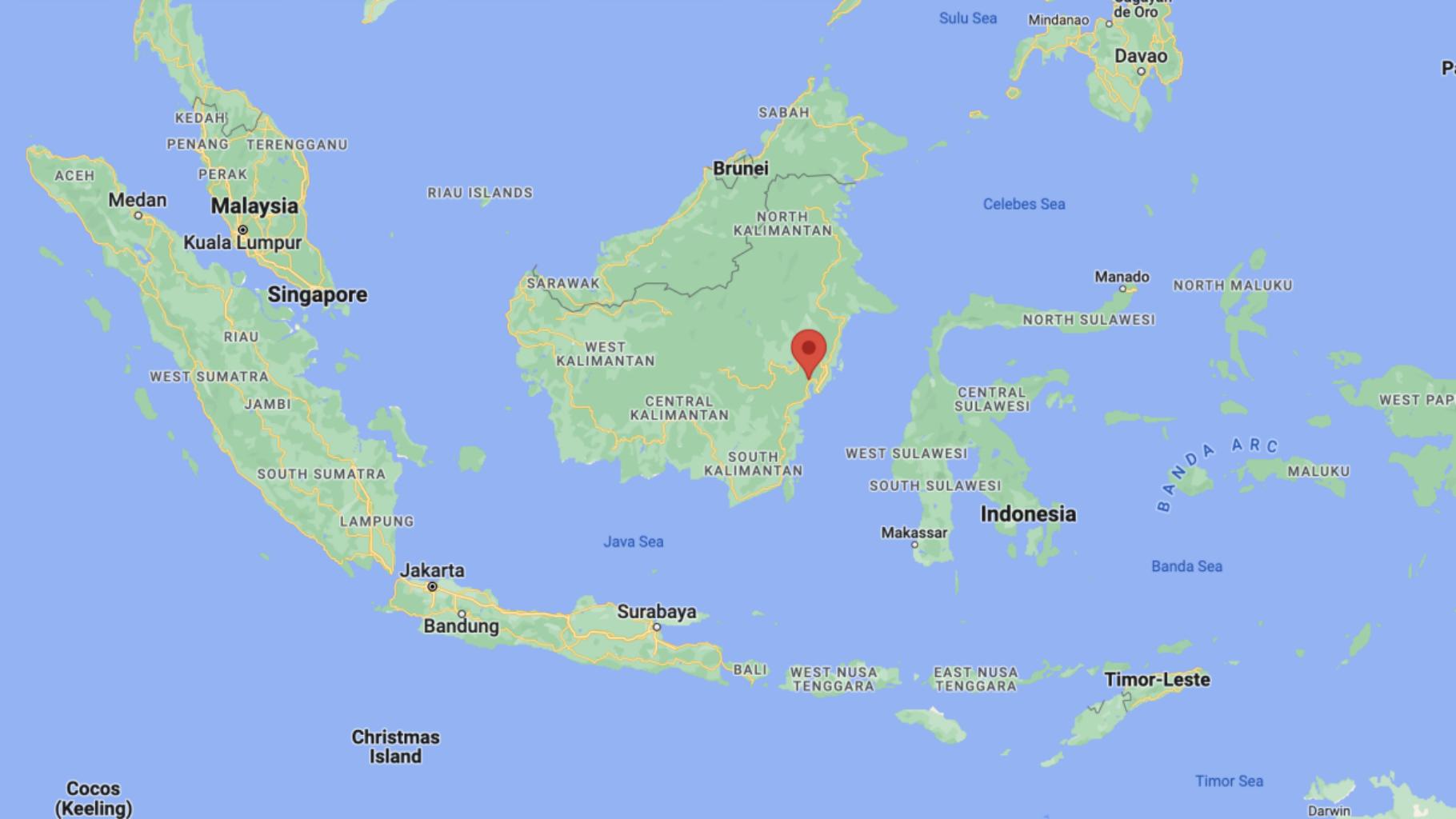
### Tahap B

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)

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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  $d^n > d^*$ ,  $g^n > g^*$

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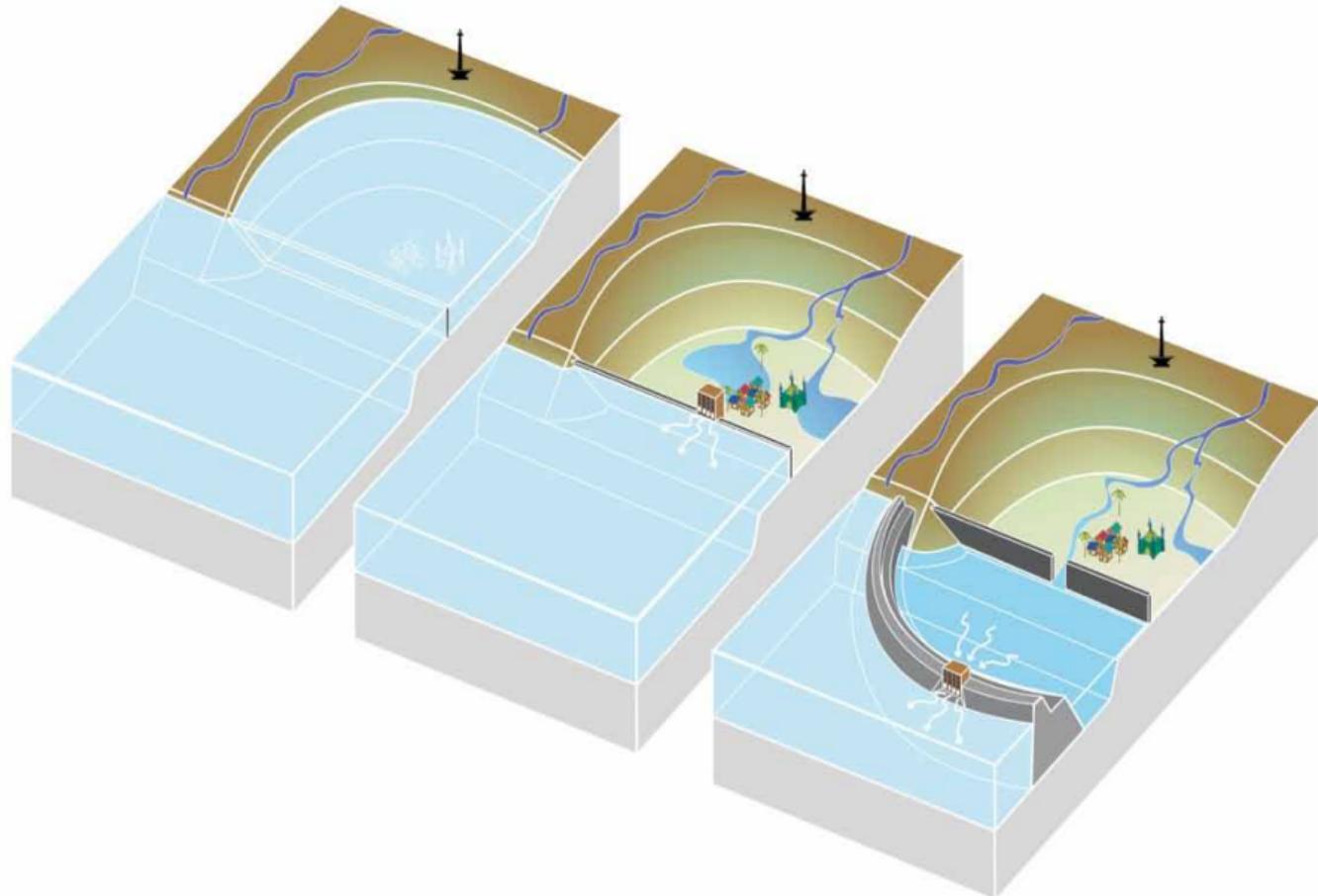
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$$[g^n] \quad r'(g) = f'(g)$$

- 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)

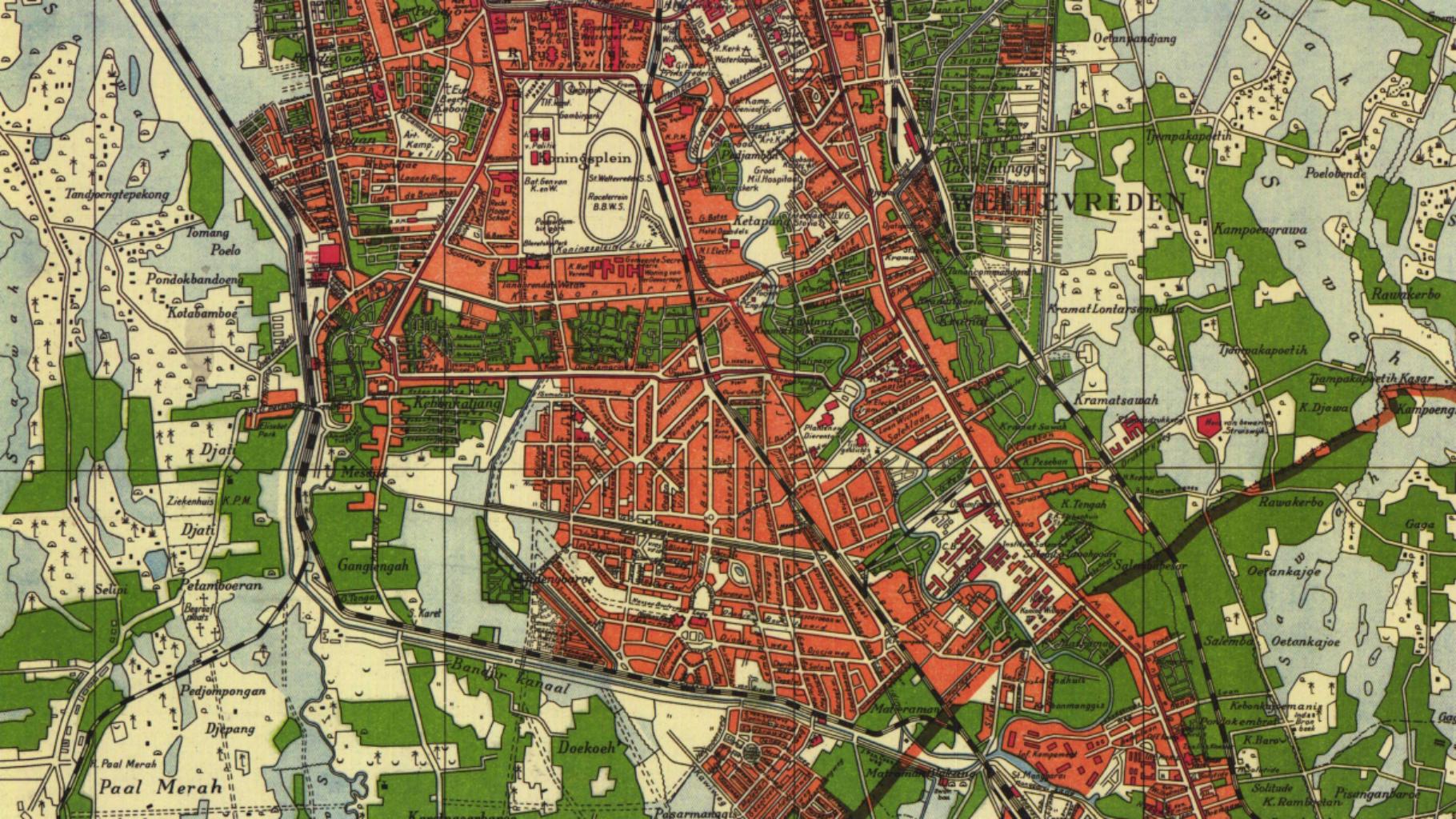
Variable	Source	Map
Building construction	GHSL	<a href="#">Map</a>
Populations	GHSL	<a href="#">Map</a>
Property values	99.co, brickz.id	<a href="#">Map</a>
Land values	Jakarta Smart City	<a href="#">Map</a>
Flood risk	(Hydrological model)	<a href="#">Map</a>

Flooding ↓ ⇒ value ↑ ⇒ construction ↑

	Land value (\$/m <sup>2</sup> )			
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 <sup>3</sup> )				
Land value (\$/m <sup>2</sup> )	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]
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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

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

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

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

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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

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

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

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

# Rents

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

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

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

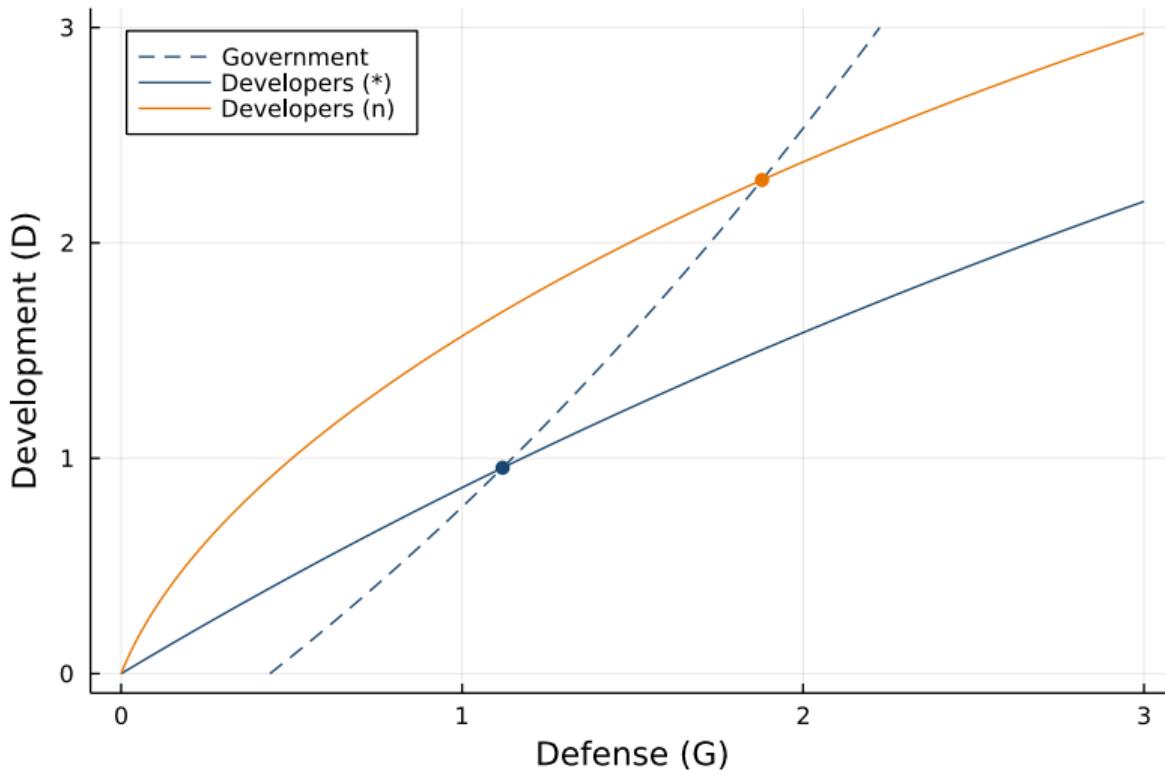
# Government

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

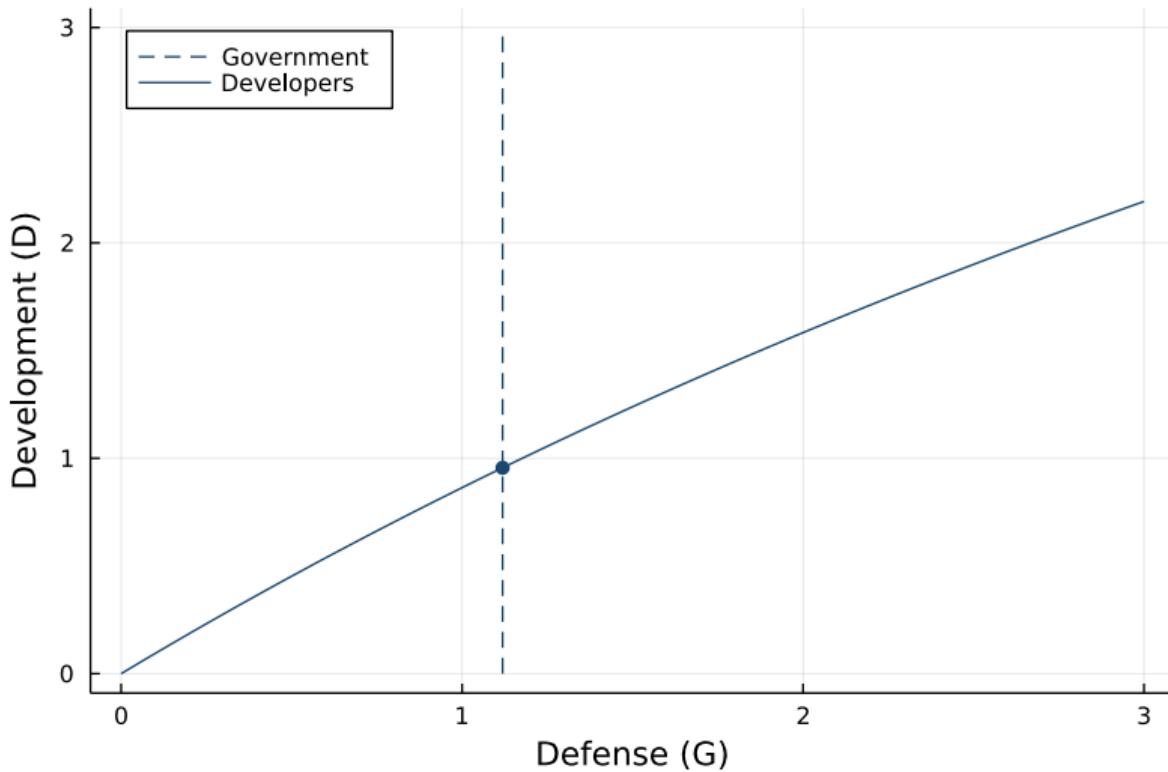
Defense  $g \rightarrow$  flooding  $s$  by **hydrological** model  
 $\rightarrow$  rents  $r$  by **demand** model  
 $\rightarrow$  development  $d$  by **supply** model

# Simulations

# Over-development and over-defense

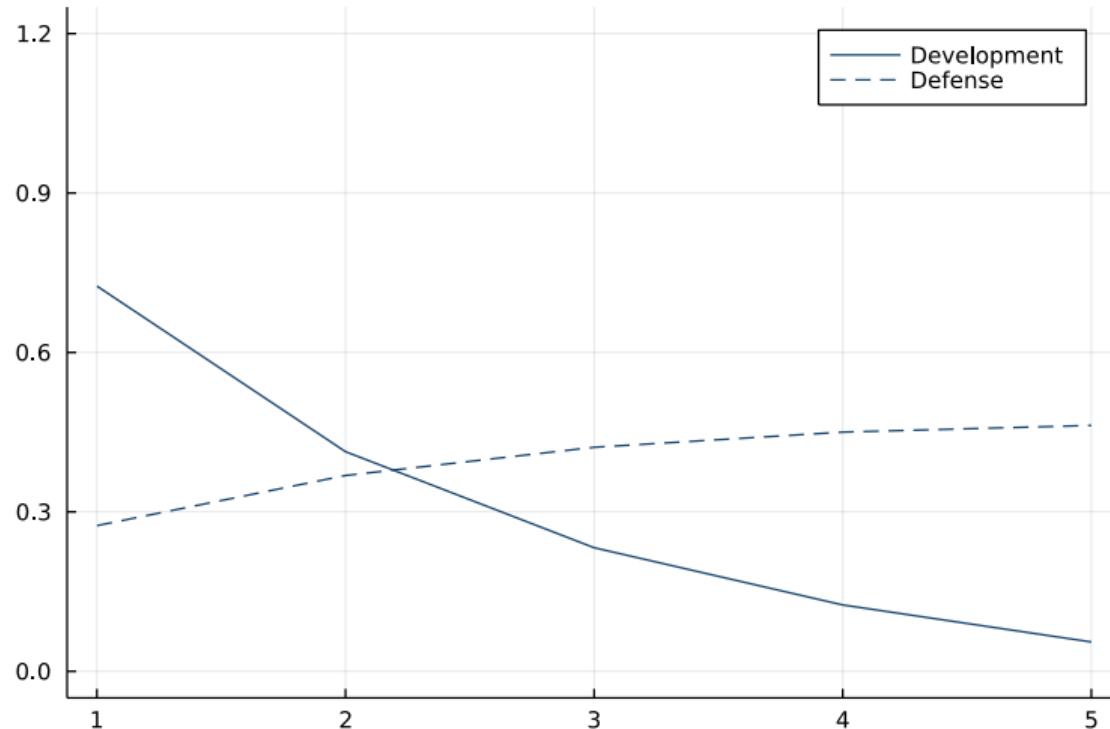


## Over-development and over-defense



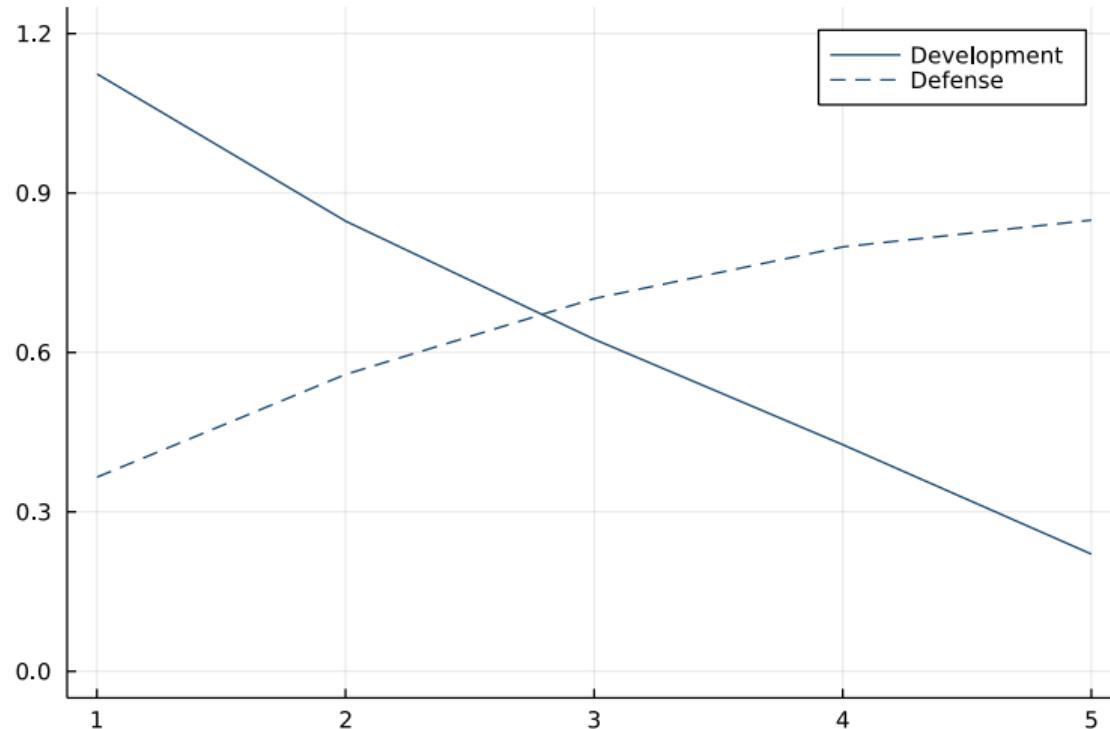
# Development and defense

## Full commitment



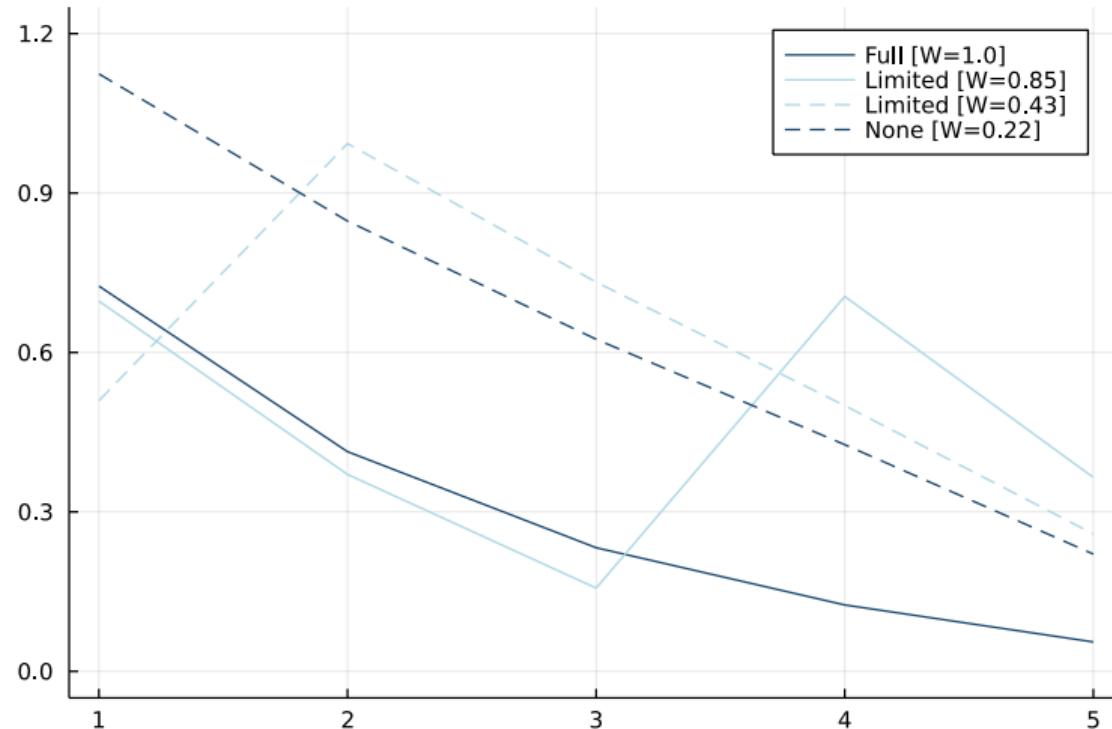
# Development and defense

No commitment



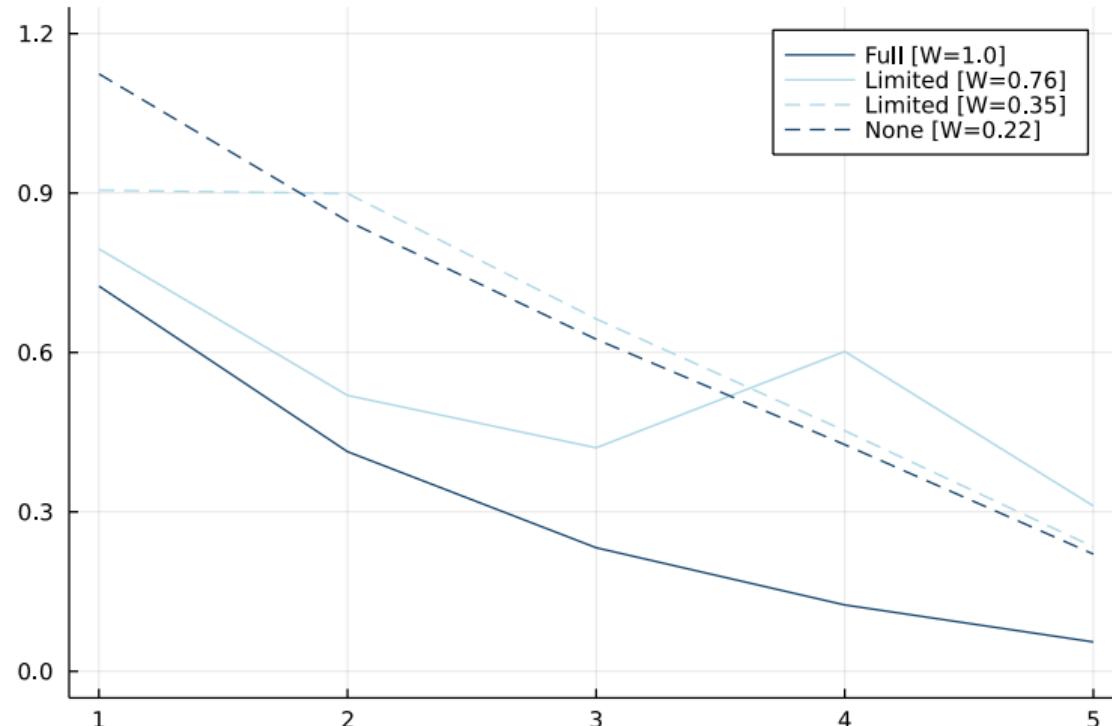
# Development

## Forward-looking



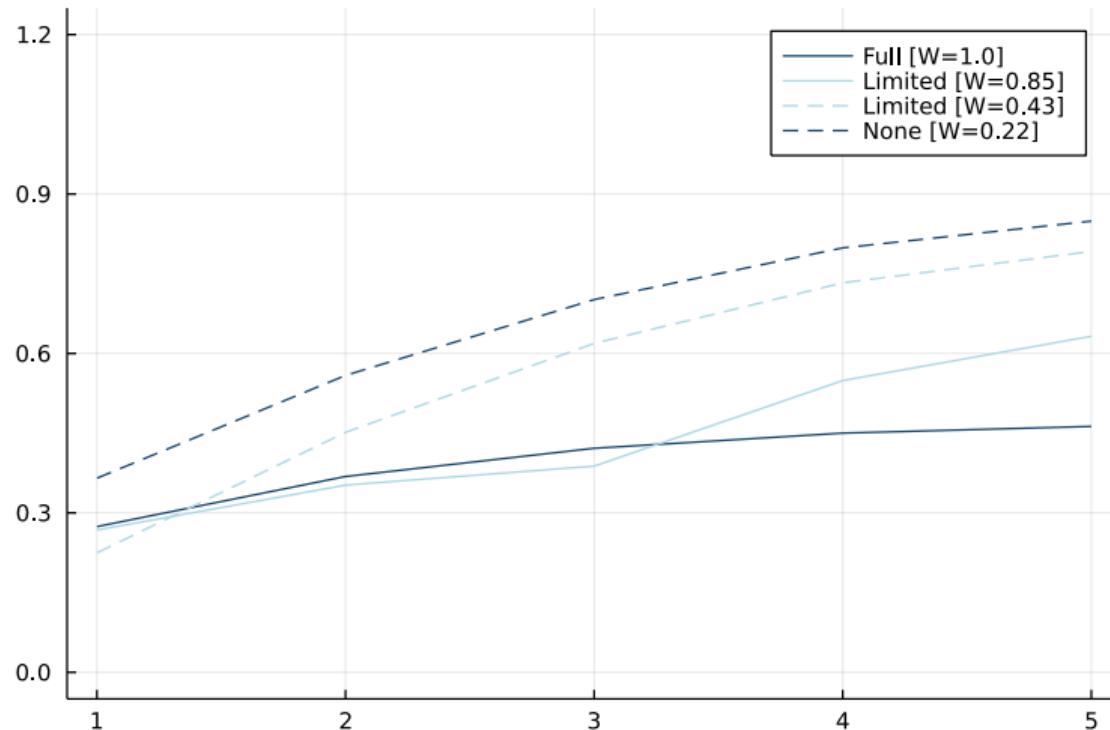
# Development

Politically myopic



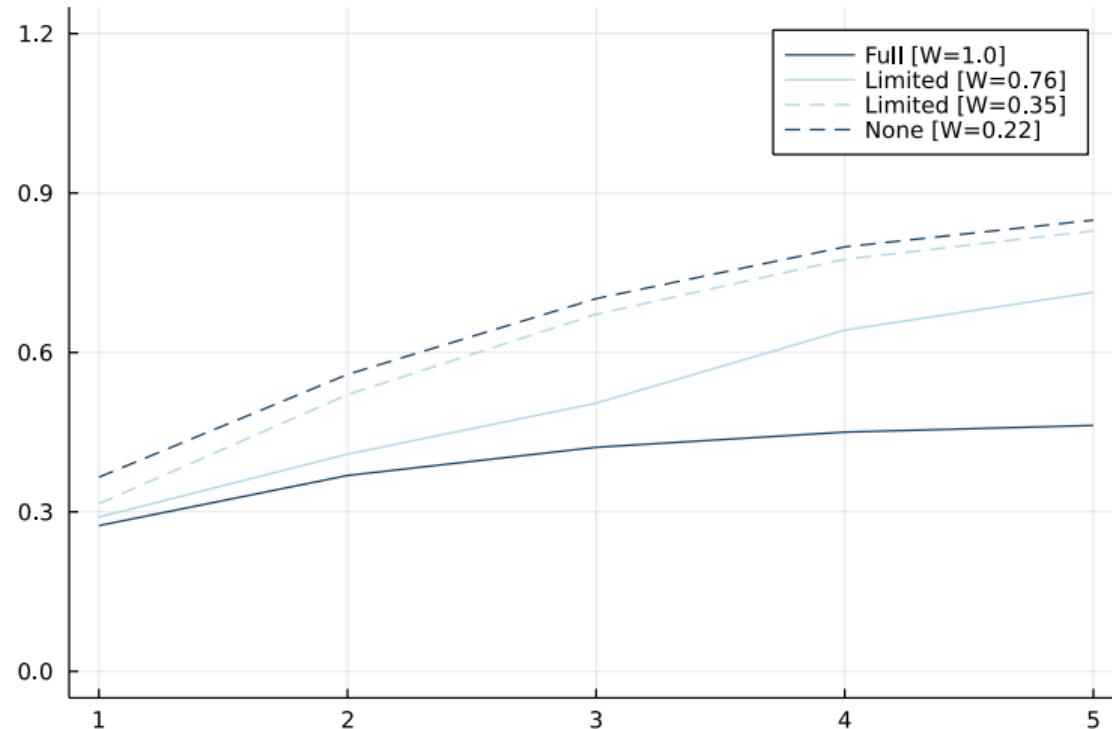
# Defense

## Forward-looking



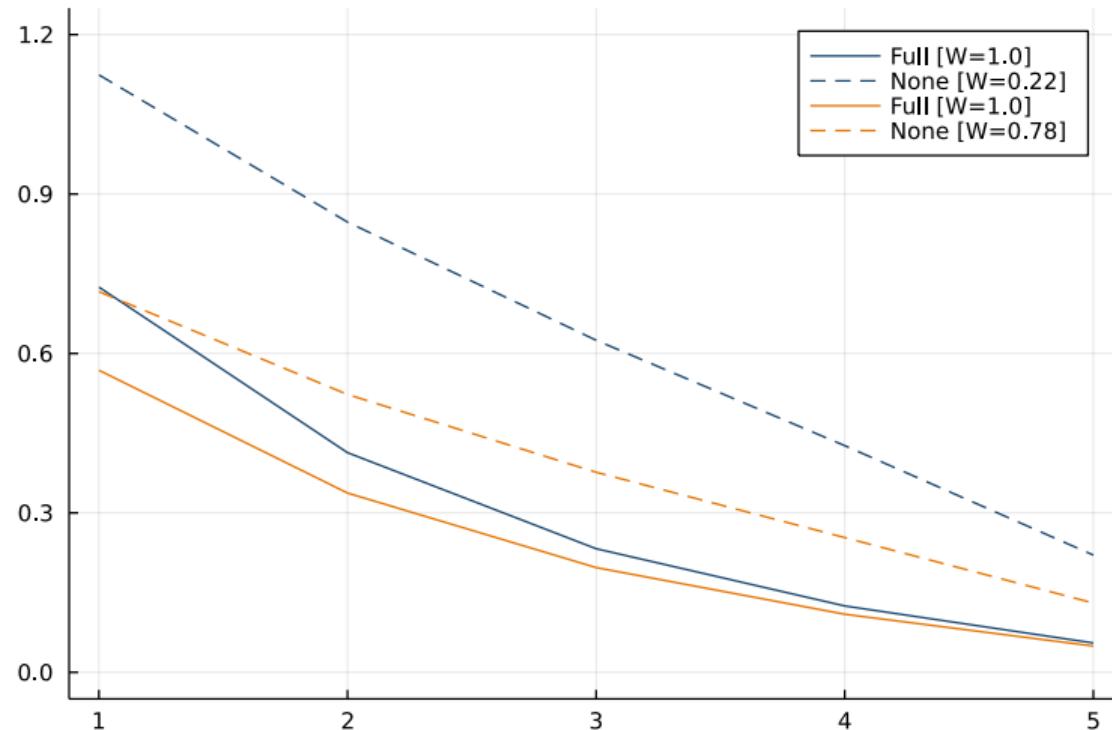
# Defense

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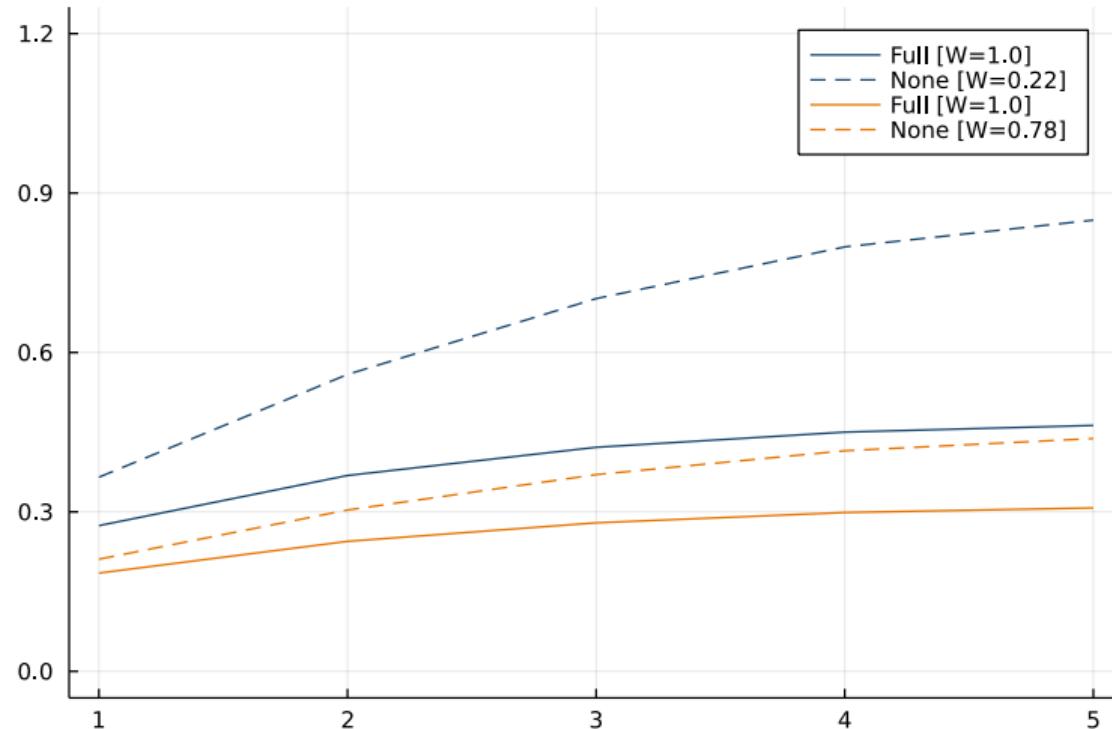
# Moving capital

## Development



# Moving capital

## Defense



# 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  $W_1 + \beta W_2$ .

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

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

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

## Commitment over time (2)

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

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

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

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

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

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

## Commitment over time (2)

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

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

**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  $\left(\frac{\partial D_2}{\partial G_2}, \frac{\partial G_2}{\partial D_2} > 0\right)$ .

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

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

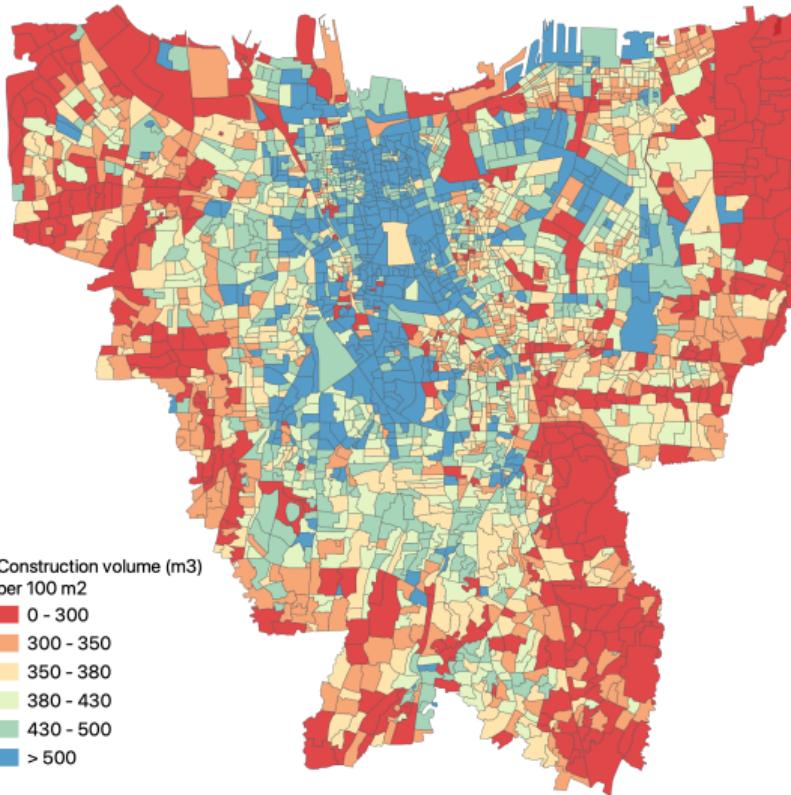
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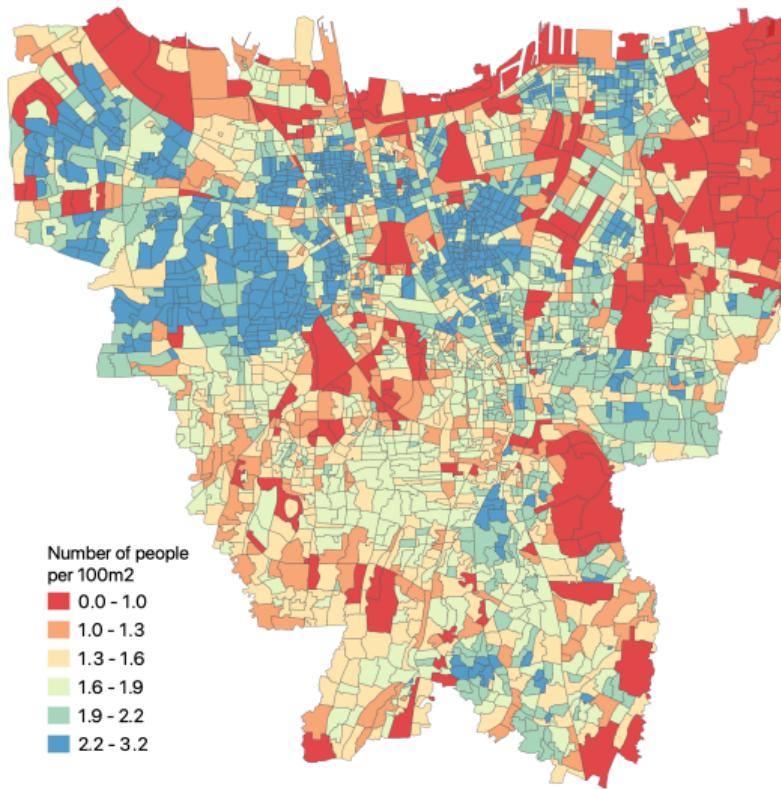
# Building construction

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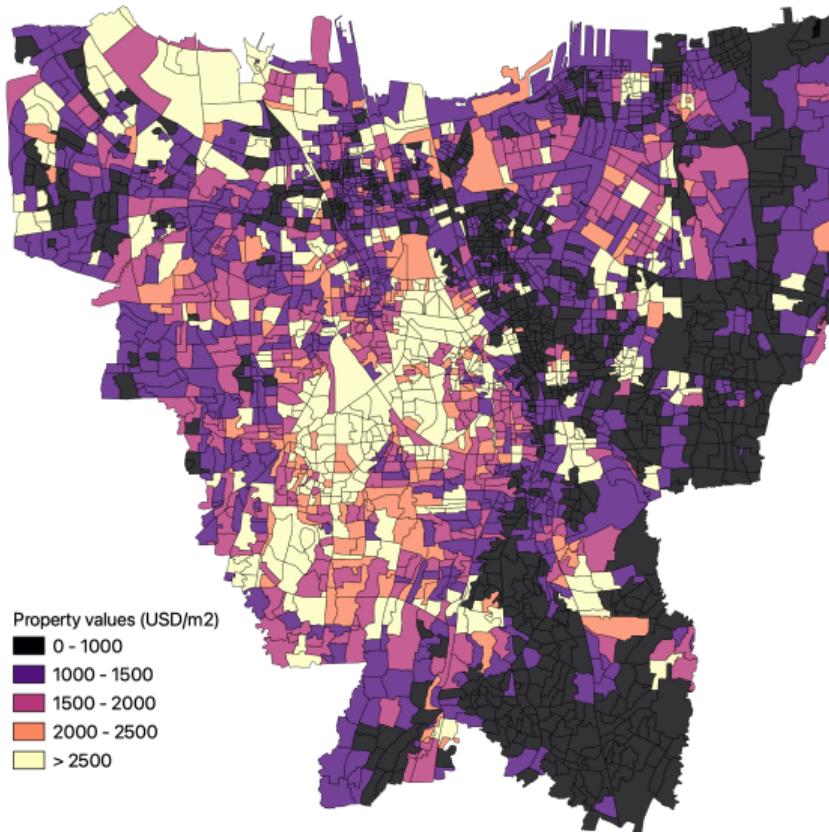
# Populations

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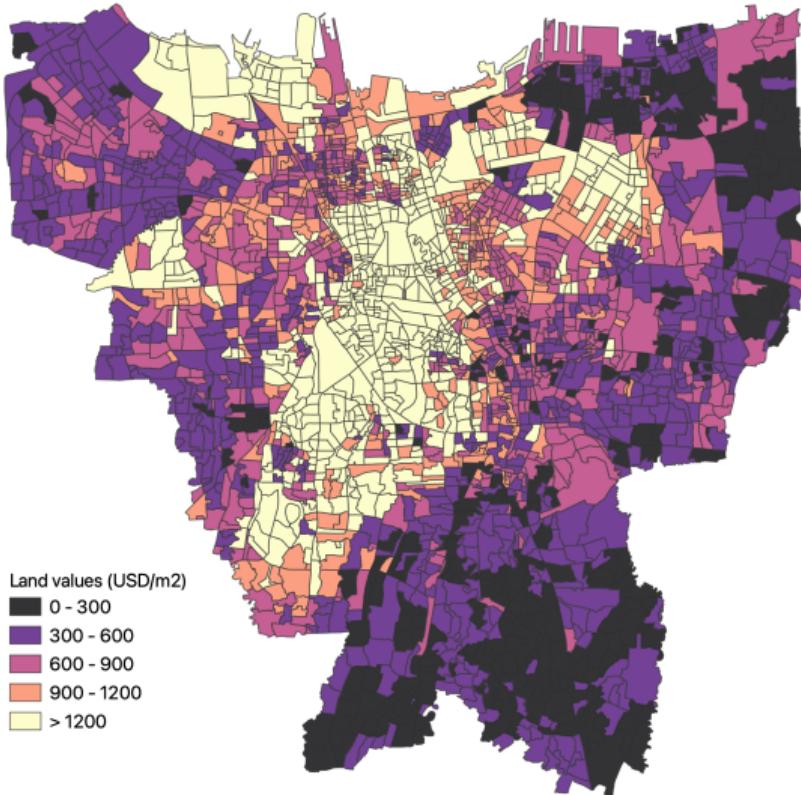
# Property values

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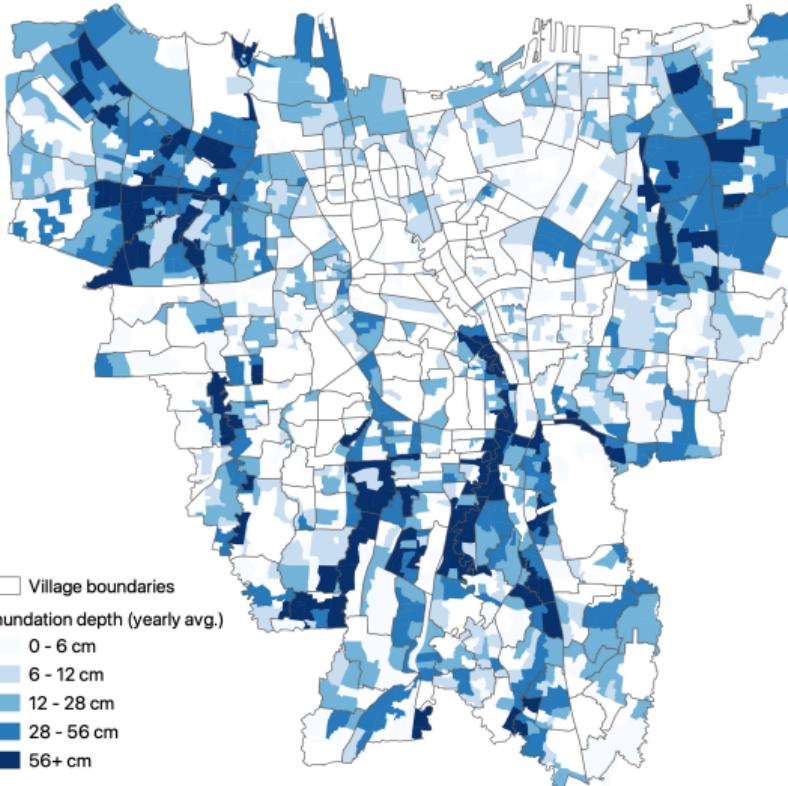
# Land values

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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  $\delta$  by contraction mapping

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

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

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

③ Estimate  $\theta_2$  by minimizing GMM objective function

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