Sea Level Rise and Urban Adaptation in Jakarta

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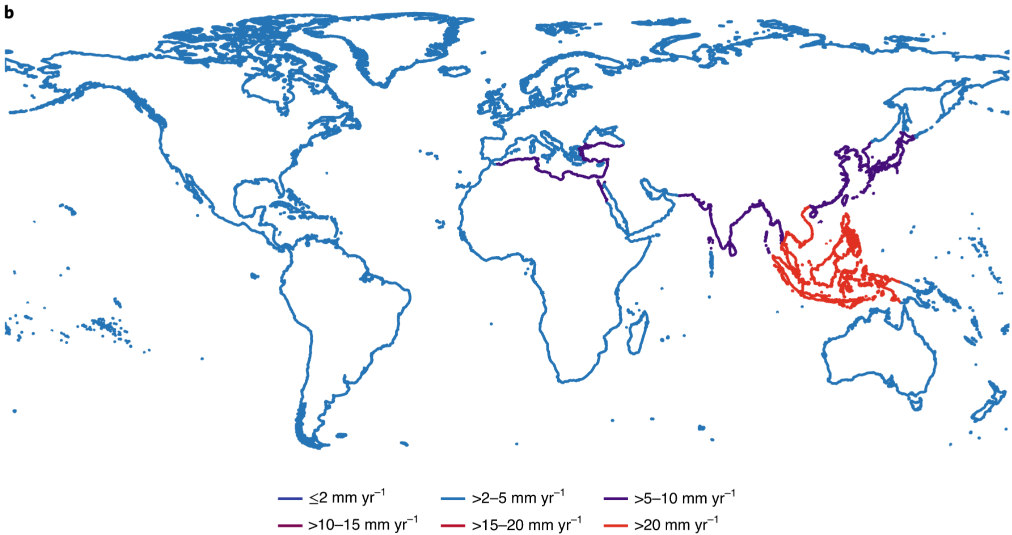
Sea levels are rising globally (Nicholls et al. 2021)

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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 effective are these investments for Jakarta?**
  - How does government intervention affect long-run adaptation?

This paper

- **Dynamic spatial model** of coastal development and government defense
  - Applied to planned government intervention in Jakarta

- Long-run adaptation requires moving inland, but
  1. Moral hazard from government intervention
  2. Lock-in from durable capital

- **Result:** limited adaptation without government commitment

Contributions

- **Frictions facing adaptation** to coastal flooding
  - Kydland & Prescott 1977, Glaeser & Gyourko 2005, Vigdor 2008, Boustan et al. 2012, Balboni 2021, Desmet et al. 2021, Baylis & Boomhower 2022, Fried 2022
- **Dynamic spatial methods**
  - Dynamics: Hopenhayn 1992, Ericson & Pakes 1995, Hall 1978, Hansen & Singleton 1982, Hotz & Miller 1993, Arcidiacono & Miller 2011, Aguirregabiria & Magesan 2013, Scott 2013, Kalouptsidi 2014, Kalouptsidi et al. 2021
  - Spatial: Desmet et al. 2018, Caliendo et al. 2019, Kleinman et al. 2022
- Empirical estimates for **Jakarta**
  - Budiyono et al. 2015, Takagi et al. 2016, Wijayanti et al. 2017, Andreas et al. 2018

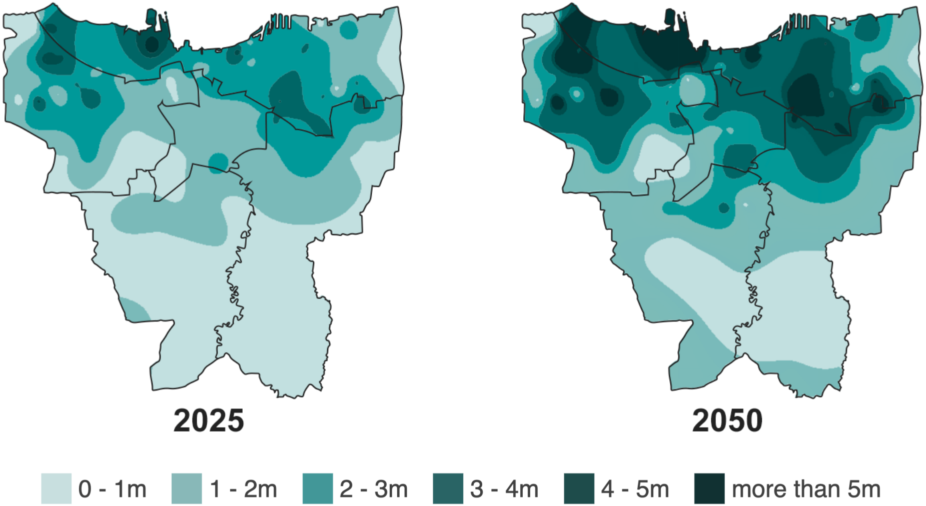
Outline

1. **Setting**
2. **Theory**
3. **Empirics**
4. **Simulations**

Setting

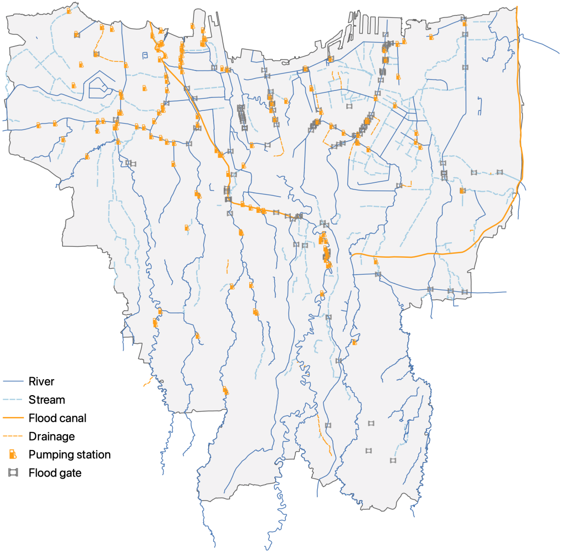

PaninBank

Future land subsidence (SLR 1m by 2100)



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

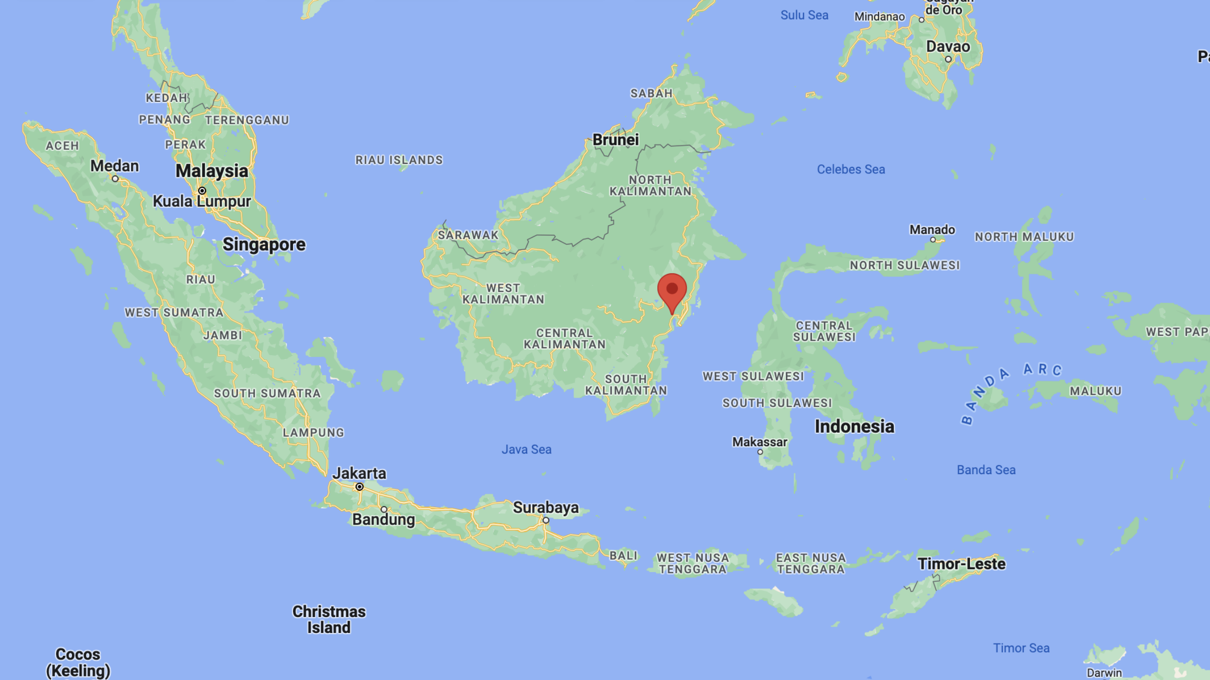
Tahap B

Konstruksi: 2018-2022
Flood Safety: 2030

Tahap C

Konstruksi: 2022

Jalan Cilincing
Tol
Jalan Kamal Raya
Jalan Tipar Cakung
Jakarta
Jalan Bekasi Raya
Jalan Tol Lingkar
Jalan Pemuda
Kebon Jeruk
1
2
13



Sulu Sea
Mindanao
de Oro
Davao
KEDAH
PENANG
TERENGGANU
PERAK
ACEH
Medan
Malaysia
Kuala Lumpur
RIAU ISLANDS
SABAH
Brunei
Celebes Sea
NORTH KALIMANTAN
Singapore
SARAWAK
Manado
NORTH MALUKU
NORTH SULAWESI
RIAU
WEST KALIMANTAN
WEST SUMATRA
JAMBI
CENTRAL KALIMANTAN
CENTRAL SULAWESI
WEST PAP
BANDA ARC
SOUTH KALIMANTAN
WEST SULAWESI
MALUKU
SOUTH SUMATRA
SOUTH SULAWESI
Indonesia
LAMPUNG
Makassar
Java Sea
Banda Sea
Jakarta
Surabaya
Bandung
BALI
WEST NUSA TENGGARA
EAST NUSA TENGGARA
Timor-Leste
Christmas Island
Cocos (Keeling)
Timor Sea
Darwin


PUPR
SIGAP MEMBANGUN NEGERI

Theory

Development and defense at the coast

1. **Developers** choose d_t at cost $c(d_t)$ for $c'' > 0$
   - Total $D_t = D_{t-1} + d_t$ (dynamics)
2. **Government** chooses g_t at cost $f(g_t)$ for $f'' > 0$
   - Total $G_t = g_t$ (repeated intervention)
3. **Residential value** $r(D_t, g_t)$ for $\kappa = r_{dg} > 0$
   - Demand curve $r_d(D_t, g_t)$ (aggregate risk)
   - Shifted up by defense g_t (complementarity)

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Commitment

$$W = r(d,g) - c(d) - f(g)\,, \quad \pi = r'(d) + \kappa g'(d) - c'(d)$$

- The **social planner** maximizes welfare $W(d,g)$

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

- **Developers** consider profits $\pi(d)$, and the **government** welfare $W(\cdot,g)$

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

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

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

Commitment (2)

- Solution 1: **commit** to g^*
  - $g'(d) = 0$ implies $\kappa g'(d) = 0$
  - 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

Commitment over time

1. Moral hazard arises across periods
   - Developers exploit both current and future governments
   - Current governments may exploit future governments
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

Flood risk $\downarrow$ $\Rightarrow$ land value $\uparrow$ $\Rightarrow$ construction $\uparrow$

	Land value ($/m^2)			
Flood risk (m/yr)	-2.31***	-1.29***	-0.59**	-0.93***
	(3.00)	(3.12)	(2.15)	(2.78)
District FE		x		
Sub-district FE			x	
Neighborhood FE				x
Observations	2,777	2,777	2,777	2,777

Flood risk $\downarrow$ $\Rightarrow$ land value $\uparrow$ $\Rightarrow$ construction $\uparrow$

	Building construction (m^3)			
Land value ($\$/m^2$)	0.21***	0.27***	0.37***	0.30***
	(0.03)	(0.03)	(0.05)	(0.05)
District FE		x		
Sub-district FE			x	
Neighborhood FE				x
Observations	2,777	2,777	2,777	2,777

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)
  - Rent r_k, flood safety s_k, amenity ξ_k, distance m_{jk}, logit shock ϵ_{ijk}
  - Moving inland abandons high-amenity places and incurs migration costs
  - Will add firms to endogenize (some) amenities

- **Estimation** with population shares and instruments (BLP 1995) Details
  - Price endogeneity from correlation of rents and unobserved amenities
  - IV with soil quality and ruggedness as supply shifters

Supply from developers

$$
\begin{aligned}
V_k(w_t) &= r_k(w_t)D_{kt} + \mathbb{E}_{kt}[\max\{v_k^1(w_t) + \epsilon_{kt}^1, v_k^0(w_t) + \epsilon_{kt}^0\}] \\
v_k^1(w_t) &= -c(x_{kt}, \zeta_{kt}) + \beta\mathbb{E}_{kt}[V_k(w_{t+1}^1)] \\
v_k^0(w_t) &= \beta\mathbb{E}_{kt}[V_k(w_{t+1}^0)]
\end{aligned}
$$

- **Dynamic model** of developer choice (tract k, time t, $\mathbb{E}_{kt} = \mathbb{E}_k[\cdot|w_t]$)
  - State $w_t = (\{D_{kt}\}, \{G_{kt}\})$, rent $r_k(w_t)$, cost c_{kt}, logit shocks $(\epsilon_{kt}^1, \epsilon_{kt}^0)$
  - 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

Data as continuation values

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

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

- Property and land values as V^1, V^0, and numeraire
  - Still need atomistic developers
  - Don't need $t+1$ data, rent data, or long-lived developers
  - Rational expectations by market instead of by individual developers
  - Net of future demand, supply, and government intervention (including $t+1$)
  - Flow costs capitalize into property and land values

Euler CCPs

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

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

- Today vs. tomorrow as Euler perturbation, $\Delta X_{kt} = X_{kt} - \beta X_{kt+1}$ (Scott 2013)
  - Need atomistic, long-lived developers with rational expectations, no depreciation
  - Need $t+1$ data and rents as mortgage payments (or rent data)

Rents

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

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

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

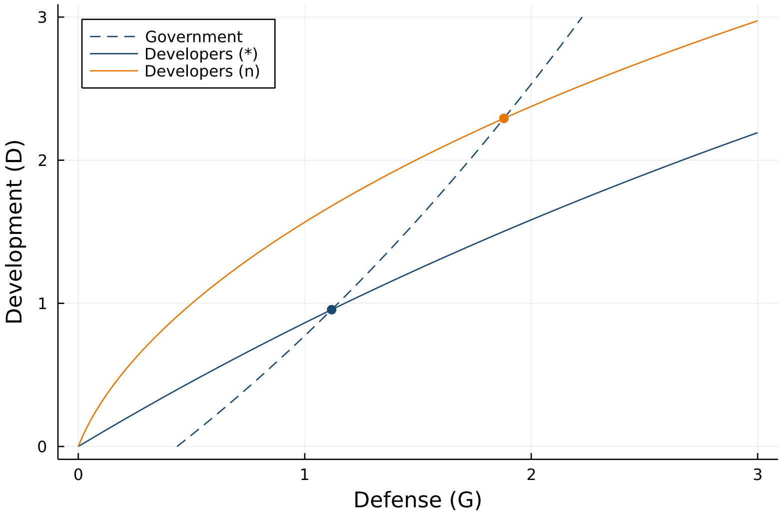
Government

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

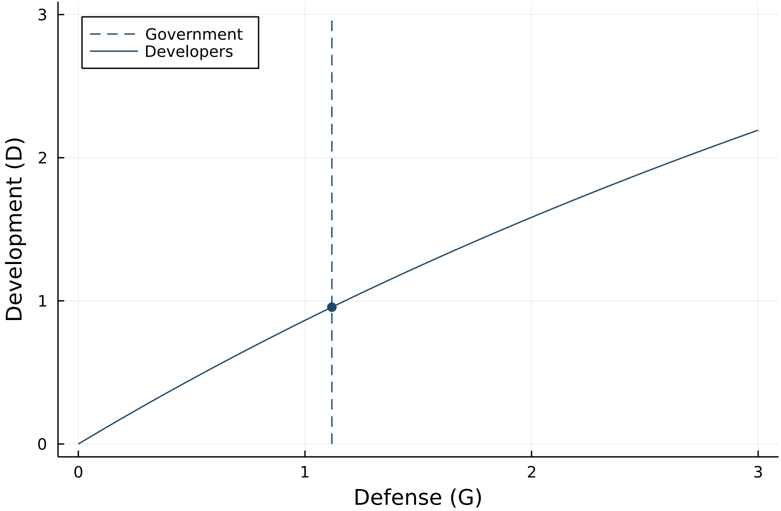
- Intervention increases flood safety in affected parcels
  - Resident demand $\uparrow$, so rents rise
  - Then developer supply $\uparrow$, attentuating rise in rents

Simulations

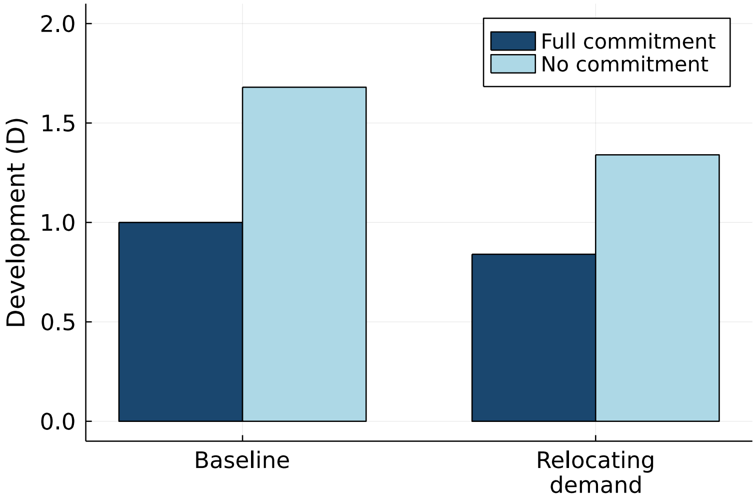
Over-development and over-defense



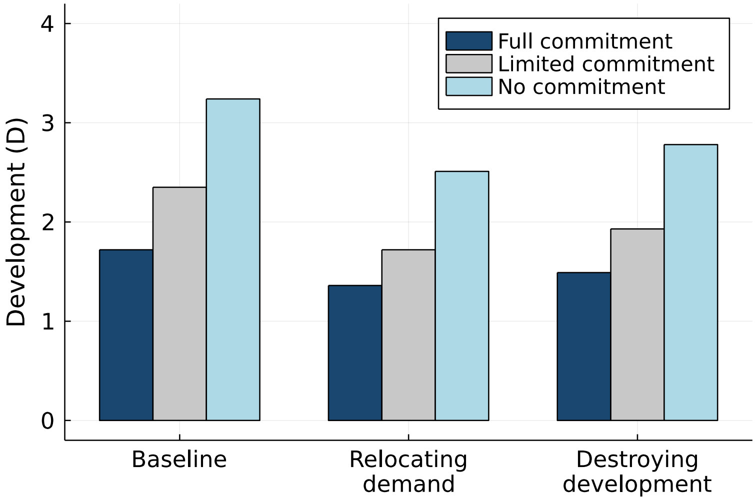
Over-development and over-defense



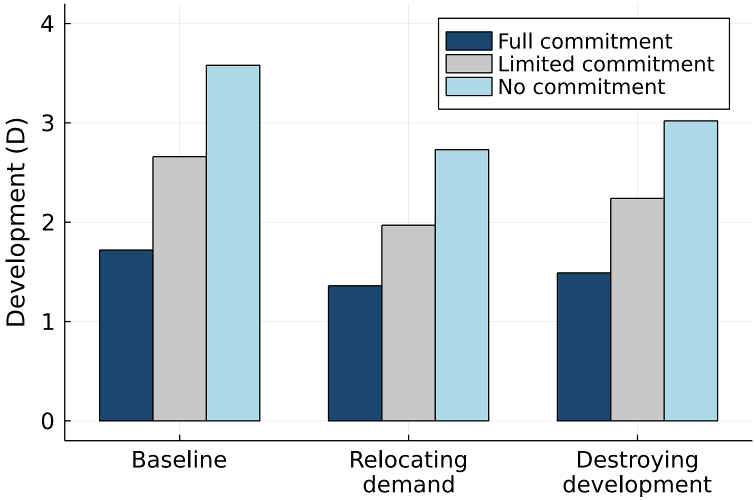
Short-run development



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)

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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 $f(G_2)$

Back

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 $f(G_2)$

Back

Commitment over time (2)

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

$$\begin{array}{ll} [D_1^*] & \tilde{r}(G_1, G_2) = c'(D_1) \\ [G_1^*] & r'(G_1) D_1 = f'(G_1) \end{array}$$

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

Back

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

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

$$[D_1] \quad \tilde{r}(G_1, G_2) = c'(D_1) + \beta r'(G_2) D_2 G_2'$$
$$[G_1] \quad r'(G_1) D_1 = f'(G_1) + \beta r'(G_2) D_2 G_2'$$

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

$$\begin{aligned} [D_1] &\quad \tilde{r}(G_1, G_2) + r'(G_1) D_1 G_1' + \beta r'(G_2) D_1 G_2' = c'(D_1) \\ [G_1] &\quad r'(G_1) D_1 = f'(G_1) + \beta r'(G_2) D_2 G_2' \end{aligned}$$

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

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

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

Back

Commitment over time (3)

Lock in: over-development today raises development tomorrow.

$$\begin{aligned}
[D_2] \quad & r(G_2) + r'(G_2)D_2G_2' = c'(D_2)\,, \\
[G_2] \quad & r'(G_2)(D_1 + D_2) = f'(G_2)\,,
\end{aligned}$$

$D_1 \uparrow$ 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

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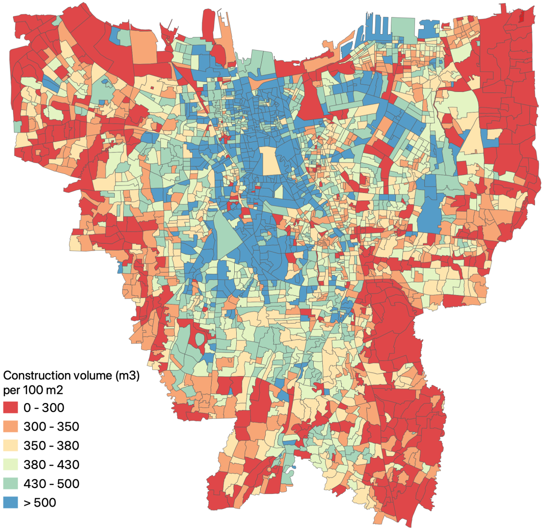
Back

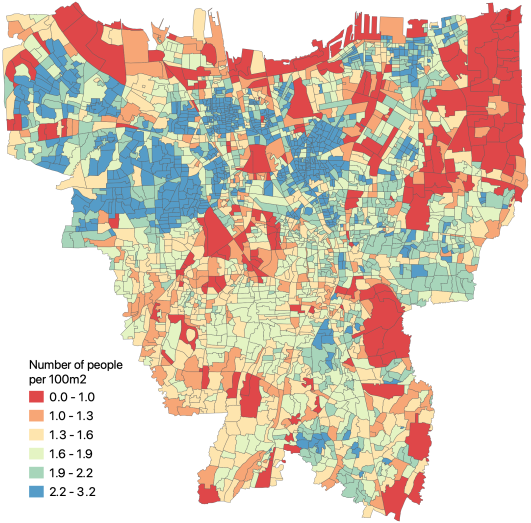
Building construction

Back



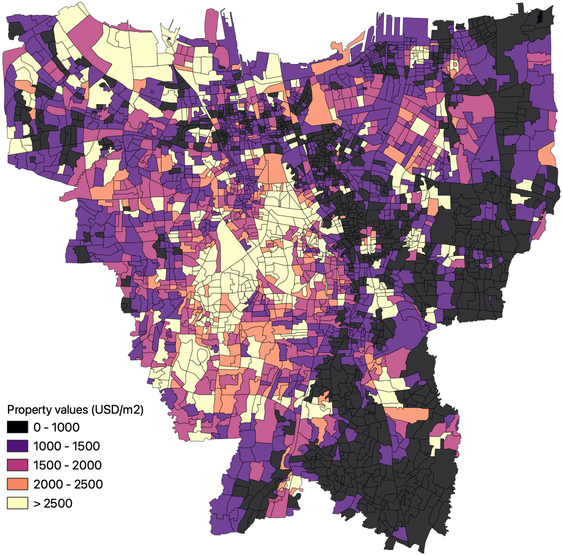
Populations

Back



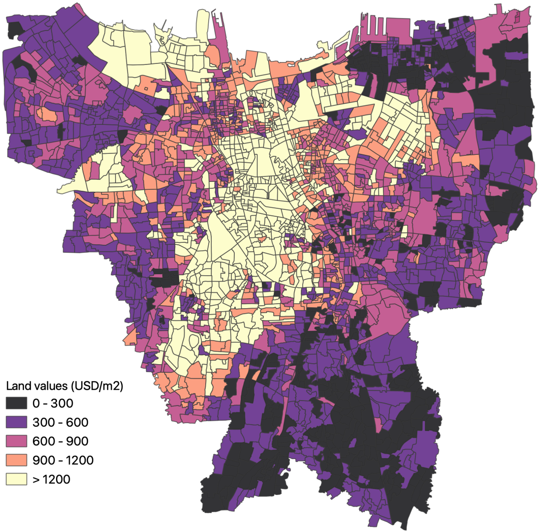
Property values

Back



Land values

Back



Flood risk

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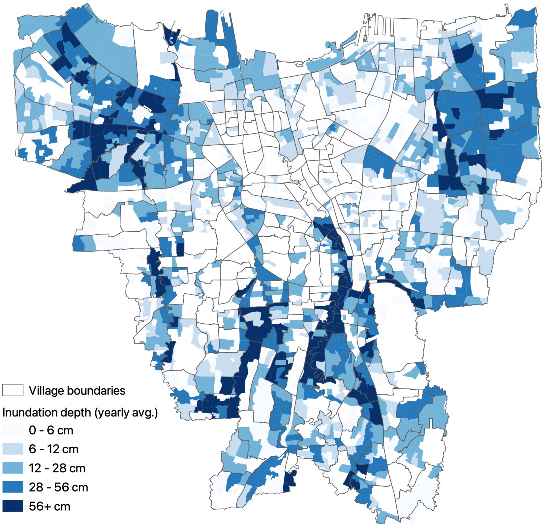

Estimating demand

- 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

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

Back