# Sea Level Rise and Urban Adaptation in Jakarta

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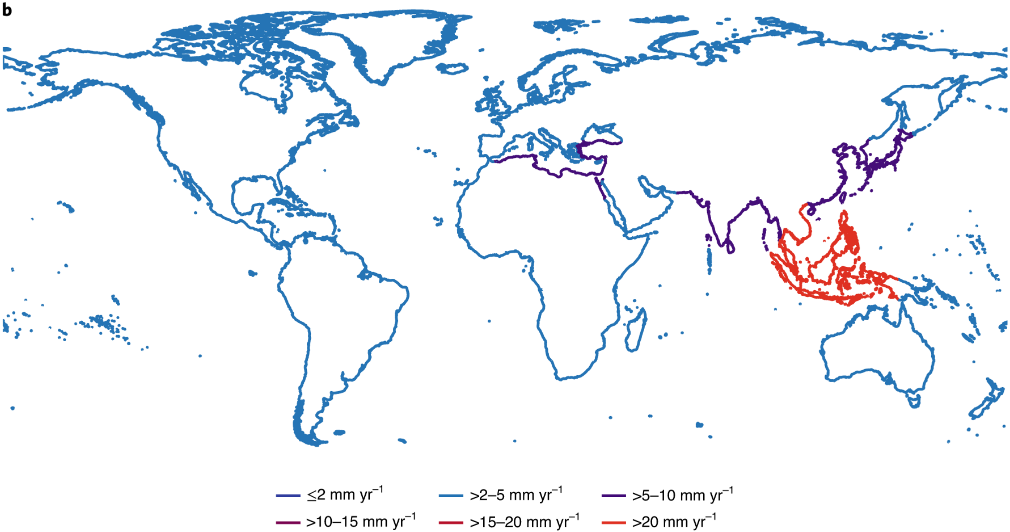
# Sea levels are rising globally (Nicholls et al. 2021)




#CLIMATE NO JUSTICE

# 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

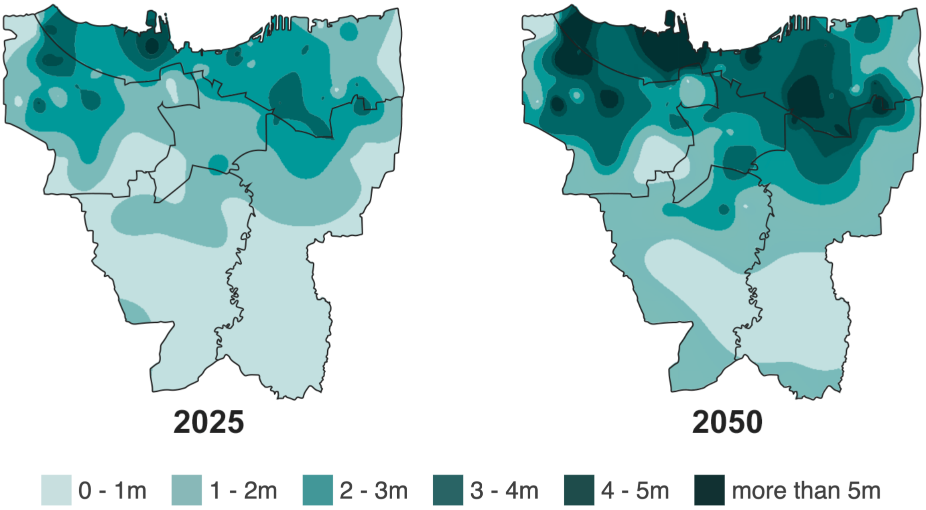
# Outline

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

# Setting

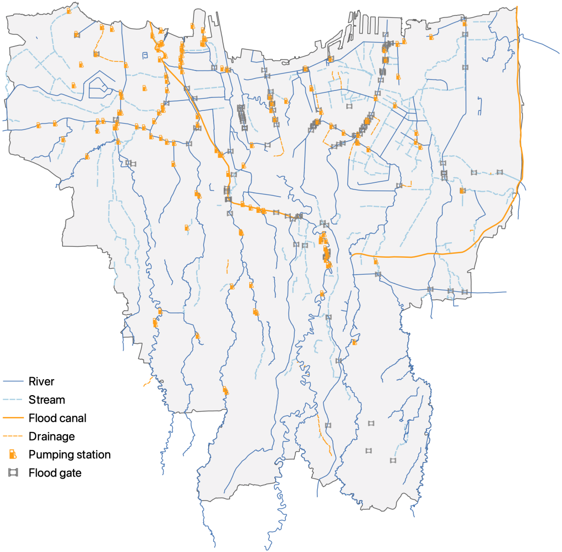

PaninBank

# 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

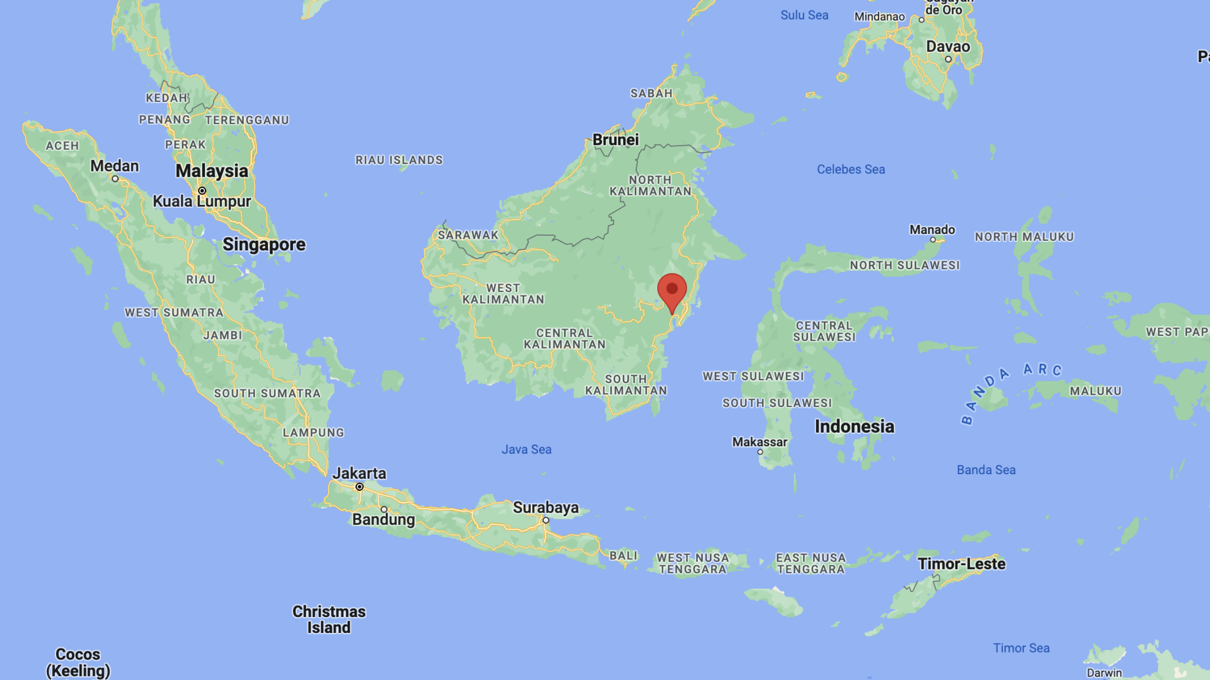
**Sumber:** *Kementerian PU-Pera, berbagai sumber, diolah*


## Target Konstruksi

### Tahap A
Konstruksi: 2014-2017
Flood safety: 2030

### Tahap B
Konstruksi: 2018-2022
Flood Safety: 2030

### Tahap C
Konstruksi: 2022


Sulu Sea
Mindanao
de Oro
Davao
SABAH
Brunei
KEDAH
PENANG
TERENGGANU
PERAK
ACEH
Medan
Malaysia
Kuala Lumpur
RIAU ISLANDS
NORTH KALIMANTAN
Celebes Sea
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

# 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, no $f$)

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# Moral hazard

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

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

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

$$\begin{array}{ll} [d^n] & r'(d) + r'(g)\,g'(d) = c'(d) \\ [g^n] & r'(g) = f'(g) \end{array}$$

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

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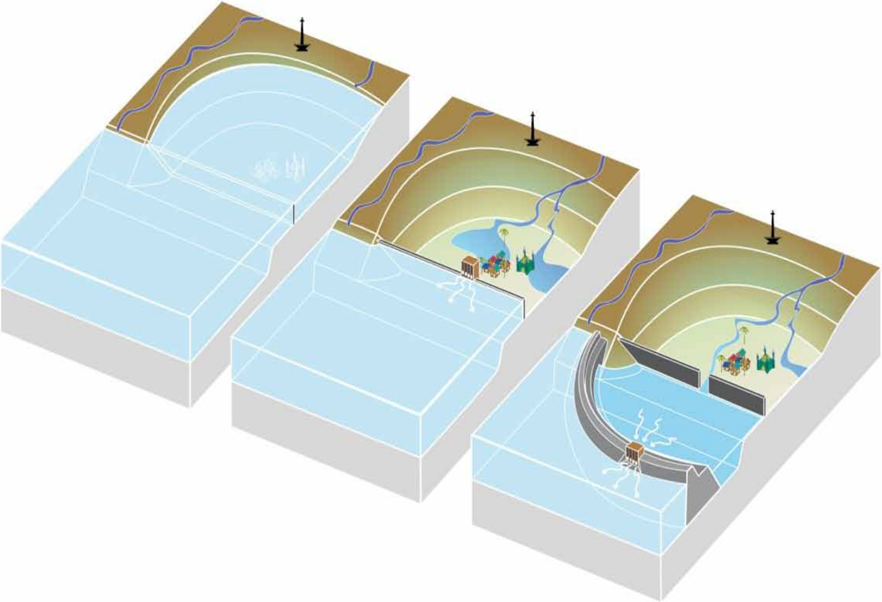
- Moral hazard when $g'(d) > 0$ implies $d^n > d^* > 0,\ g^n > g^* > 0$

# 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
- 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
  - [If $g(d) = 0$, no moral hazard but also no intervention to begin with]



# 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

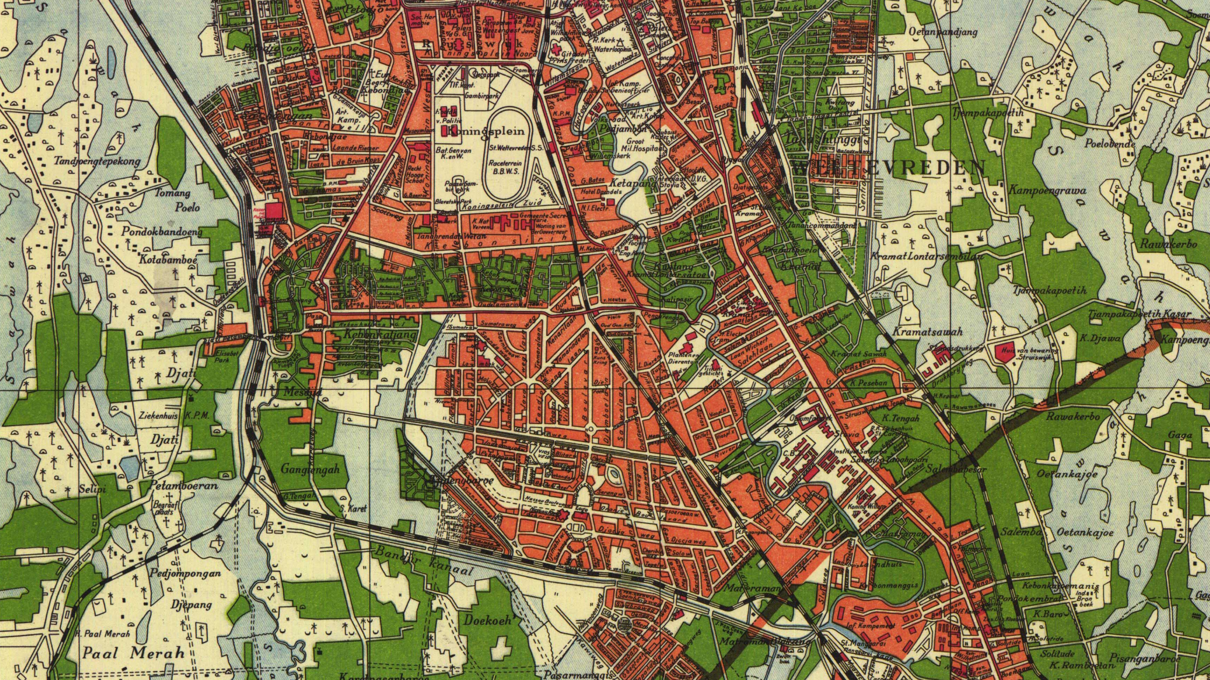
# Empirical framework

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

- $r(d, s(g))$: **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 |


Rijswijk
Koningsplein
Koningsplein Zuid
Gambirpark
St. Weltevreden S.S.
Raceterrein B.B.W.S.
WELTEVREDEN
Pedjambon
Groot Mil. Hospitaal
Willemskerk
Ketapang
Kwitang
Kalipasir
Kramat
Tanahrendah Wetan
Kebonsirih
Sumatraweg
Tandjoengtepekong
Tomang
Poelo
Pondokbandoeng
Kotabamboe
Kebonkatjang
Djati
Mesdjid
Ziekenhuis
K.P.M.
Selipi
Petamboeran
Gangtengah
Pedjompongan
Djepang
Paal Merah
Doekoeh
Bandjir kanaal
Materaman
Salemba
Salembabesar
Oetankajoe
Oetanpandjang
Tjempakapoetih
Tjempakapoetih Kasar
Poelobende
Kampoengrawa
Rawakerbo
Kramat Lontarsembilan
Kramatsawah
Kramat Sawah
K. Djawa
Gaga
K. Tengah
K. Baroe
Solitude
K. Ramboetan
Pisanganbaroe
Pasarmanggis

# 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) Details
  - Price endogeneity from correlation of rents and unobserved amenities
  - IV with soil quality and ruggedness as supply shifters

# Demand estimates

| **First stage** | Rents |
|---|---|
| Ruggedness | 0.010*** |
| | (0.001) |
| Flood safety | 7.888** |
| | (4.018) |
| Coastal distance | -0.630*** |
| | (0.082) |
| District FE | x |
| Observations | 2,181 |
| F-stat | 76.38 |

| **IV** | Population |
|---|---|
| Rents | -0.113*** |
| | (0.019) |
| Flood safety | 1.031** |
| | (0.507) |
| Coastal distance | -0.072*** |
| | (0.016) |
| District FE | x |
| Observations | 2,181 |

# 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

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

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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

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

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

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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

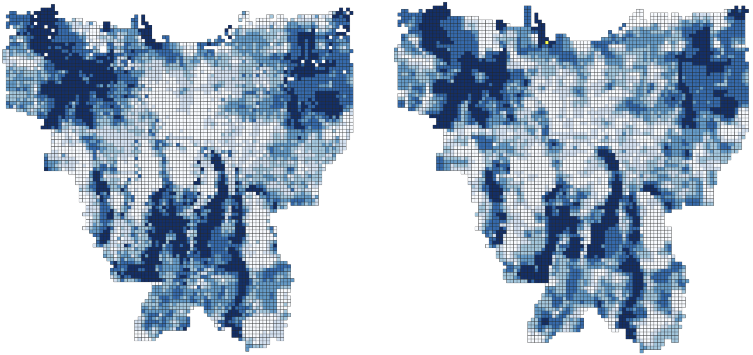
$$D_{kt}^{\text{res}} = D_{kt}^{\text{dev}}$$

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

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

# Flood risk

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



Predicted vs. observed

## Government

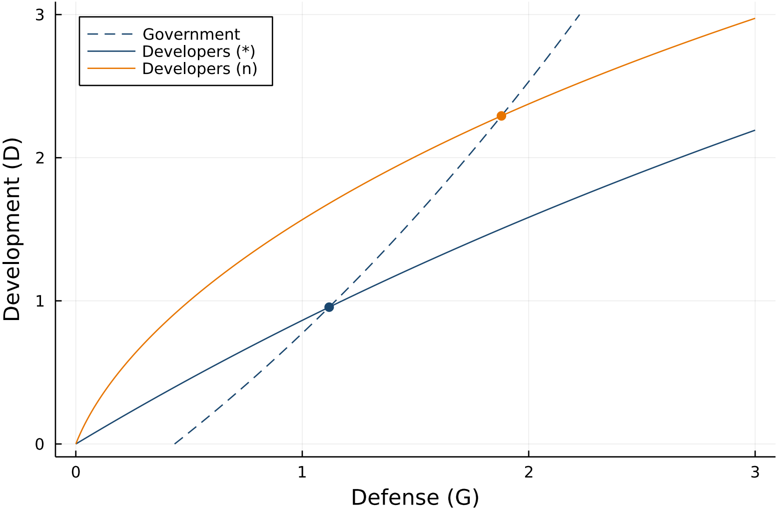
- Commitment level and political turnover by assumption
  - Hydrological model of flood risk $s_k(G)$
  - Engineering estimates of costs $f(G)$

- Counterfactuals

$$\begin{aligned} \text{Defense } g &\rightarrow \text{ flooding } s \text{ by } \textbf{hydrological} \text{ model} \\ &\rightarrow \text{ rents } r \text{ by } \textbf{demand} \text{ model} \\ &\rightarrow \text{ development } d \text{ by } \textbf{supply} \text{ model} \end{aligned}$$

# Simulations

# Over-development and over-defense



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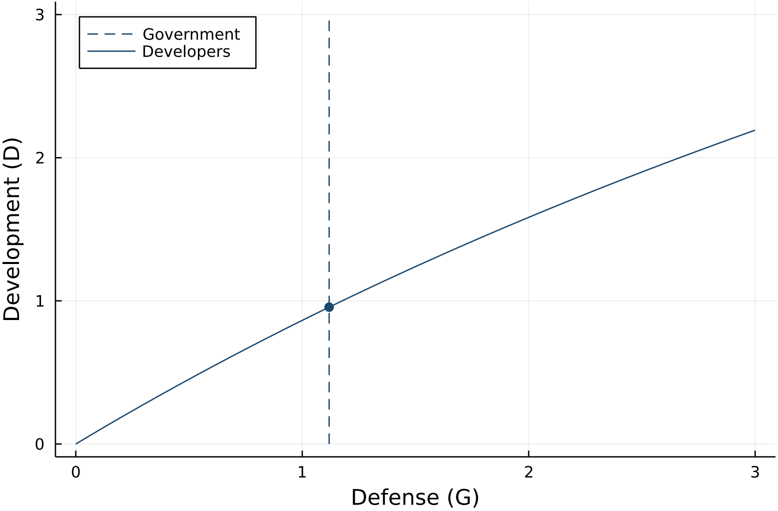
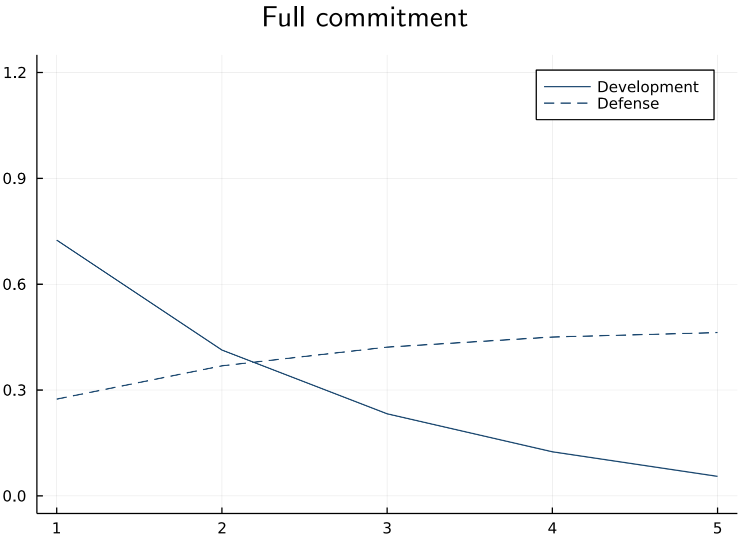


# Development and defense



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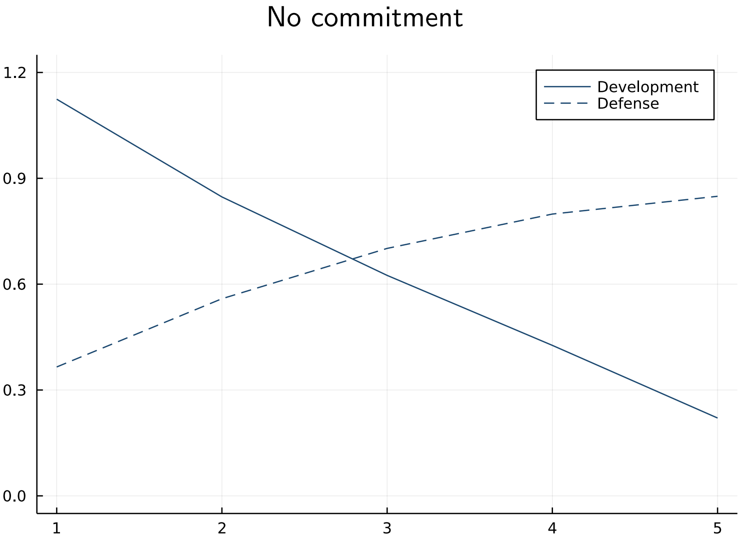

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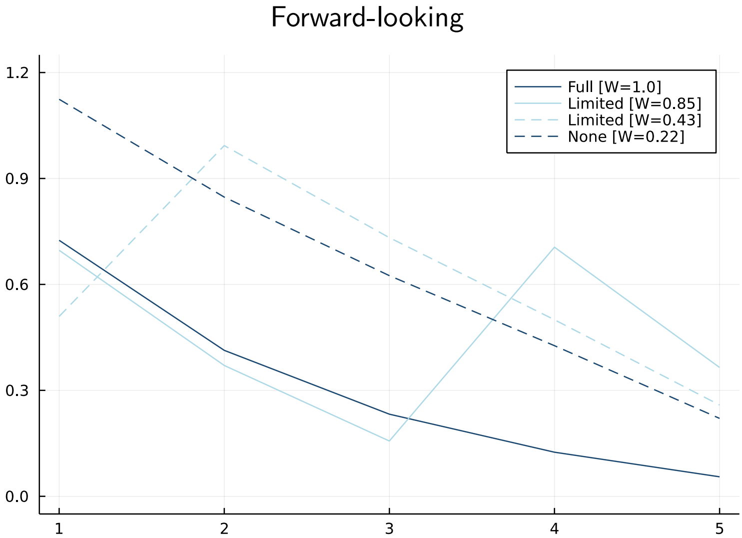

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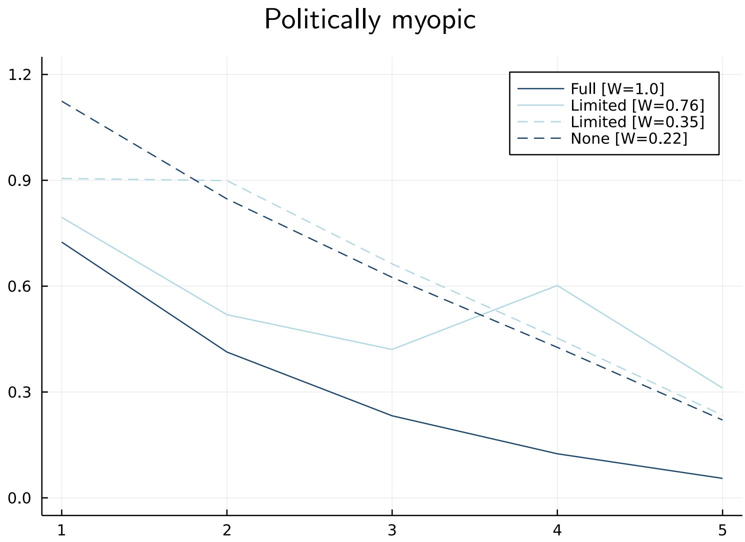

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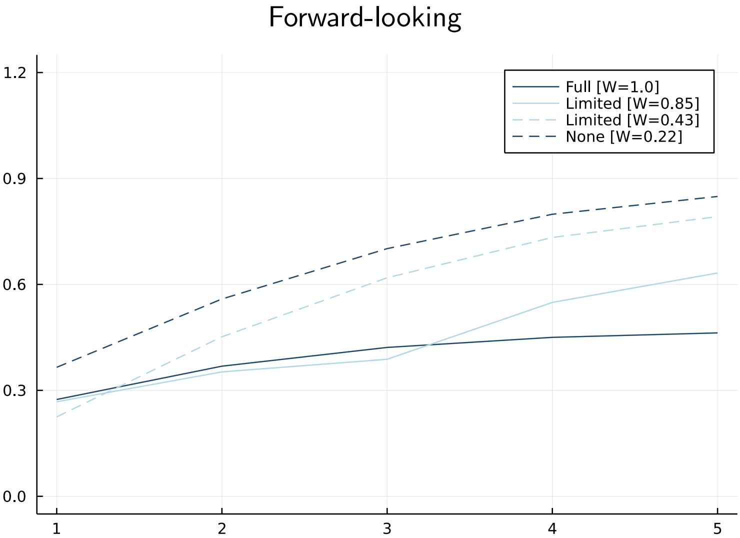
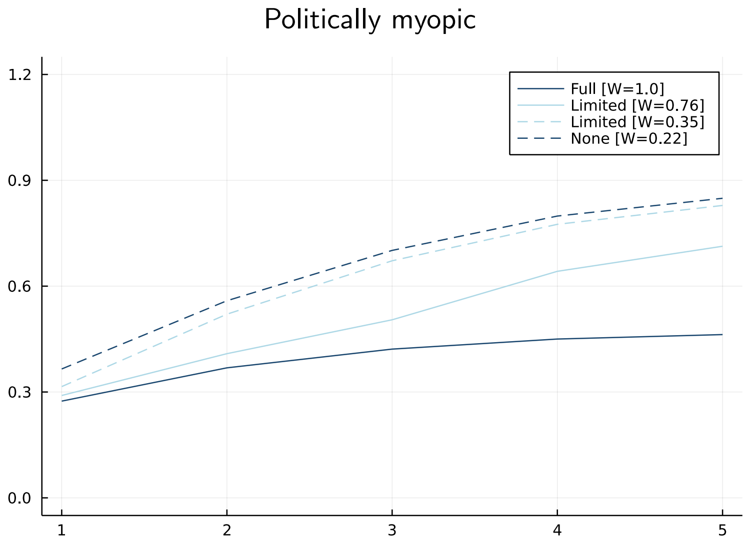
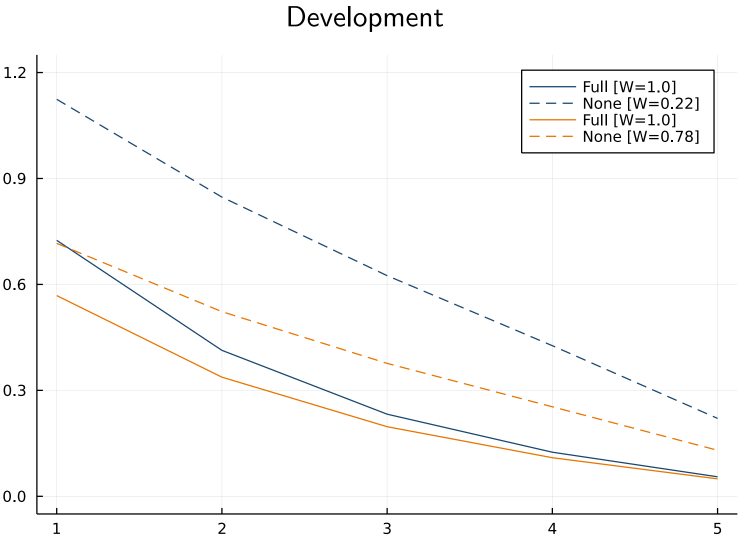


Forward-looking
1.2
0.9
0.6
0.3
0.0
1
2
3
4
5
Full [W=1.0]
Limited [W=0.85]
Limited [W=0.43]
None [W=0.22]

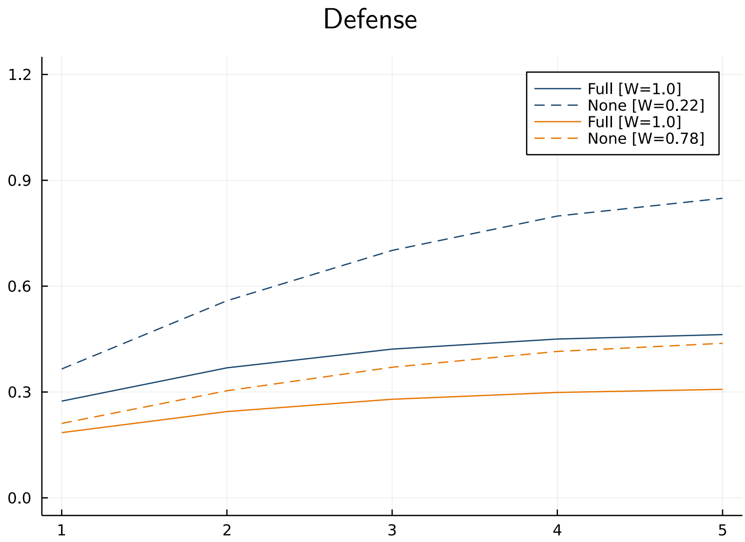
# Defense


Politically myopic
Full [W=1.0]
Limited [W=0.76]
Limited [W=0.35]
None [W=0.22]
1.2
0.9
0.6
0.3
0.0
1
2
3
4
5

# Moving capital



# Moving capital



# 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)


#CLIMATE NO JUSTICE

# 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

$$\begin{aligned} W_2 &= r(G_2)D_2 - c(D_2) - f(G_2)\,, \\ \pi_2 &= r(G_2)D_2 - c(D_2)\,. \end{aligned}$$

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 $W_1 + \beta W_2$.

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

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

Back

# Commitment over time (2)

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

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[G_1^*] &\quad r'(G_1) D_1 = f'(G_1)
\end{aligned}
$$

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

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

Back

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

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

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

$$\begin{aligned} [D_1] &\quad \tilde{r}(G_1, G_2) + r'(G_1)D_1G_1' + \beta r'(G_2)D_1G_2' = c'(D_1) \\ [G_1] &\quad r'(G_1)D_1 = f'(G_1) + \beta r'(G_2)D_2G_2' \end{aligned}$$

Back

# Commitment over time (2)

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

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

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

$$[D_1] \quad \tilde{r}(G_1, G_2) + r'(G_1)D_1G_1' + \beta r'(G_2)D_1G_2' = c'(D_1)$$
$$[G_1] \quad r'(G_1)D_1 + \beta r'(G_2)D_1G_2' = f'(G_1)$$

Back

# Commitment over time (3)

**Lock in:** over-development today raises development tomorrow.

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

$D_1 \uparrow$ 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

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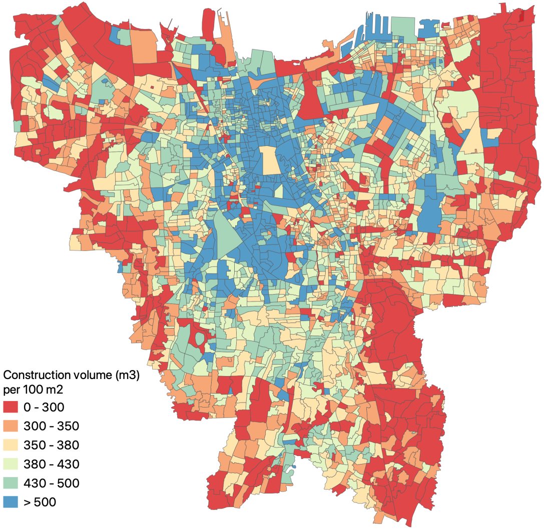
Back

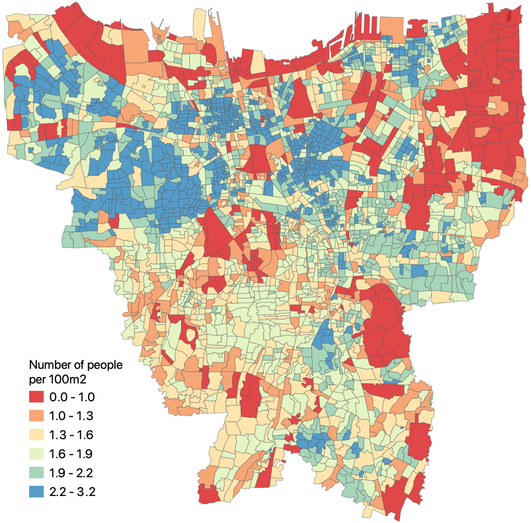
# Building construction

Back



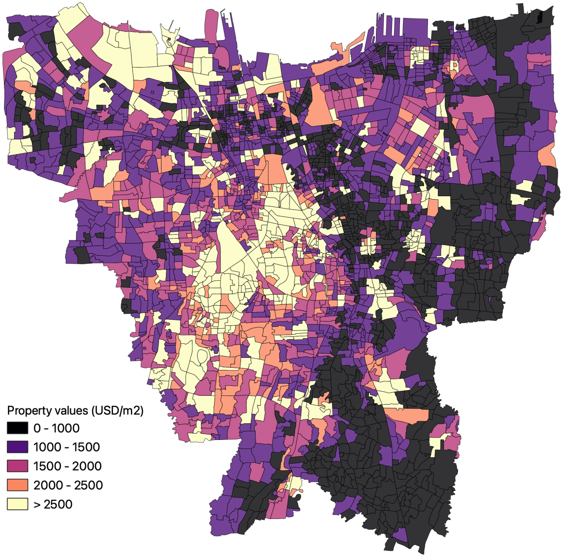
# Populations

Back



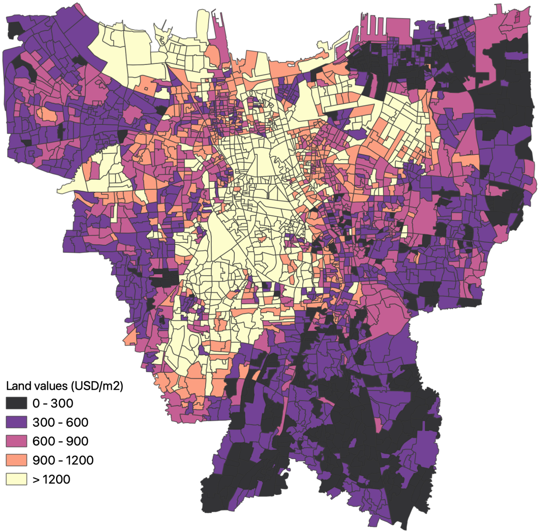
# Property values

Back



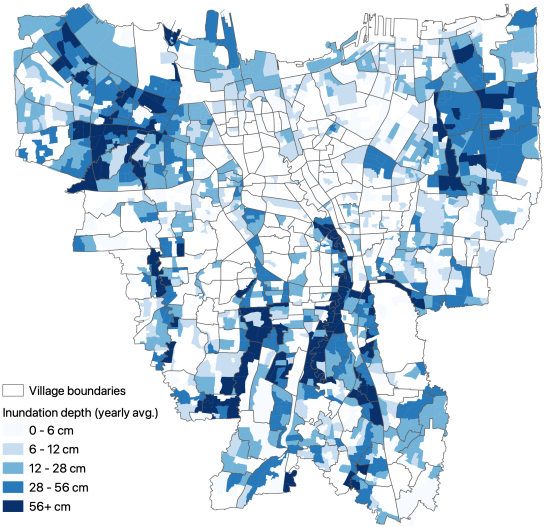
# Land values

Back



# Flood risk

Back



# 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

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

Back