Sea Level Rise and Urban Adaptation in Jakarta

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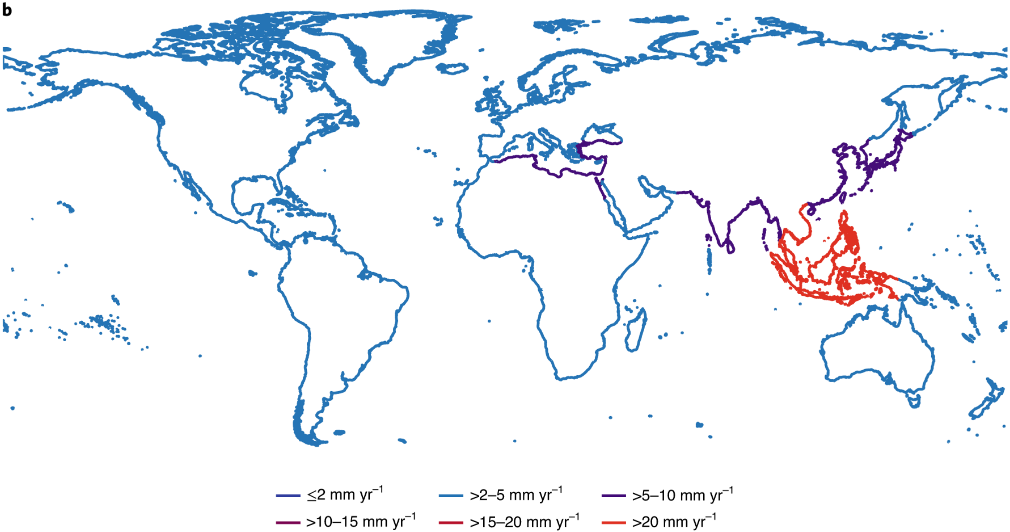
Sea levels are rising globally (Nicholls et al. 2021)

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

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

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

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

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

Moral hazard

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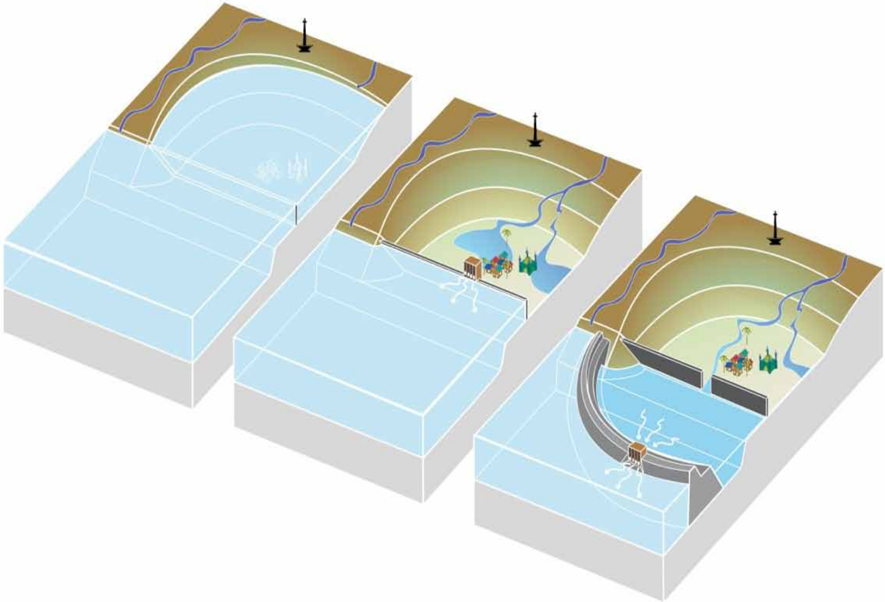
- Moral hazard when $g'(d) > 0$ implies $d^n > d^* > 0, \; g^n > g^* > 0$

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)

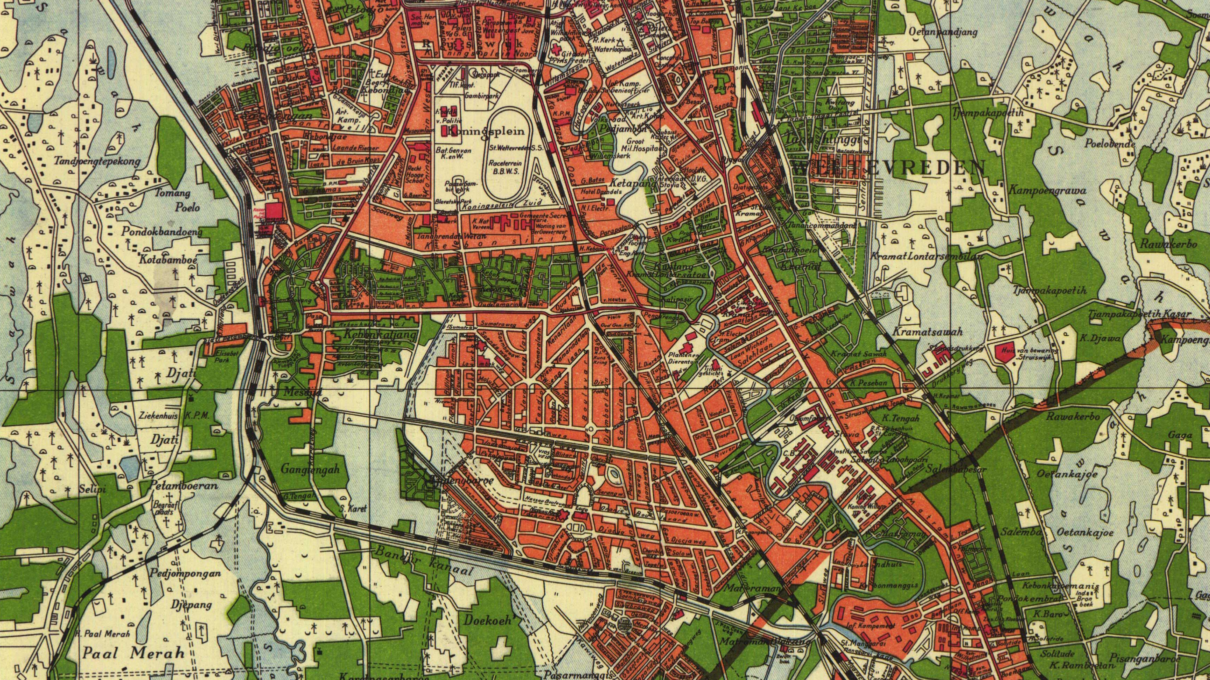
Details

Empirics

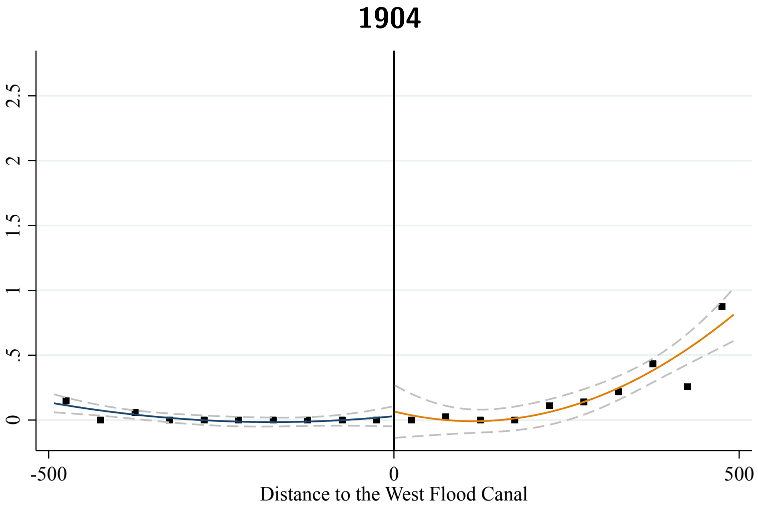
Empirical framework

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

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


Rijswijk
Koningsplein
Koningsplein Zuid
St. Weltevreden S.S.
Raceterrein B.B.W.S.
Gambirpark
Pedjambon
Ketapang
WELTEVREDEN
Oetanpandjang
Tjempakapoetih
Poelobende
Kampoengrawa
Rawakerbo
Kramat Lontarsembilan
Kramatsawah
Kramat Sawah
K. Djawa
Tandjongtepekong
Tomang
Poelo
Pondokbandoeng
Kotabamboe
Kebonkatjang
Djati
Mesdjid
Ziekenhuis
K.P.M.
Selipi
Petamboeran
Begraafplaats
Gangtengah
Gondangdia
S. Karet
Bandjir kanaal
Pedjompongan
Djepang
Paal Merah
Doekoeh
Materaman
Matraman
Salembabesar
Salemba
Oetankajoe
Oetankadjoe
Rawakerbo
Gaga
K. Tengah
K. Peseban
Landhuis
Kebonmanggis
Kebonkosemanis
Pondokembrat
K. Baroe
Solitude
K. Rambetan
Pisanganbaroe
Inf. Kampement
St. Manggarai
Pasarmanggis
Kampoeng
Tjampakapoetih
Tjampakapoetih Kasar
Kramatpoelo
Kwitang
Kalipasir
Tanahabang
Tanahrendah Wetan
Gemeente Secretarie
Scottweg
Sumatraweg
Oud Gon. Batik

West Flood Canal (1918)



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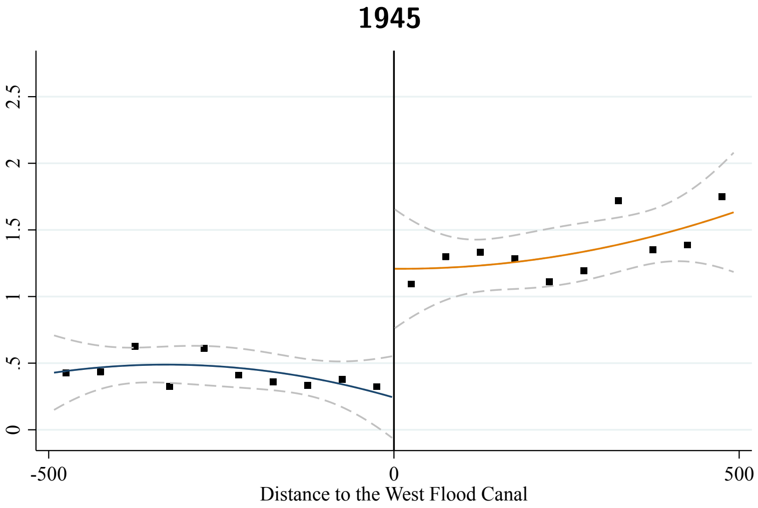
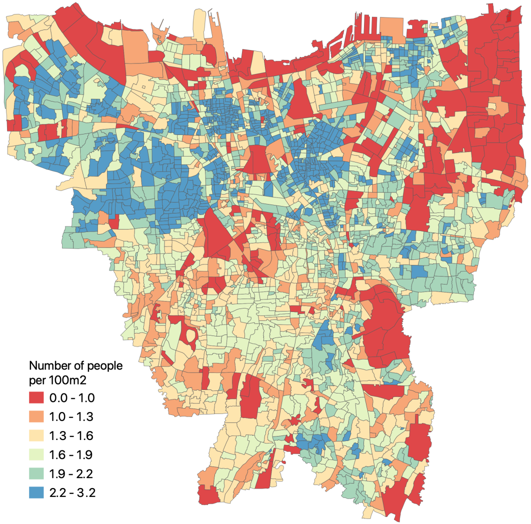


Demand from residents

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

- **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) Details
  - Price endogeneity from correlation of rents and unobserved amenities
  - IV with ruggedness as supply shifter

Populations



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

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

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

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

- **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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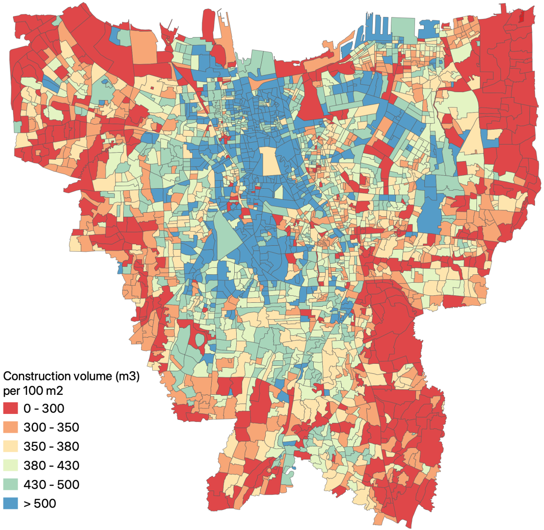
Data as continuation values

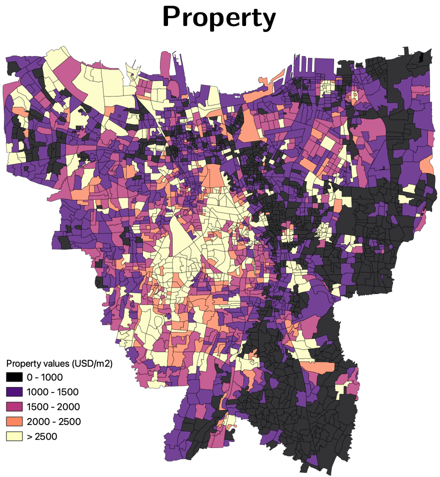
$$
\begin{aligned}
\ln p_{kt}^1 - \ln p_{kt}^0 &= v_k^1(D, L) - v_k^0(D, L) \\
&= -c_{kt}(d; \varepsilon) + \beta \mathbb{E}[V_{kt+1}(D+1, L-1) - V_{kt+1}(D, L)] \\
&= -c_{kt}(d; \varepsilon) + P_{kt}^D d - P_{kt}^L d
\end{aligned}
$$

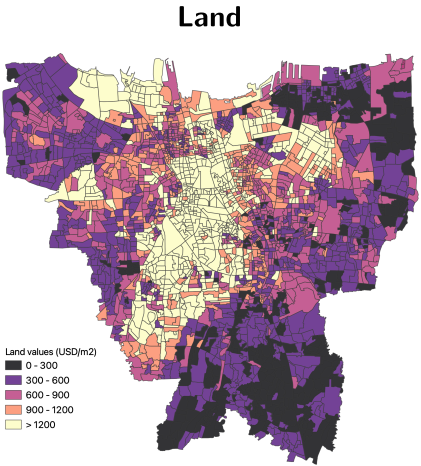
- Simple IV estimation
    - Key assumption: $\beta \mathbb{E}[V_{kt+1}(D+d, L-d)] = P_{kt}^D (D+d) - P_{kt}^L (L-d)$
    - Need efficient real estate markets and atomistic developers
    - Do not need rational expectations

Building construction



Real estate prices





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

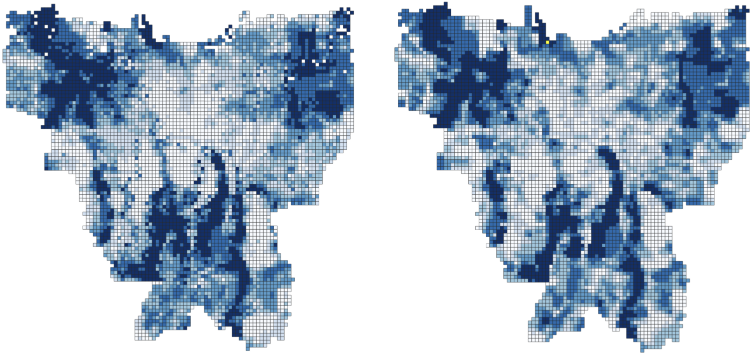
$$D_{kt}^{\mathsf{res}} = D_{kt}^{\mathsf{dev}}$$

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

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

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

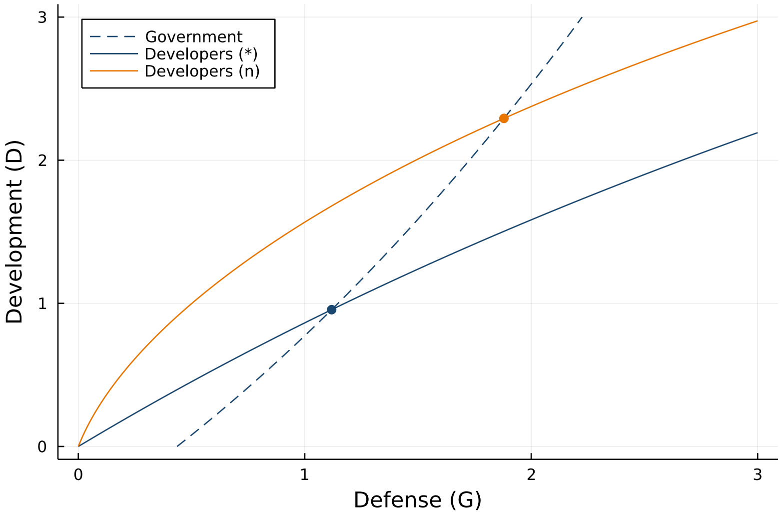
- Commitment level and political turnover by assumption
  - Hydrological model of flood risk $s_k(G)$
  - Engineering estimates of costs $e(G)$

- Counterfactuals

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

Simulations

Coastal over-development and over-defense



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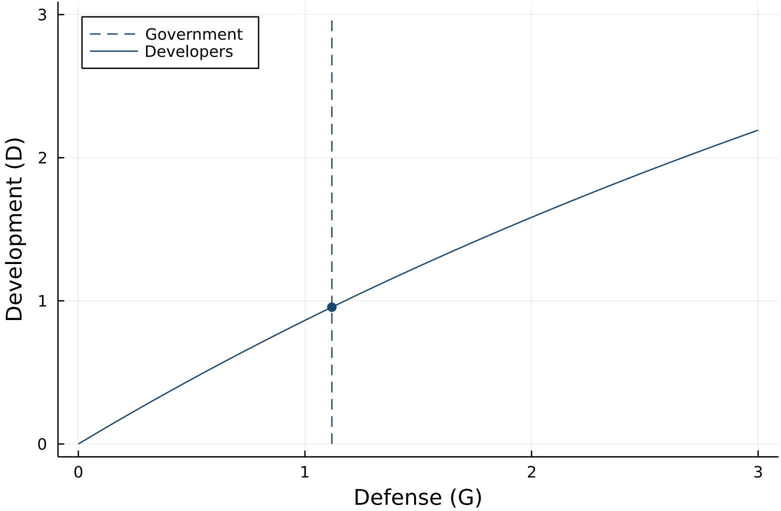
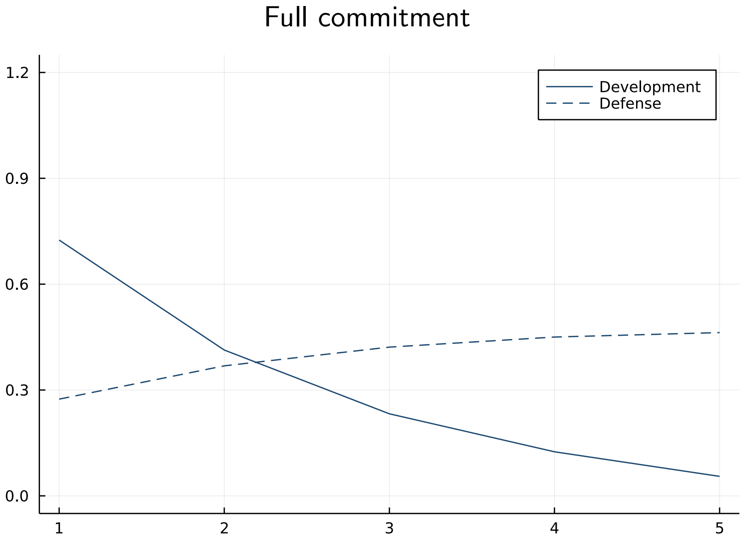


Development and defense over time



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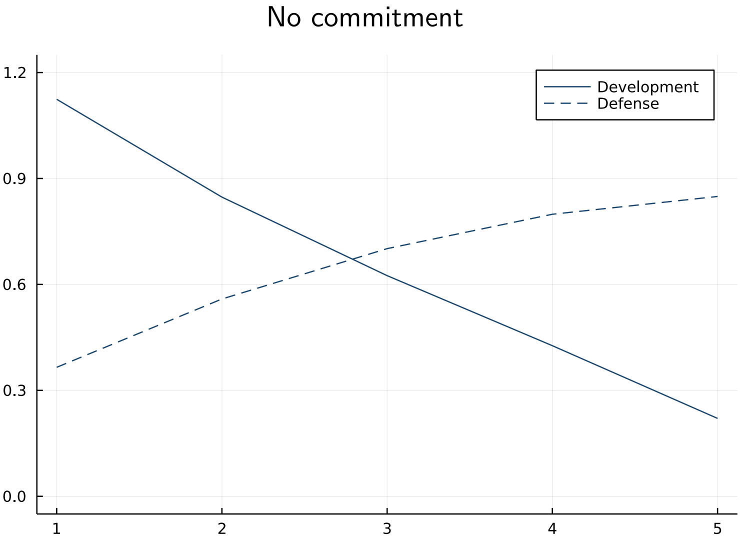
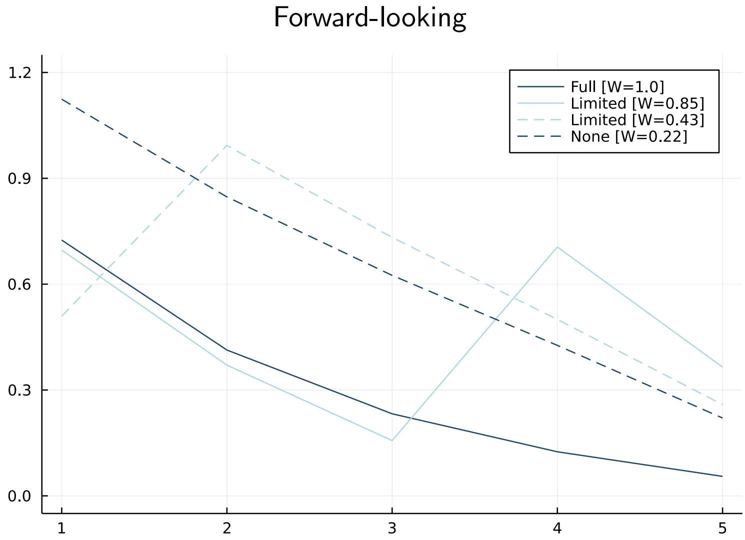


Limited commitment (development)



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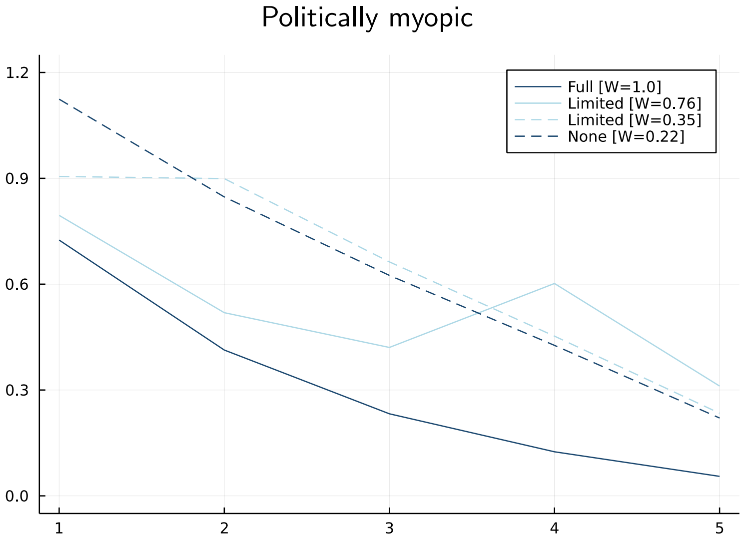

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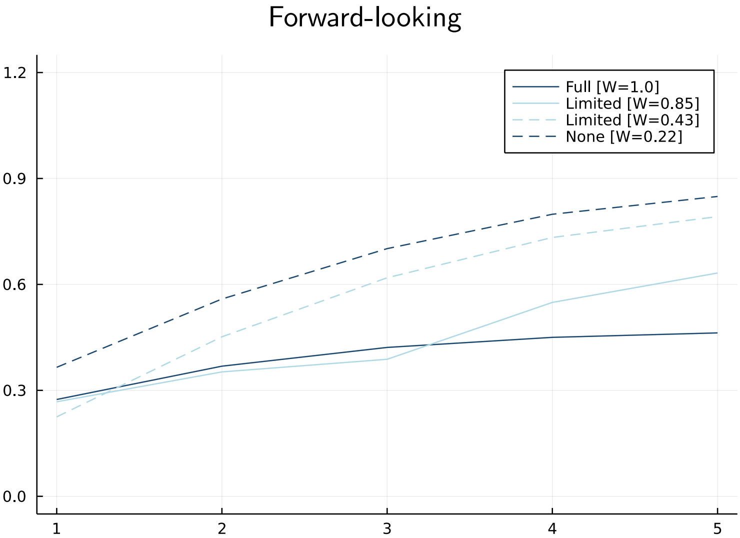

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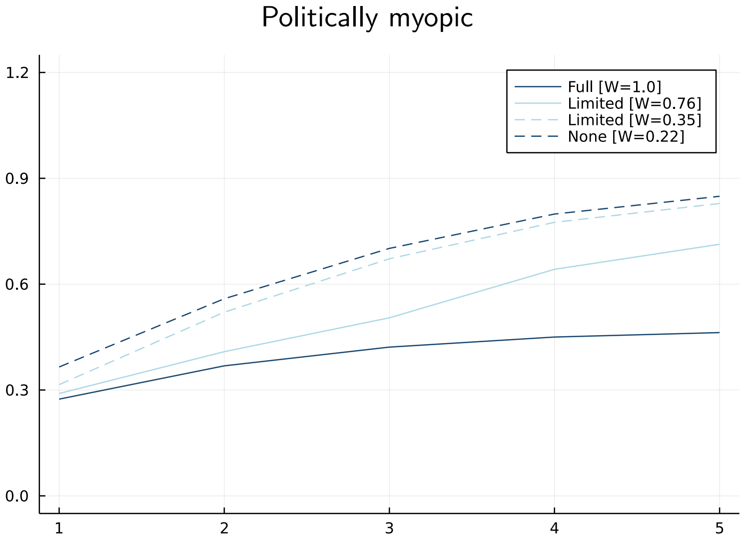
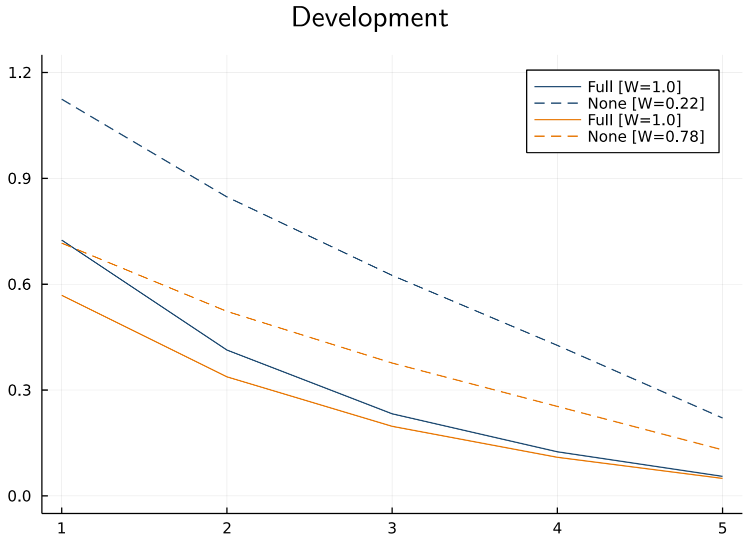
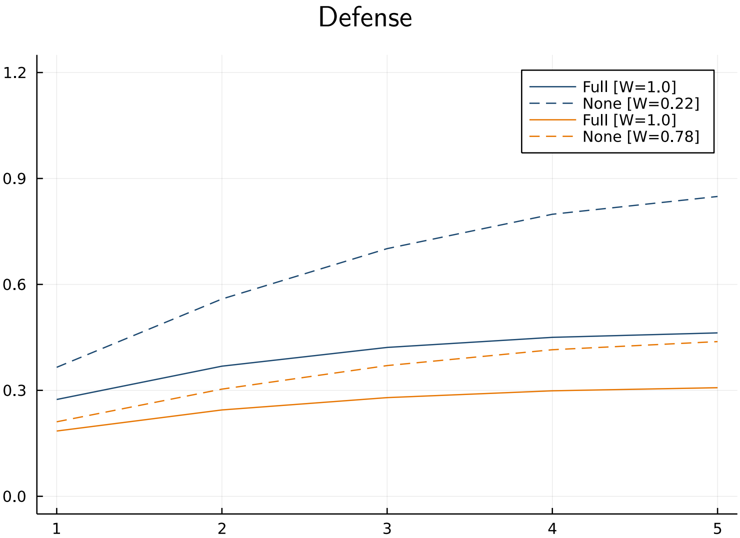


Reducing coastal demand



Reducing coastal demand



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


HARKAS

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

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

Back

Commitment over time (2)

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

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

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.

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

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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.

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

$D_1 \uparrow$ 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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Building construction

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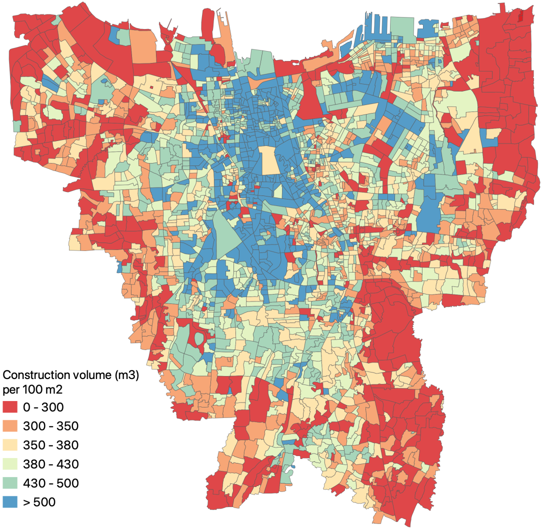

Construction volume (m3)
per 100 m2

- 0 - 300
- 300 - 350
- 350 - 380
- 380 - 430
- 430 - 500
- > 500

Populations

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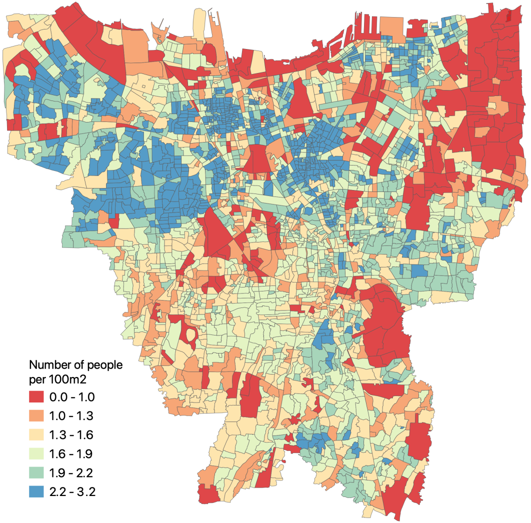

Property values

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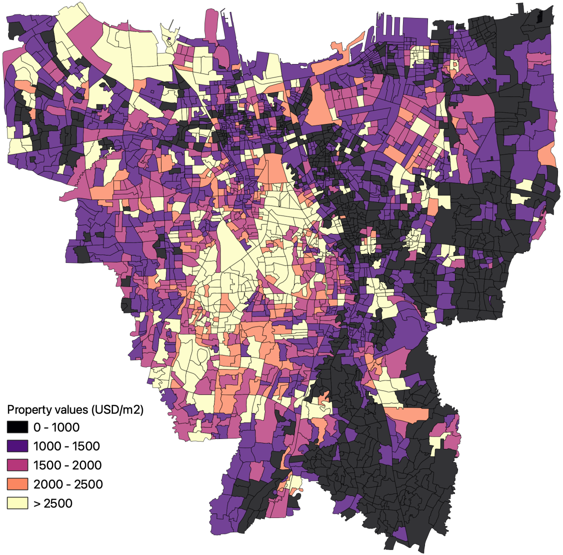

Land values

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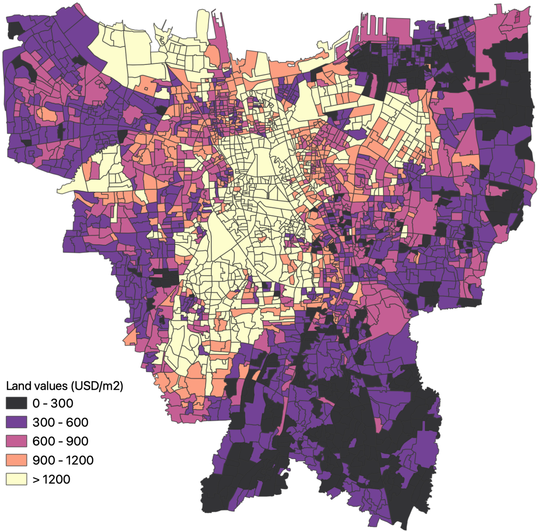

Flood risk

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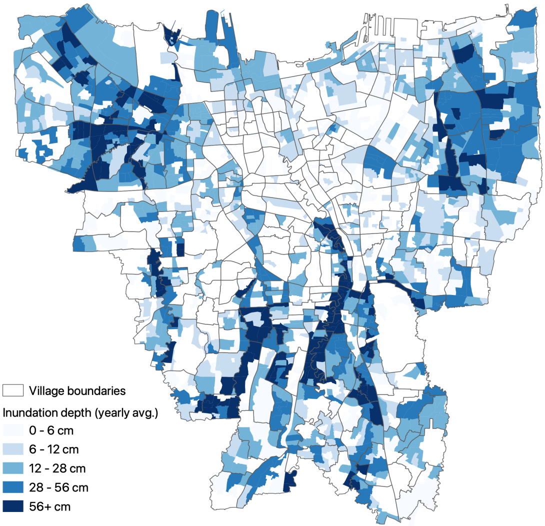

Estimating demand

- 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

$$\text{population}_k = \frac{1}{\phi} D_k^{\text{res}}(\delta, \theta_2)$$

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

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

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