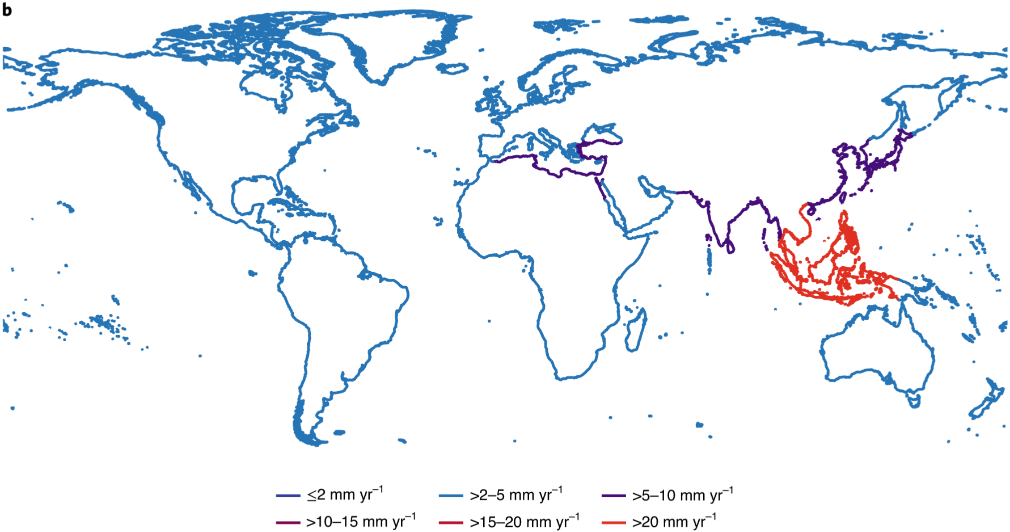
Sea Level Rise and Urban Adaptation in Jakarta

Allan Hsiao
Princeton University

March 7, 2023

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




#CLIMATE NO JUSTICE

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)
  - Proposed sea wall at up to $40B
- **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, Bakkensen & 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 π', externality e)

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 π', externality e)

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 π', externality e)

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 π', externality e)

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 π', externality e)

Moral hazard

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

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

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

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

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

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 $d^n > d^*$, $g^n > g^*$ (for $d^*, g^* > 0$)

Moral hazard

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

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

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

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

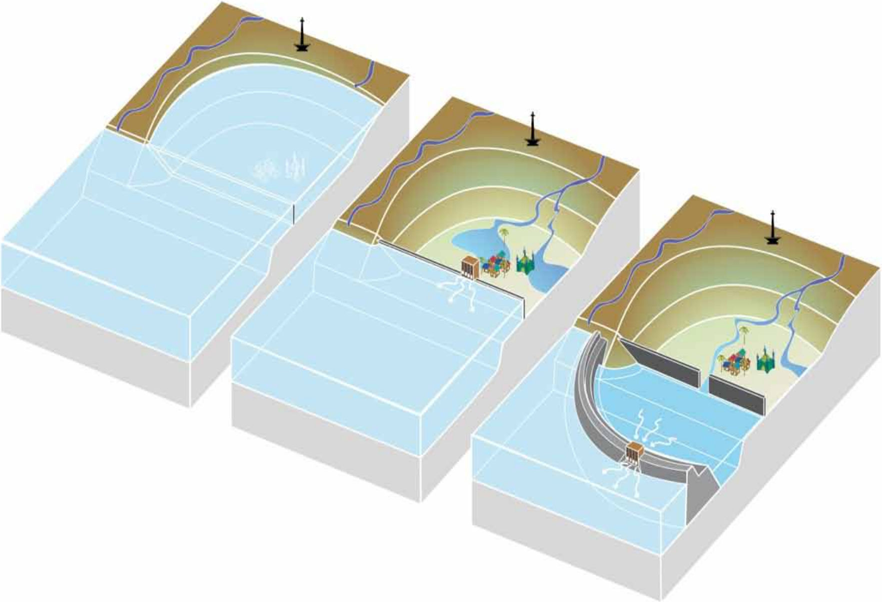
- Moral hazard when $g'(d) > 0$ implies $d^n > d^*$, $g^n > g^*$ (for $d^*, g^* > 0$)

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)
- 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
  - Political 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)



Empirics

Empirical framework

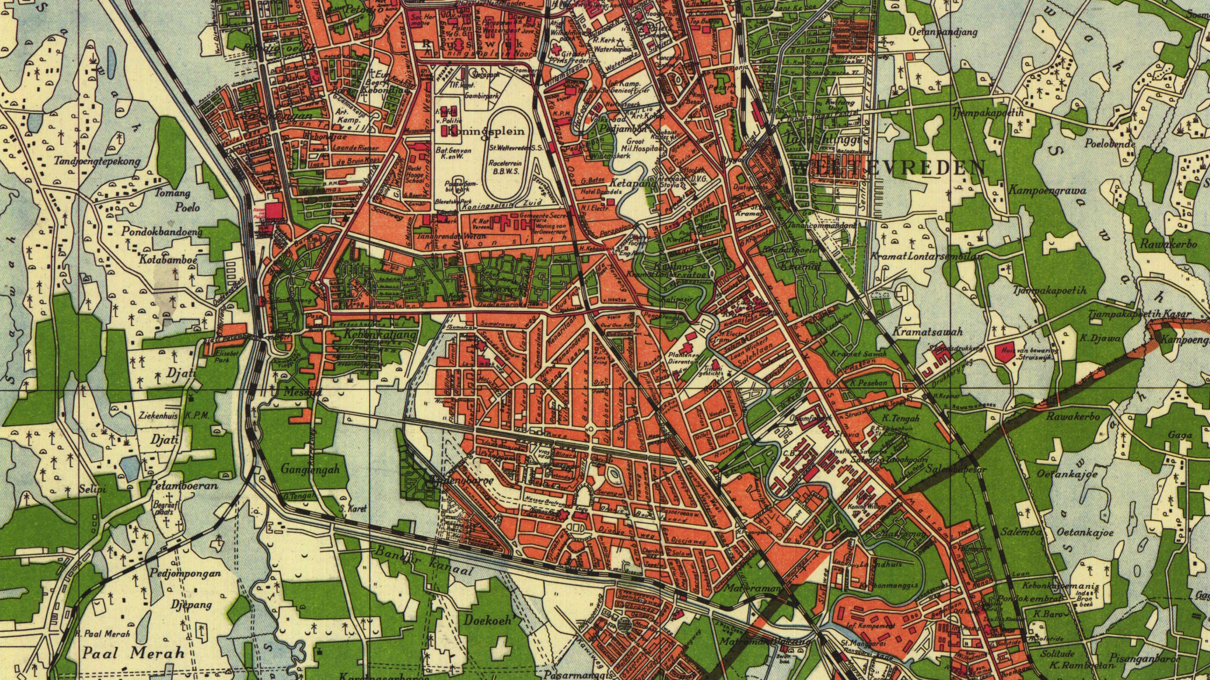
$$W = r(d, g) - c(d) - e(g)$$

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

An historical example

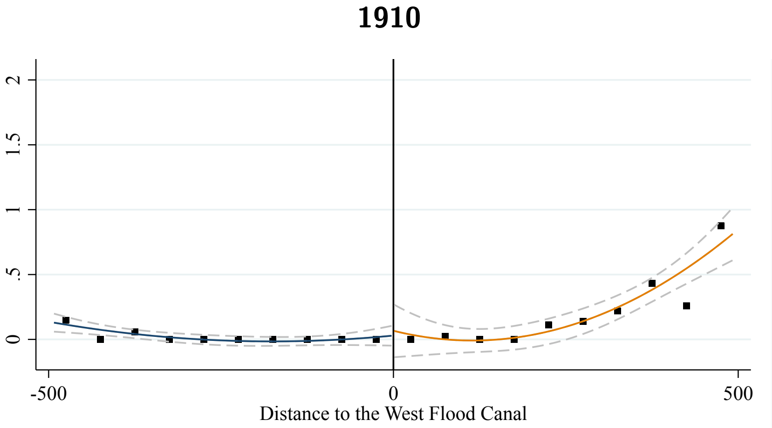
- Has government intervention increased development before? $(g \rightarrow d)$
  - West Flood Canal (1918)
  - Land development from Dutch colonial maps (1887-1945)

- Spatial regression discontinuity
  - Flood protection for the north, but not the south
  - By diverting floodwaters that flow south to north

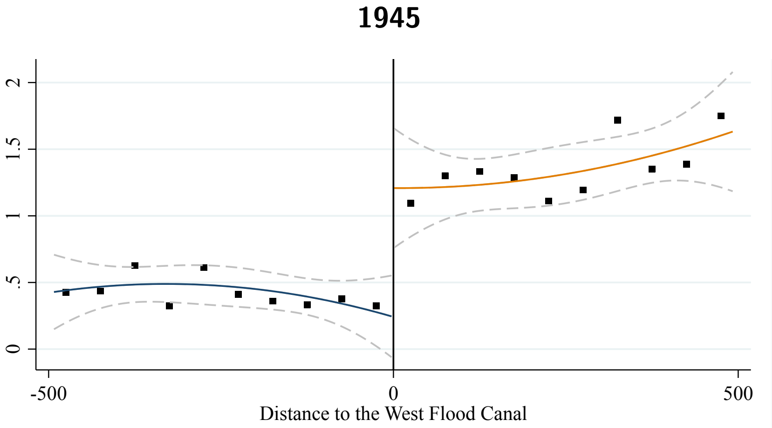


WELTEVREDEN
Koningsplein
Raceterrein B.B.W.S.
St. Weltevreden S.S.
Gambirpark
Koningsplein Zuid
Pedjambon
Ketapang
Kampoengrawa
Tjempakapoetih
Poelobende
Oetanpandjang
Rawakerbo
Kramat Lontarsembilan
Tjampakapoetih
Tjampakapoetih Kasar
Kramatsawah
Kramat Sawah
K. Djawa
K. Peseban
K. Tengah
Rawakerbo
Gaga
Oetankajoe
Salembabesar
Salemba
Oetankadjoe
Kebonkajoemanis
Pondokembrat
K. Baroe
Solitude
K. Ramboetan
Pisanganbaroe
Materaman
Kebonmanggis
Inf. Kampement
St. Manggarai
Pasarmanggis
Bandjir kanaal
Doekoeh
Gangtengah
Gondangdia
S. Karet
Petamboeran
Selipi
Pedjompongan
Djepang
Paal Merah
K. Paal Merah
Djati
Mesdjid
Kebonkatjang
Elisabet Park
Ziekenhuis
K.P.M.
Tandjoengtepekong
Tomang Poelo
Pondokbandoeng
Kotabamboe
Kebon Sirih
Tanahrendah Wetan
Kalipasir
Kwitang
Kramat Lontarsatoe
Kramat
Kramatpoelo
Tanahcommandant
Planten Dierentuin
Salehloan
Sumatraweg
Nassau Boulevard
Scottweg
Rechtshoogeschool
Hotel Des Indes
Groot Mil. Hospitaal
Willemskerk
Art. Kamp.
Paleis v. G. G.
Rijswijk
Kebondjae

West Flood Canal (1918)



West Flood Canal (1918)

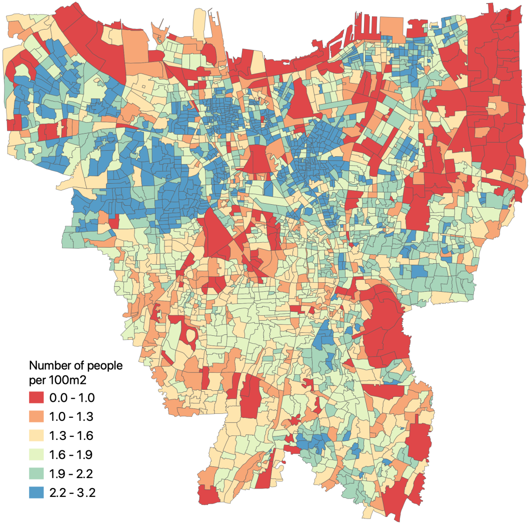


Demand from residents

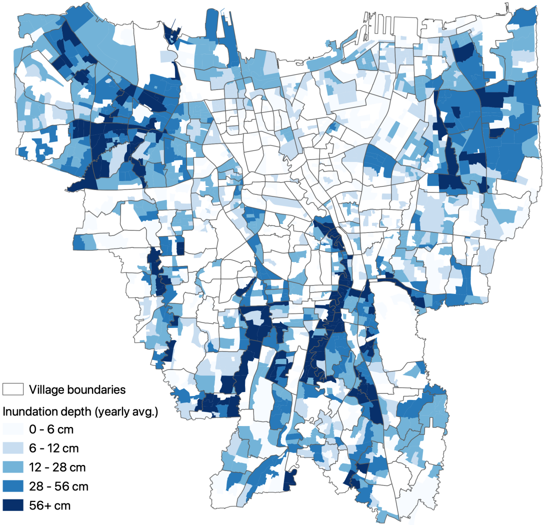
$$U_{ijk} = \underbrace{\alpha r_k + \phi f_k + x_k \gamma + \varepsilon_k}_{\delta_k} + \tau m_{jk} + \epsilon_{ijk}$$

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

Population (global data)



Flooding (2013-2020, past → future)



Demand estimates

	IV		First stage	
	Estimate	SE	Estimate	SE
Rents	-0.032***	(0.004)		
Ruggedness			12.20***	(1.176)
Flooding	-0.490***	(0.097)	-15.53***	(2.485)
Residential amenities	0.110***	(0.018)	1.540***	(0.469)
Distance to city center	-0.141***	(0.018)	-3.878***	(0.245)
Distance to coast	0.024***	(0.006)	-0.091	(0.154)
Distance to major road	-0.060***	(0.020)	1.344**	(0.546)
District FE	x		x	
Observations	5,780		5,780	
F-statistic			108	

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

Supply from developers

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

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

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

- **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

Supply from developers

$$V_{kt}(D,L) = r_{kt}(D) + \mathbb{E}[\max_{d\in\{0,1\}}\{v^d_{kt}(D,L) + \epsilon^d_{ikt}\}]$$
$$v^1_{kt}(D,L) = -c_{kt}(x,\varepsilon) + \beta\mathbb{E}[V_{kt+1}(D+1,L-1)]$$
$$v^0_{kt}(D,L) = \beta\mathbb{E}[V_{kt+1}(D,L)]$$

- **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

Data as continuation values

$$\begin{aligned}\ln p^1_{kt} - \ln p^0_{kt} &= v^1_{kt}(D,L) - v^0_{kt}(D,L) \\ &= -c_{kt}(x,\varepsilon) + \beta\mathbb{E}[V_{kt+1}(D+1,L-1) - V_{kt+1}(D,L)] \\ &= -c_{kt}(x,\varepsilon) + \alpha P^D_{kt} - \alpha P^L_{kt}\end{aligned}$$

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

- Simple IV estimation
  - Need efficient real estate market ($P \to \mathbb{E}[V]$, frictions as ε)
  - And atomistic developers (P as data, 14k developers)
  - But not rational expectations (P as market offer)

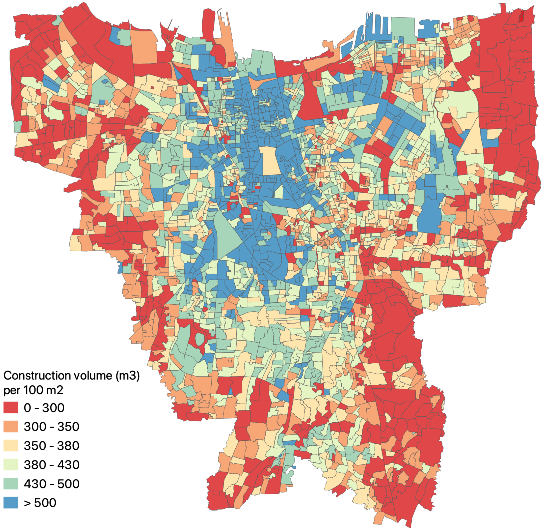
Data as continuation values

$$\begin{aligned}
\ln p^1_{kt} - \ln p^0_{kt} &= v^1_{kt}(D,L) - v^0_{kt}(D,L) \\
&= -c_{kt}(x,\varepsilon) + \beta\mathbb{E}[V_{kt+1}(D+1,L-1) - V_{kt+1}(D,L)] \\
&= -c_{kt}(x,\varepsilon) + \alpha P^D_{kt} - \alpha P^L_{kt}
\end{aligned}$$

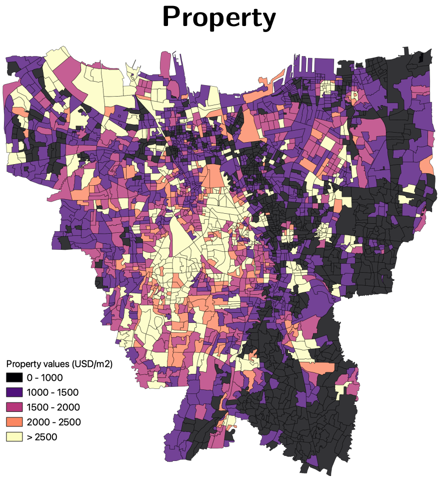
$$P^D_{kt}D + P^L_{kt}L = \frac{1}{\alpha}\Big(\beta\mathbb{E}[V_{kt+1}(D,L)]\Big) \qquad (*)$$

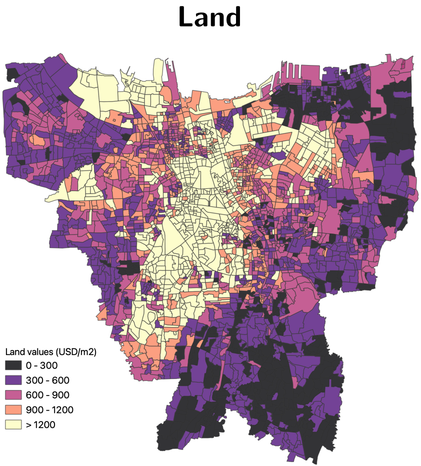
- Simple IV estimation
  - Need efficient real estate market ($P \to \mathbb{E}[V]$, frictions as ε)
  - And atomistic developers (P as data, 14k developers)
  - But not rational expectations (P as market offer)

Building construction (global data)



Real estate prices (urban data)





Supply estimates

	IV		First stage	
	Estimate	SE	Estimate	SE
Prices	0.171***	(0.041)		
Residential amenities			0.182***	(0.043)
Flooding	0.064	(0.044)	-0.842***	(0.216)
Ruggedness	-0.143***	(0.054)	1.268***	(0.103)
Distance to city center	0.084***	(0.011)	-0.224***	(0.023)
Distance to coast	-0.028***	(0.003)	0.012	(0.014)
Distance to major road	-0.005	(0.008)	0.101**	(0.050)
District FE	x		x	
Observations	5,780		5,780	
F-statistic			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

(transparent identification)

Rents

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

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

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

Government

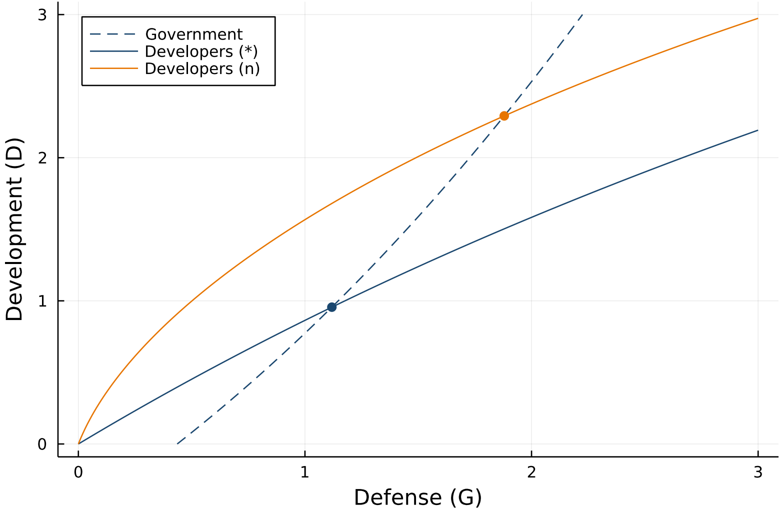
- Commitment level and political turnover by assumption
  - Hydrological model of flood risk $s_k(G)$
  - Engineering estimates of costs $e(G)$

- Counterfactuals (need to solve model)

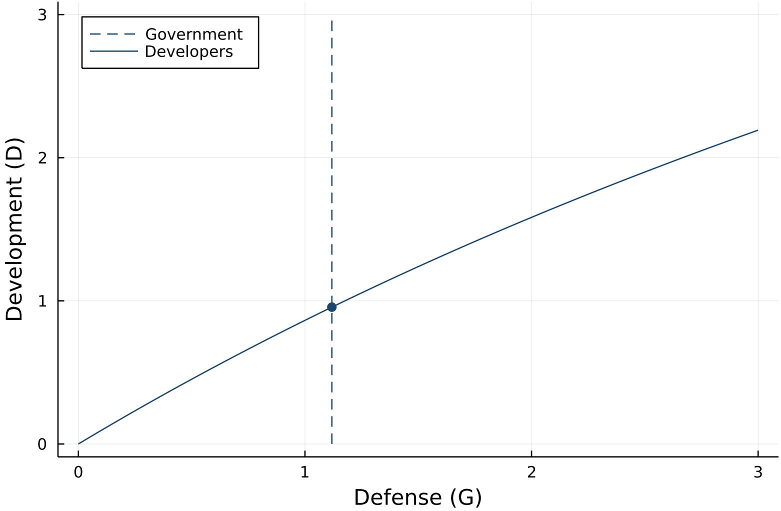
$$\begin{aligned} \text{Defense } g &\rightarrow \text{ flooding } s \text{ by } \textbf{hydrological} \text{ model} \\ &\rightarrow \text{ rents } r \text{ by } \textbf{demand} \text{ model} \\ &\rightarrow \text{ development } d \text{ by } \textbf{supply} \text{ model} \end{aligned}$$

Simulations

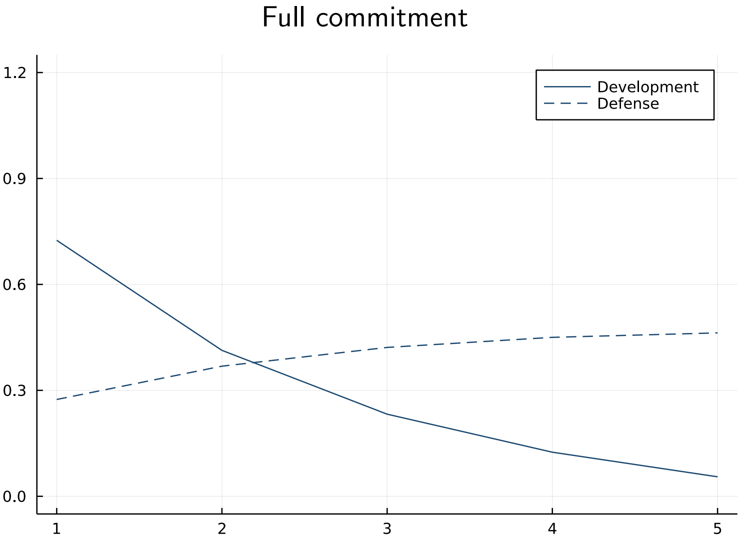
Coastal over-development and over-defense



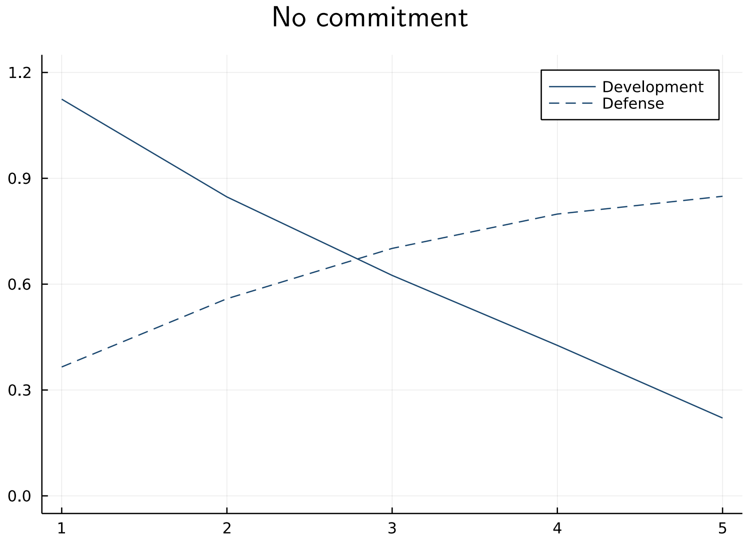
Coastal over-development and over-defense



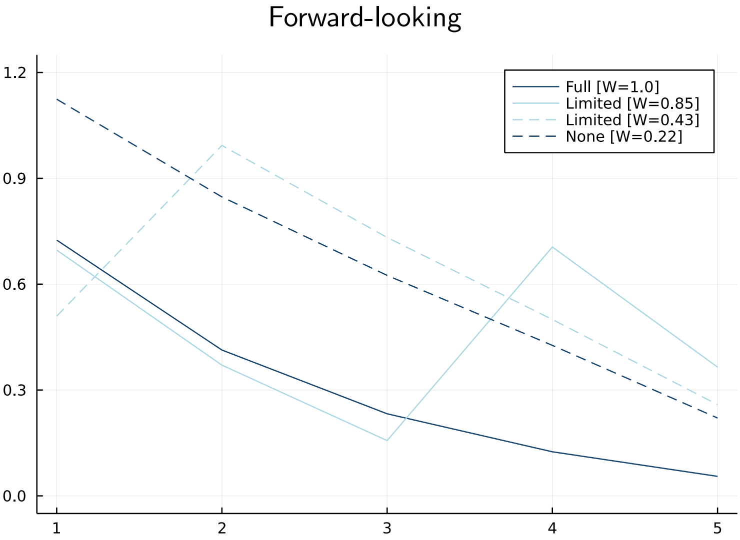
Development and defense over time



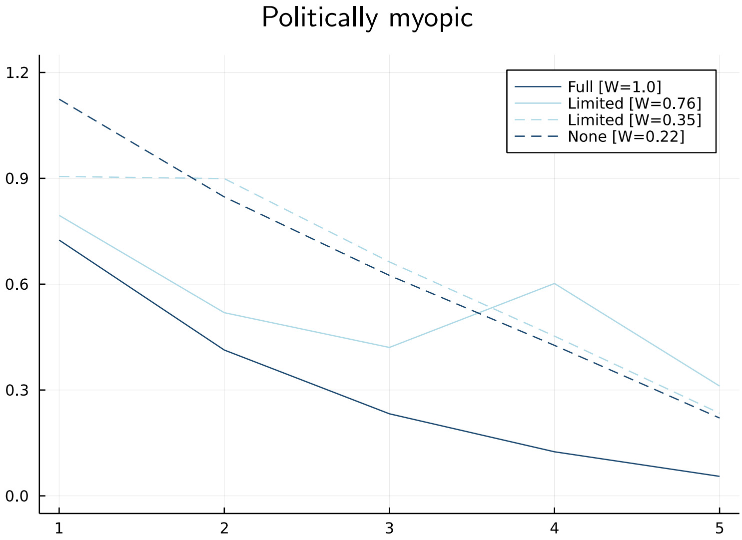
Development and defense over time



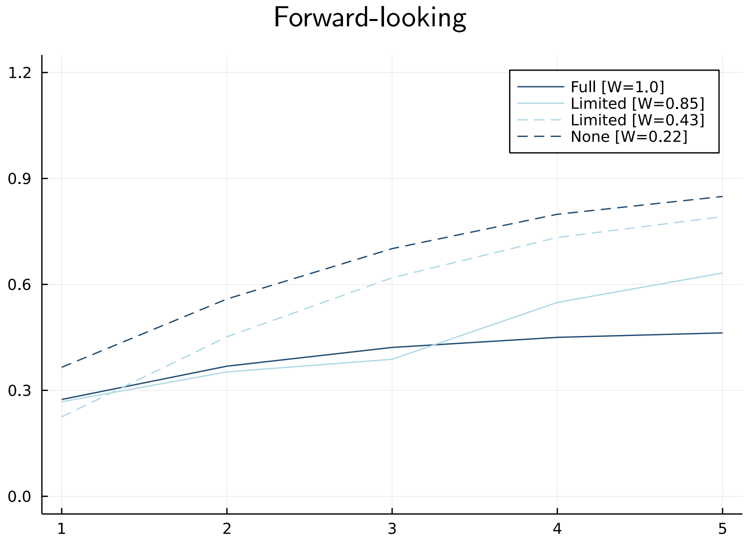
Limited commitment (development)



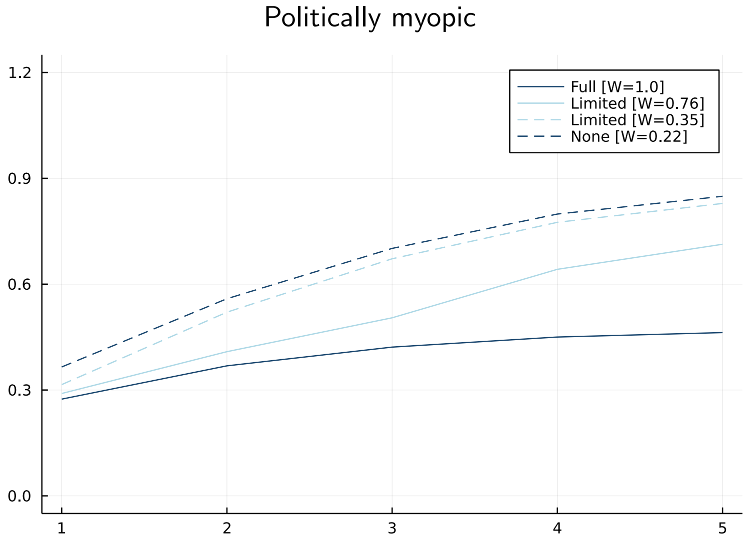
Limited commitment (development)



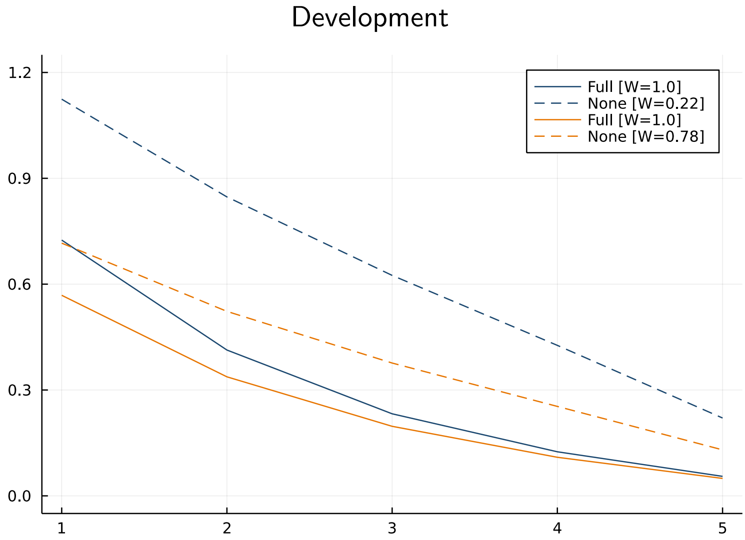
Limited commitment (defense)



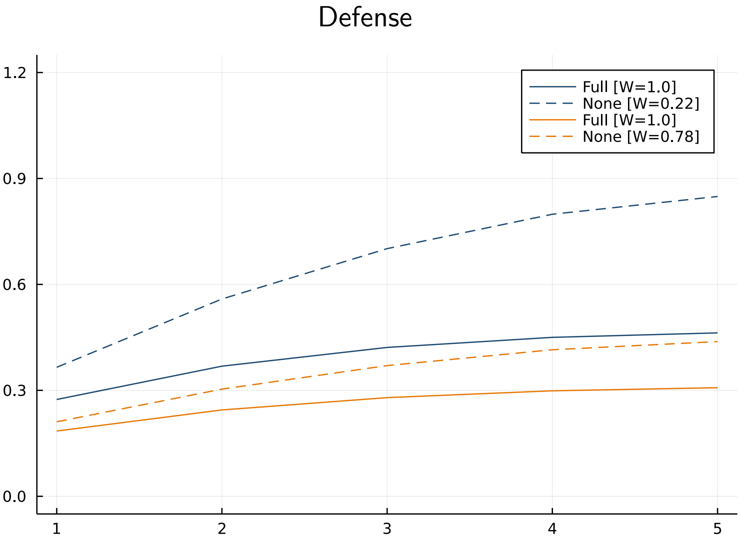
Limited commitment (defense)



Reducing coastal demand



Reducing coastal demand



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)


#CLIMATE NO JUSTICE


HARKAS