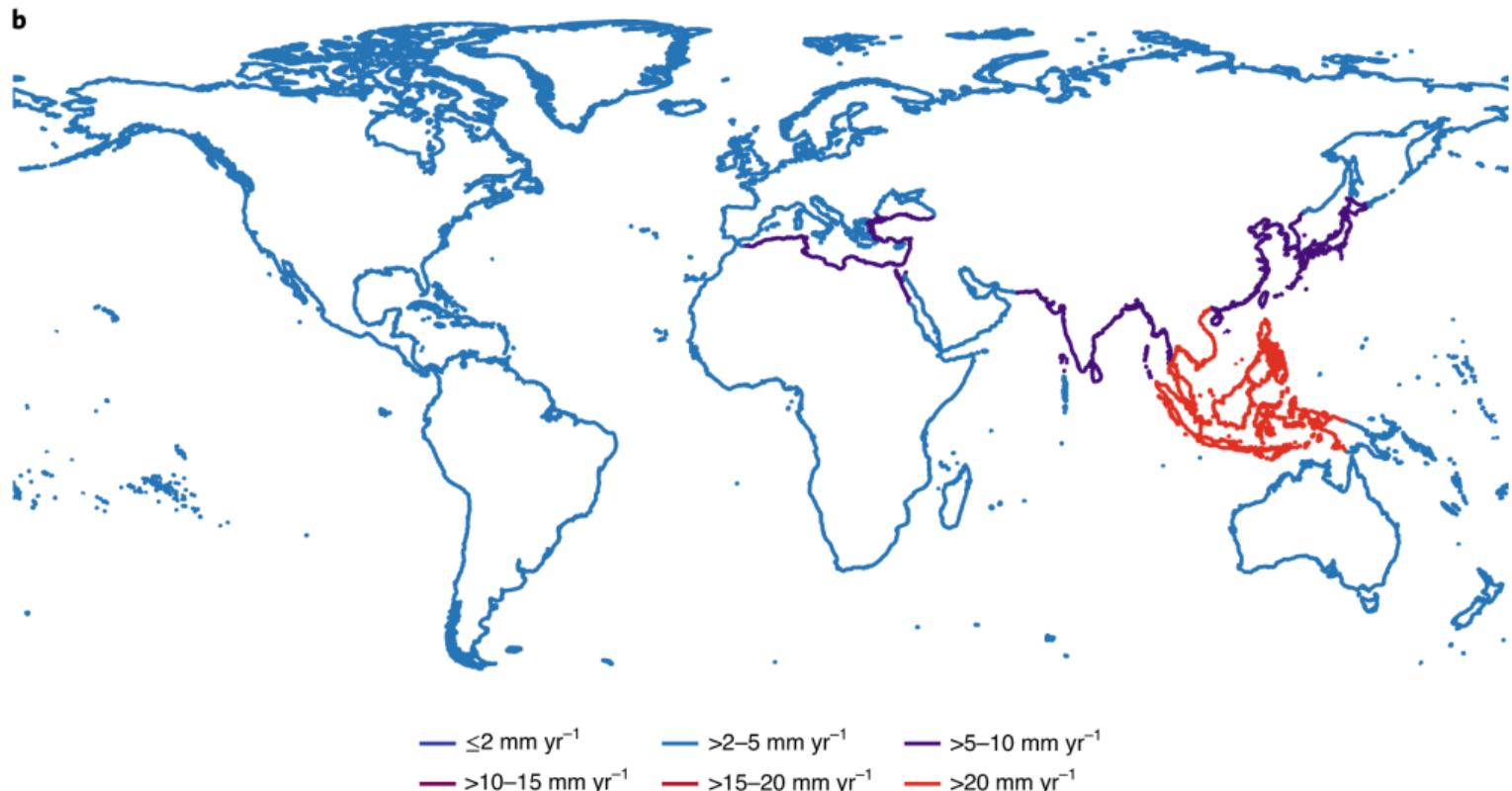


# Sea Level Rise and Urban Adaptation in Jakarta

Allan Hsiao  
Princeton University

February 3, 2023

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





# 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

# 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, Desmet et al. 2021, Vigdor 2008, Kocornik-Mina et al. 2020, Balboni 2021, Castro-Vicenzi 2022, Jia et al. 2022, Peltzman 1975, Kousky et al. 2006, Boustan et al. 2012, Kousky et al. 2018, Baylis & Boomhower 2022, Fried 2022, Mulder 2022, Wagner 2022
- **Dynamic spatial model** of urban development
  - Kalouptsidi 2014, Hopenhayn 1992, Ericson & Pakes 1995, Hotz & Miller 1993, Arcidiacono & Miller 2011, Scott 2013, 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 Theory
- ② Empirics
- ③ Simulations

# Theory

# Coastal development and defense

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

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# Moral hazard

- **First best** maximizes  $W(d, g) = r(d, g) - c(d) - e(g)$

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

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

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

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

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

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

## Moral hazard

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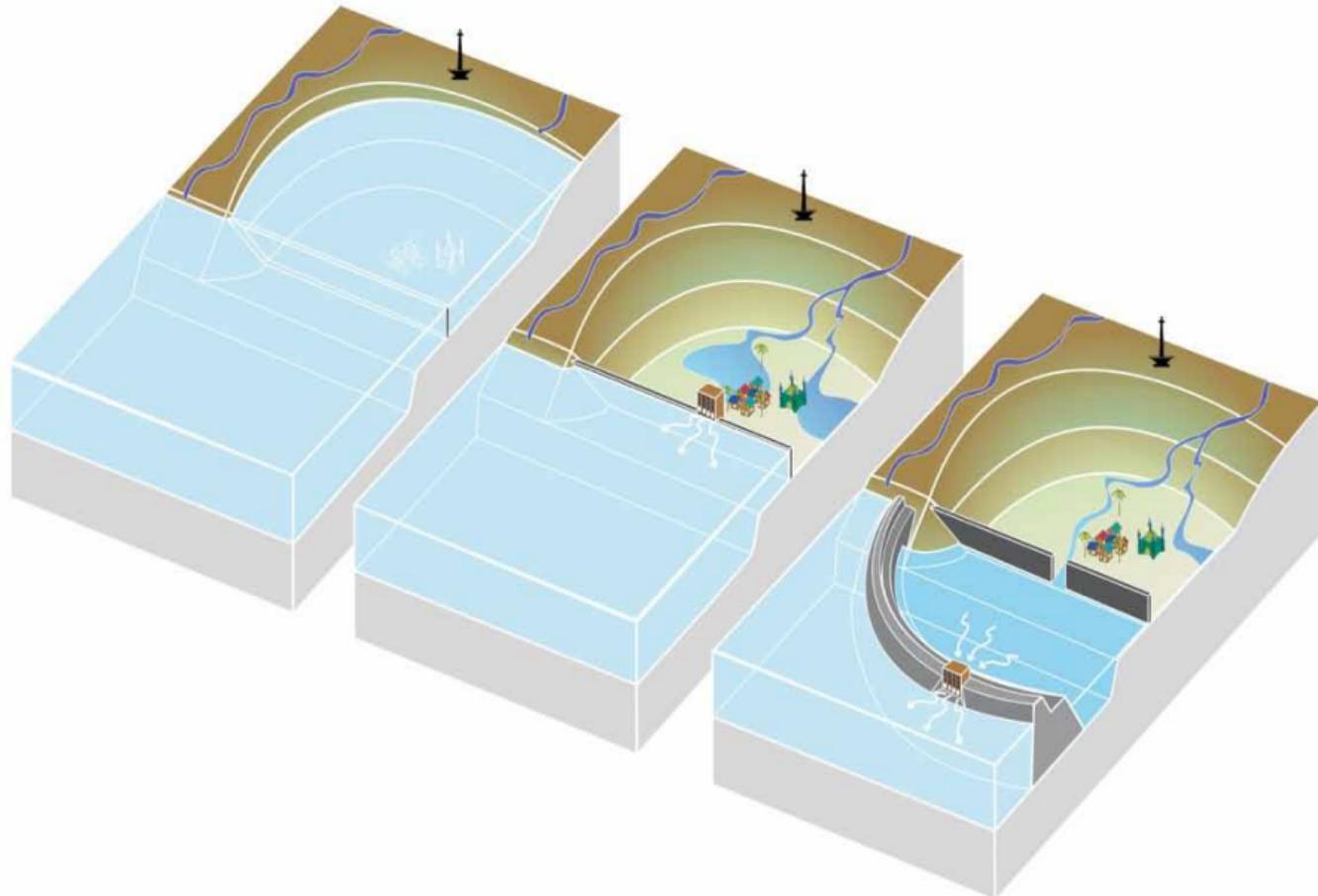
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- **Moral hazard** when  $g'(d) > 0$  implies  $d^n > d^* > 0, g^n > g^* > 0$

## 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
  - [If  $g(d) = 0$ , no moral hazard but also no intervention to begin with]
- 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 (forward-looking)
- Over-development today raises development tomorrow (path dependence)

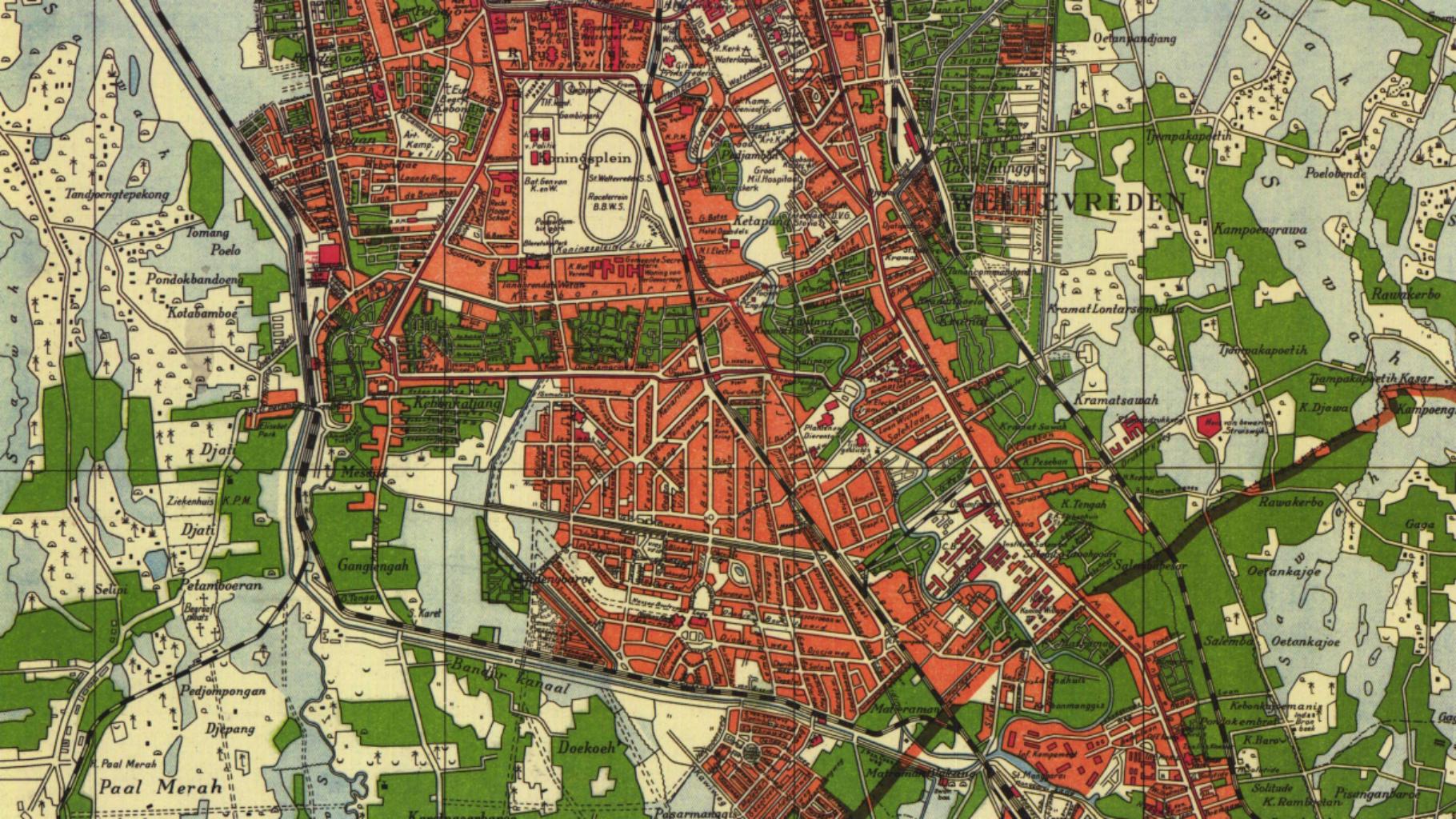
Details

# Empirics

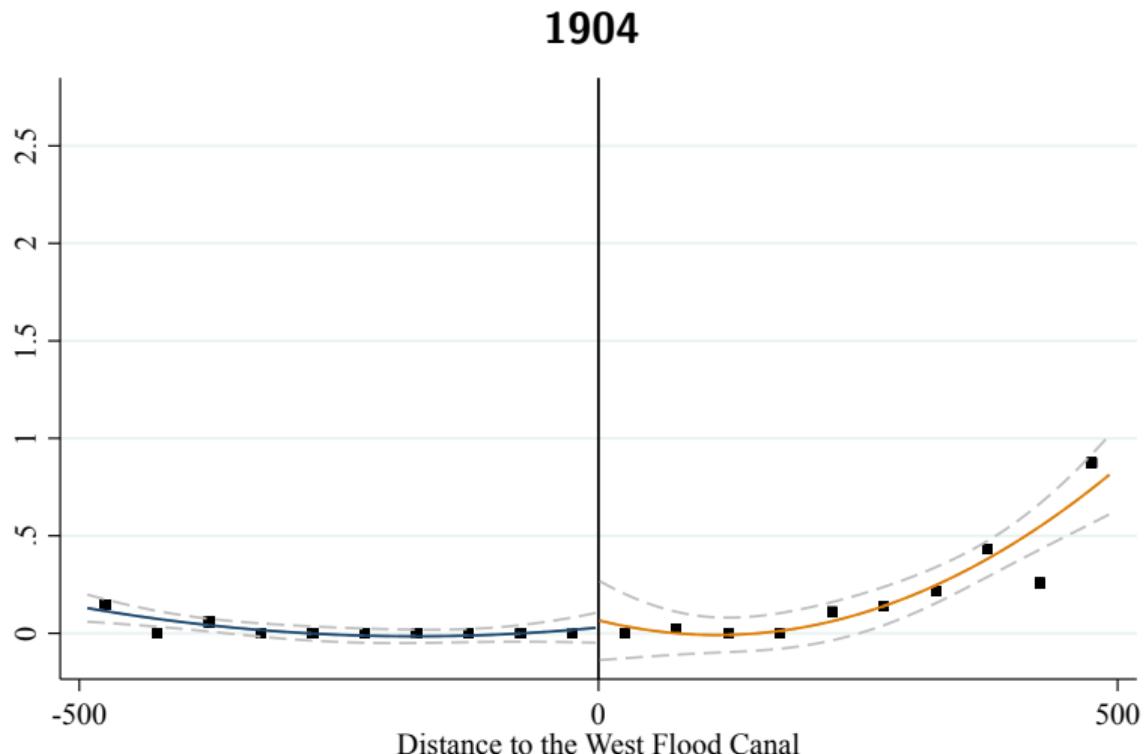
## Empirical framework

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

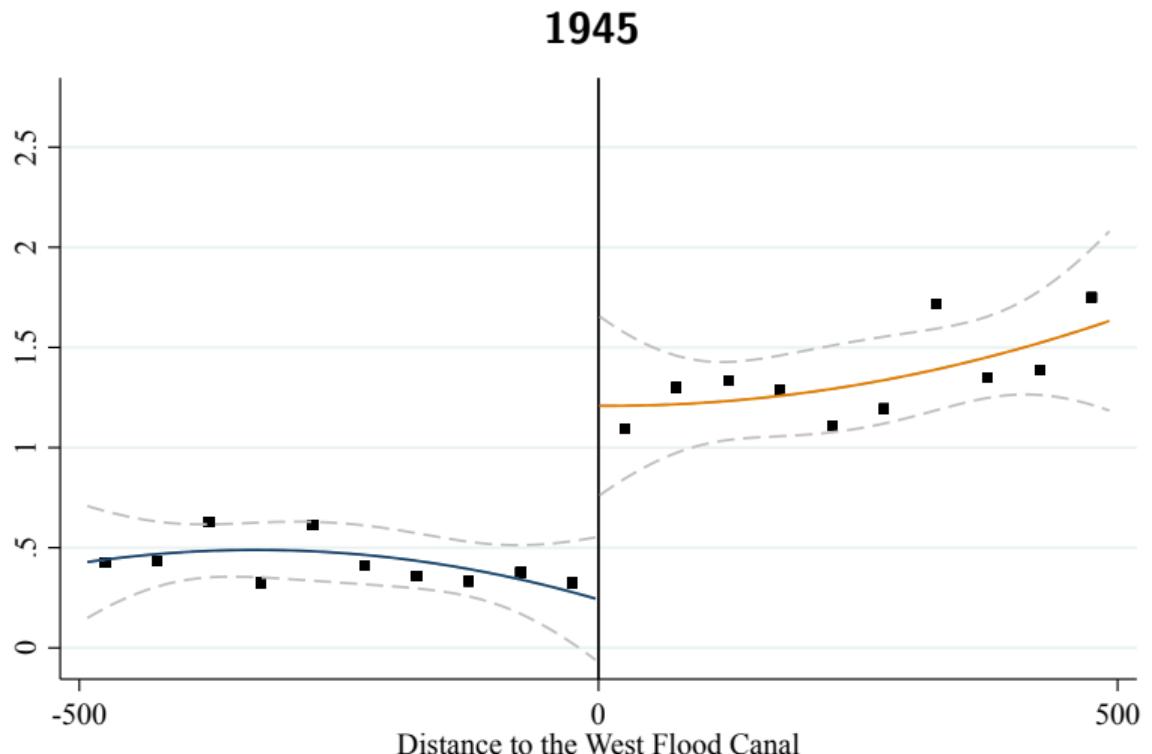
- $r(d, f(g))$ : **spatial model** of residential demand
- $f(g)$ : **hydrological model** of flood risk
- $c(d)$ : **dynamic model** of developer supply
- $e(g)$ : **engineering estimates**



# West Flood Canal (1918)



# West Flood Canal (1918)



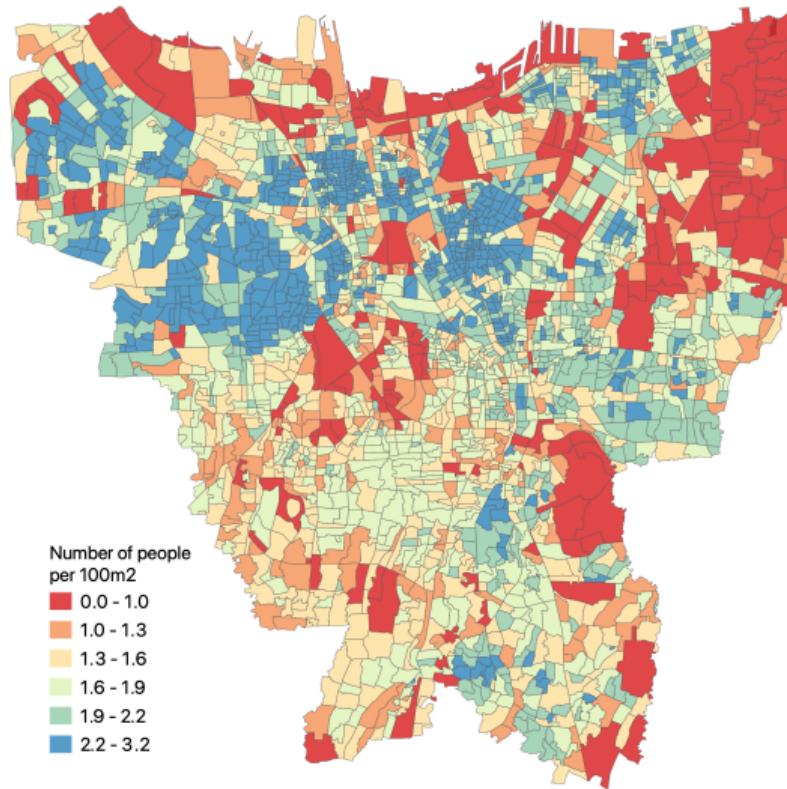
## Demand from residents

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

- **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
  - 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 ruggedness as supply shifter

Details

# Populations



## 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

$$V_{kt}(D, L) = r_{kt}(D) + \mathbb{E}[\max_{d \in \{0,1\}} \{v_{kt}^d(D, L) + \epsilon_{ikt}^d\}]$$

$$v_{kt}^1(D, L) = -c_{kt}(d; \varepsilon) + \beta \mathbb{E}[V_{kt+1}(D + 1, L - 1)]$$

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

- **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 resident demographics as demand shifters

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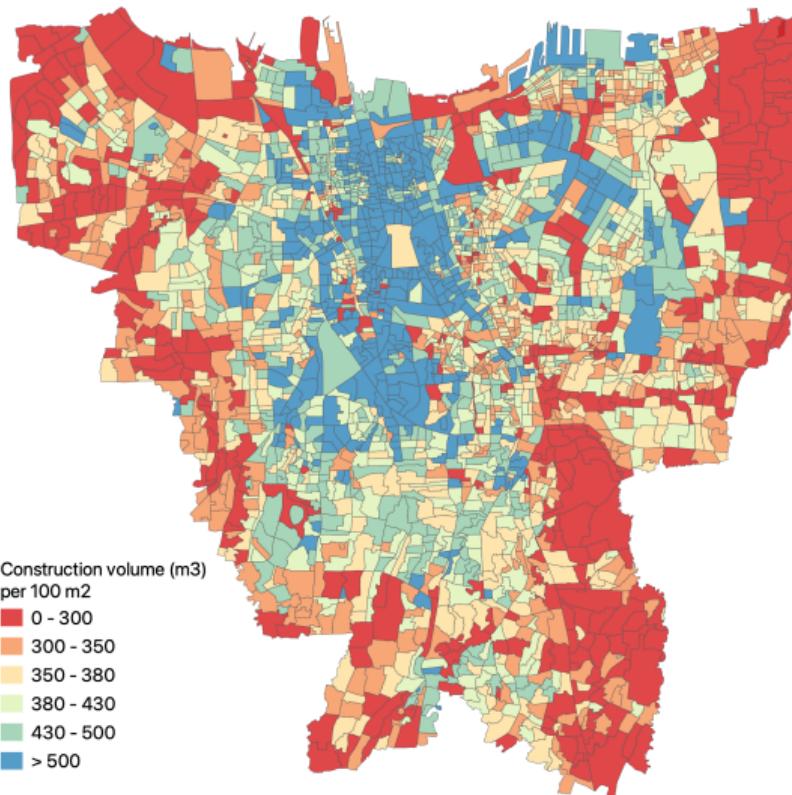
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  - IV with resident demographics as demand shifters

## Data as continuation values

$$\begin{aligned}\ln p_{kt}^1 - \ln p_{kt}^0 &= v_k^1(D, L) - v_k^0(D, L) \\ &= -c_{kt}(d; \varepsilon) + \beta \mathbb{E}[V_{kt+1}(D+1, L-1) - V_{kt+1}(D, L)] \\ &= -c_{kt}(d; \varepsilon) + P_{kt}^D d - P_{kt}^L d\end{aligned}$$

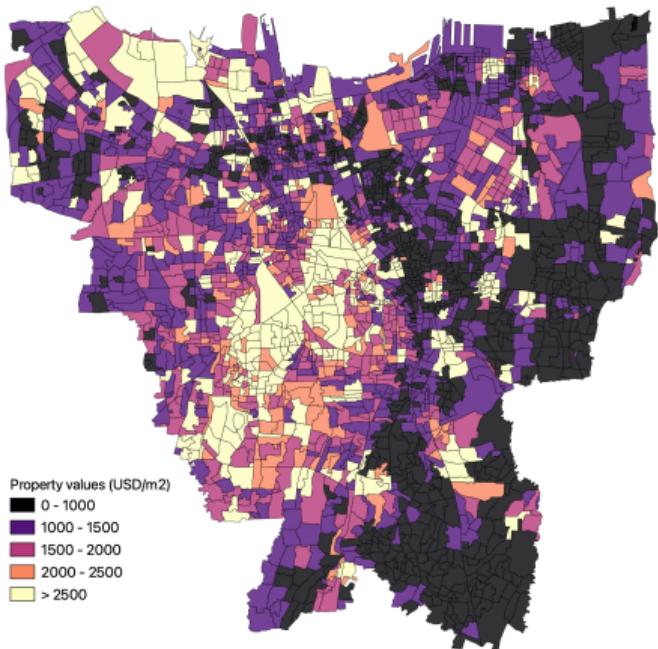
- Simple IV estimation
  - Key assumption:  $\beta \mathbb{E}[V_{kt+1}(D+d, L-d)] = P_{kt}^D(D+d) - P_{kt}^L(L-d)$
  - Need efficient real estate markets and atomistic developers
  - Do not need rational expectations

# Building construction

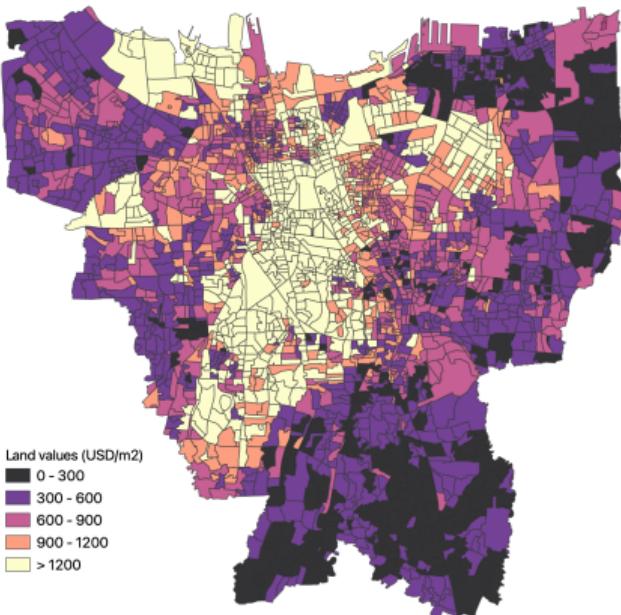


# Real estate prices

Property



Land



## Comparing approaches

Estimation	Speed	Expectations	Atomistic
Full-solution (NFP)	Slow	Specified	No
Two-step (BBL)	Fast	Specified	No
Euler CCPs	Fast	Rational	Yes
Baseline	Fast	Measured	Yes

# Rents

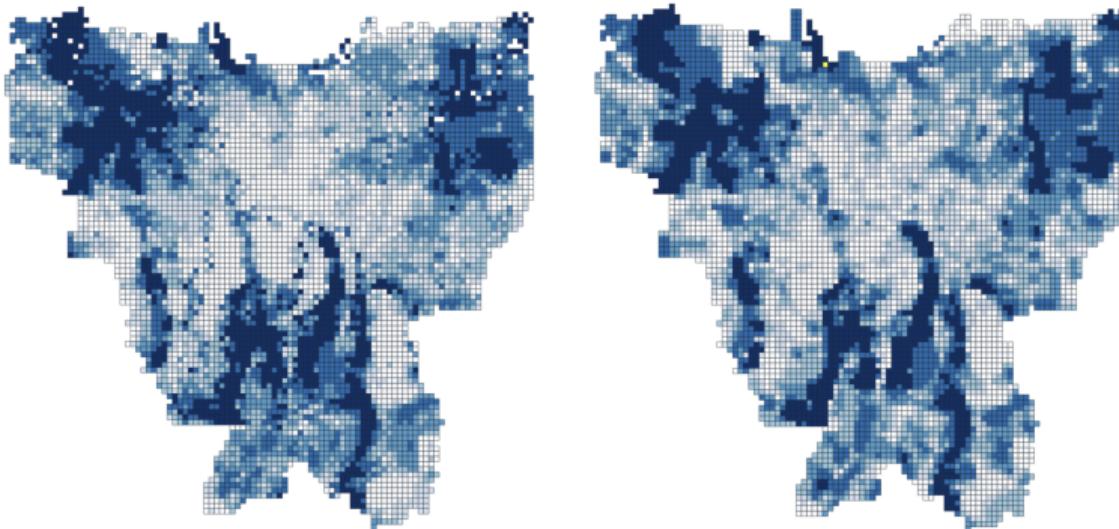
$$D_{kt}^{\text{res}} = D_{kt}^{\text{dev}}$$

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

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

# Flooding

- Physical vs. prediction-based hydrological models (Mosavi et al. 2018)
  - Random forest algorithm to match monthly observed flooding (2013-2020)



Predicted vs. observed

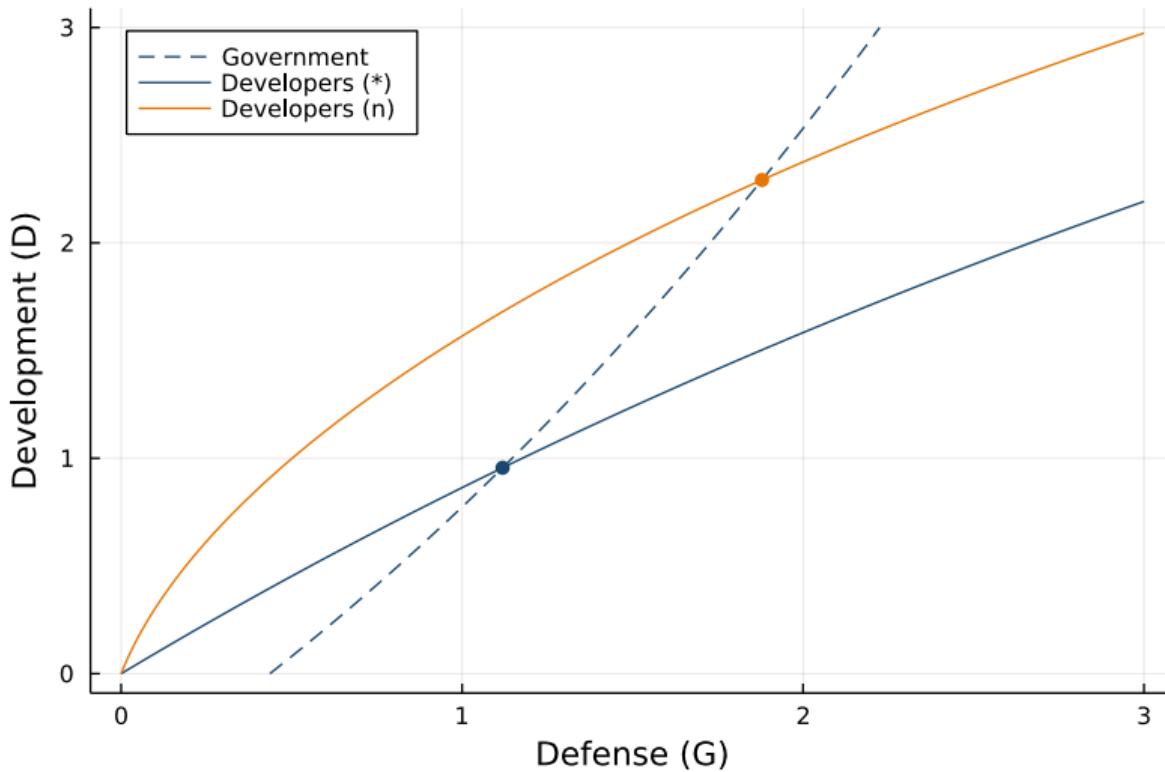
# Government

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

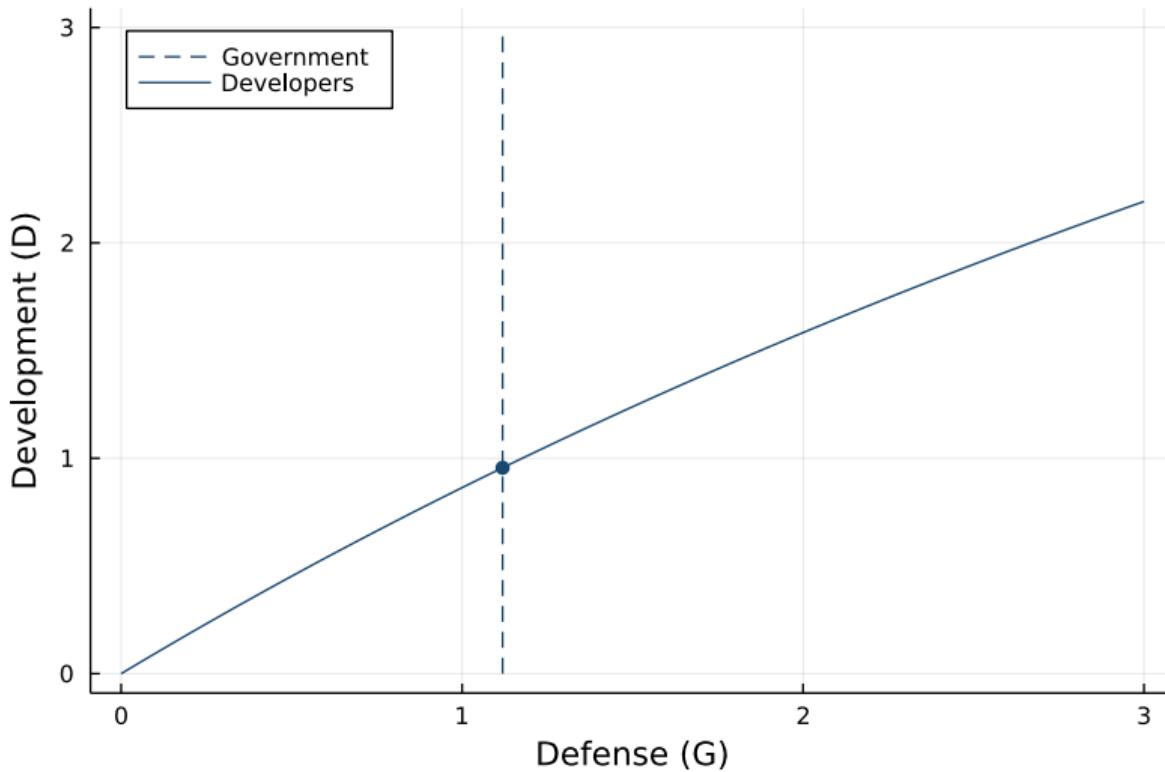
Defense  $g \rightarrow$  flooding  $s$  by **hydrological** model  
 $\rightarrow$  rents  $r$  by **demand** model  
 $\rightarrow$  development  $d$  by **supply** model

# Simulations

## Coastal over-development and over-defense

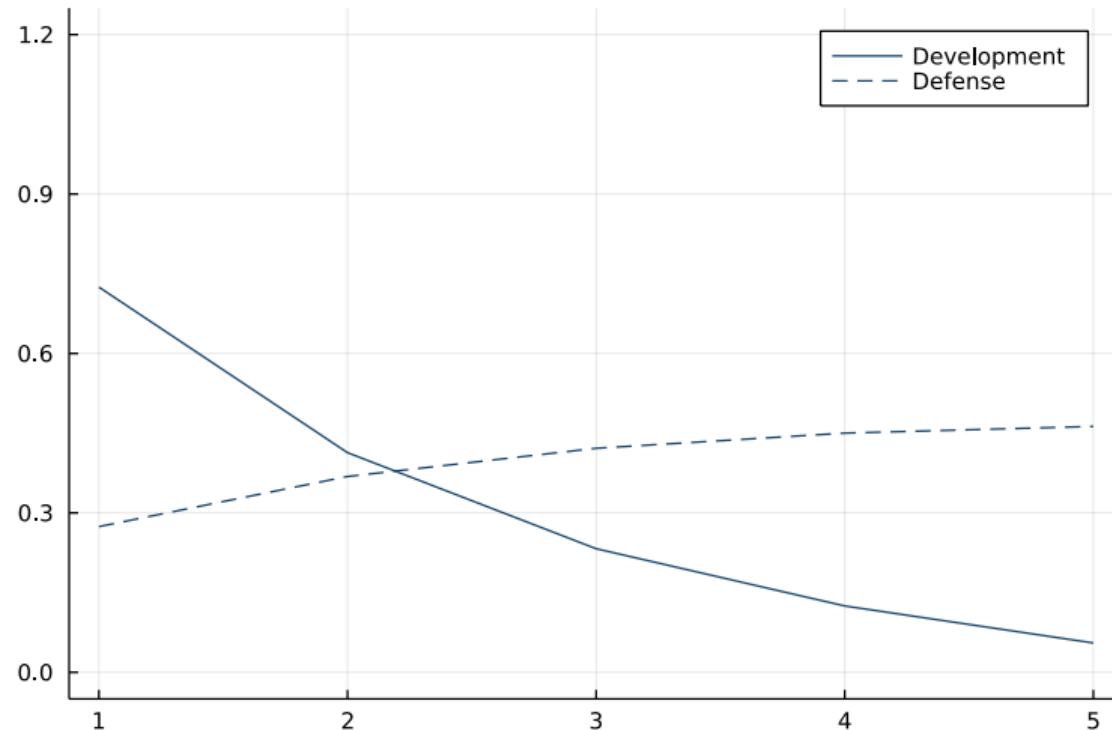


## Coastal over-development and over-defense



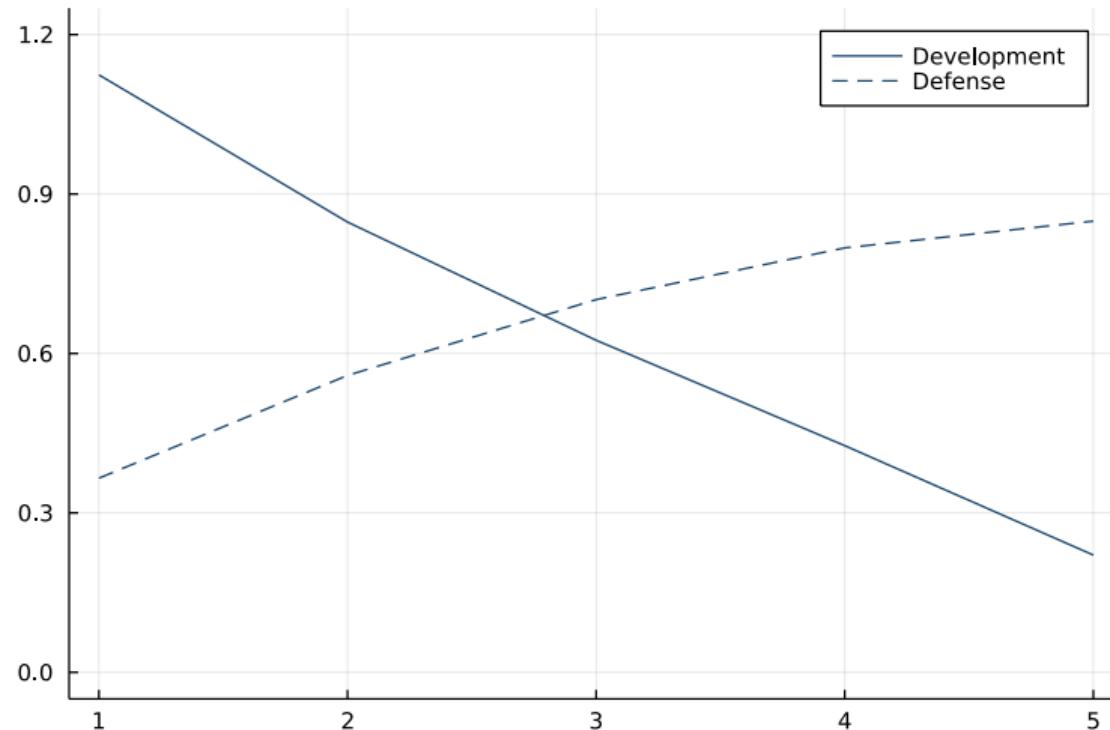
# Development and defense over time

Full commitment



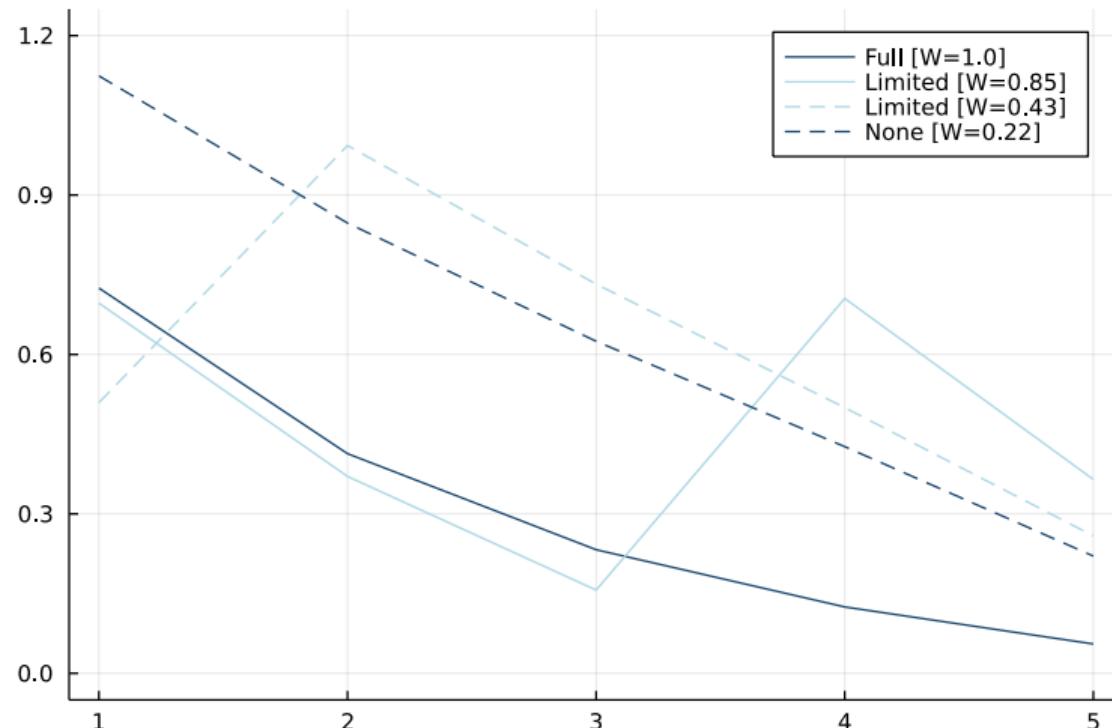
# Development and defense over time

No commitment



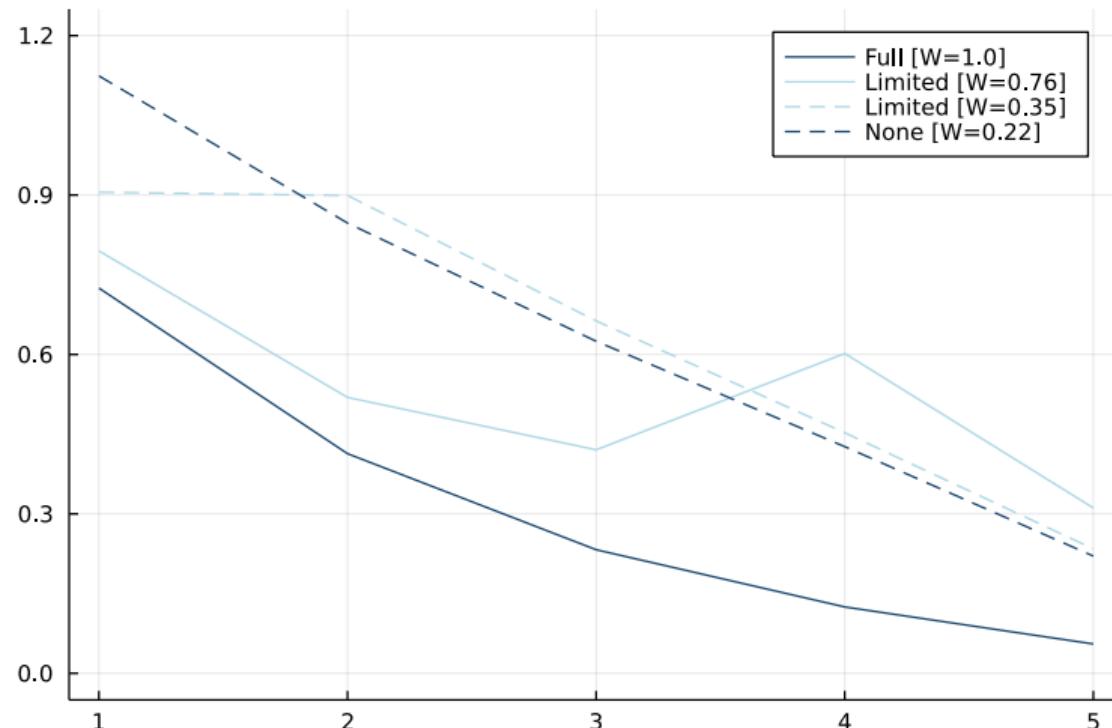
# Limited commitment (development)

Forward-looking



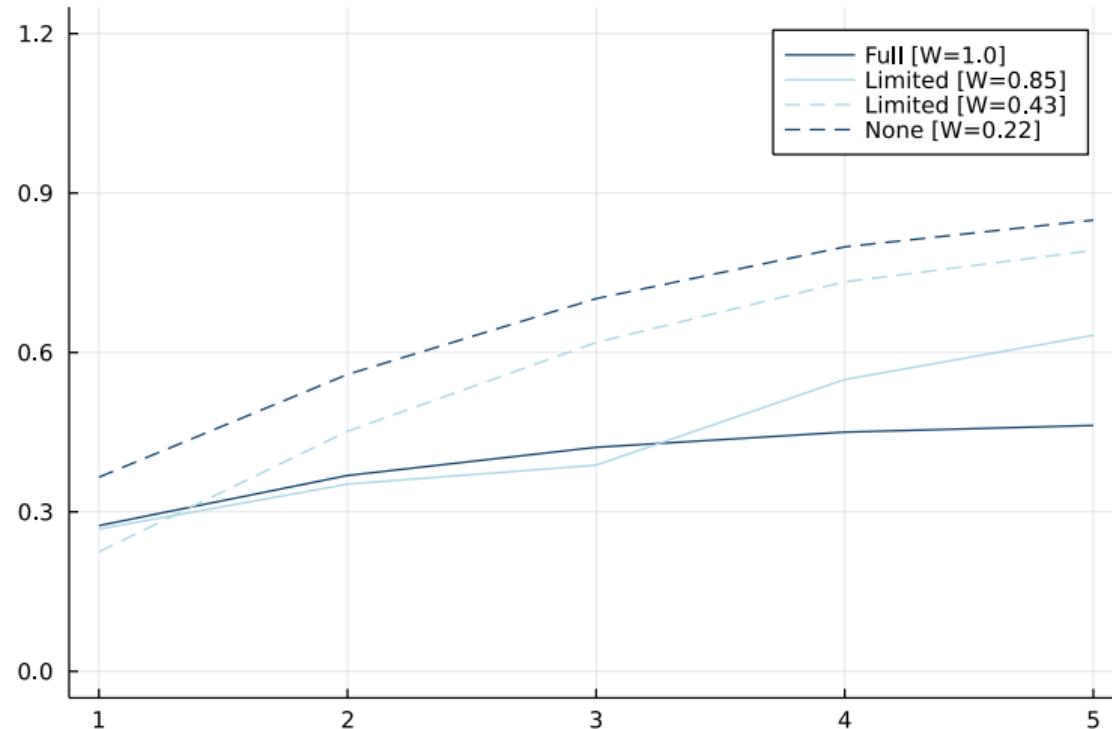
# Limited commitment (development)

Politically myopic



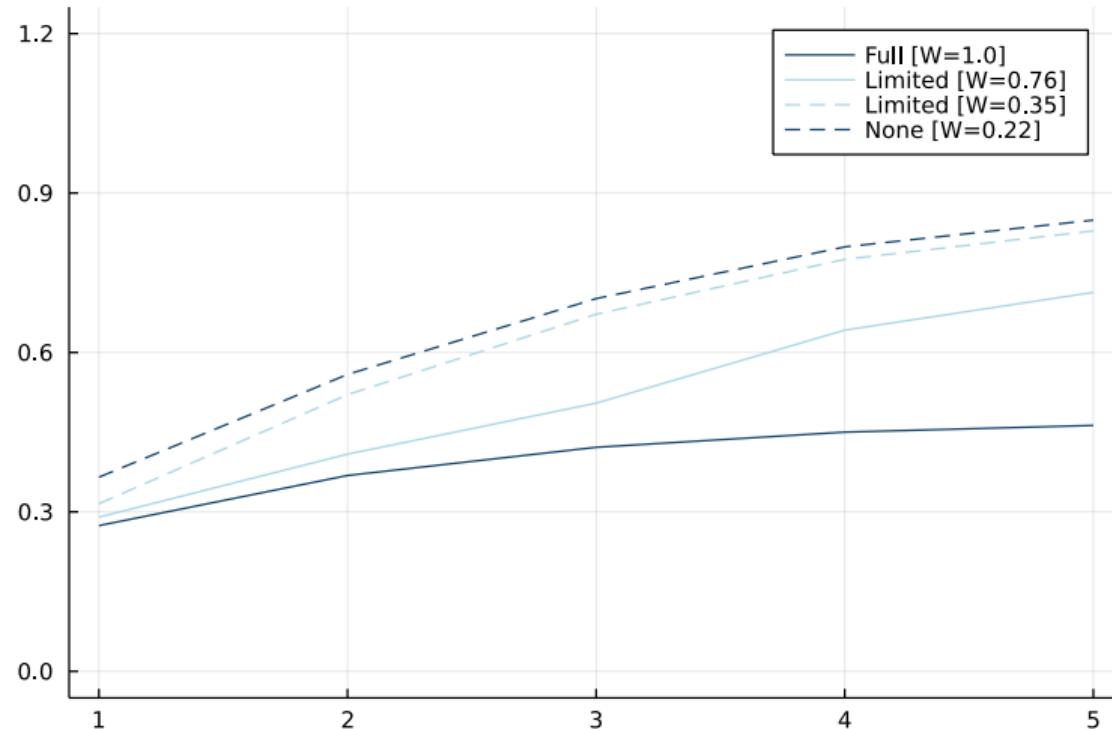
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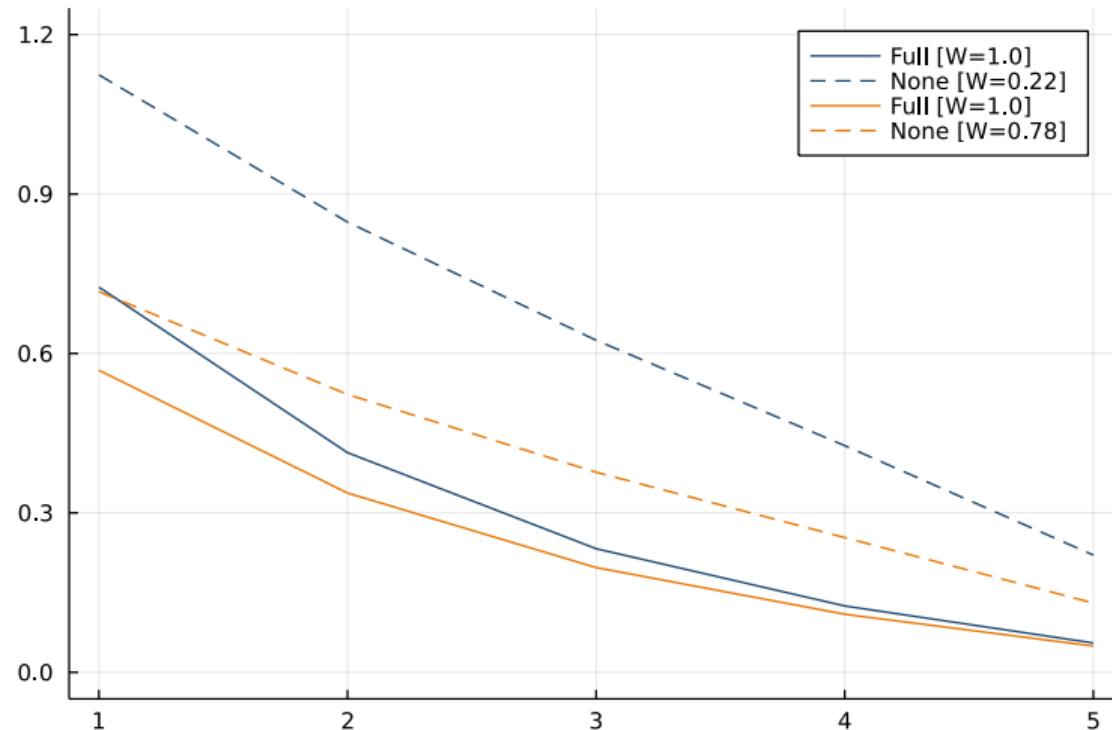
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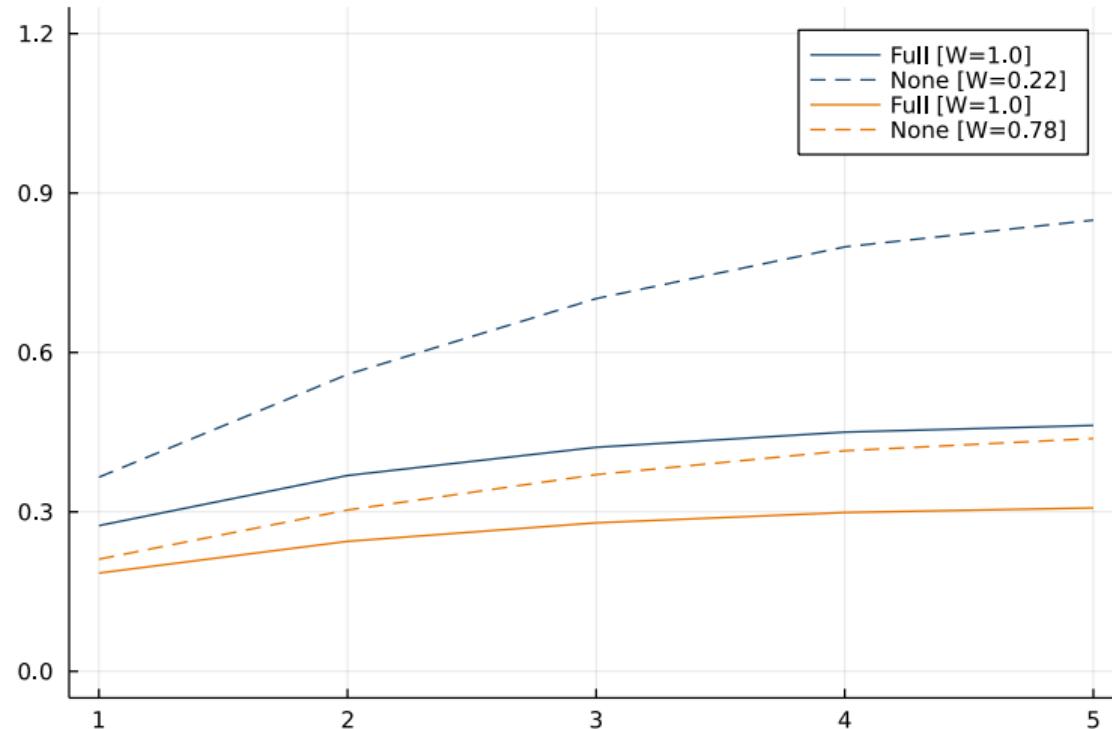
# Reducing coastal demand

## Development



# Reducing coastal demand

## 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  $W_1 + \beta W_2$ .

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## 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**  $t = 1$ : 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  $W_1 + \beta W_2$ .

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**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.

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

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

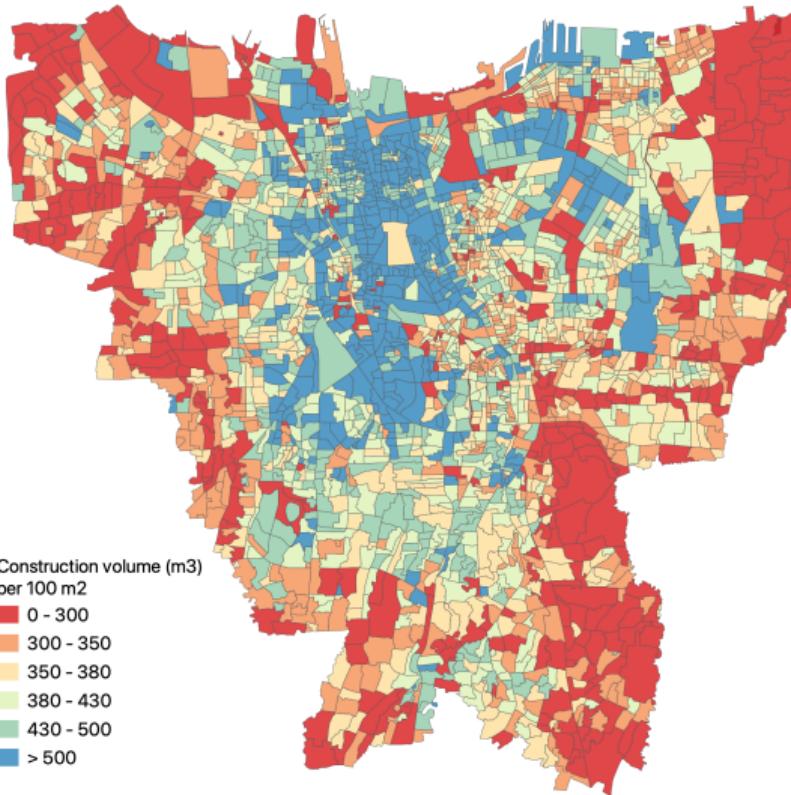
$D_1 \uparrow$  implies  $G_2 \uparrow$  given more to defend.

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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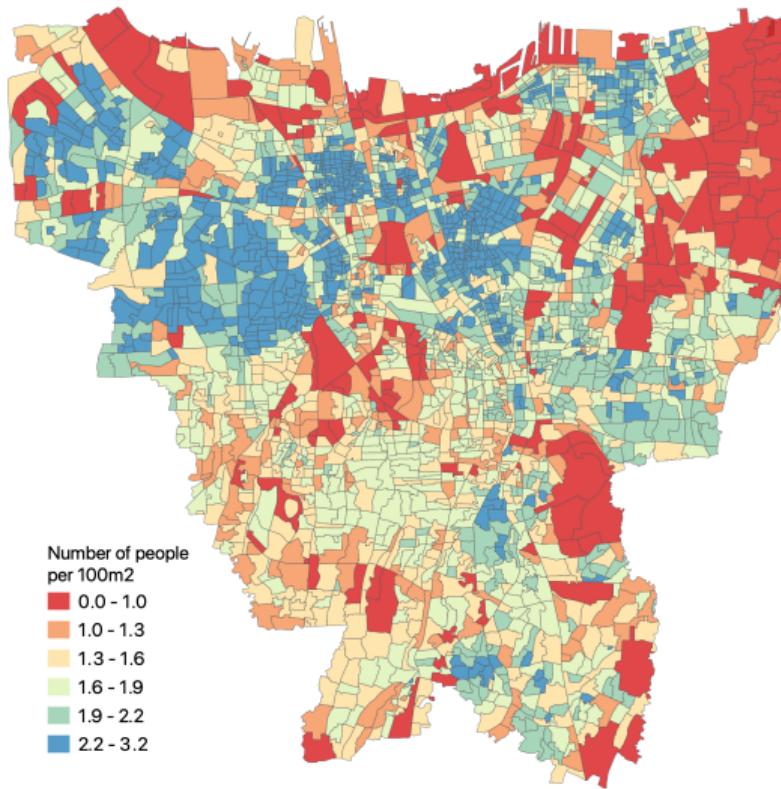
# Building construction

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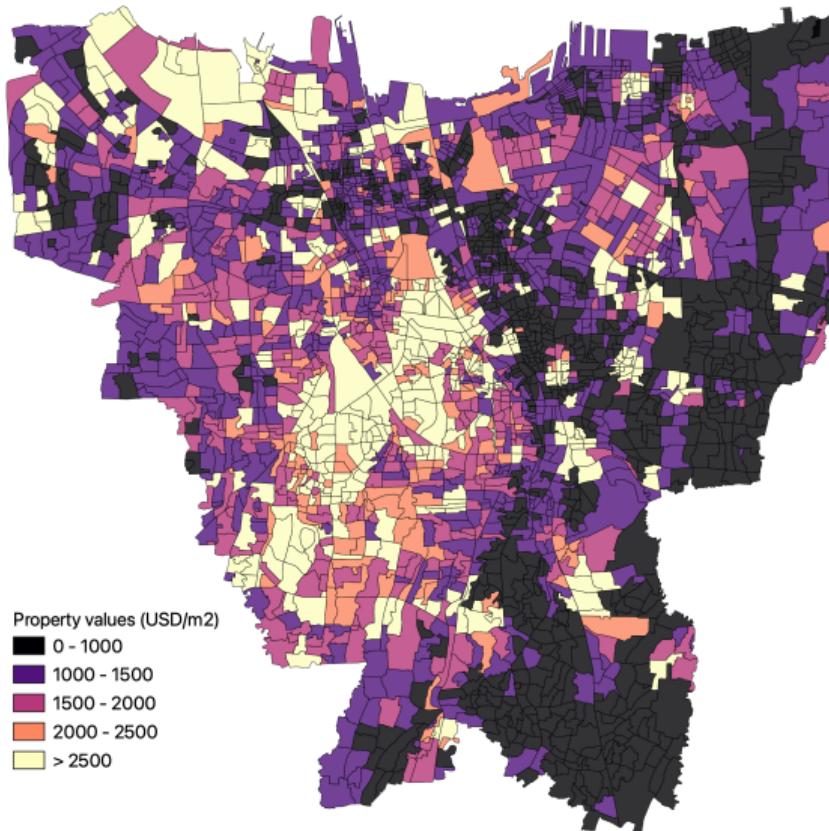
# Populations

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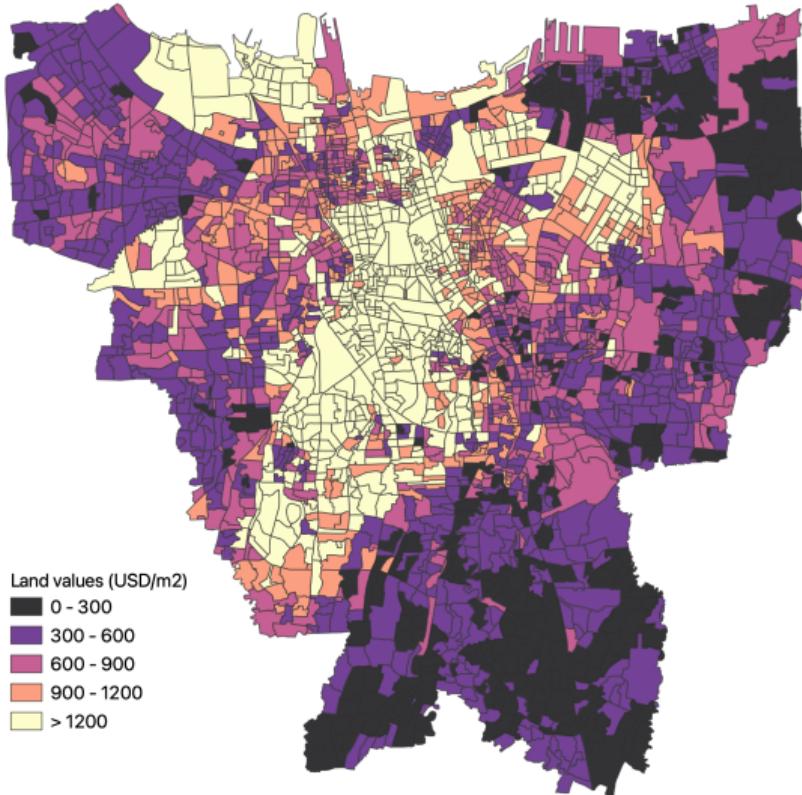
# Property values

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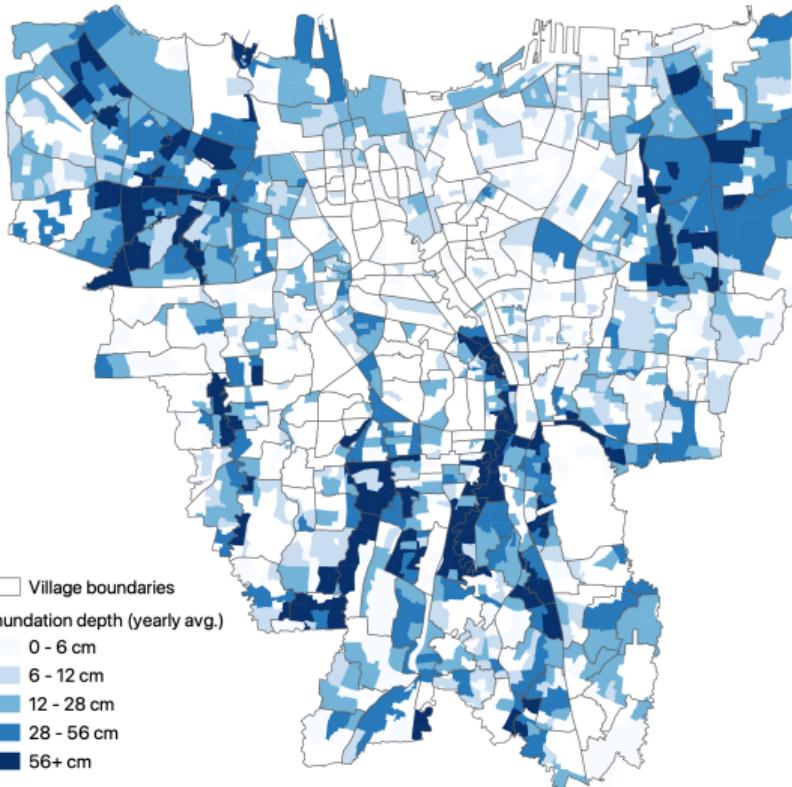
# Land values

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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  $\delta$  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

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