Sea Level Rise and Urban Adaptation in Jakarta

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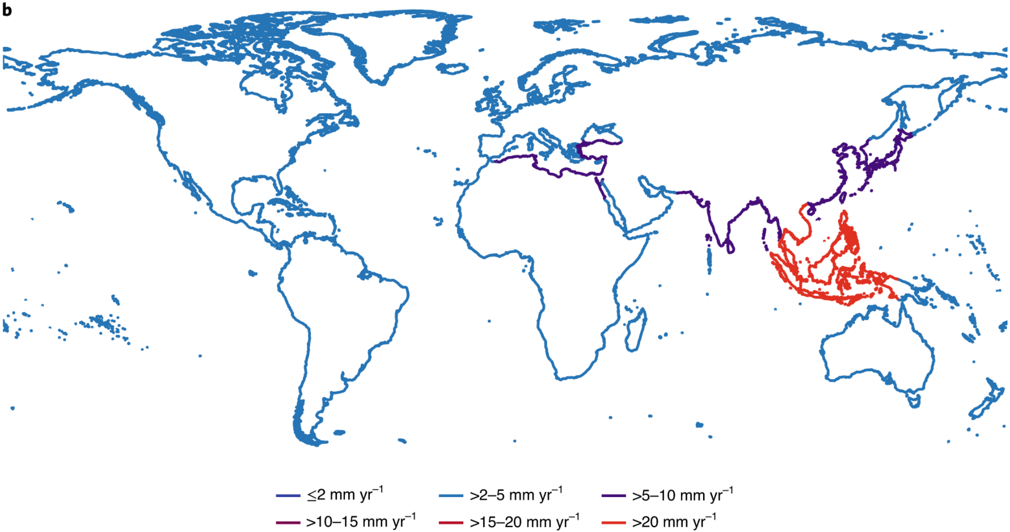
Sea levels are rising globally (Nicholls et al. 2021)




#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

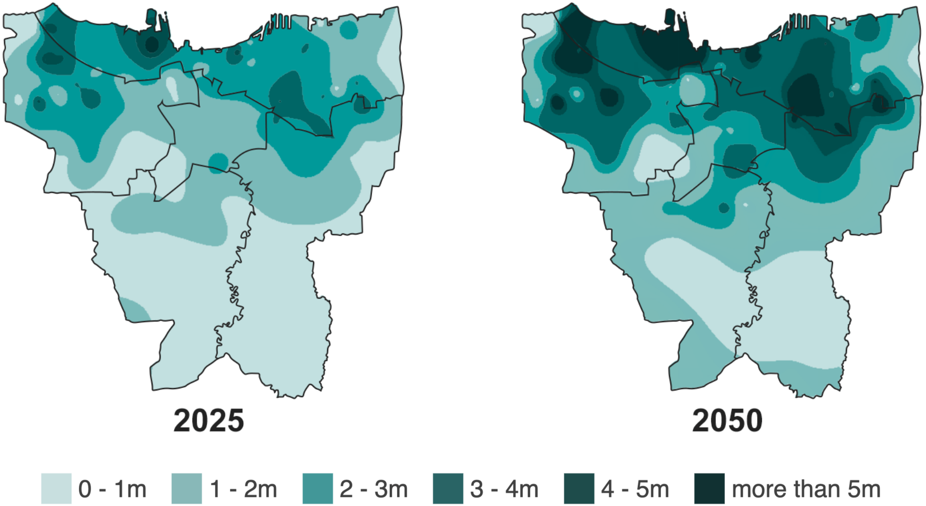
- **Adaptation frictions** under endogenous government intervention
  - Kydland & Prescott 1977, Glaeser & Gyourko 2005, Vigdor 2008, Boustan et al. 2012, Balboni 2021, Desmet et al. 2021, Baylis & Boomhower 2022, Fried 2022, Mulder 2022, Wagner 2022
- **Dynamic spatial model** of urban development
  - 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

Setting

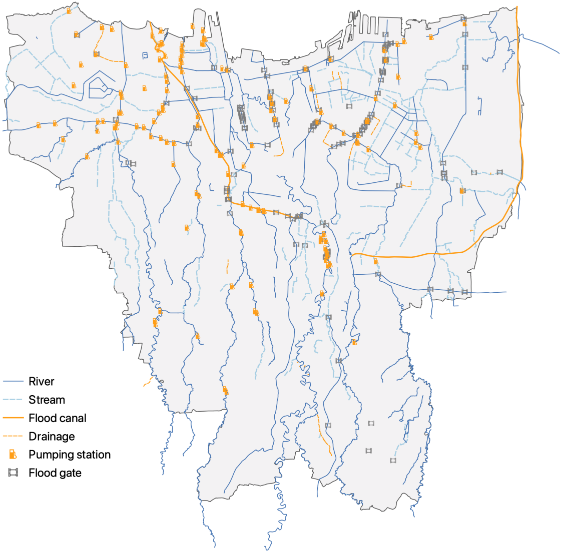

PaninBank

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

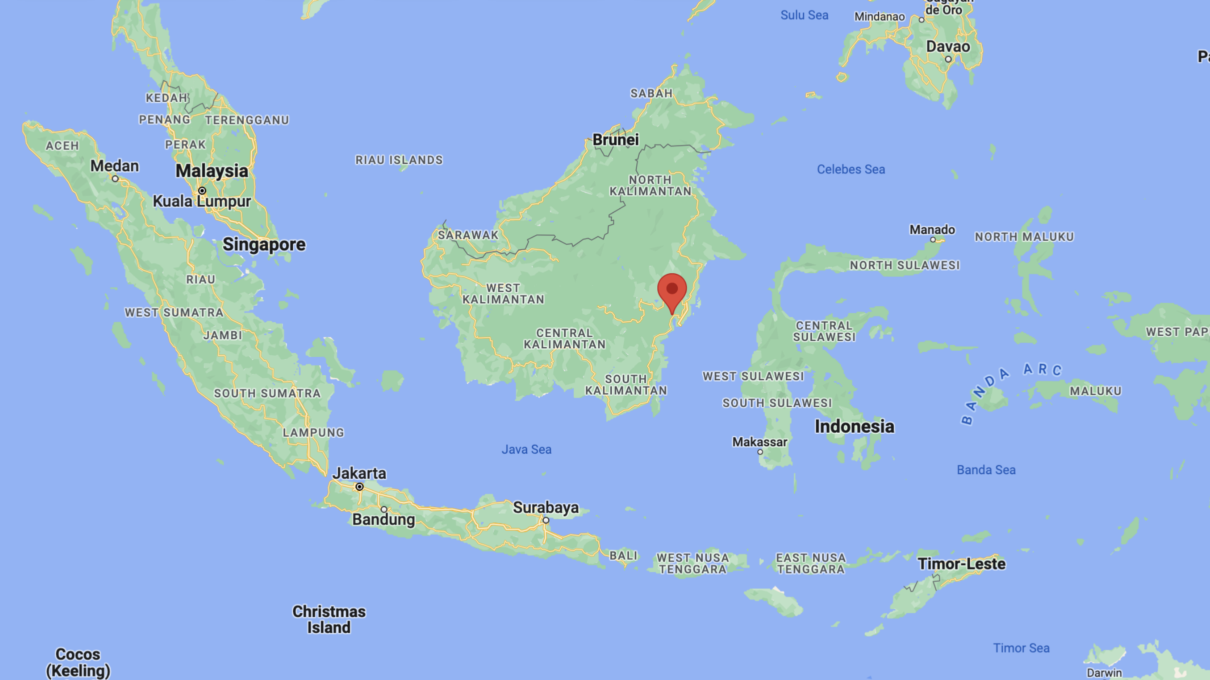
Konstruksi: 2014-2017
Flood safety: 2030

Tahap B

Konstruksi: 2018-2022
Flood Safety: 2030

Tahap C

Konstruksi: 2022


Sulu Sea
Mindanao
Davao
SABAH
Brunei
KEDAH
PENANG
TERENGGANU
PERAK
ACEH
Medan
Malaysia
Kuala Lumpur
RIAU ISLANDS
Celebes Sea
NORTH KALIMANTAN
Manado
NORTH MALUKU
SARAWAK
Singapore
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)

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Moral hazard

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

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

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

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

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

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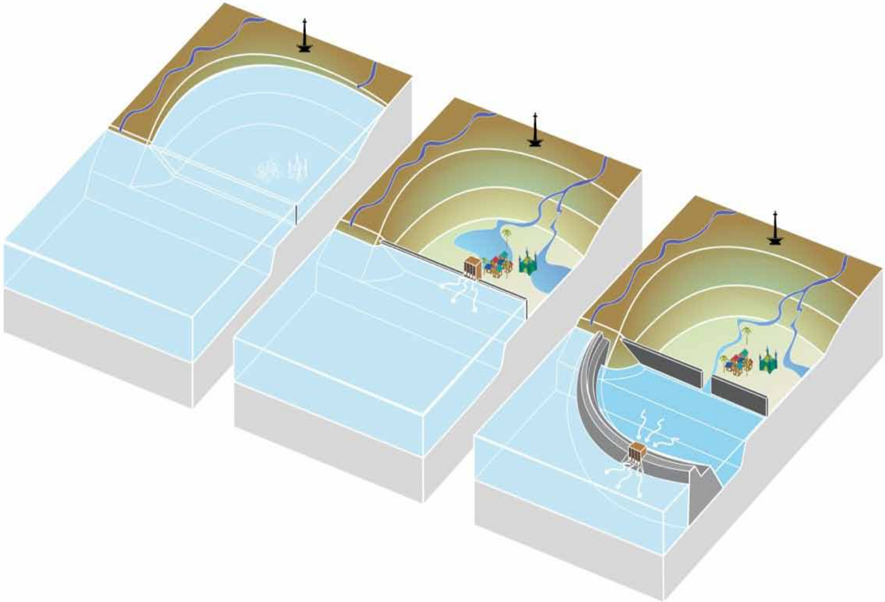
Commitment + challenges

- 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)

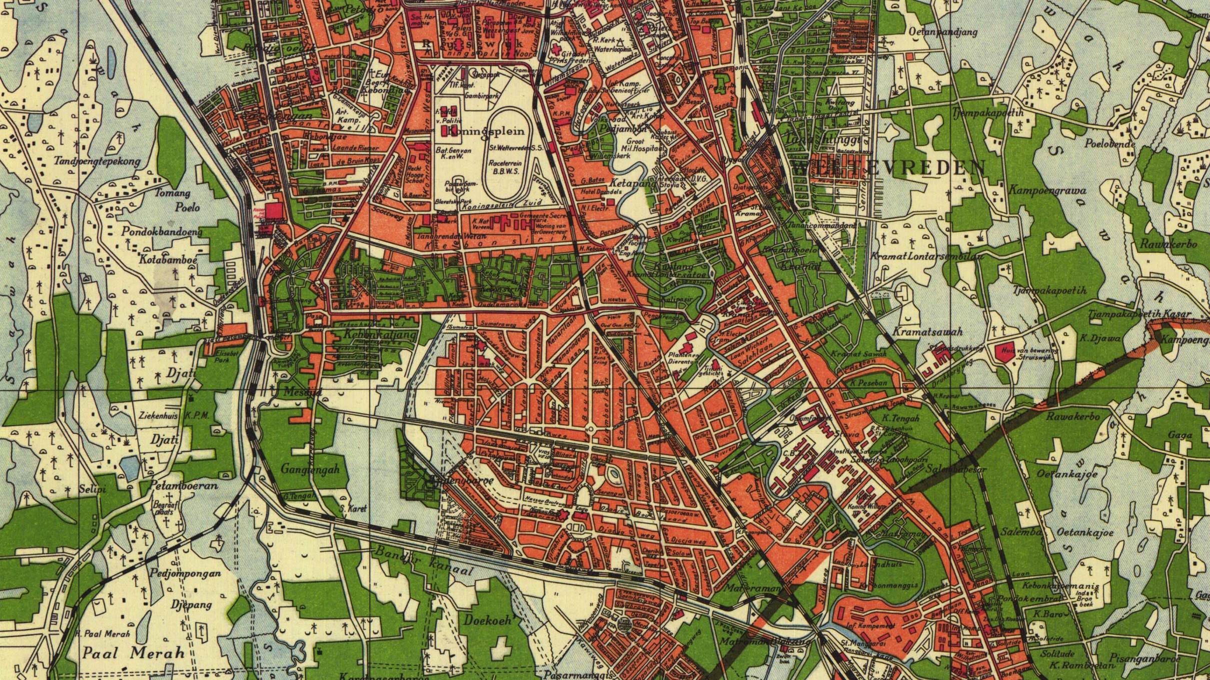
Variable	Source	Map
Building construction	GHSL	Map
Populations	GHSL	Map
Property values	99.co, brickz.id	Map
Land values	Jakarta Smart City	Map
Flood risk	(Hydrological model)	Map

Flooding $\downarrow$ $\Rightarrow$ 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	2,722	2,722	2,722	2,722

Flooding $\downarrow$ $\Rightarrow$ 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	2,722	2,722	2,722	2,722



Rijswijk
Koningsplein
Koningsplein Zuid
Gambirpark
St. Weltevreden S.S.
Raceterrein B.B.W.S.
Bat. Gen. van K. en W.
Weltevreden
Tanahtinggi
Oetanpandjang
Tjempakapoetih
Poelobende
Kampoengrawa
Rawakerbo
Kramat Lontarsembilan
Tjempakapoetih
Tjempakapoetih Kasar
Kramatsawah
Kramat Sawah
K. Djawa
Huis van bewaring Struiswijk
Tandjoengtepekong
Tomang
Poelo
Pondokbandoeng
Kotabamboe
Tanahabang
Kebonkatjang
Ketapang
Pedjambon
Groot Mil. Hospitaal
Willemskerk
Hotel Des Indes
Parapatan
Kwitang
Kramat
Tanahcommandant
Kebonsirih
Menteng
Gondangdia
Djati
Mesdjid
Elisabet Park
Ziekenhuis K.P.M.
Djati
Selipi
Petamboeran
Begraafplaats
Gangtengah
Gondangdia
S. Karet
Pedjompongan
Djepang
Paal Merah
Paal Merah
Bandjir kanaal
Doekoeh
Materaman
Matraman
Pasarmanggis
Salemba
Salembabesar
Oetankajoe
Oetankajoe
Salemba
K. Tengah
Rawakerbo
Gaga
Kebonmanggis
Landhuis
Kebonkajoemanis
Pondokembrat
K. Baroe
Solitude
K. Rambeetan
Pisangbaroe
Inf. Kampement
St. Manggarai
Manggarai

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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\begin{aligned}
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\end{aligned}
$$

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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

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

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

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

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Comparing approaches

Estimation	Speed	Expectations
Full-solution (NFP)	Slow	Specified
Two-step (BLP)	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

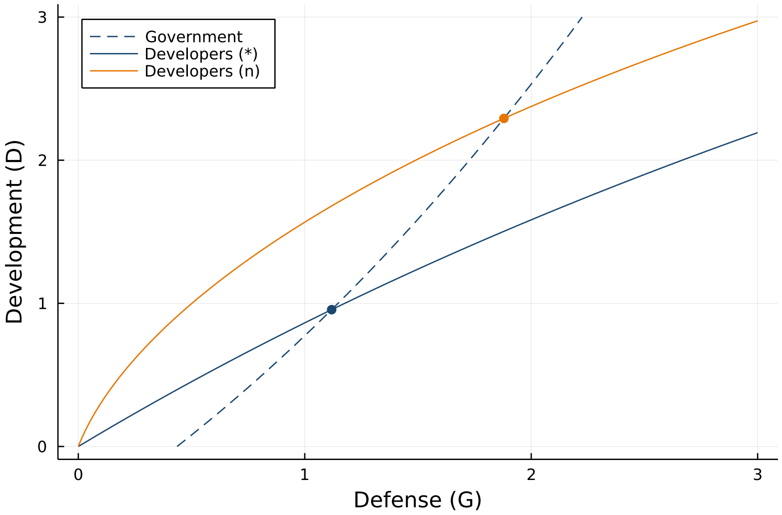
- Commitment level and political turnover by assumption
  - Hydrological model of flood risk $s_k(G)$
  - Engineering estimates of costs $f(G)$

- Counterfactuals

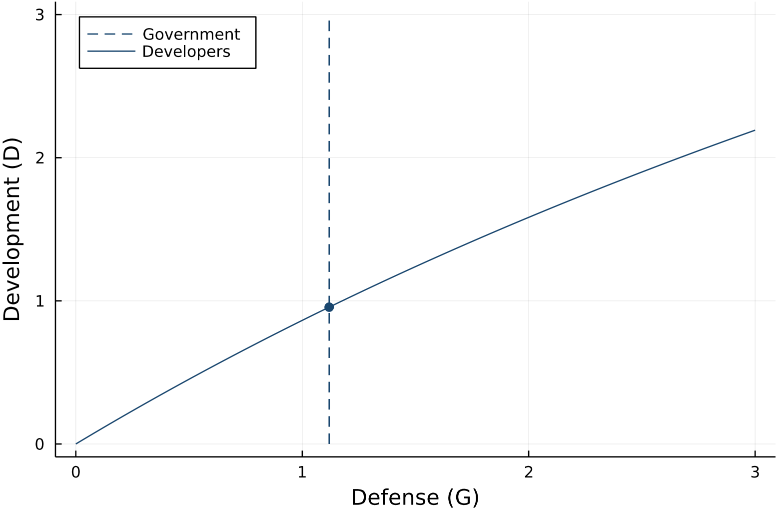
$$\begin{aligned} \text{Defense } g &\rightarrow \text{ flooding } s \text{ by } \textbf{hydrological} \text{ model} \\ &\rightarrow \text{ rents } r \text{ by } \textbf{demand} \text{ model} \\ &\rightarrow \text{ development } d \text{ by } \textbf{supply} \text{ model} \end{aligned}$$

Simulations

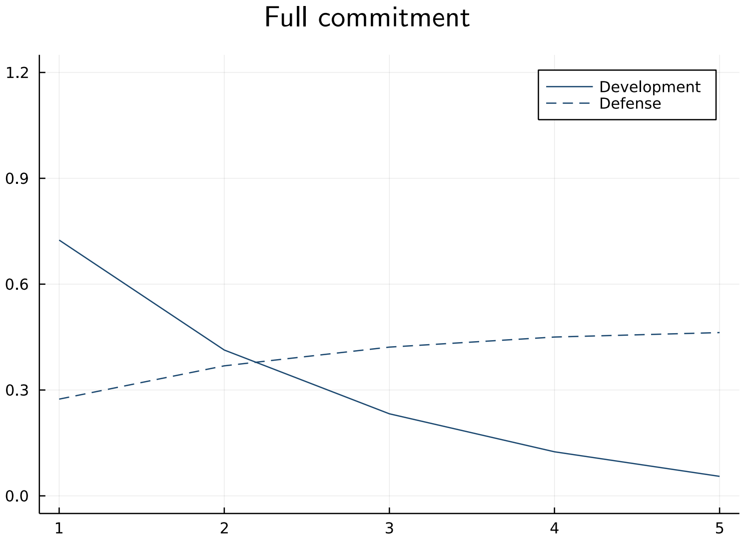
Over-development and over-defense



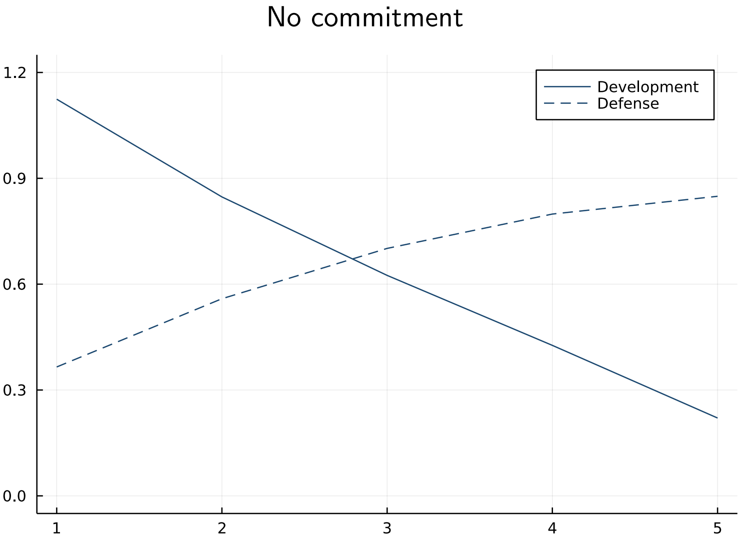
Over-development and over-defense



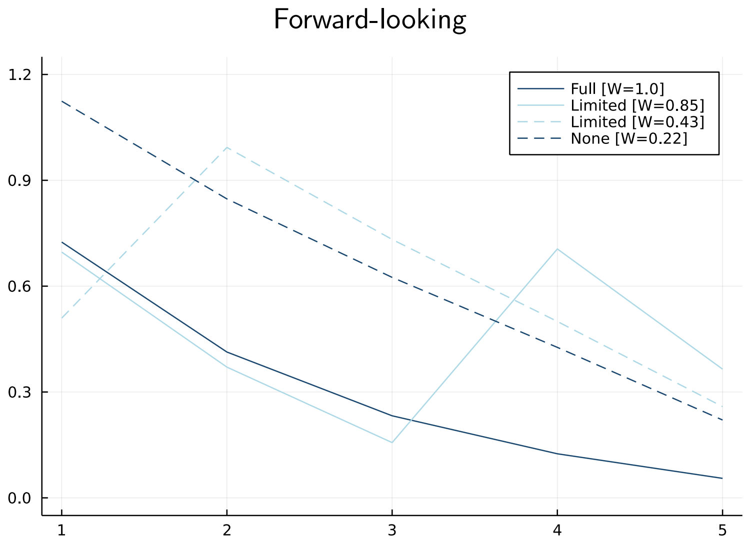
Development and defense



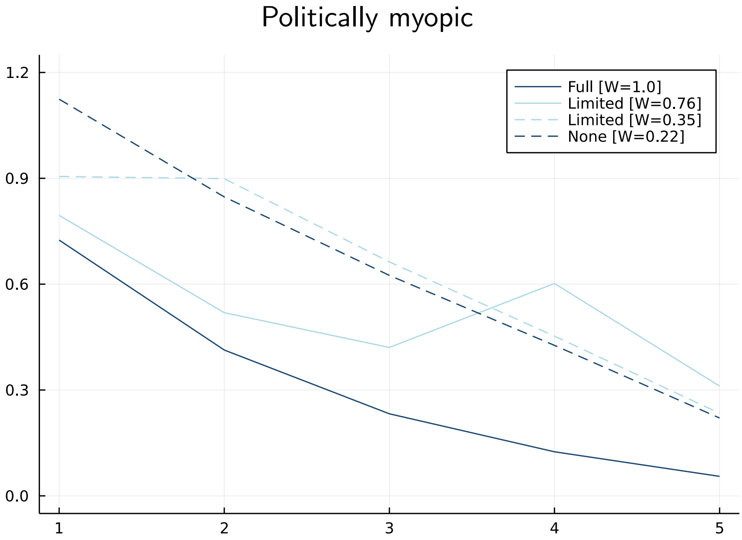
Development and defense



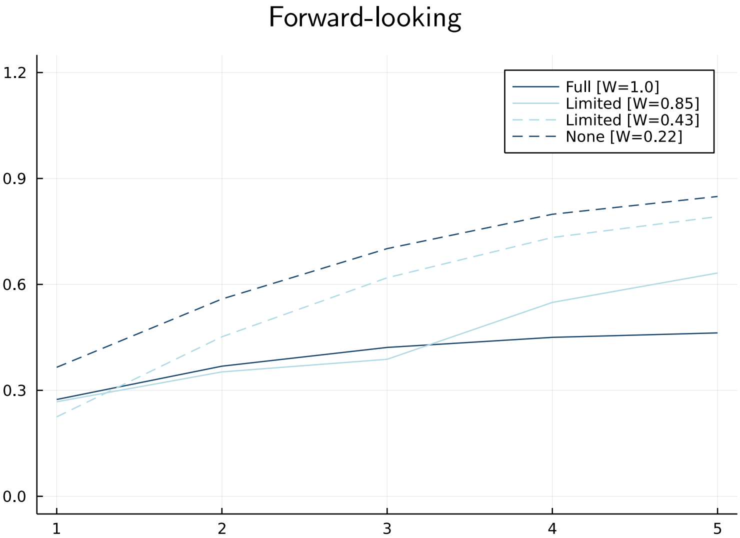
Development



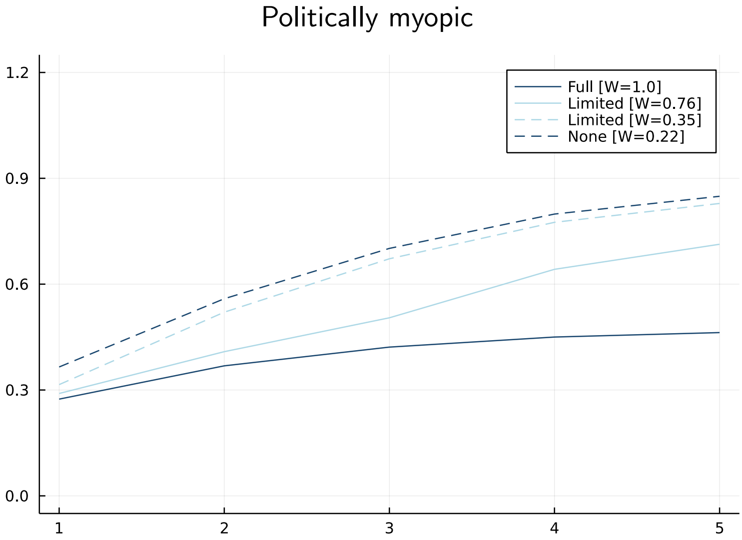
Development



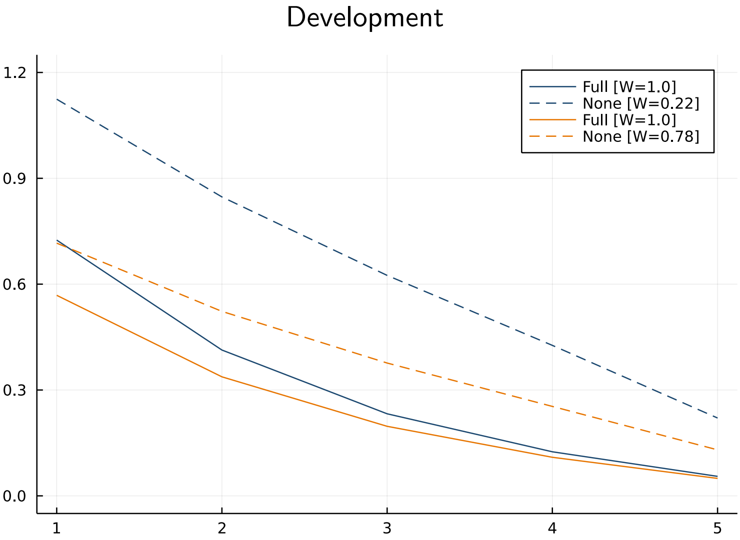
Defense


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

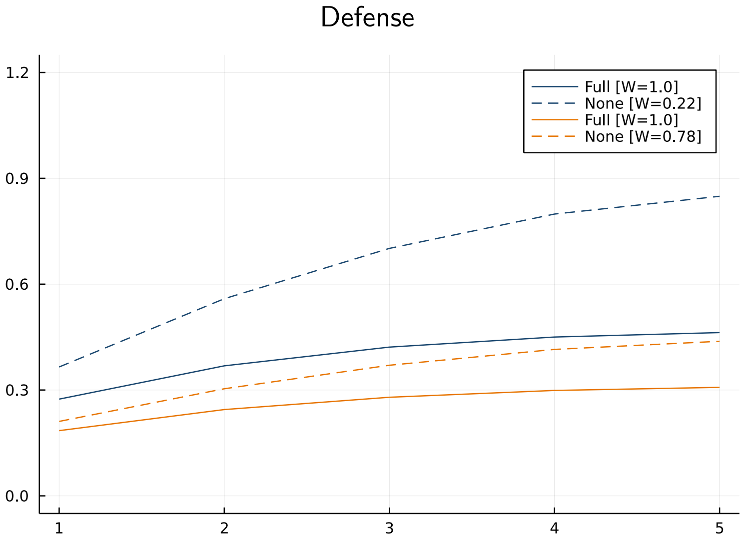
Defense


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

$$W_2 = r(G_2)D_2 - c(D_2) - f(G_2)\,,$$
$$\pi_2 = r(G_2)D_2 - c(D_2)\,.$$

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 $f(G_2)$

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Commitment over time (2)

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

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

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

Back

Commitment over time (2)

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

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

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

Commitment over time (2)

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

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

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

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

Back

Commitment over time (2)

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

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

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

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

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

Commitment over time (3)

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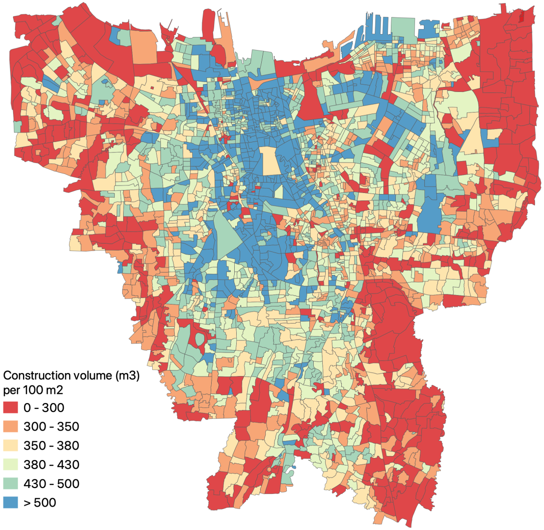
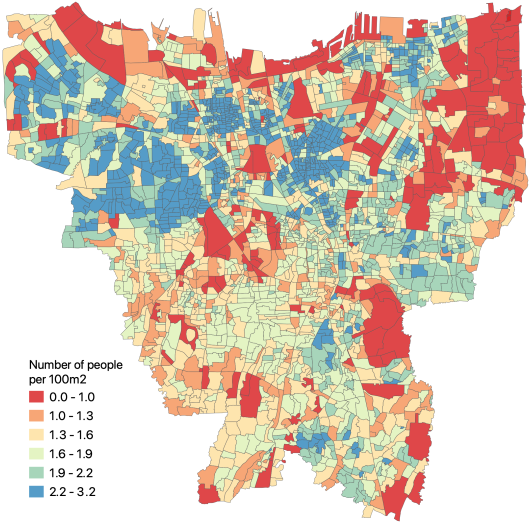
Building construction

Back

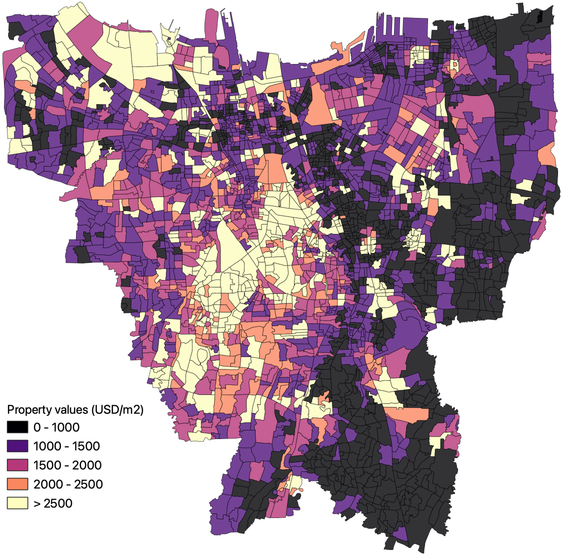


Populations

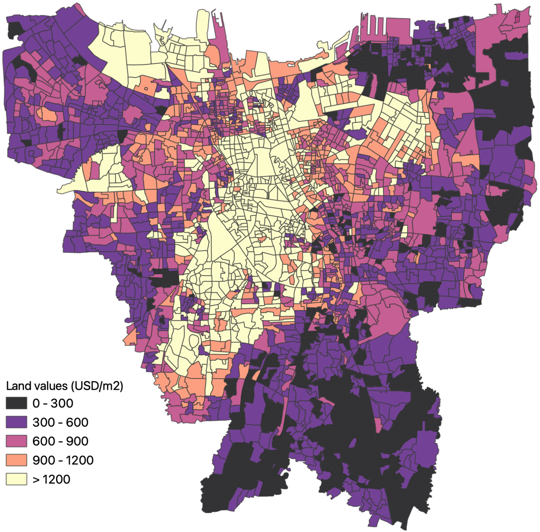
Back



Property values Back

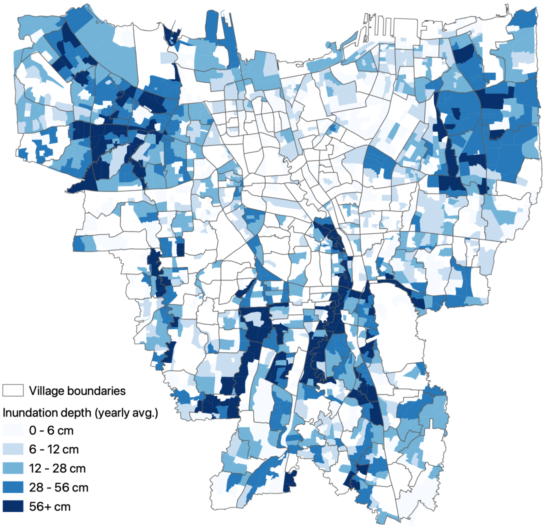


Land values Back



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 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