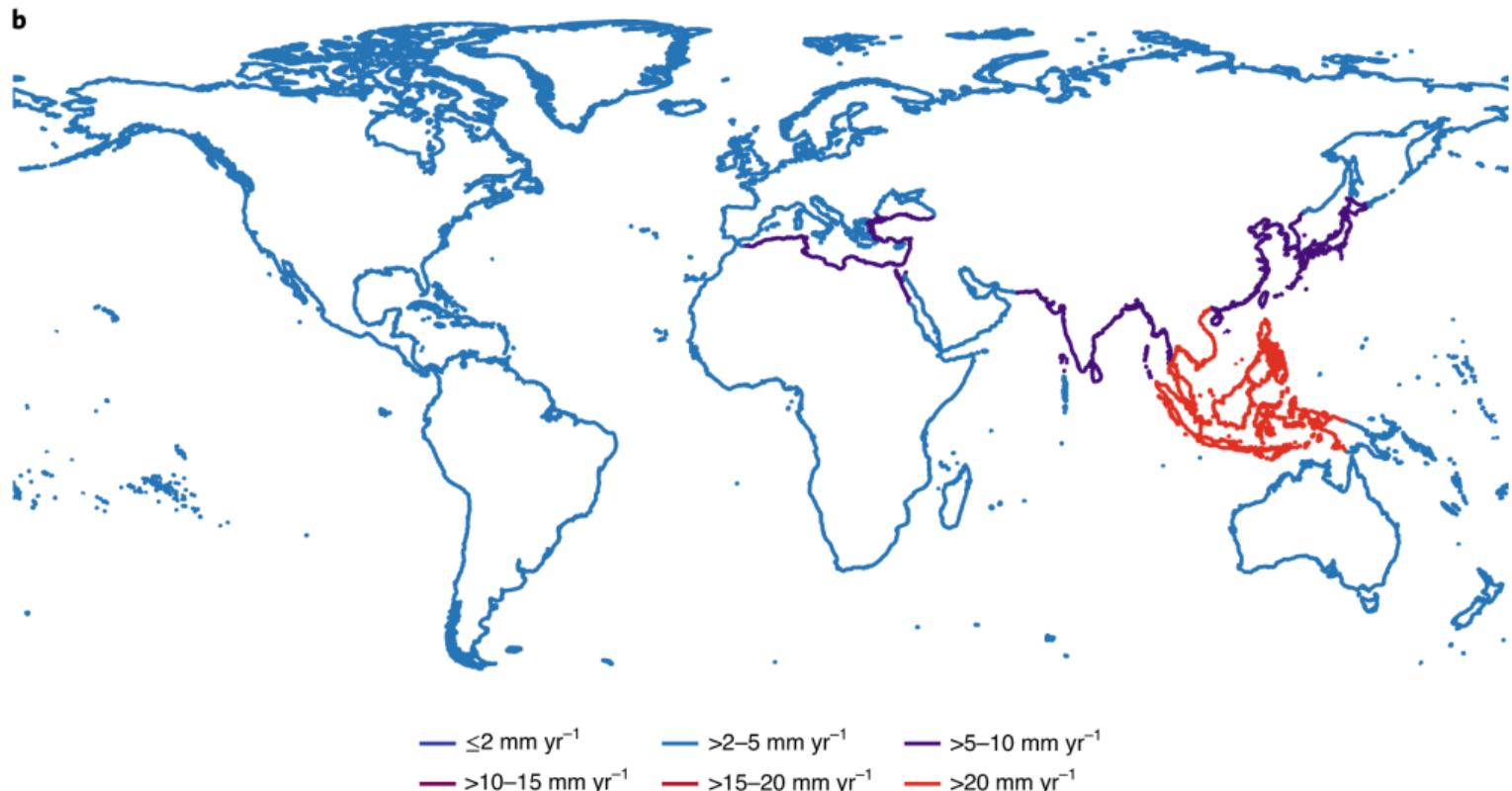


Sea Level Rise and Urban Adaptation in Jakarta

Allan Hsiao
Princeton University

February 20, 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, Balboni 2021, Castro-Vicenzi 2022, Jia et al. 2022, Peltzman 1975, Kousky et al. 2006, Boustan et al. 2012, Annan & Schlenker 2015, Kousky et al. 2018, Baylis & Boomhower 2022, Fried 2022, Coate 1995, Mulder 2022, Wagner 2022
 - Rationalize: Kocornik-Mina et al. 2020, Hino & Burke 2021, Bakkenes & Barrage 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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 - **Profits** $\pi(d) = r(d, g) - c(d)$ (zero at margin)

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

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

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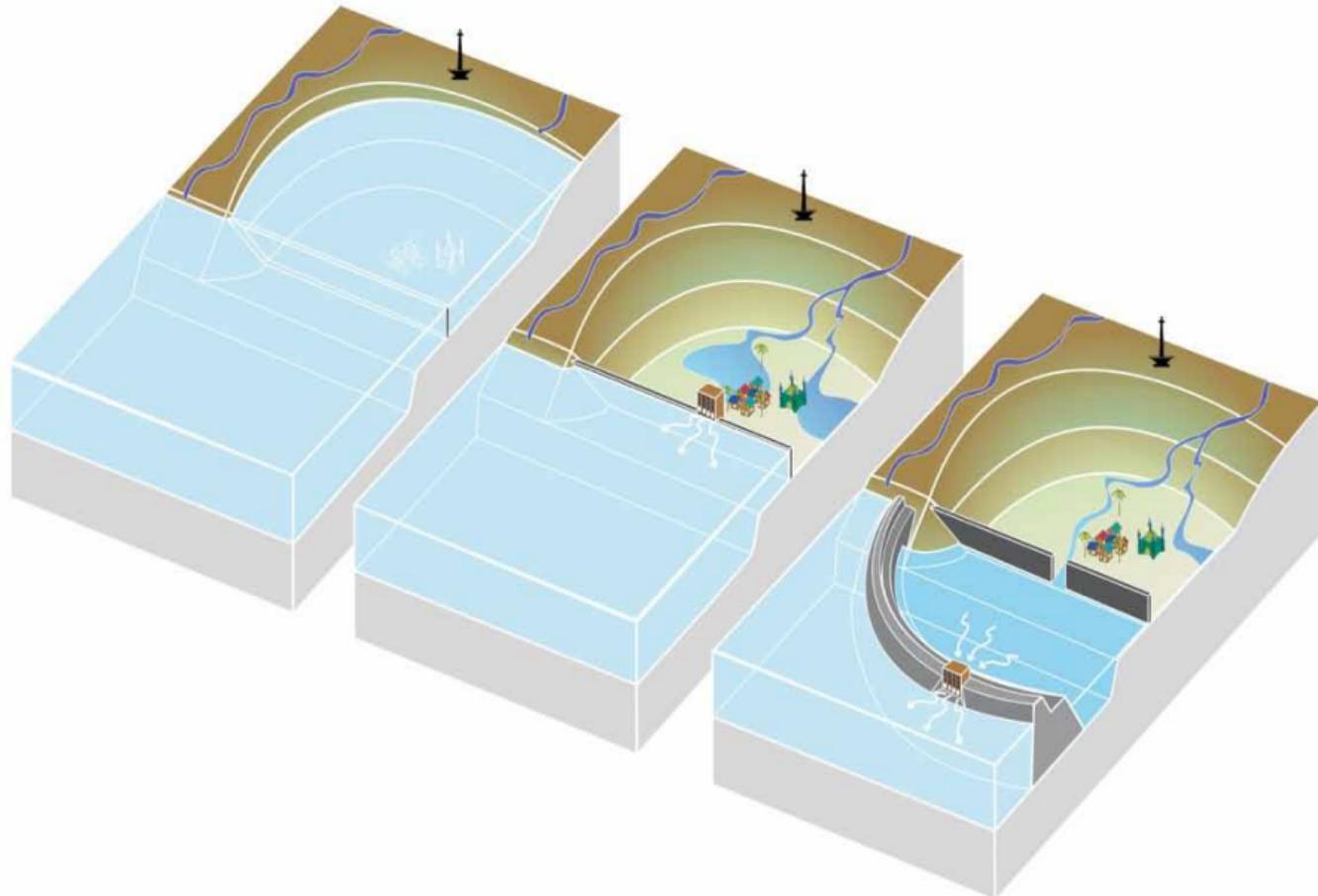
$$[d^n] \quad r'(d) + r'(g) g'(d) = c'(d)$$

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

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

Commitment + challenges

- Solution 1: **commit to g^***
 - $g'(d) = 0$ implies $r'(g) g'(d) = 0$
 - But optimal to over-defend ex post (even absent politics)
 - [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 (rezoning, NFIP 2.0)
- Too much coastal defense \Rightarrow too little long-run adaptation
 - Static incentive to pursue short-run gain at long-run cost



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)

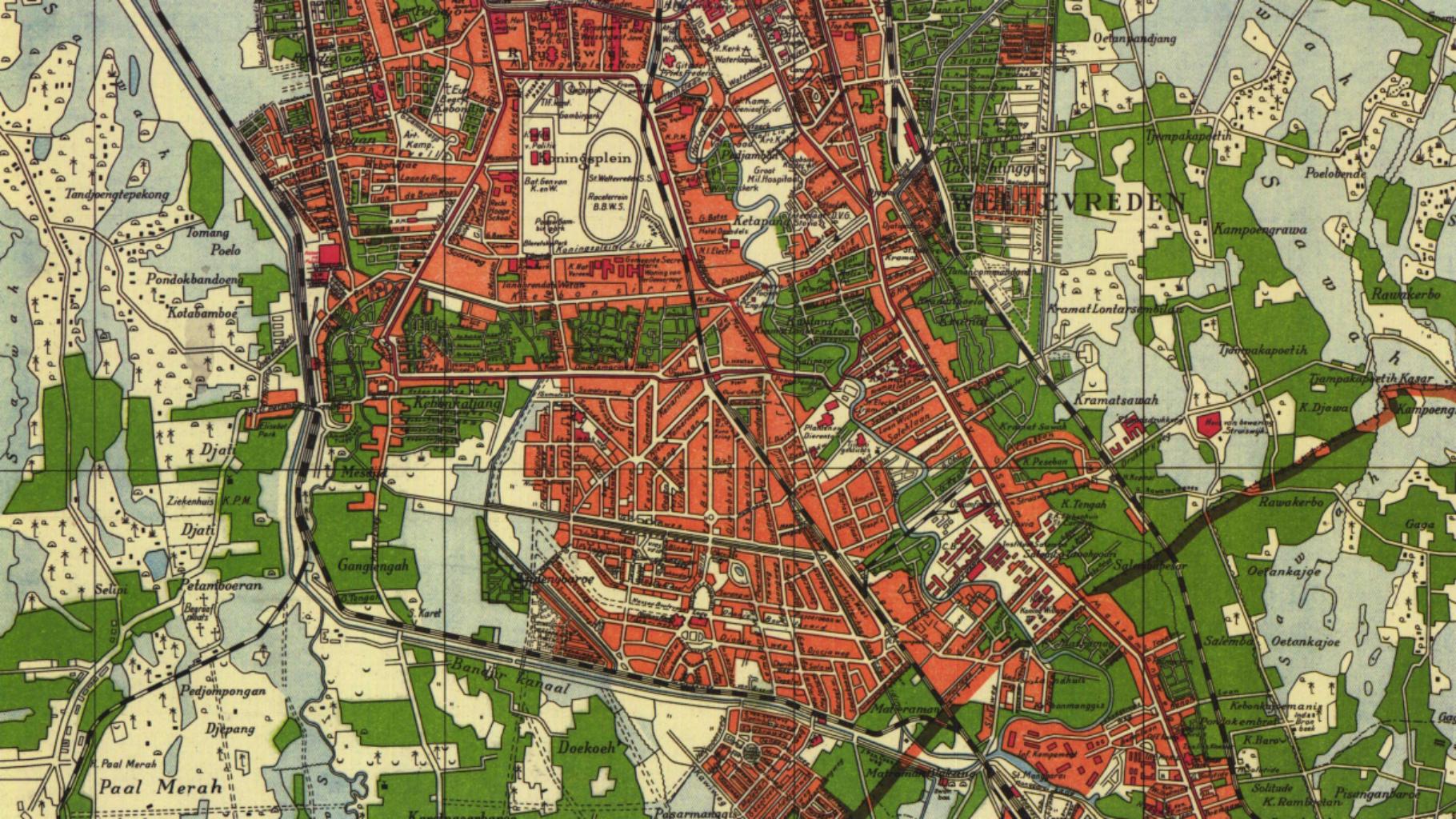
Details

Empirics

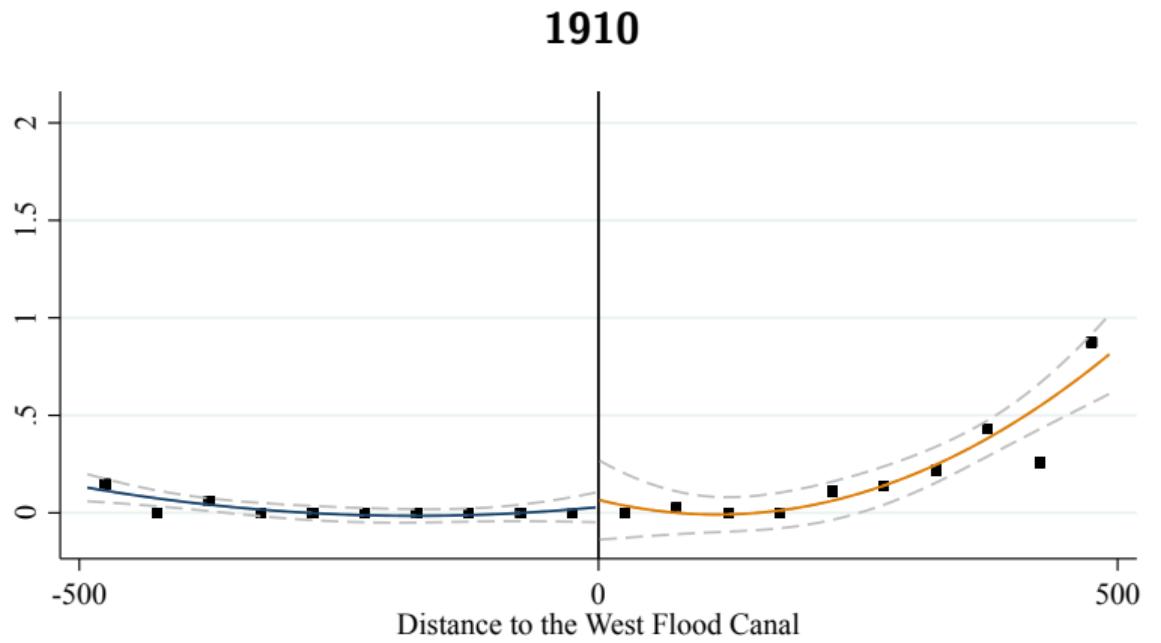
Empirical framework

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

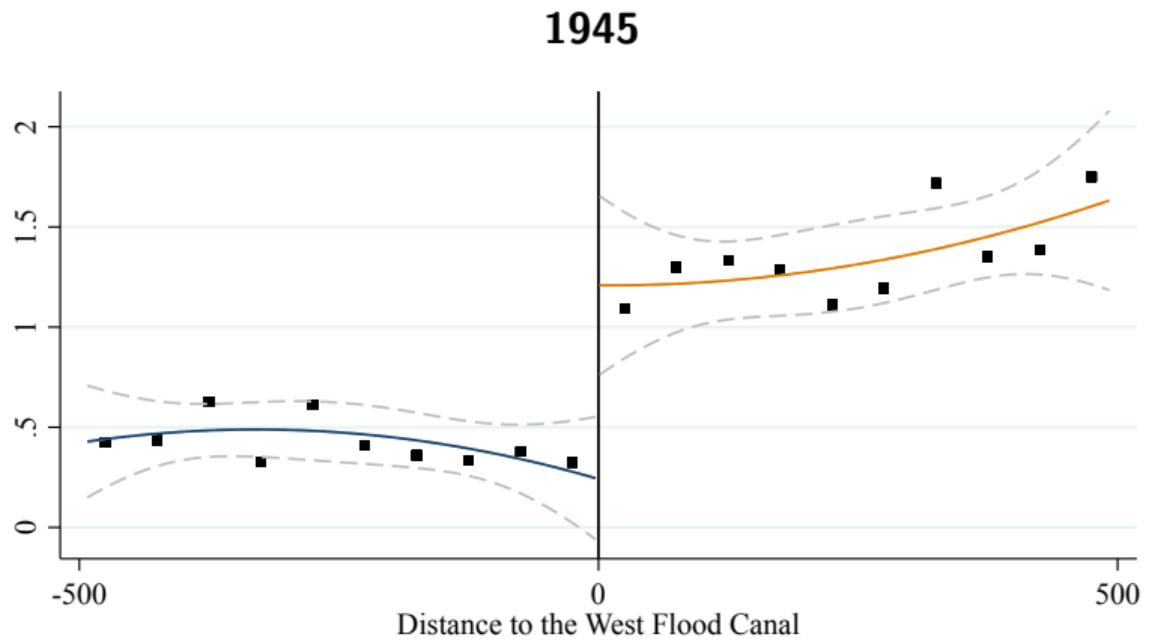
- $r(d, f(g))$: **spatial model** of residential demand
- $f(g)$: **hydrological model** of flood risk
- $c(d)$: **dynamic model** of developer supply
- $e(g)$: **engineering estimates**



West Flood Canal (1918)



West Flood Canal (1918)



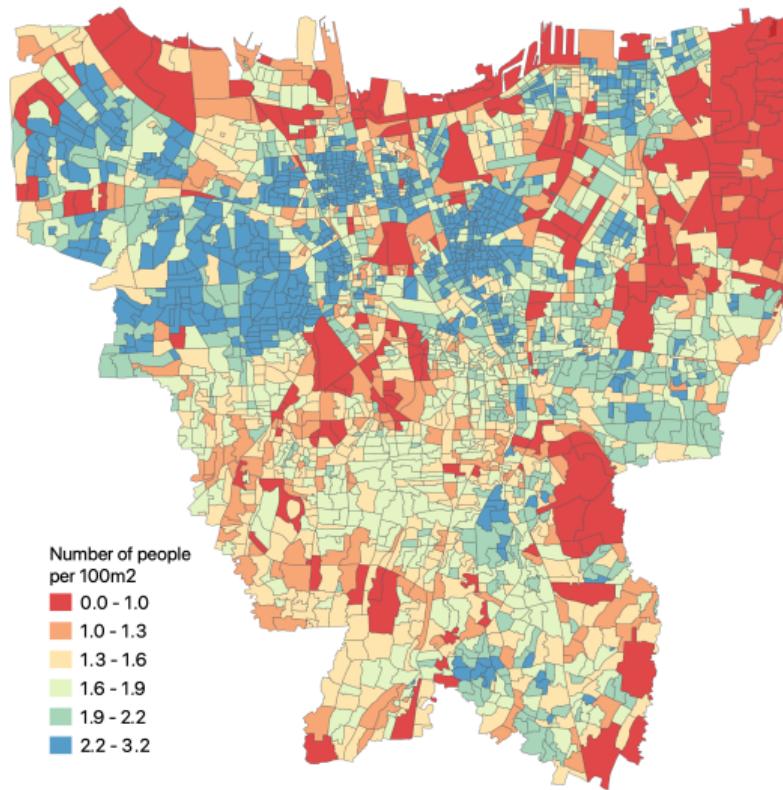
Demand from residents

$$U_{ijk} = \underbrace{\alpha r_k + \phi f_k + x_k \gamma + \varepsilon_k}_{\delta_k} + \tau m_{jk} + \epsilon_{ijk}$$

- **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
 - Can endogenize observed 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

	IV		First stage	
	Estimate	SE	Estimate	SE
Rents	-0.221***	(0.026)		
Ruggedness			1.743***	(0.168)
Flooding	-1.223***	(0.243)	-5.547***	(0.889)
Residential amenities	0.110***	(0.017)	0.220***	(0.067)
Distance to city center	-0.141***	(0.017)	-0.554***	(0.035)
Distance to coast	0.024***	(0.005)	-0.013	(0.022)
Distance to major road	-0.059***	(0.020)	0.192**	(0.078)
District FE	x		x	
Observations	5,780		5,780	
F-stat			107.5	

Supply from developers

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

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

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

- **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 residential amenities as demand shifters

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Data as continuation values

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

$$P_{kt}^D D + P_{kt}^L L = \frac{1}{\alpha} \left(\beta \mathbb{E}[V_{kt+1}(D, L)] \right) \quad (*)$$

- Simple IV estimation with numeraire
 - Need efficient real estate markets and atomistic developers
 - Do not need rational expectations

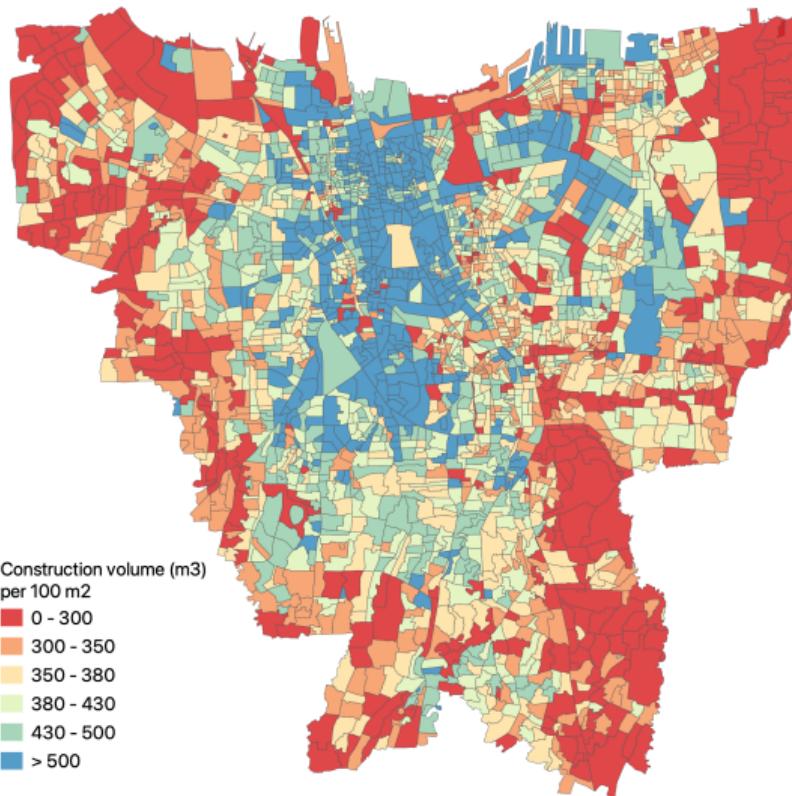
Data as continuation values

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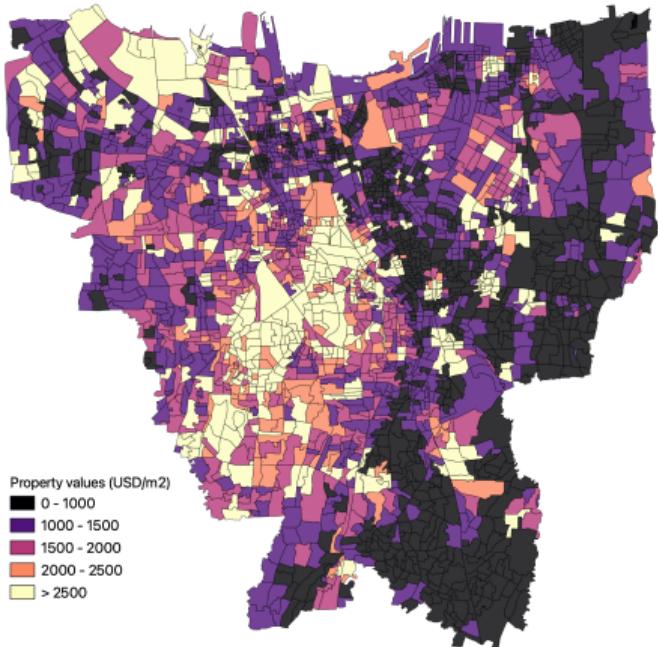
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Building construction

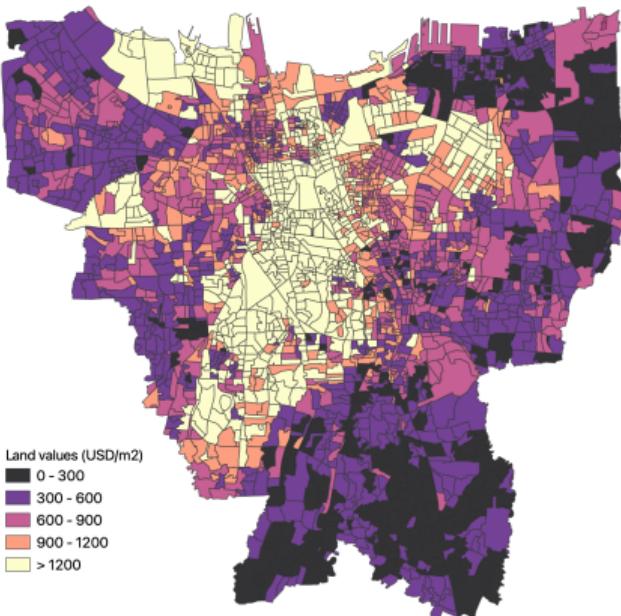


Real estate prices

Property



Land



Supply estimates

	IV		First stage	
	Estimate	SE	Estimate	SE
Prices	0.782***	(0.185)		
Residential amenities			0.259***	(0.060)
Flooding	1.047	(0.716)	-3.008***	(0.773)
Ruggedness	-0.932***	(0.353)	1.812***	(0.146)
Distance to city center	0.548***	(0.069)	-0.320***	(0.032)
Distance to coast	-0.184***	(0.017)	0.016	(0.020)
Distance to major road	-0.035	(0.049)	0.144**	(0.070)
District FE	x		x	
Observations	5,780		5,780	
F-stat			18.14	

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

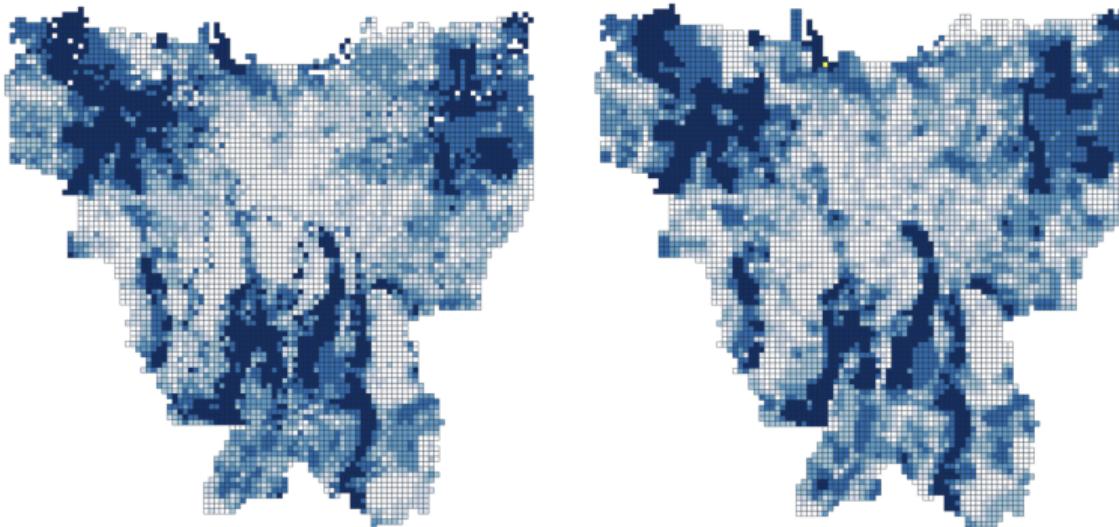
$$D_{kt}^{\text{res}} = D_{kt}^{\text{dev}}$$

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

Flooding

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



Predicted vs. observed

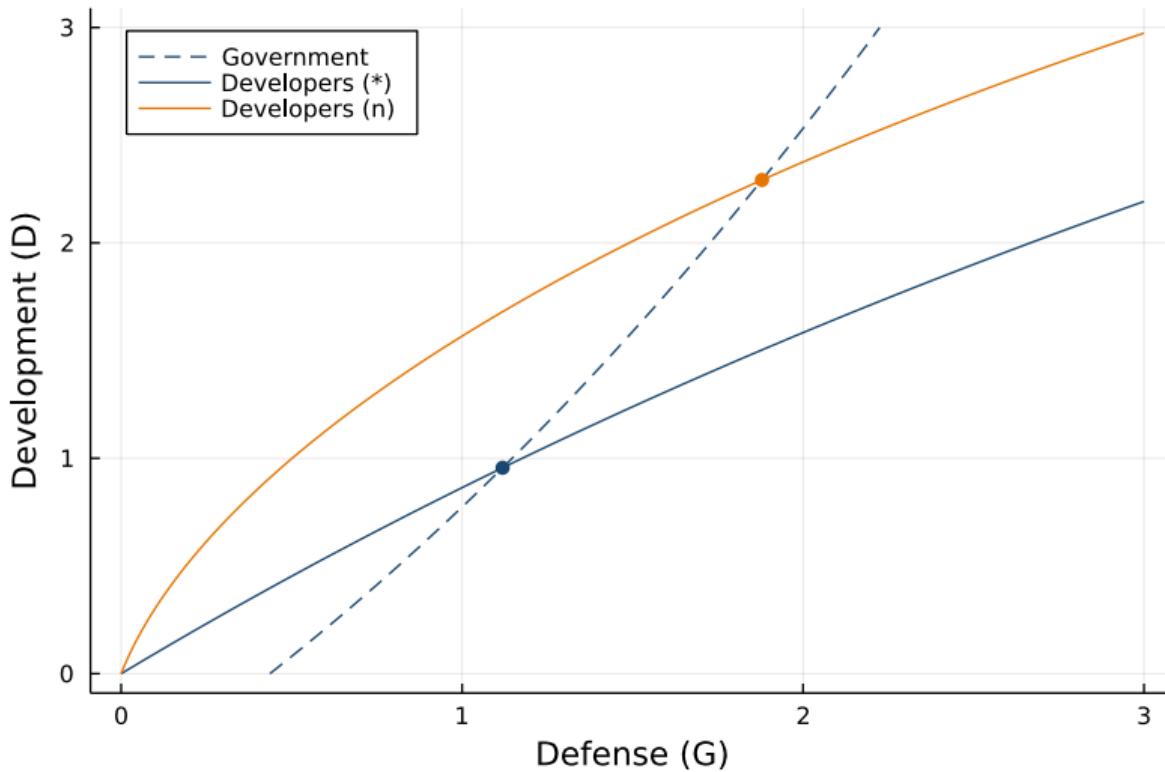
Government

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

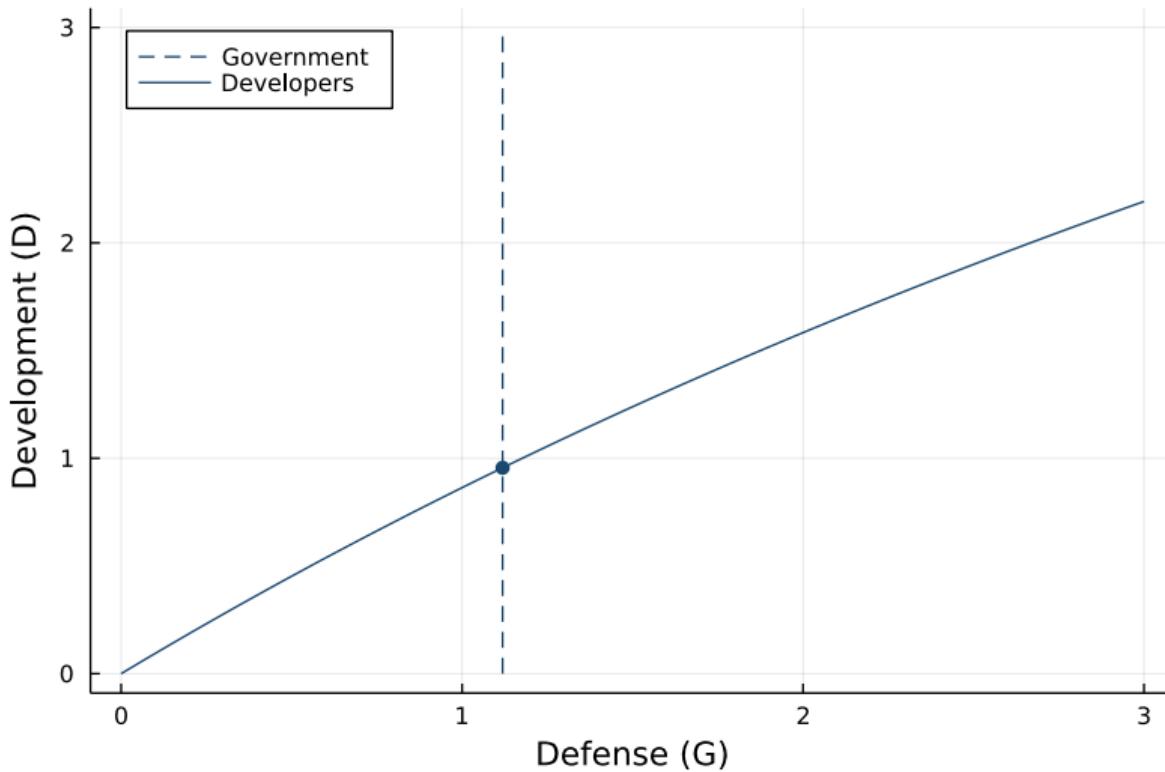
Defense $g \rightarrow$ flooding s by **hydrological** model
 \rightarrow rents r by **demand** model
 \rightarrow development d by **supply** model

Simulations

Coastal over-development and over-defense

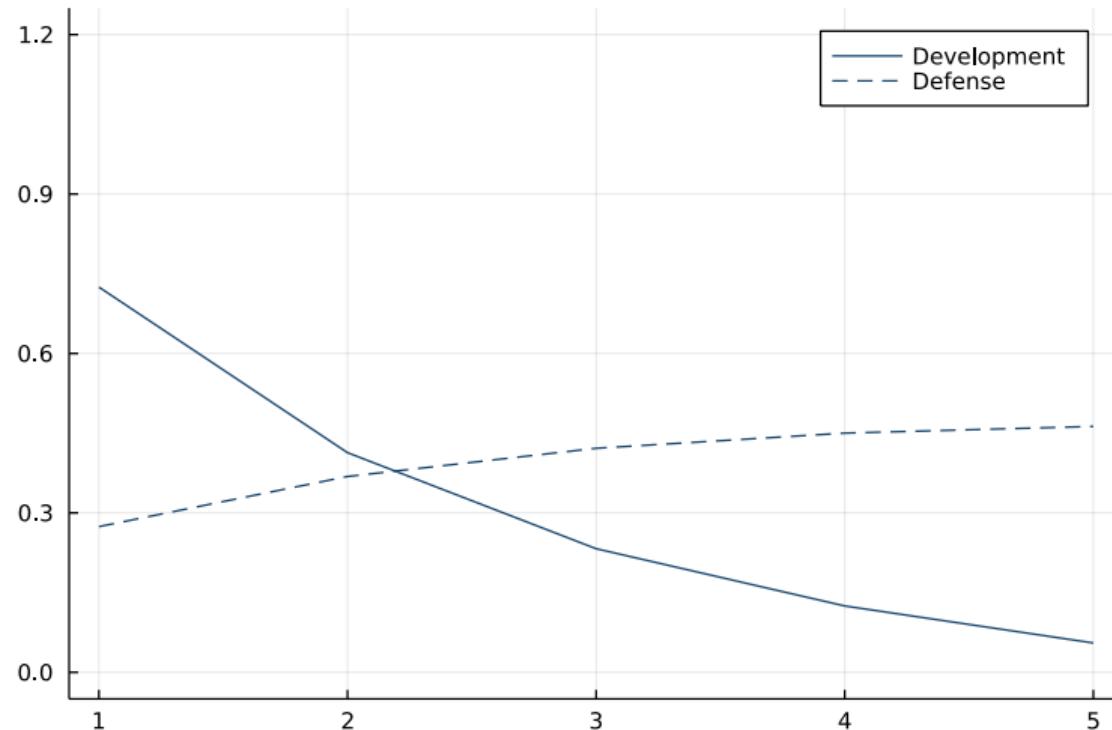


Coastal over-development and over-defense



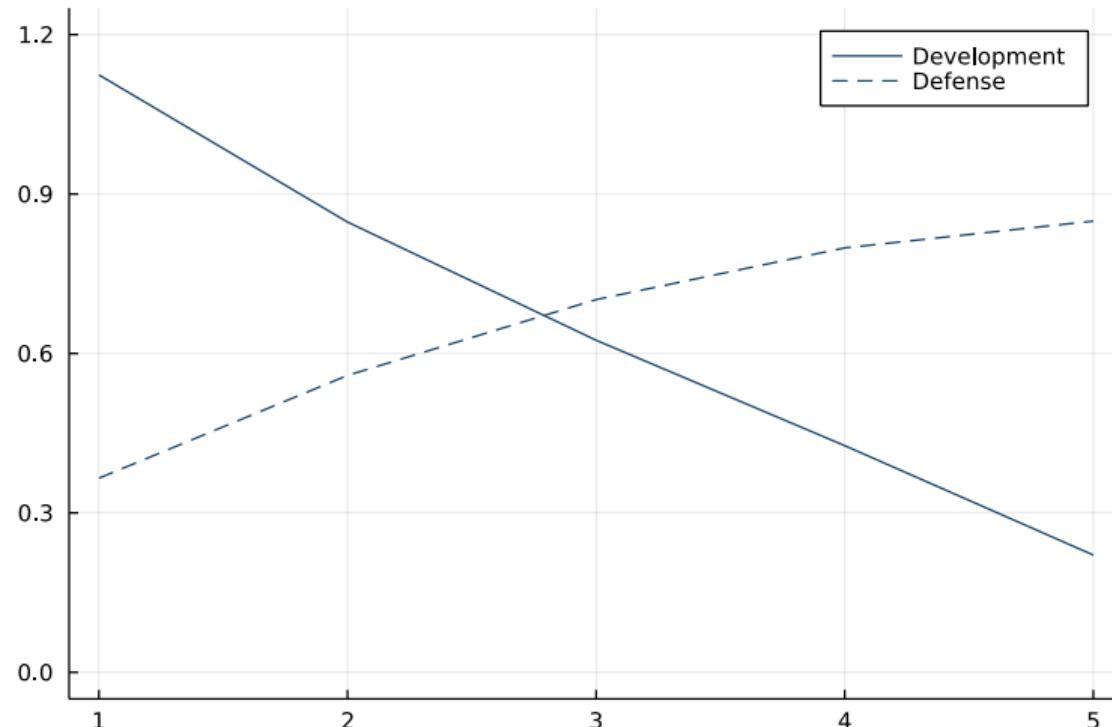
Development and defense over time

Full commitment



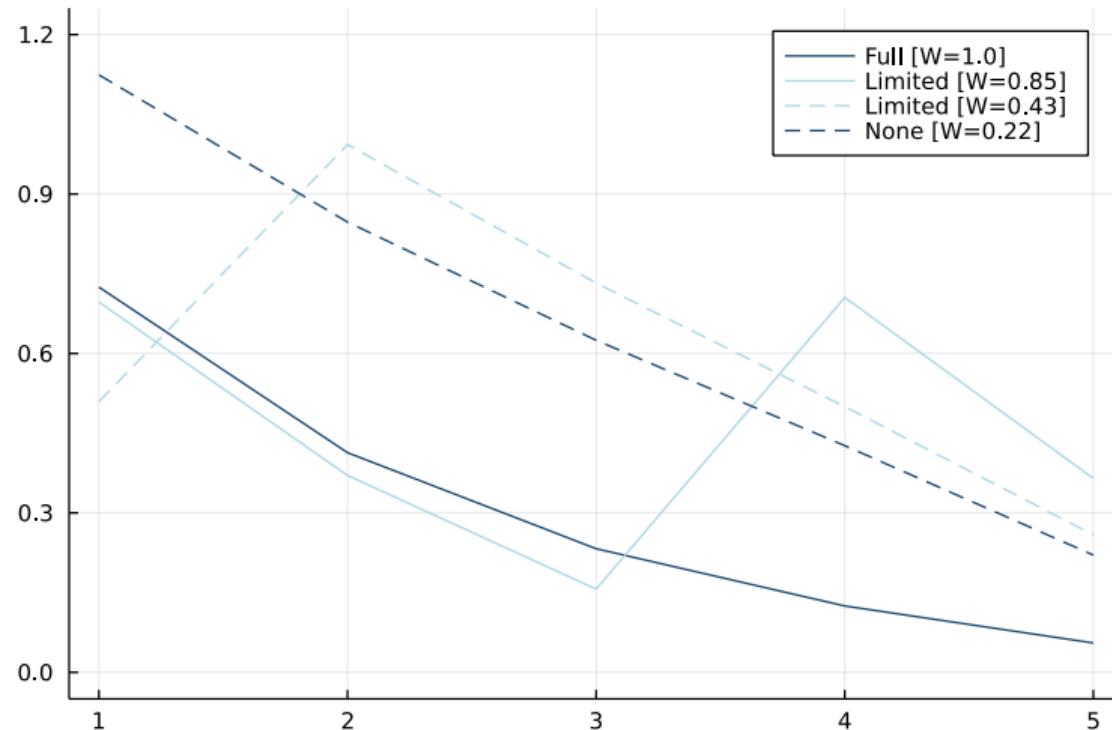
Development and defense over time

No commitment



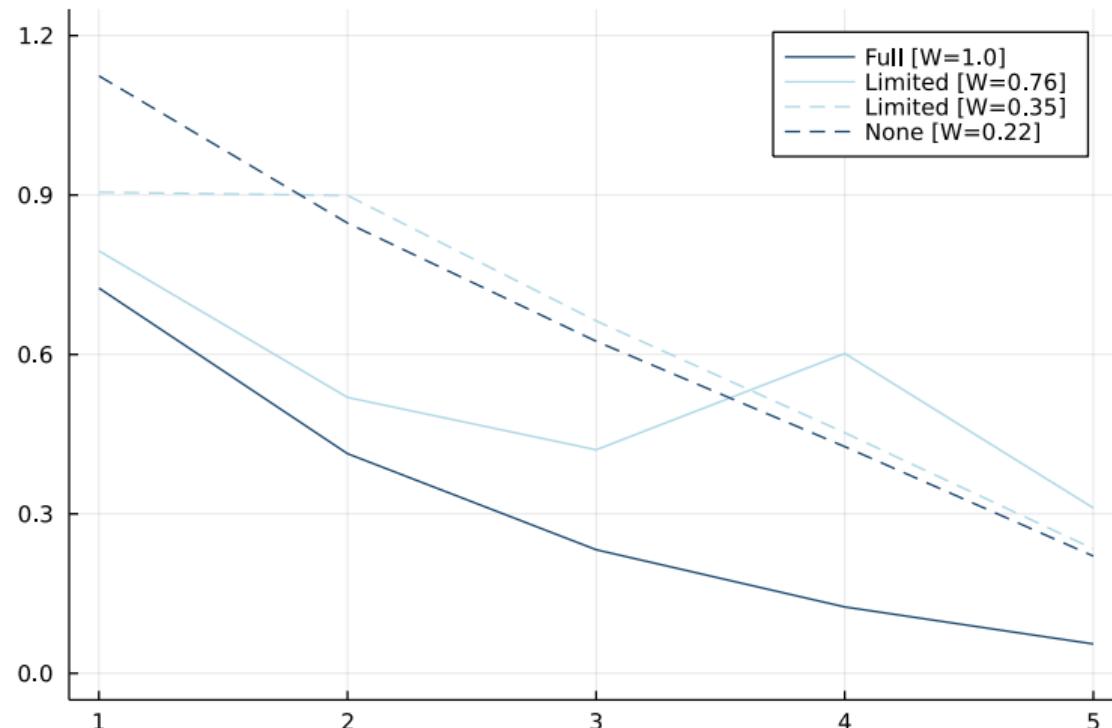
Limited commitment (development)

Forward-looking



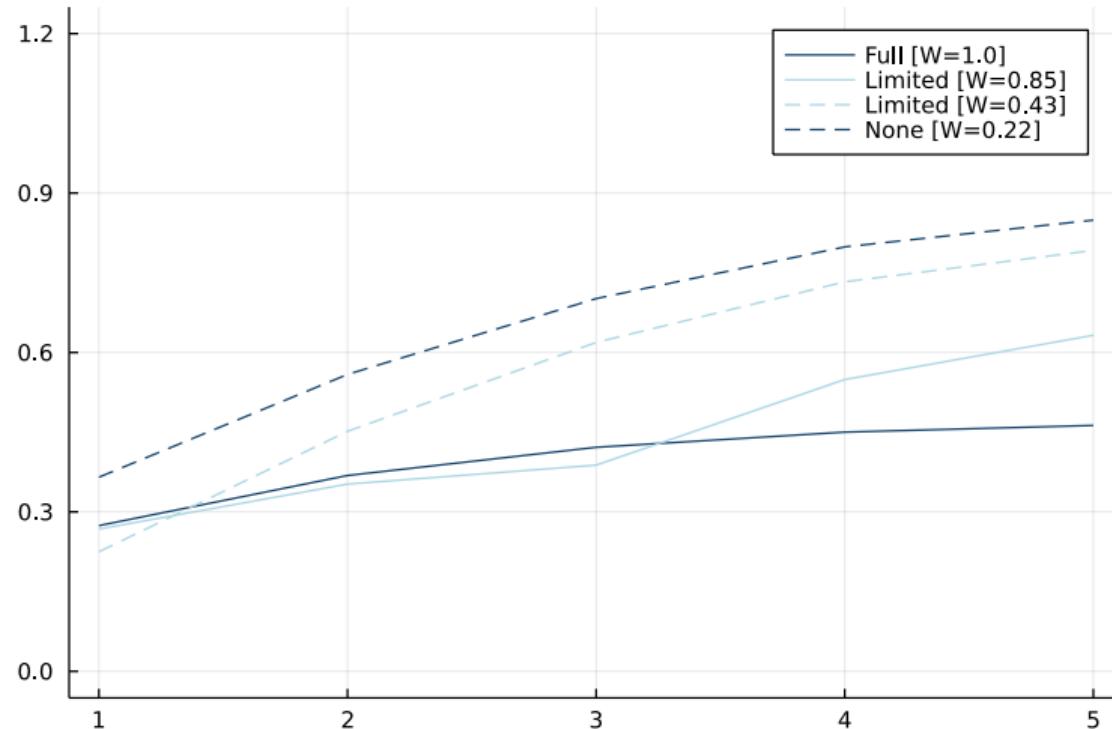
Limited commitment (development)

Politically myopic



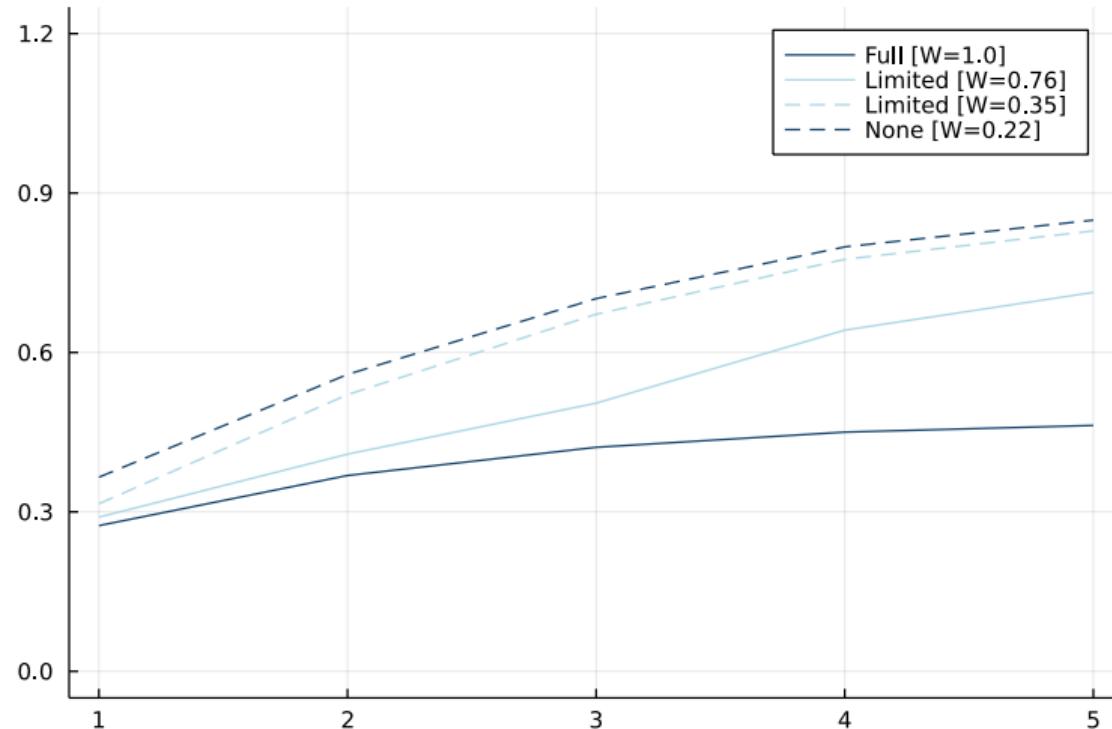
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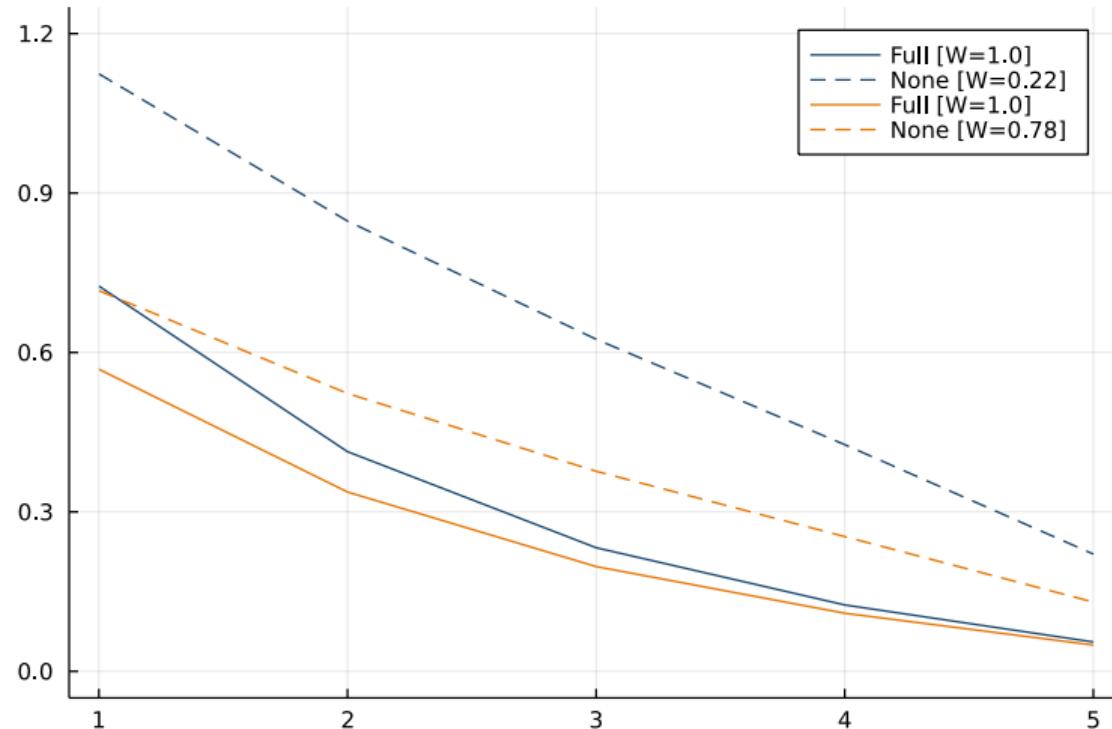
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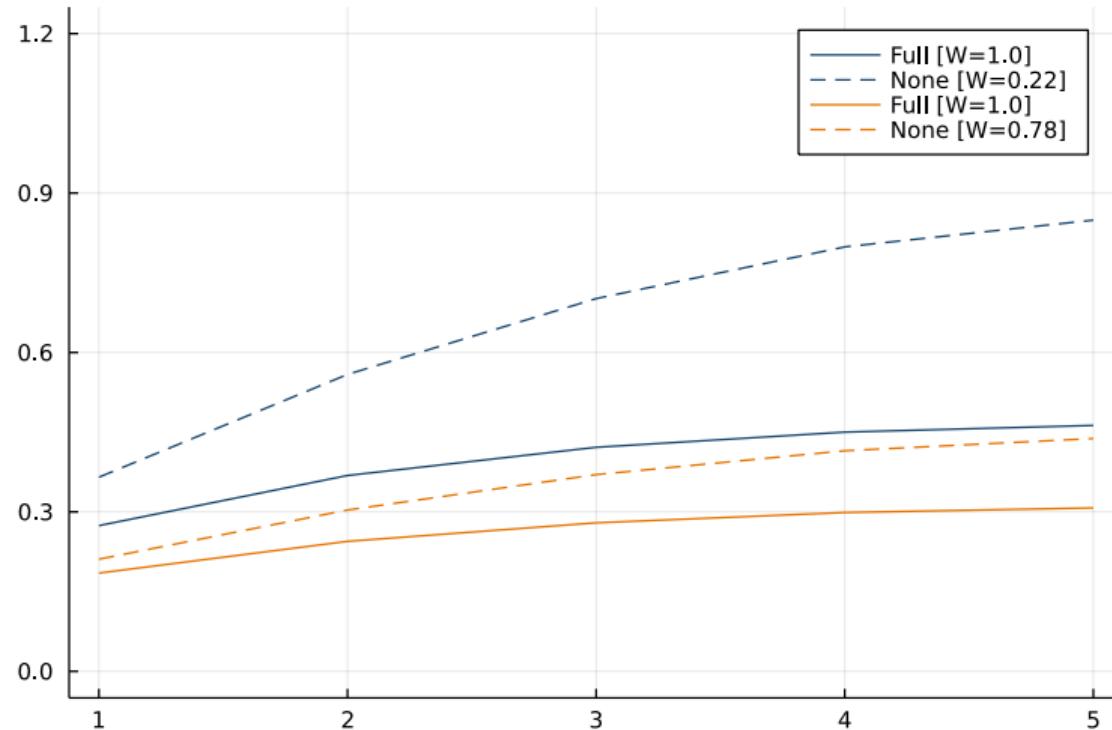
Reducing coastal demand

Development



Reducing coastal demand

Defense



Policy implications

① Political economy matters

- Commitment is the simple theoretical solution, but difficult in practice
- Politics can hinder adaptation and exacerbate damages

② Some policies are more politically feasible

- Encourage vs. punish, indirect vs. direct (e.g., inland subsidies)
- Even if below the theoretical first best

③ Policy has dynamic effects

- Persistence amplifies good policy, even if temporary
- Interactions across administrations add to moral hazard

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 $W_1 + \beta W_2$.

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

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

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

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Commitment over time (3)

Lock in: over-development today raises development tomorrow.

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

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

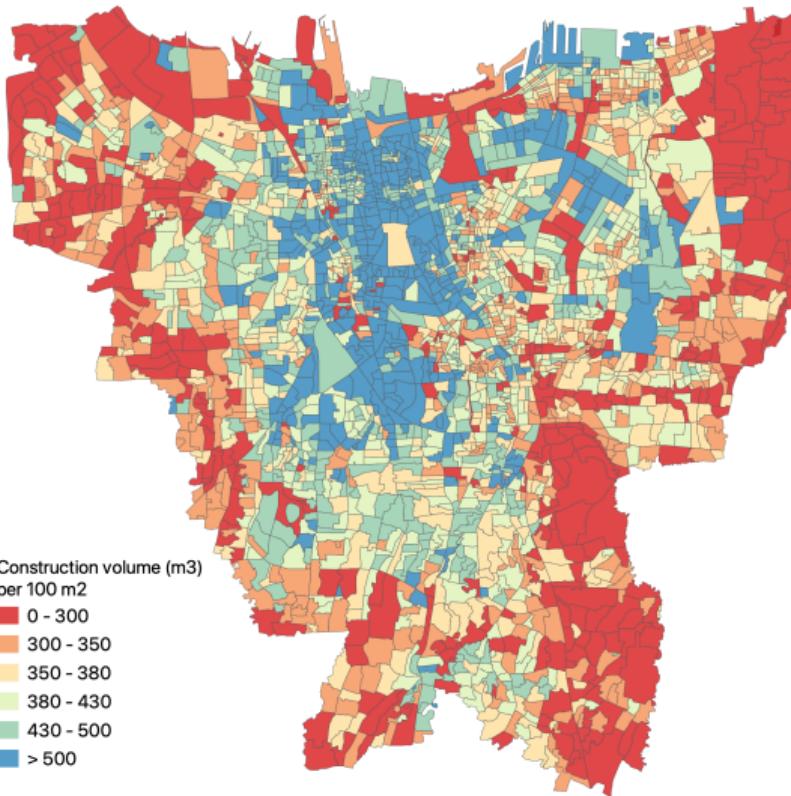
$D_1 \uparrow$ implies $G_2 \uparrow$ given more to defend.

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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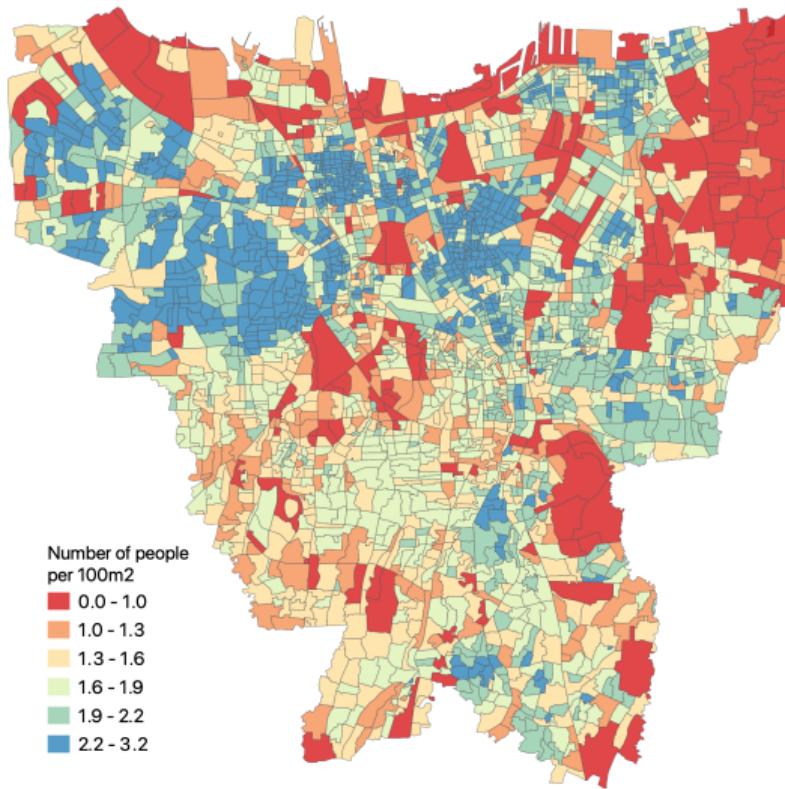
Building construction

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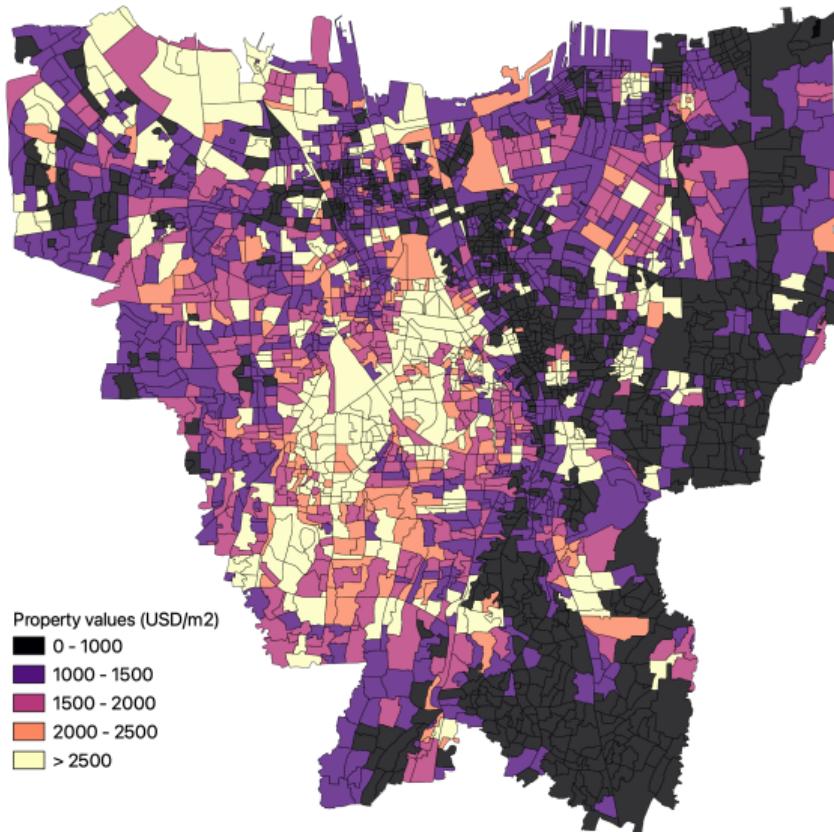
Populations

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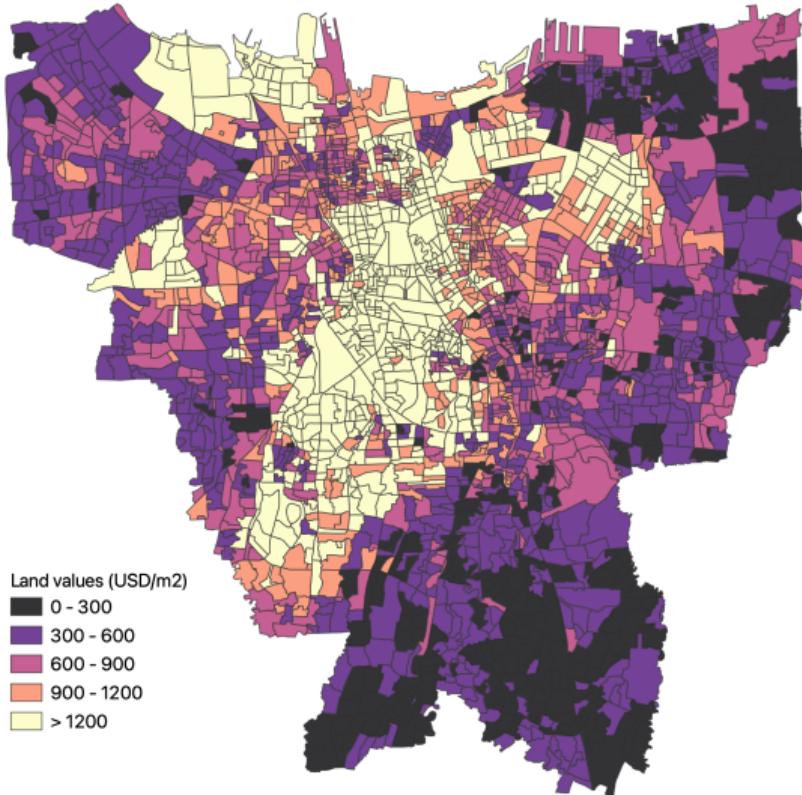
Property values

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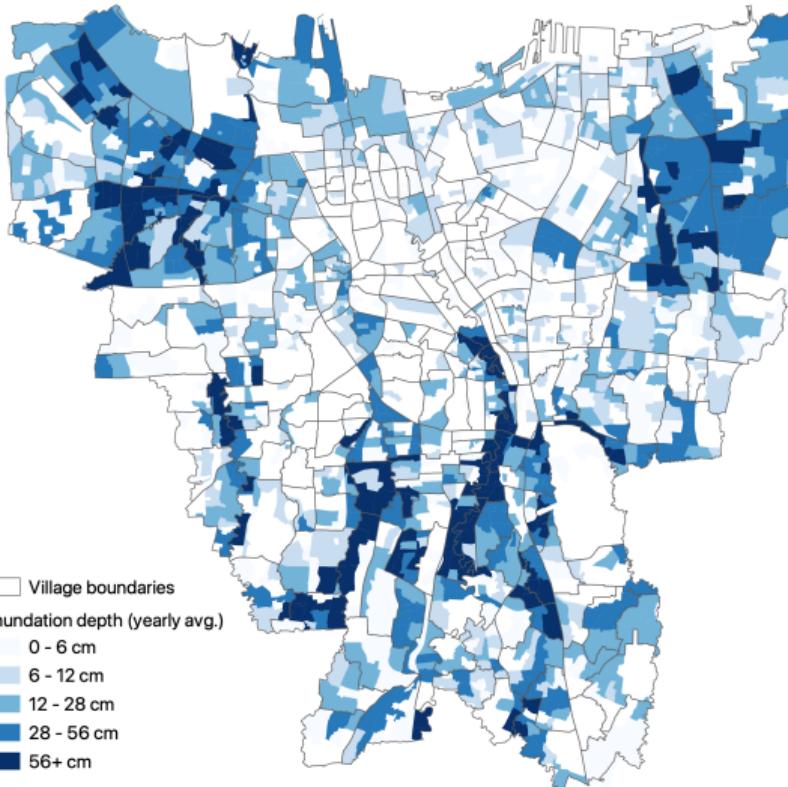
Land values

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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

$$n_k = \frac{\lambda}{\varphi} D_k^{\text{res}}(\delta, \theta_2)$$

- ② Estimate $\theta_1 = (\alpha, \phi, \gamma)$ and ε by regression

$$\varepsilon_k = \delta_k - \alpha r_k - \phi f_k - x_k \gamma$$

- ③ Estimate θ_2 by minimizing GMM objective function

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