Sea Level Rise and Urban Adaptation in Jakarta

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October 26, 2022
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Sea level rise poses an existential threat to Jakarta, which faces frequent and worsening flooding. The government has responded with a proposed sea wall. In this setting, I study how government intervention complicates long-run adaptation to climate change. I show that government intervention creates coastal moral hazard, and I quantify this force with a dynamic spatial model in which developers and residents act with flood risk in mind. I find that moral hazard generates severe lock-in and limits migration inland, even over the long run.

Email: ajhsiao@princeton.edu. Wenqing Yu, Luong Nguyen, and Ghifari Firman provided exceptional research assistance. I am grateful to Nina Harari and Maisy Wong for their kind help in procuring data, and I acknowledge generous support from the Becker Friedman Institute International Economics and Economic Geography Initiative.

1 Introduction

Sea level rise is a major threat to economic development. Globally, 680 million people currently live in low-elevation coastal zones, with more than one billion expected by 2050 as sea levels continue to rise (IPCC 2019). The situation is especially severe in Southeast Asia, where land subsidence contributes to inundation rates that exceed those elsewhere by up to an order of magnitude.[1] Particularly vulnerable are the 31 million residents of the Jakarta metropolitan area, which is on pace to overtake Tokyo as the world's most populous megacity by 2030 (Euromonitor 2018).

Jakarta faces severe and frequent flooding, with damages exceeding \$300 million annually (Budiyono et al. 2015). Sea level rise adds substantial additional risk in the years to come. In response, the Indonesian government has proposed up to \$40 billion in flood infrastructure investments, including in a sea wall. This paper quantifies how effective such investments will be for Jakarta over the long run. In particular, I study how government intervention complicates adaptation by inducing moral hazard. The government tends to protect development ex post despite not wanting to ex ante, and developers over-invest at the coast in anticipation of this protection. The government thus faces a commitment problem, and indeed Kydland and Prescott (1977) offer flood protection as a leading example in their seminal paper.[2]

I quantify these forces for Jakarta with a dynamic spatial model of urban development. In the model, developers and residents make investment and location decisions with flood risk in mind. Residential demand is spatial, as individuals make location decisions based on rents, flood risk, neighborhood amenities, and migration costs. Moving inland abandons high-amenity areas and incurs migration costs. Developer supply is dynamic, as forward-looking developers make sunk investment decisions in immobile buildings. They do so trading off a stream of future rents against the upfront costs of construction. Moving inland abandons high-rent areas and incurs construction costs. Total supply arises as a dynamic competitive equilibrium among atomistic developers, as in Hopenhayn (1992). Rents clear the market for development in each period, equalizing residential demand and developer supply.

Estimation leverages granular data on developers and residents. I estimate residential demand by matching changes in the spatial distribution of population between 2015 and 2020. Estimation is in the spirit of Berry et al. (1995),

[1] In Southeast Asia, population-weighted rates of relative sea level rise are 3.2 times as large as those in South Asia, 11.2 times those in Russia, and 3.9 times those elsewhere (Nicholls et al. 2021). Relative sea level rise combines absolute sea level rise and land subsidence.

[2] Kydland and Prescott (1977), page 477. "For example, suppose the socially desirable outcome is not to have houses built in a particular flood plain but, given that they are there, to take certain costly flood-control measures. If the government's policy were not to build the dams and levees needed for flood protection and agents knew this was the case, even if houses were built there, rational agents would not live in the flood plains. But the rational agent knows that, if he and others build houses there, the government will take the necessary flood-control measures. Consequently, in the absence of a law prohibiting the construction of houses in the flood plain, houses are built there, and the army corps of engineers subsequently builds the dams and levees."

integrating over origins and addressing the endogeneity of rents with instruments. I estimate developer supply by matching the spatial distribution of new construction between 2015 and 2020. Estimation relies on reading continuation values from data on market prices, in the style of Kalouptsidi (2014), and again addresses the endogeneity of rents with instruments. For intuition, consider the binary choice to develop or not. Property values capture the stream of rents over time from developing, while land values capture the option value from not developing (but perhaps developing in the future). Each is inclusive of market expectations, including over the government intervention that is central to my analysis. Where market frictions prevent long-term revenues from capitalizing fully into prices, differencing eliminates the resulting bias to the extent that it is systematic.

In simulations, I quantify the moral hazard force over both the short and long run. I assess the effects of both non-commitment and political myopia, and I study demand relocation and development destruction. I find that non-commitment leads to large increases in coastal development, including over the long run. Political myopia raises coastal development further, as current governments over-defend in failing to internalize the costs to future administrations. Relocating demand away from the coast lowers both moral hazard and coastal development and is consistent with the moving of the political capital from Jakarta. This move also requires commitment, but the government may find such commitment more politically feasible than commitment not to intervene. To this end, destroying existing development also slows coastal development by reducing government intervention. Full policy counterfactuals are in progress.

This paper's main contribution is to quantify how endogenous government intervention limits adaptation to sea level rise. While coastal investment has high long-run costs (Balboni 2021), adaptation via moving inland can greatly reduce damages (Desmet et al. 2021). Endogenizing government intervention, however, leads to moral hazard that prompts continued coastal investment (Vigdor 2008; Boustan et al. 2012; Baylis and Boomhower 2022; Fried 2022), delaying the move inland. Durable capital then prolongs this delay by inducing persistence (Glaeser and Gyourko 2005). The result is severe coastal lock-in, in sharp contrast to the smooth inland transition of Desmet et al. (2021).

Methodologically, I estimate a model of industry dynamics in the tradition of Hopenhayn (1992) and Ericson and Pakes (1995), drawing on dynamic discrete choice methods from Hotz and Miller (1993) and Arcidiacono and Miller (2011). I build on Kalouptsidi (2014), who shows how to avoid computing continuation values, at least in estimation, by reading them from data. I show how this insight greatly simplifies estimation of dynamic developer models with data generally available in urban settings. A major benefit of this approach is that it accommodates developer expectations with significantly more flexibility than full-solution approaches that must specify long-run expectations, and even two-step approaches that require only rational expectations, as in the Euler conditional choice probability approach of Scott (2013). In incorporating geography, I also complement a growing literature that brings dynamics to spatial models (Desmet et al. 2018; Caliendo et al. 2019; Kleinman et al. 2022).

Finally, I provide quantitative estimates and recommendations for Jakarta, drawing on work in environmental studies that assesses current and future flood risk (Budiyono et al. 2015; Takagi et al. 2016; Wijayanti et al. 2017; Andreas et al. 2018). Land subsidence in Jakarta effectively accelerates sea level rise, bringing questions of adaptation to the fore. Jakarta thus foreshadows the future that most coastal cities will face by century's end, including as sea walls enter policy discussions worldwide.[3] Jakarta's challenges are the world's challenges.

2 Background

Flooding has long plagued Jakarta. Historical records capture flooding as early as 1621, shortly after the Dutch East India Company established its capital of Batavia near the north coast of the present-day city (Abeyasekere 1987). Recurring inundation persists today, with widespread flooding in 1996, 2002, 2007, 2013, and 2020. Geography makes flooding inescapable, as Jakarta occupies a delta where thirteen rivers meet the ocean. This nexus of waters both nurtures and menaces the city.

Fluvial (river) flooding in times of extreme rainfall has been the key challenge to date. Historical flood policy thus focused on infrastructure aimed at managing river water (Caljouw et al. 2005; Ward et al. 2011; Octavianti and Charles 2019). Major investments include a westward canal (*Westerse Vaart*) in 1725, the West Flood Canal (*Banjir Kanal Barat*) in 1918, and the East Flood Canal (*Banjir Kanal Timur*) in 2002. Each operates within a broader system of dams, reservoirs, drainage systems, pumping stations, and flood gates. Figure 1 maps this infrastructure alongside historical flooding.

Coastal flooding adds significant additional risk in the coming decades. North Jakarta faces near total submersion by 2050, as sea level rise combines with rapid land subsidence. Subsidence in some coastal neighborhoods is projected to exceed five meters by 2050, compared to projected sea level rise of 25 centimeters (Andreas et al. 2018; Kulp and Strauss 2019). The government has responded with two key initiatives.

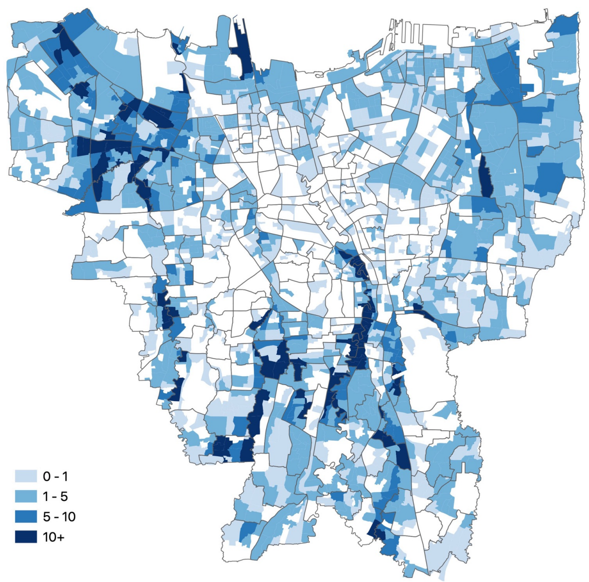
First, a sea wall has been in discussion since 2011, with costs as high as $40 billion (Garschagen et al. 2018; Colven 2020). Proposals have varied in scope and ambition, but each has prioritized onshore walls for short-term protection. The Jakarta Coastal Defense Strategy (JCDS) in 2011 became the National Capital Integrated Coastal Development Masterplan (NCICD) in 2014 – the so-called "Great Garuda Project" – and was further revised in 2016. Progress then slowed with a 2016 moratorium and the 2017 election of Anies Baswedan, whose gubernatorial campaign called for halting construction. Work later resumed with the Integrated Flood Safety Plan (IFSP) in 2019.

[3] China plans 15,000 km of coastline sea wall, and Japan has built 400 km along the Tohoku coastline. The Northern European Enclosure Dam project proposes dams from France to England and Scotland to Norway. Miami has proposed 10 km of coastline sea wall, and New York has proposed the BIG U project covering Lower Manhattan.

Figure 1: Flooding in Jakarta

(a) Infrastructure

(b) Flood frequency, 2013-2020



Source: Regional Disaster Management Agency (*BPBD* via *data.jakarta.go.id*). The top figure maps flood infrastructure, and the bottom figure shows flood incidents at the tract (*rukun warga*) level. For the latter, I plot the average number of months per year with registered floods, as well as neighborhood (*kelurahan*) boundaries.

Second, the government plans to establish a new political capital called Nusantara, at once hedging against flood risk and relieving congestion in Jakarta. The move to what is currently East Kalimantan province comes at a proposed cost of \$32 billion, with inauguration slated for Indonesia's national day on August 17, 2024. The government envisions a planned, modern city nestled in the forests of Borneo, named in tribute to the ancestral word for the archipelago. Official goals include employment of nearly five million and net-zero emissions by 2045 (IKN 2022).

3 Theory

I show how coastal development forces government intervention both today and tomorrow, leading to over-development and over-defense at high social cost.

3.1 Development and defense

I model flood-prone coastal development and the government investment aimed at defending it. In each period t, developers undertake development d_t at cost $c(d_t)$, and the government undertakes defense g_t at cost $f(g_t)$. Costs are increasing and convex. Residential value $r(D_t, g_t)$ is increasing and concave in each argument, with complementarity $\kappa = \frac{\partial^2 r}{\partial d \partial g} > 0$ and total $D_t = D_{t-1} + d_t$.[4] Dynamics arise from the durability of development, which benefits from both current and future defense.[5]

In the first best, the social planner chooses development and defense over time to maximize social welfare. The government also aims to maximize welfare, but frictions arise as it only directly chooses defense. Development is instead chosen by developers with private profits in mind. Welfare is

$$W^t = \sum_{t'=0}^{T-t} \beta^{t'} w_{t+t'}, \quad w_t = r(D_t, g_t) - c(d_t) - f(g_t)$$

for net present value W^t and current w_t. Similarly, define

$$X^t = \sum_{t'=0}^{T-t} \beta^{t'} x_{t+t'} \quad \text{for} \quad x_t \in \{r(D_t, g_t), c(d_t), f(g_t)\}.$$

[4] For costs, $\frac{dc}{dd}, \frac{d^2c}{dd^2}, \frac{df}{dg}, \frac{d^2f}{dg^2} > 0$. For $r(D, g)$, $\frac{\partial r}{\partial d}, \frac{\partial r}{\partial g} > 0$ and $\frac{\partial^2 r}{\partial d^2}, \frac{\partial^2 r}{\partial g^2} < 0$ given $\frac{\partial}{\partial d} = \frac{\partial}{\partial D}$. Fixing g_t, $r(d_t)$ captures downward-sloping residential demand. It measures the area under the demand curve for development $[0, d_t]$. The demand curve itself is $r'(d_t)$. Higher g_t shifts demand upward, subject to diminishing marginal returns to g_t. Let $\kappa(d, g) = \kappa$.

[5] For simplicity, I consider nondurable defense with repeated intervention. Such a model is isomorphic to one with durable defense but repeated intervention due to rising sea levels. Furthermore, I model defense with physical infrastructure in mind, but it encompasses any government intervention that raises residential value, including flood insurance. Under aggregate coastal risk, note that insurance effectively transfers inland premiums to coastal claimants. Coastal infrastructure built with citywide taxes is thus a similar transfer.

Developers do not internalize the costs of defense, implying profits

$$\pi^t = \frac{\partial}{\partial d_t}\big(R^t - c_t\big)$$

for the marginal developer given $c_t = c(d_t)$. Revenues are $\frac{\partial}{\partial d_t}R^t$ and costs $\frac{\partial}{\partial d_t}c_t$. The social planner maximizes W^t, as does a forward-looking government. A politically myopic government maximizes $R^t - C^t - f_t$, weighing future benefits but ignoring future costs. Such a government may value political credit for future resident welfare, or it may experience lobbying by forward-looking developers. Developers consider profits, with $\pi^t = 0$ under perfect competition.

3.2 Commitment

Over-development arises when the government lacks commitment power. The government tends to defend development ex post despite not wanting to ex ante, and developers take advantage to force defense at suboptimally high levels. Setting $D_0 = 0$ for simplicity, consider the one-period case with social welfare

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

In the first best, the social planner chooses development and defense to maximize social welfare. The resulting first order conditions are

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

for $r'(x) = \frac{\partial}{\partial x} r(d, g)$. Both lines equalize marginal benefits and costs.[6]

Without commitment, the government revises its choice of defense after development is sunk, and developers act in anticipation of this response. The equilibrium conditions are

$$[d^n] \quad r'(d) + \kappa g'(d) = c'(d), \tag{1d}$$

$$[g^n] \quad r'(g) = f'(g). \tag{1g}$$

Equation 1d equalizes marginal revenues and costs, as developers are perfectly competitive, while equation 1g remains as above.[7] First, defense responds to sunk development. Differentiating equation 1g with respect to development,

$$\kappa + r''(g)\, g'(d) = f''(g)\, g'(d).$$

It follows that $g'(d) > 0$ given $\kappa > 0$, $r''(g) < 0$, and $f''(g) > 0$. Second, this response creates moral hazard, as over-development anticipates over-defense. In

[6] The same analysis also captures a world in which defense is durable and requires only one-time investment, with welfare components r, c, and f capturing net present values.

[7] Atomistic marginal developer d does not itself affect residential values or defense. But its revenues $r'(d) + \kappa g'(d)$ are set by mass $[0, d)$ of inframarginal developers.

equation 1d, $\kappa g'(d) > 0$ implies $d^n > d^*$ given $r''(d) < 0$ and $c''(d) > 0$. Moral hazard raises developer returns and thus development.

Commitment avoids over-development. Committing to first-best defense g^* yields $g'(d) = 0$, eliminating moral hazard. The challenge is that the government finds it optimal to protect over-development ex post, particularly if lobbying or upcoming elections increase its returns to doing so. An alternative is to target first-best development d^* by committing to tax κg on development. Restricting permits or zoning achieves similar outcomes by regulating quantities instead of prices. The challenge is that developers will lobby against enforcement of taxes and restrictions, particularly if lobbying is facilitated by corruption.

3.3 Commitment over time

With two periods, the social planner chooses development and defense across periods to maximize welfare $W^1 = w_1 + \beta w_2$. The first order conditions are

$$\begin{aligned}
[d_1^*] \quad & r_1'(d_1) + \beta r_2'(d_1) = c'(d_1), \\
[g_1^*] \quad & r_1'(g_1) = f'(g_1), \\
[d_2^*] \quad & r_2'(d_2) = c'(d_2), \\
[g_2^*] \quad & r_2'(g_2) = f'(g_2)
\end{aligned}$$

for $r_t'(x) = \frac{\partial}{\partial x} r(D_t, g_t)$. With full commitment across periods, the government achieves this first best. Commitment power allows it to set (d_1, g_1, d_2, g_2) and thus to act as social planner.

Without commitment in period two, the government chooses g_2 to maximize welfare W^2, and developers choose d_2 considering profits π^2. The resulting equilibrium conditions mirror equations 1.

$$[d_2^n] \quad r_2'(d_2) + \kappa g_2'(d_2) = c'(d_2), \tag{2d}$$
$$[g_2^n] \quad r_2'(g_2) = f'(g_2) \tag{2g}$$

Period one depends on government commitment and horizon. With limited commitment, the government chooses (d_1, g_1) in period one anticipating no commitment in period two. A forward-looking government $(^f)$ does so to maximize W^1, while a politically myopic government $(^m)$ maximizes $R^1 - c^1 - f_1$.

$$[d_1^f] \quad r_1'(d_1) + \beta r_2'(d_1) = c'(d_1) + \beta \kappa g_2'(d_1), \tag{3d}$$
$$[g_1^f] \quad r_1'(g_1) = f'(g_1) + \beta \kappa g_2'(g_1) \tag{3g}$$

$$[d_1^m] \quad r_1'(d_1) + \beta r_2'(d_1) + \beta r_2'(g_2)\, g_2'(d_1) = c'(d_1) + \beta \kappa g_2'(d_1), \tag{4d}$$
$$[g_1^m] \quad r_1'(g_1) + \beta r_2'(g_2)\, g_2'(g_1) = f'(g_1) + \beta \kappa g_2'(g_1) \tag{4g}$$

With no commitment, the government only chooses g_1. Development is set by developers with π^1 in mind, while defense depends on government horizon. Both anticipate no commitment by the government in period two.

$$[d_1^n] \quad r_1'(d_1) + \beta r_2'(d_1) + \kappa g_1'(d_1) + \beta \kappa g_2'(d_1) = c'(d_1) - \beta r_2''(d_2)\, d_2'(d_1) \tag{5d}$$

A forward-looking government acts with equation 3g, and a politically myopic government with equation 4g.

Moral hazard arises both within and across periods. Within periods, developers exploit the government. Both $\kappa g_2'(d_2) > 0$ in period two (equation 2d) and $\kappa g_1'(d_1) > 0$ in period one (equation 5d) prompt over-development. Across periods, current developers exploit the future government, as $\beta\kappa g_2'(d_1) > 0$ in period one (equation 5d) prompts current over-development that forces future over-defense. Similarly, a politically myopic current government exploits the future government, as $\beta r_2'(g_2)g_2' > 0$ in period one (equations 4) encourages over-investment given uninternalized costs to future administrations.

Furthermore, development has persistent effects. On one hand, this persistence creates lock-in at the coast. Over-development in period one prompts over-defense in period two, as the government seeks to protect sunk $d_1 > d_1^*$.[8] The result is over-development in period two, even when the period-two government has commitment power. On the other hand, this persistence gives the current government a means of helping future governments. In particular, $\beta\kappa g_2' > 0$ in period one (equations 3 and 4) prompts under-defense, offsetting over-defense from moral hazard in period two. Commitment power strengths this force by pairing under-defense with under-development.

As before, commitment avoids over-development. Commitment to first-best defense (g_1^*, g_2^*) eliminates moral hazard, as does targeting development (d_1^*, d_2^*) with commitment to taxes or restrictions. Commitment thus demands that the government resist its static incentives – as well as lobbying – not only in period one, but also in period two. More generally, the challenge is that commitment avoids over-development only if it holds over the long run. Even if the current government has commitment power, over-development proceeds as long as a future government does not.

Alternative policies constrain long-run development more indirectly. Lower coastal demand reduces the returns to defense, decreasing the responsiveness of defense to development and thus lessening moral hazard. The government can lower coastal demand by relocating residents with direct mandates, migration subsidies, or improvements to non-coastal amenities. Such policies may be more politically feasible over the long run than direct attempts to regulate development, and they can have persistent effects even if implemented temporarily. Capital destruction can also constrain long-run development. A smaller stock of development reduces the need for defense, which lowers new development. But it also increases the extent to which new development drives defense, thereby raising moral hazard. Appendix B considers extensions.

[8] Downward-sloping demand generates an opposing force if d_1 lowers $r_2(d_1)$ by enough to dominate the positive effect of $g_2(d_1)$, such that $d_2'(d_1) < 0$. Indeed, equation 5d captures how this forces affects development: if $d_2'(d_1) > 0$, then d_1 raises d_2 and lowers r_2. For large stock D_0, however, lock-in via defense $g_2(d_1)$ will dominate this pecuniary effect.

4 Empirics

I describe how I bring the theory to data, and I document stylized facts consistent with the theory.

4.1 Theory

The theory above frames the empirical analysis. Consider components $r(d, g)$, $c(d)$, and $f(g)$ of social welfare given development and defense (d, g) in the one-period case. I obtain residential value $r(d, s(g))$ as a function of development and flood safety by estimating a model of residential demand, where development demanded is decreasing in price and increasing in flood safety s. I obtain costs $c(d)$ of development by estimating a model of developer supply, where development supplied is increasing in price and decreasing in costs of construction. I compute flood safety $s(g)$ and costs $f(g)$ of defense directly rather than estimating them from the data. A hydrological model describes flooding under any given level of defense, and costs are from engineering estimates.

4.2 Data

I compile high-resolution spatial data on building construction, populations, real estate values, and flood risk across Jakarta at the tract level. Jakarta consists of five districts (*kota*), 44 sub-districts (*kecamatan*), 267 neighborhoods (*kelurahan*), and 2,722 tracts (*rukun warga*).[9] Figure 2 illustrates the data, and appendix C describes the data in further detail.

The Global Human Settlement Layer provides data on the spatial distribution of building construction and population across Jakarta (GHSL 2022). Each is measured at the 100m grid cell level at five-year intervals from 1975 to 2020. Building construction data include measures of both built-up surface area and volumes, and I verify these data with building-level construction derived separately from 2015 satellite imagery.

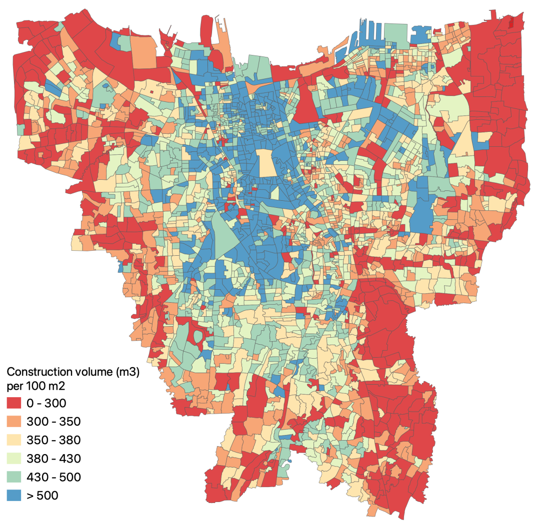
Real estate values include property and land values, where property values include constructed buildings. I construct property values for 2015 by combining data on property transactions and listings from two major real estate websites, 99.co and brickz.id, covering both residential and non-residential properties. Land values for 2015 come from Jakarta Smart City, a government initiative to update property tax appraisals by computing granular land values from transactions, listings, and measurements in the field.

Flood risk will be derived from a hydrological model of Jakarta, but for now is computed from realized flooding as in figure 1b. Flooding data comes from the Regional Disaster Management Agency and measures flood frequency and depth at the tract level from 2013 to 2020.

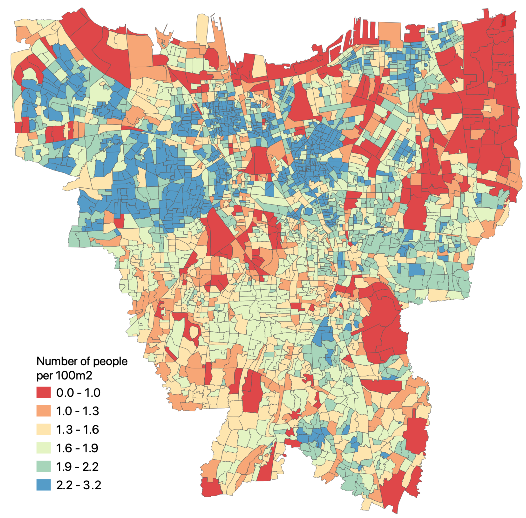
[9] I focus on Jakarta proper, although the empirical analysis accounts for movement across the broader metropolitan area. I exclude the islands of *Kepulauan Seribu* district.

Figure 2: Data (2015)

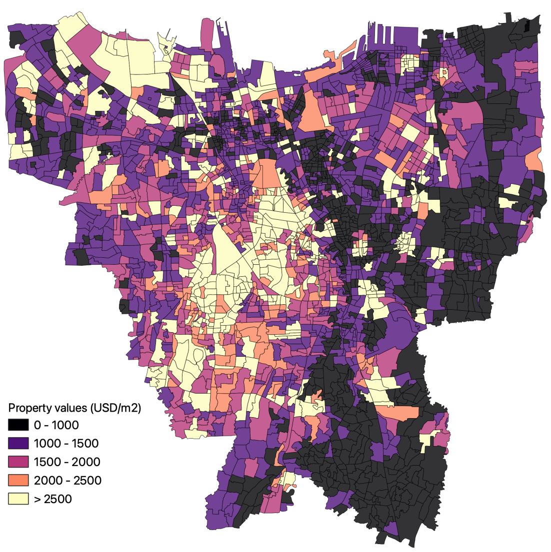
(a) Building construction



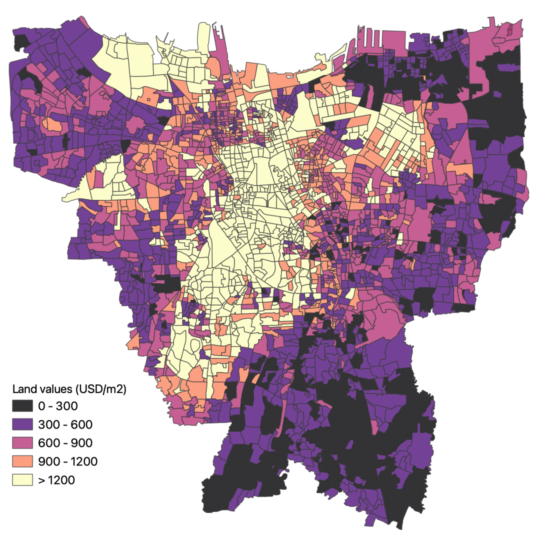
(b) Population



(c) Property value



(d) Land value



Building construction and populations come from the Global Human Settlement Layer. I construct property values with transactions and listings data from 99.co and brickz.id. Land values come from the Smart City initiative of the Jakarta city government.

Table 1: Flood risk, land values, and building construction

(a) 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

(b) 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

Each observation is a tract, and each column a regression. Flood risk is realized flooding from 2013 to 2020, land values are from the Jakarta Smart City initiative, and building construction is from the Global Human Settlement Layer. *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$.

4.3 Stylized facts

The above data help illustrate the moral hazard problem. I find that lower flood risk is associated with higher land values, which in turn correspond to higher levels of building construction. Table 1 presents these results with cross-tract regressions that control for unobservables at the district, sub-district, and neighborhood levels. The concern is that increased flood protection simply prompts increased construction in areas facing long-term flood risk.

A more careful analysis would consider whether historical investments in flood protection led to higher levels of building construction. The opening of the West flood canal in 1918 allows me to study this dynamic over the last century, with historical maps from the Dutch colonial era to the present providing measures of building construction over time and space. I use a hydrological model to quantify how the flood canal affects the distribution of flood risk over space, and I apply this variation in a difference-in-differences framework. In particular, I ask whether places that experienced larger decreases in flood risk because of the flood canal also experienced more building construction.

5 Empirical model

I present an equilibrium model that combines spatial demand by residents with dynamic supply by developers. I capture the geography of Jakarta at the tract level, with 2,731 units that each contain around 4,000 people.

5.1 Demand

Residents make static location choices with flood risk in mind. For an individual i in origin j considering destination k, utility is

$$U_{ijk} = \underbrace{-\alpha r_k + \rho s_k + \xi_k}_{\delta_k} - \tau m_{jk} + \epsilon_{ijk} \tag{6}$$

for rent r_k, flood safety s_k, amenity ξ_k, migration distance m_{jk}, logit shock ϵ_{ijk}, and destination-specific utility δ_k. Residents seek low rents, high flood safety, high amenities, and short distances. Distance introduces spatial dependence.[10] Residential demand sums over origins given populations n_j and choice probabilities p^{res}_{jk}. The development demanded by residents in each tract is thus

$$D^{\text{res}}_k = \sum_j n_j p^{\text{res}}_{jk} \phi, \quad p^{\text{res}}_{jk} = \frac{\exp(\delta_k - \tau m_{jk})}{\sum_{\hat{k}} \exp(\delta_{\hat{k}} - \tau m_{j\hat{k}})} \tag{7}$$

given floor space per resident ϕ. Moving inland is costly because it abandons high-amenity tracts and incurs migration costs. Price endogeneity arises because rents are correlated with unobserved amenities.

5.2 Supply

Developers make forward-looking investment choices in dynamic competitive equilibrium. Developers are atomistic and each control one tract k. They choose whether to develop and the extent of development in each period t. Development is sunk and immobile. State $w_t = (D_t, G_t)$ tracks development $D_t = \{D_{kt}\}$ and defense $G_t = \{G_{kt}\}$ by tract. For $\mathbb{E}_{kt}[\cdot] = \mathbb{E}_k[\cdot|w_t]$,

$$V_k(w_t) = r_k(w_t)D_{kt} + \mathbb{E}_{kt}[\max\{v^1_k(w_t) + \epsilon^1_{kt}, v^0_k(w_t) + \epsilon^0_{kt}\}]. \tag{8}$$

Developers choose to develop or not subject to logit shocks ϵ_{kt}. Expectations are over these shocks. The choice-specific conditional value functions are

$$v^1_k(w_t) = v^1_k(d^*_{kt}, w_t), \tag{9a}$$

$$v^0_k(w_t) = \beta\mathbb{E}_{kt}[V_k(w_{t+1}) \,|\, 0]. \tag{9b}$$

Choosing not to develop leads to the same choice in the next period, with expectations over the next-period state and $D_{kt+1} = D_{kt}$ given $d_{kt} = 0$. Choosing to develop implies a choice over the extent d_{kt} of development.

[10] Although all origins respond proportionally to changes in destination characteristics given IIA substitution, migration from faraway origins is low at baseline because the disutility of distance dominates. Random coefficients would strengthen spatial dependence, as (α_j, ρ_j) coefficients that depend on distance would relax IIA and allow nearby origins to respond disproportionately to changes in destination characteristics.

This choice over d_{kt} trades off the increased revenue from added floor space against the higher cost of constructing it.

$$v_k^1(d_{kt}, w_t) = -c_{kt}(d_{kt}) + \beta \mathbb{E}_{kt}[V_k(w_{t+1}) \mid d_{kt}],$$
$$c_{kt}(d_{kt}) = \left(\frac{1}{2}\psi d_{kt} + x_{kt}\gamma\right) d_{kt} + \zeta_{kt}$$

Upfront costs c include convexities ψ, observed x_{kt}, and unobserved ζ_{kt}.[11] Revenues come from stock D_{kt+1} of rentable development, with $D_{kt+1} = D_{kt} + d_{kt}$ given new d_{kt}. Flow costs are passed onto residents and thus capitalize into rents. Time to build is one period, and expectations are over future states.

$$d_{kt}^* = \arg\max_{d_{kt}} \{v_k^1(d_{kt}, w_t)\} = \frac{1}{\psi}\left(- x_{kt}\gamma + \sum_{t'=1}^{\infty} \beta^{t'} \mathbb{E}_{kt}[r_k(w_{t+t'})]\right)$$

Developers seek high rents and low costs. Developer supply sums over old and new supply given probability p_{kt}^{dev} and extent d_{kt}^* of development. The development supplied by developers in each tract is thus

$$D_{kt+1}^{\text{dev}} = D_{kt} + d_{kt}^* p_{kt}^{\text{dev}}, \quad p_{kt}^{\text{dev}} = \frac{\exp\{v_k^1(w_t)\}}{\exp\{v_k^1(w_t)\} + \exp\{v_k^0(w_t)\}} \tag{10}$$

I impose that $p_{kt}^{\text{dev}} = 0$ if $D_{kt} + d_{kt}^*$ exceeds upper bound $\bar{D}_k$ of development. Moving inland is costly because it abandons high-rent tracts and incurs construction costs. Price endogeneity arises because rents are correlated with unobserved construction costs.

5.3 Rents and government

In equilibrium, rents equalize the development demanded by residents and supplied by developers in each tract k.

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

I consider government intervention under a range of assumed levels of commitment and political turnover. A hydrological model of flood risk captures how flood safety $s(G_{kt})$ responds to any given mode of government intervention G_t, and engineering estimates determine the associated costs $f(G_t)$ of this intervention. Intervention increases flood safety in affected cells, raising resident demand and thus rents in these cells. Higher rents induce increased developer supply, which in turn attenuates the rise in rents. Defense is durable and follows

$$G_{kt+1} = G_{kt} + g_{kt}.$$

6 Estimation

Demand estimation matches population shares, and supply estimation leverages data as a substitute for computing continuation values.

[11] Cost factors can include flood safety s_{kt} if flood protection generates upfront costs.

6.1 Demand

I estimate demand by matching changes in the spatial distribution of population between 2015 and 2020. I address the endogeneity of rents by instrumenting with soil quality and ruggedness, which shift supply by affecting the ease of construction. I take rents to be mortgage payments on observed property values. I define origin populations as populations in 2015, augmented by a uniform population growth rate. I focus on residential choice within the core of Jakarta, but I include the option of a location that aggregates over the periphery.[12] Total metropolitan population evolves exogenously.

Estimation follows Berry (1994) and Berry et al. (1995), except that I integrate over origins instead of over a broader set of demographics. I estimate $\theta = (\theta_1, \theta_2)$ for $\theta_1 = (\alpha, \rho)$ and $\theta_2 = \tau$. First, fixing θ_2, I match observed and model-implied populations by computing $\delta = \{\delta_k\}$ by contraction mapping.[13] Suppressing dependence on data (n, m), equation 7 implies

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

Second, I regress $\hat{\delta}$ on data (r, s) to obtain estimates $\hat{\theta}_1$ and residuals $\hat{\xi}$.

$$\xi_k = \delta_k + \alpha r_k - \rho s_k$$

Third, I compute the GMM objective function

$$Q(\theta) = g(\xi(\theta))' W g(\xi(\theta))$$

for weighting matrix W and sample analog $g(\xi(\theta)) = \sum_k Z_k \xi_k(\theta)$ of moment condition $\mathbb{E}[Z\xi(\theta)] = 0$. Fourth, I search over θ_2 to minimize $Q(\theta)$.

$$\hat{\theta}_2 = \arg\min_{\theta_2} Q(\theta_1(\theta_2), \theta_2)$$

One concern is that flood risk is correlated with water-related amenities. For example, proximity to the coast has positive amenity value but also raises flood risk. Failing to control for this proximity thus attenuates the estimated effect of flood risk on residential demand. I separate such amenities from flood risk by controlling for neighborhood fixed effects and distance to the coast. Including more controls reduces the bias from uncaptured amenities, but it also reduces the remaining variation in flood risk. Another approach is to rely on discontinuities in flood risk maps (Bakkensen and Ma 2020), but my flood risk data vary smoothly over space because they come from a hydrological model rather from than government risk maps.

[12] I take this periphery to be free of flood risk and to have rents set at the minimum observed within the core. Individuals originating at the periphery face distance m_{0k} to destination k defined as the minimum distance from k to the core-periphery border.

[13] Intuitively, $\text{population}_k > D_k^h(\delta_k^h)$ at iteration h is remedied by $\delta_k^{h+1} > \delta_k^h$ at $h+1$.

6.2 Supply

I estimate supply by matching the spatial distribution of new construction between 2015 and 2020. I address the endogeneity of rents by instrumenting with resident demographics, which shift demand by affecting local consumption of development.[14]

Estimation involves applying the logit inversion, then reading continuation value from the data in the spirit of Kalouptsidi (2014). Inverting equation 10,

$$\ln p_{kt}^{\text{dev}} - \ln\bigl(1 - p_{kt}^{\text{dev}}\bigr) = v_k^1(w_t) - v_k^0(w_t). \tag{11}$$

Substituting equations 9,

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

where development d_{kt}^* is as observed in the construction data. If future profits capitalize into real estate prices, then price data capture the forward-looking terms and allow me to sidestep the typical challenge of computing continuation values. For prices P_{kt}^1 per square meter of development and P_{kt}^0 per square meter of land required for development,

$$\begin{aligned}
\beta \mathbb{E}_{kt}[V_k(w_{t+1}) \,|\, d_{kt}^*] &= P_{kt}^1(D_{kt} + d_{kt}^*) + P_{kt}^0(\bar{D}_k - D_{kt} - d_{kt}^*) + \eta_{kt}^1, \\
\beta \mathbb{E}_{kt}[V_k(w_{t+1}) \,|\, 0] &= P_{kt}^1 D_{kt} + P_{kt}^0(\bar{D}_k - D_{kt}) + \eta_{kt}^0.
\end{aligned}$$

Real estate prices reflect the stream of future rents embodied in value function V_k, up to expectational errors η_{kt} given information set $\mathcal{J}_{kt}$. Developed land generates rents, while undeveloped land has the option value of future development. For $\Delta X_{kt} = X_{kt}^1 - X_{kt}^0$, I thus obtain estimating equation

$$\ln p_{kt}^{\text{dev}} - \ln\bigl(1 - p_{kt}^{\text{dev}}\bigr) = -c_{kt}(d_{kt}^*) + \Delta P_{kt} d_{kt}^* + \Delta \eta_{kt}. \tag{12}$$

This approach relies on several key assumptions. First, developers are independent and atomistic. The challenge is that entry by large developers changes real estate prices from observed values. That is, equation 12 has P_{kt}^1 and P_{kt}^0 that are conditional on present and future development $\{d_{kt}^*, d_{kt+1}^*, \ldots\}$, but v_k^1 and v_k^0 involve entry that departs from this path. Second, I require real estate data on both property and land values. Such data are available for Jakarta and likely many other urban settings, although perhaps less so for rural settings. Third, I require that these real estate data accurately capture the continuation values of interest. Other work has documented how flood risk may not fully capitalize into housing prices, and I discuss below how my approach can at least partially accommodate such frictions.

An alternative is an Euler conditional choice probability approach, applying methods from Scott (2013) that I build on in previous work (Hsiao 2022). The intertemporal comparison between developing today and tomorrow implies an

[14] Resident demographics also capture local labor, which directly affects supply. For robustness, I can construct demographics omitting low-income, construction-sector residents.

estimating equation that I derive in appendix D. Like the baseline approach, it avoids computing continuation values by appealing to finite dependence as in Arcidiacono and Miller (2011). It also requires atomistic developers: actions by a large developer prompt reactions by other developers, shifting the evolution of the economy and causing finite dependence to fail. Unlike the baseline approach, the Euler approach requires data in both periods t and $t + 1$, as well as on rents.[15] The Euler approach also requires long-lived developers that control land for multiple periods and thus can choose the timing of development. By contrast, the baseline approach is isomorphic to short-lived entrants that buy land, develop, and sell before exiting the market. More broadly, the focus is on periods t versus $t + 1$ in the Euler approach, instead of property versus land values in the baseline approach.

Both approaches flexibly accommodate future expectations, including over government intervention that is particularly salient in my context. The Euler approach appeals to rational expectations among developers, which allows long-run expectations to difference out. It thus accommodates expectations without the need to specify them explicitly. The baseline approach weakens rational expectations in two ways. First, it relies only on rational expectations at the level of the market, rather than for each individual developer. Optimistic developers will lower prices as rational competitors undercut them, while pessimistic developers will raise prices as rational arbitragers compete to claim profits. An efficient market thus ensures that asset prices reflect underlying value. Second, it relies only on the difference between property and land values, such that common bias cancels.[16] Indeed, such bias can include flood risk that does not fully capitalize into real estate values. Differential bias loads onto cost parameters, which counterfactuals hold fixed.

At the same time, accommodating non-atomistic agents remains difficult. Market power complicates both Euler and baseline estimation, and it greatly increases the computational burden of solving the model for counterfactuals. However, offsetting mechanisms may limit bias. Under-development arises from typical price-setting incentives, while over-development arises as market power increases developers' influence on government intervention. Furthermore, each force is muted by the stock of existing development. I therefore abstract from market power in the baseline approach, although I can accommodate it in a reduced-form way in assessing robustness.[17]

The dynamic discrete choice literature broadly offers two other approaches. The full-solution approach, following the nested-fixed point algorithm of Rust (1987), requires computing continuation values and solving the model repeatedly. It is thus computationally intensive and requires specifying expectations

[15] Data on property values are sufficient if one assumes that rents mirror mortgage payments.

[16] That is, $\Delta\eta_{kt} = \eta^1_{kt} + \bar{\eta}_{kt} - \eta^0_{kt} - \bar{\eta}_{kt}$ remains unaffected by common bias $\bar{\eta}_{kt}$.

[17] An imperfect but simple way of capturing market power is with the ratio of new relative to existing development. This ratio can enter as a cost factor, or alternatively as an adjustment to expected real estate prices. In the second approach, I can estimate the observed relationship between this ratio and real estate prices. In both approaches, extensive new development places downward pressure on prices. Neither approach fully models the effects of market power on the broader dynamic game, but each retains computational tractability.

explicitly. The specifying of expectations, including over the far-out future, is much stronger than assuming rational expectations by either individuals or the market. Two-step approaches, as reviewed in Ackerberg et al. (2007), simplify computation by estimating continuation values nonparametrically from the data in a first step, then estimating model parameters in a second step.[18] However, the first step requires a recurrent class of states that my non-stationary model does not achieve.

7 Counterfactuals

I simulate how coastal development and defense vary with government commitment. I also study the relocation of demand and the destruction of development.

7.1 Simulations

Table 2 presents calibrated simulations. In the short-run panel, a lack of commitment increases coastal development as moral hazard takes hold. Relocating residential demand elsewhere lessens coastal development, not only because lower coastal revenues decrease the returns to coastal development, but also because lower coastal revenues reduce the moral hazard gains from exploiting the government. It is therefore consistent with the relocating of the political capital away from Jakarta. In the long-run panel, I present cumulative development that shows continued investment at the coast. Moral hazard boosts this investment, particularly when a lack of commitment is accompanied by political myopia. In this case, coastal development in both periods exceeds that in the committed one-period case. Relocating demand reduces coastal investment, as does allowing flooding to destroy period-one development before period-two investment. Full policy counterfactuals are in progress.

8 Conclusion

This paper studies adaptation to sea level rise in Jakarta, the second-most populous metropolitan area in the world. I show that adaptation faces major frictions, including over the long run, as government intervention worsens lock-in by creating moral hazard for private developers. Government commitment reduces this friction but is subject to fundamental challenges. Jakarta thus provides an early view into the future for other major coastal cities like Miami, New York, and Shanghai as sea levels continue to rise worldwide.

[18] Hotz and Miller (1993) and Hotz et al. (1994) develop such methods in the single-agent setting. Rust (1994) suggests extending these insights to multiple-agent games, and Jofre-Benet and Pesendorfer (2003), Aguirregabiria and Mira (2007), Bajari et al. (2007), Pakes et al. (2007), and Pesendorfer and Schmidt-Dengler (2008) show how to do so. The Euler approach is also a two-step approach, but unlike earlier work allows for non-stationarity.

Table 2: Simulations

	Baseline	Relocating demand	Destroying development
Short run (one period)			
Full commitment	1.00	0.84	–
No commitment	1.68	1.34	–
Long run (two periods)			
Full commitment	1.72	1.36	1.49
Limited commitment			
Forward looking	2.35	1.72	1.93
Political myopia	2.66	1.97	2.24
No commitment			
Forward looking	3.24	2.51	2.78
Political myopia	3.58	2.73	3.02

In the one-period panel, government commitment to defense either holds or not. In the two-period panel, full commitment is for two periods, limited commitment is for the first period, and no commitment is for zero periods. In the latter two cases, political myopic adds a further friction in which the period-one government do not internalize the costs of defense borne by the period-two government. Relocating demand reduces revenues by 25%, and destroying development reduces the stock of existing development by 25%. One-period, full-commitment development is normalized to one, and two-period development is cumulative.

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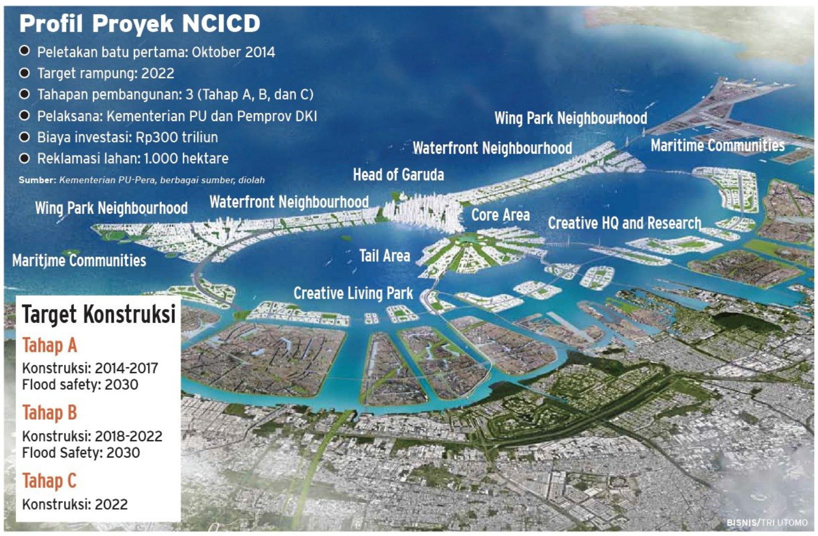
APPENDIX

A Background

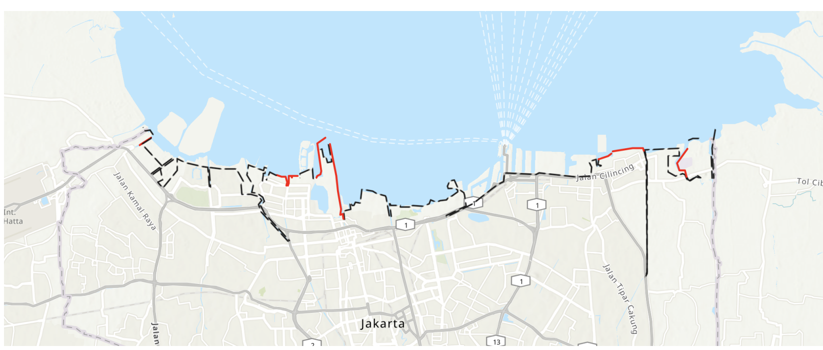
Sea wall in Jakarta

Figure A1: Sea wall plans and progress

(a) Plans in 2014



(b) Progress



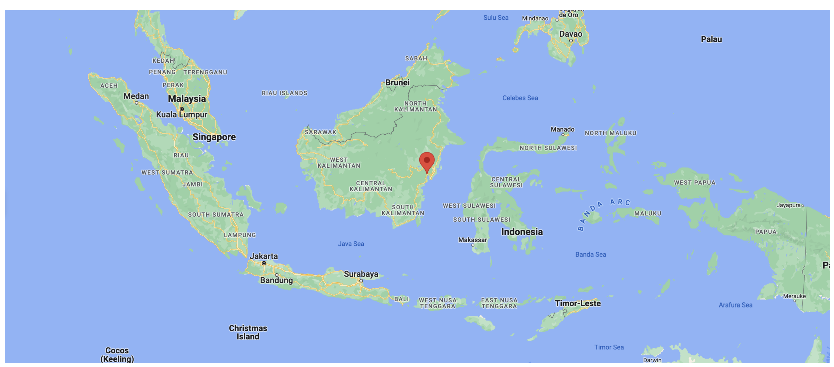
Source: Ministry of Public Works and Public Housing (*Kementerian PUPR* via *Bisnis*) and Jakarta city government (*Pemerintah Provinsi DKI Jakarta* via *Jakarta Satu*). The top figure shows the 2014 version of the National Capital Integrated Coastal Development masterplan. The bottom figure shows the near-term coastal wall that has survived through various iterations of the plan. Black sections are planned, and red sections are completed.

Moving capital to Nusantara

Figure A2: Nusantara plans

(a) Plans

(b) Location



Source: Ministry of Public Works and Public Housing (*Kementerian PUPR* via *ikn.go.id*) and Google Maps. The top figure shows a government visualization of the planned city. The bottom figure shows its location in what is currently East Kalimantan province.

B Theory

Extensions

I consider inland development that does not require flood defense. The typical adaptation narrative is that flood risk prompts a move inland, reestablishing agglomeration forces away from flood zones over the long run. Endogenizing government intervention complicates this narrative by inducing coastal over-defense. The result is significant delay to the move inland, as coastal and inland development are rival. Agglomeration does not take hold inland as long as coastal over-development keeps residents at the coast. Allowing inland development thus increases the welfare losses of the baseline model.

To this end, I consider endogenous rents determined in equilibrium. Coastal defense protects against flooding, raising the returns to coastal development. But as development increases at the coast, greater supply places downward pressure on rents. At the same time, a countervailing force is that lower rents encourage individuals and firms to move in, with greater demand placing upward pressure on rents. The quantitative exercise considers these forces in spatial equilibrium by modeling individuals and firms that co-locate across coastal and non-coastal neighborhoods.

Finally, I consider durable defense. In this case, defense investments are largely upfront: if defense is optimal tomorrow, then it is optimal today because it protects development for an additional period. Future defense investment are thus minimal under the baseline assumptions, particularly if defense depreciates slowly. In reality, however, rising sea levels increase flood risk over time and prompt continued investment in defense. Similarly, rising rents and falling costs prompt continued development, as do convex costs that force development to be spread over time. Non-durable defense thus captures the repeated government intervention observed in the richer model, as well as in practice.[19]

Anecdotal evidence

The co-determination of development and defense is also salient in practice. In Jakarta, figure B1 shows examples of interdependence. Developers cite government defense in planning for and marketing private development on the flood-prone coast. At the same time, the government cites private development in planning for and marketing proposed investments in coastal defense.

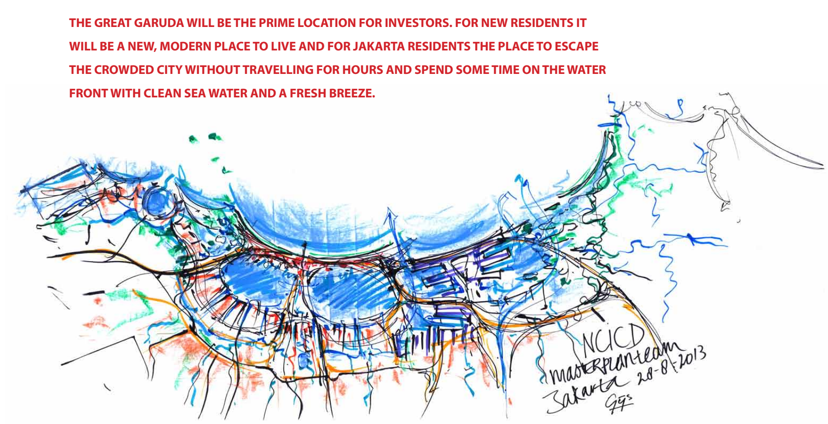
Similar dynamics arise in the United States. In New Orleans, the National Flood Insurance Program has enabled continued development in flood-prone neighborhoods, such as the Lower Ninth Ward. In North Carolina, increased coastal development led business groups to lobby for House Bill 819, which restricts state agencies in applying sea level rise projections to policy. In Florida, developers lobbied for Urban Development Boundary zoning expansions to allow for new construction in hurricane-prone areas. And the Florida legislature has dismantled the Department for Community Affairs, which managed long-term development risk with initiative like the Flood Mitigation Assistance program.

[19] Non-durable defense has another benefit. Durable defense and two periods lead to a government desire to reduce defense in period two. Period-one defense protects development for two periods, but period-two defense protects for only one period and thus has lower benefits. However, this effect is an artifact of the two-period model and disappears over the infinite horizon. Non-durable defense eliminates it even in the two-period case.

Figure B1: Co-determination of development and defense

(a) Development given defense

(b) Defense given development



Source: PIK2 Sedayu Indo City (via *https://www.sedayuindocitypik2.com/lokasi.html*) and National Capital Integrated Coastal Development Masterplan (2014, page 48). The figures show private development plans given proposed government defense, and government defense plans (at early, hand-drafted conception) given proposed private development.

C Data

Building construction and populations

These data come from the Global Human Settlement Layer, with measurements at the 100m pixel level. Jakarta consists of 65,260 such pixels. For building construction, 1,900 pixels feature an increase in measured built-up volume between 2015 and 2020. I verify these data with 2015 data from Visicom, a company that produces satellite-derived 3D maps that capture building heights at the 1m pixel level. These maps rely on light detection and ranging (lidar) data, which satellites collect by emitting pulsed laser beams and measuring reflection times. Beams that reflect quickly imply taller building heights, with measurements accurate to the meter. When aggregated to the tract level, the correlation between Global Human Settlement Layer and Visicom measures is 0.90 for built-up surface and 0.92 for built-up volume. Figure C1 shows the comparison visually.

For populations, the data are downscaled from regional administrative data using the distribution, density, and classification of built-up areas identified with satellite imagery. Downscaling focuses on residential built-up surface area and thus captures residential populations. The implicit assumption is that populations follow and occupy new development, which is indeed consistent with my empirical model in which rents clear the market for development.

Property values

I collect property values in four steps. First, I scrape data on property listings in October 2022 from 99.co Indonesia (*www.99.co/id*), a major real estate website. I focus on properties for sale, with listings covering both residential and non-residential properties in Jakarta. Residential properties include apartments and homes, and non-residential properties include shops and offices. Listings contain prices, floor spaces, land areas, addresses, and descriptions.

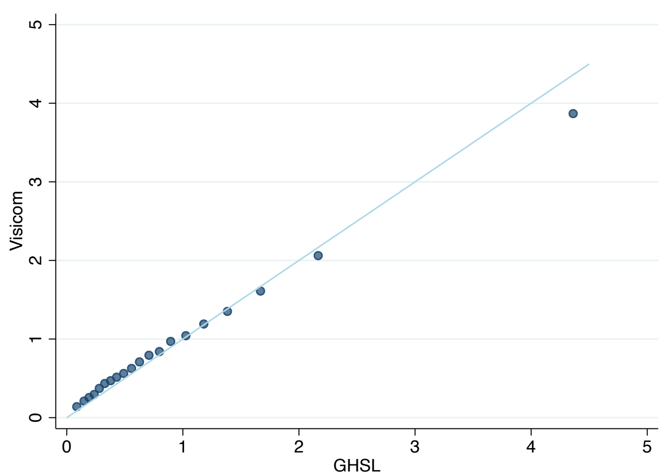
Second, I geo-locate listings with the Google Maps API. As inputs, I supply property addresses, types, and districts. Property addresses include street names and sometimes street numbers. I identify street names with the keyword *jalan* where possible. For apartments, I also include apartment complex names given keyword *apartemen.* As outputs, I obtain formatted addresses with geographic coordinates and return types. I keep the following return types: street addresses, routes, establishments, points of interest, premises, and sub-premises. Routes are associated with entire streets and thus require additional processing to geocode. I identify short streets as those under 1 km in length, where I compute lengths based on the geometric bounds associated with each street. I drop long streets, and I geocode what remains by street centroid. The cutoff length of 1 km avoids dropping data excessively while still maintaining accuracy at the tract level. Table C2 shows the high rate of success in geocoding.

Third, I construct property values at the tract level. I compute prices per square meter by dividing prices by floor space. I drop the 1% of listings without information on prices or building areas. I collapse listings with identical

Table C1: Data sources

Period	Source	Description
1975-2020	Global Human Settlement Layer	Building construction and populations
2015	Visicom	Building construction
2022	99.co	Property values
2015	Brickz.id	Property values (Harari and Wong 2019)
2015	Jakarta Smart City	Land values
2013-2020	Regional Disaster Management Agency	Historical flooding

Figure C1: Building volumes (1M m^3), GHSL vs. Visicom



Source: Global Human Settlement Layer and Visicom. Each observation of the binned scatterplot measures 2015 built-up volume at the tract level. I plot the 45° line in light blue.

Table C2: Geocoding property listings

Type	All	Apartment	Home	Shop	Office
Geocoded proportion	65.5%	84.0%	52.6%	56.0%	39.8%
Geocoded observations	56,222	29,733	17,182	7,786	1,521

Property listings for sale come from 99.co, and geocoding is with the Google Maps API.

addresses – primarily apartment listings within complexes – into single observations by taking means. I then aggregate to the tract level as follows. For the 70% of tracts with more than five observations, I take the mean. For the 30% of tracts with less than five observations, I compute an inverse distance weighted mean of nearby observations.[20] I thus obtain 2022 property values.

Fourth, I backcast the 2022 values using a more limited set of property values from 2015. I obtain data on 2015 property transactions from Brickz (*www.brickz.id*), as scraped and kindly shared by Harari and Wong (2019). The 2015 data contain 6,929 observations that I use to compute 2015-2022 adjustment factors by district. I do so by computing district means in 2015 and 2022, reweighing 2022 values to match the property type composition of the 2015 data. The resulting adjustment factors thus capture both price changes and differences between transacted and listed prices. I then apply the adjustment factors to the 2022 data to obtain 2015 property values. Relying directly on the 2015 values would be more straightforward, but the relatively small number of geocoded observations – around half of the 6,929 transactions – complicates measurement at the tract level.

Land values

As part of the Jakarta Smart City initiative (*smartcity.jakarta.go.id*), the city government and the National Land Agency (*Badan Pertanahan Nasional*) computed 2015 land values with the goal of updating property tax appraisals and collections. They did so at a granular level by combining administrative data from transactions, market data from brokers and online platforms, and property attributes from field visits. The data include 20,892 observations at the sub-block level, with land values measured as prices per square meter. I aggregate the sub-block measures to the tract level. Harari and Wong (2019) describe these data in further detail and take additional steps to verify the quality of the data, including in informal areas.

Flood risk

For now, I capture flood risk with data on realized historical flooding from 2013 to 2020. These data come from the Regional Disaster Management Agency and measure flood frequency and depth at the tract level. Flood risk derived from a hydrological model will soon replace these measures.

[20] For the inverse distance weighting, I use a weighting power of two, a smoothing parameter of zero, a search circle radius of one kilometer, a maximum of twenty observations, and a minimum of five observations. I include observations from the periphery of Jakarta.

D Estimation

Euler conditional choice probabilities

The Euler approach compares two sequences of actions: $(d^*_{kt}, 0)$ and $(0, d^*_{kt})$. The first develops d^*_{kt} today and zero tomorrow, while the second develops zero today and d^*_{kt} tomorrow. Intuitively, developing tomorrow reduces upfront costs given discounting, but it also delays the arrival of rental revenue. Choice-specific conditional value functions are

$$\begin{aligned} v^1_k(w_t) &= -c_{kt}(d^*_{kt}) + \beta \mathbb{E}_{kt}[r_k(w_{t+1})(D_{kt} + d^*_{kt}) + \beta V_k(w_{t+2}) \qquad (13a) \\ &\quad - \ln\big(1 - p^{\text{dev}}_{kt+1}\big) \,|\, d^*_{kt}, 0], \\ v^0_k(w_t) &= \beta \mathbb{E}_{kt}[r_k(w_{t+1})D_{kt} - c_{kt+1}(d^*_{kt}) + \beta V_k(w_{t+2}) \qquad (13b) \\ &\quad - \ln p^{\text{dev}}_{kt+1} + \frac{1}{2} c''_{kt}(d^*_{kt})(d^*_{kt+1} - d^*_{kt})^2 \,|\, 0, d^*_{kt}]. \end{aligned}$$

The first and third lines impose the actions of interest to equations 9. These actions may depart from the optimal actions implied by the choice-specific conditional value functions, and so correction terms in the second and fourth lines account for this potential suboptimality. These correction terms are derived from the following.

$$\begin{aligned} V_k(w_t) - r_k(w_t)D_{kt} &= v^1_k(w_t) - \ln p^{\text{dev}}_{kt} = v^0_k(w_t) - \ln\big(1 - p^{\text{dev}}_{kt}\big), \\ v^1_k(d^*_{kt}, w_t) - v^1_k(d_{kt}, w_t) &= \frac{1}{2} c''_{kt}(d_{kt})(d^*_{kt} - d_{kt})^2 \end{aligned}$$

The first line is a special case of Arcidiacono and Miller (2011) Lemma 1, and the second line is as derived in Hsiao (2022). Substituting equations 13 into logit inversion equation 11, continuation values cancel given finite dependence with $\mathbb{E}_{kt}[V_k(w_{t+2}) \,|\, d^*_{kt}, 0] = \mathbb{E}_{kt}[V_k(w_{t+2}) \,|\, 0, d^*_{kt}]$. For $\Delta X_{kt} = X_{kt} - \beta X_{kt+1}$,

$$\Delta \ln p^{\text{dev}}_{kt} - \Delta \ln\big(1 - p^{\text{dev}}_{kt}\big) = -\Delta c_{kt}(d^*_{kt}) + \beta r_k(w_{t+1}) d^*_{kt} - \frac{1}{2}\beta\psi(d^*_{kt+1} - d^*_{kt})^2 + \eta_{kt}$$

for expectational errors η_{kt}, which by rational expectations are mean zero and orthogonal to information set $\mathcal{J}_{kt}$. That is, expectations are assumed to be correct on average and to use all available information.