The Skyscraper Revolution: Global Economic Development and Land Savings

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Outline

Context

- **Exponential growth** in global aggregate **building height**
  - Mostly in **developing countries since 1975**
  - Tall building stock worth >15 trillion dollars as of 2020
- **Spatial concentration & inequality**
  - **Urbanization**: Allow cities to accommodate more people in most productive places
  - Land savings: Save land for non-urban uses, e.g. agriculture, natural habitats
- **Welfare effects**
  - Higher wages and improved housing affordabiltiy, shorter commutes, better views
  - Density disamenities, e.g.congestion, crowding, and shadowing, etc.
- Policy effects of **height regulation** depend on
  - Agglomeration benefits (productivity) and costs (amenity)
  - Cost of building tall: Falls over time $\Rightarrow$ cost of regulation increases over time

This paper

- **Novel database** covering 90% world's urban pop
  - Population and area for 12,877 world cities in 1975 (1990 2000) 2015
  - All tall buildings ($\geq$ 55 meters) ever built worldwide (construction year & cost info)
- **Reduced-form estimation** of height elasticities:
  - Population 12%, built area -17%, population density 29%
  - Identification: bedrock depth matters $\rightarrow$ construction costs vary across cities
- **Indirect inference** using urban GE land-use model
  - Amenity elasticity of density is -11% (citywide density disamenity)
  - Variation in cost of height leads height elasticities that match reduced-form estimates
- **Welfare analysis** using GE land-use model
  - Removing all tall buildings would reduce global worker welfare by -0.8%
  - Removing all height constraints would increase worker welfare by 3.7%
    - Height limits have regressive distributional effects (from workers to landlords)

Literature

- Infrastructure
  - Baum-Snow '07, '20; Duranton & Turner '12; Faber '14; Heblich et al. '20; Brooks et al. '21; Campante & Yanagizawa-Drott '18; Alsan & Goldin '19
- Economics of density
  - Combes & Gobillon '15; Ahlfeldt & Pietrostefani '19; Duranton & Puga '20 (surveys)
  - Rosenthal & Strange '08; Combes et al. '11 (geological IVs)
  - Duranton & Puga '23 (density disamenity)
- Sprawl
  - Burchfield et al. '06; Henderson et al. '18; Harari '20; Gollin et al. '21
- Housing supply and urban development
  - Baum-Snow & Han '24; Bertaud & Brueckner '05; Henderson et al. '21 , Brueckner & Sridhar '12; Brueckner et al. '17; Tan et al. '20; Jedwab et al. '20
- Economics of skyscrapers
  - Barr '10, '12; Barr et al. '11; Ahlfeldt & McMillen '18, Liu et al. '18, '20; Ahlfeldt & Barr '20, '22, Jedwab et al. '20, '21; Jedwab & Barr '22; Jedwab '22; Curci '22

Outline

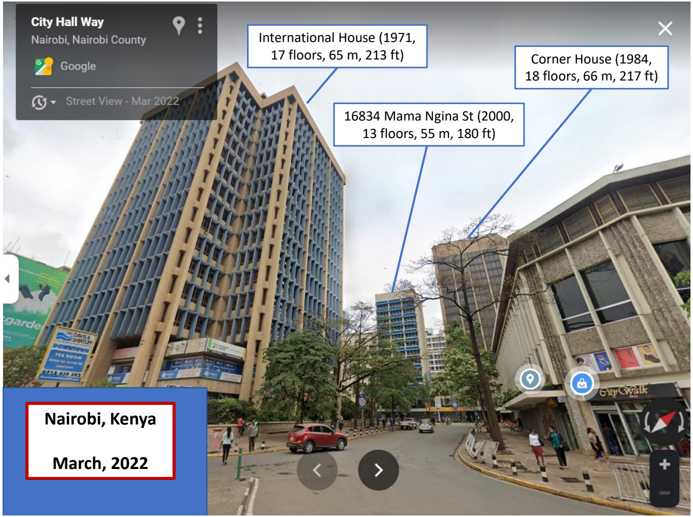
Data

- **Sample**
  - 12,877 agglomerations with 50K+ population today
  - Defined as *urban centres** from GHS
- **City-level outcomes**
  - GHS: population, built-up area, land area for 1975, (1990, 2000), and 2015
  - Night lights (DMSP, radiance calibrated), 1996–2011**
  - Land change data (deforestation, cropland, etc.), 1982–2015
- **Main variable of interest**
  - From *Emporis*: location, height ($\geq$ 55m), year of construction
  - Data covers entire building life cycle: "*Emporis collects information about the full life-cycle of each building, from idea to demolition*"
  - Tall building stock (km) by city for 1975, (1990, 2000), and 2015

* Urban centres correspond to commuting zones. For example, New York UC includes "New York; Islip; Newark; Jersey City; Yonkers; Huntington; Paterson; Stamford; Elizabeth; New Brunswick".

** Radiance calibrated = NOT top-coded at 63.

Example of Concrete Tall Buildings

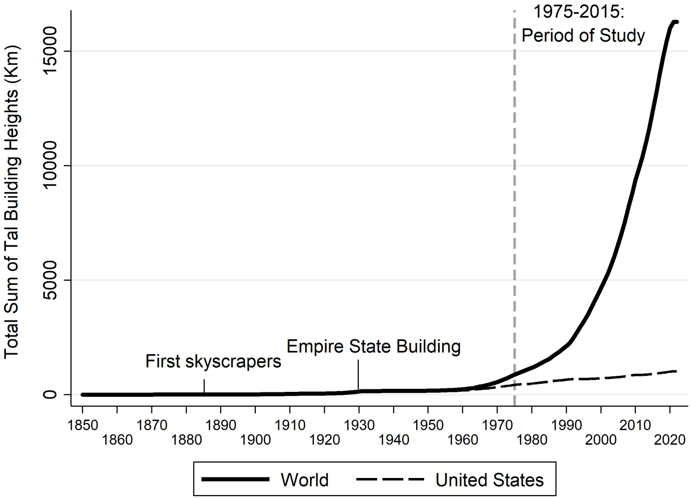


Typical building in data

- Reinforced concrete tall buildings
- At least ≥ 55 m ≈ 165 ft ≈ 14 floors
- Tall, but not super tall
- Residential use
- Not designed by starchitect

Fairly ordinary...

The Global Stock of Tall Buildings



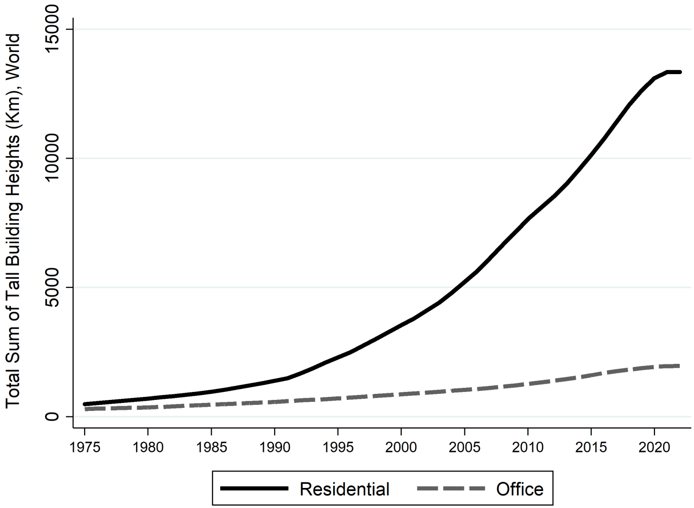
Includes all buildings $\geq$ 55 meters

- 1975–2015: +11,500 km of cumulative height increase

Equivalent to:

- $\approx$ 26,000 Empire State Buildings
- $\approx 3\times$ the straight-line distance from NYC to LA!

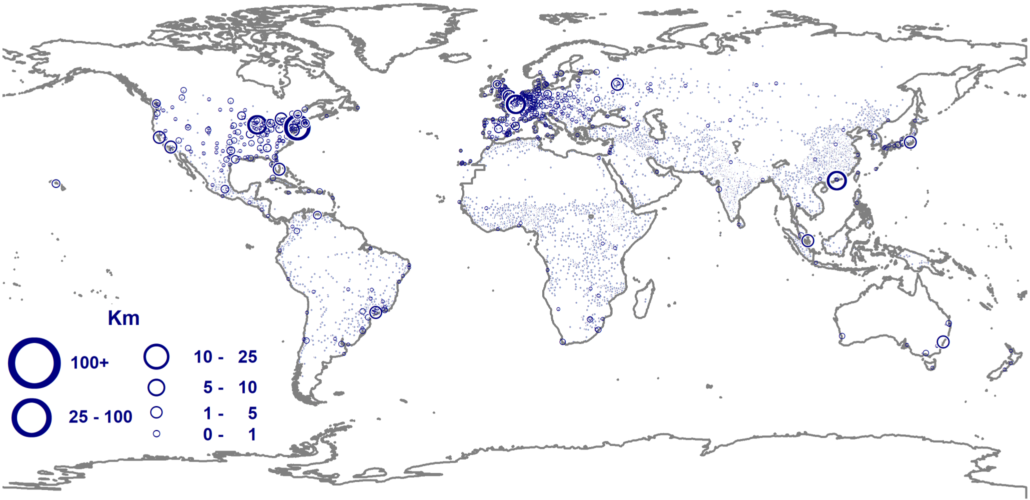
Most Recent Tall Building Construction is Residential



World of residential towers:

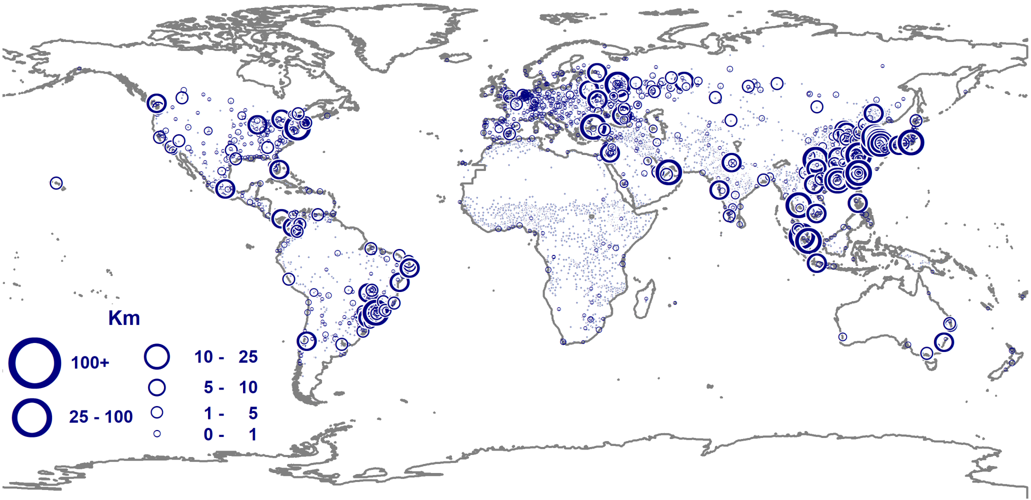
- Residential buildings (typically 55–100 m tall) have grown **7× faster** than commercial/office buildings (typically 100 m+).
- This reflects a major **shift** in vertical development—**towards housing** rather than office space.

The Stock of Skyscraper Heights in 1975



Historically, global skyline dominated by North America & Western Europe

The Flow of Skyscraper Heights 1975-2015



Rising skylines in Asia, the Gulf, Latin America & Eastern Europe

The Cost Function for Height

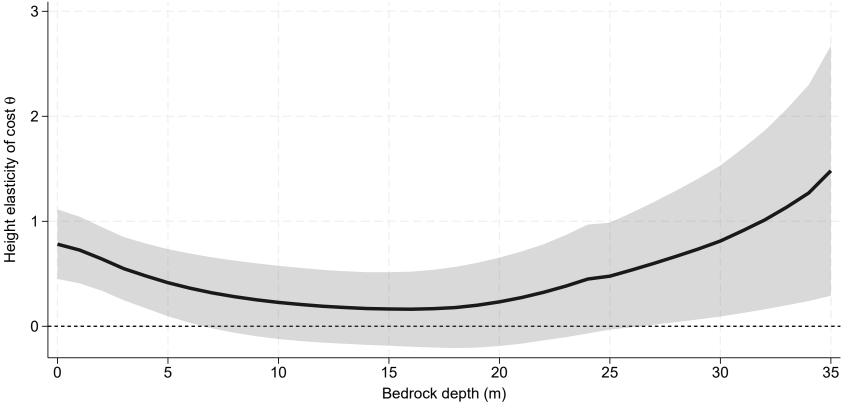
- The **total variable cost of building to height** S is:

$$C_{act}(S) = c_{act} S^{1+\theta(B_{ac},\psi_t)}$$

  - for city a in country c in year t:
- Height elasticity of per-unit construction cost θ
  - Subject to c_{act} city-year specific cost shifter
  - **Declining over time** Evidence
    - Steady technological progress ψ_t, e.g. steel frame, mainframe computing, etc.
  - **U-shaped in bedrock depth** (foundation costs) More
    - Intermediate depths are best for tall buildings
    - Best if foundations sit directly on bedrock;
    - Else, need to blast away (shallow bedrock) or build rafts or piles (deep bedrock)

Marginal Cost Minimized at Intermediate Depths

- Estimate height elasticity of unit cost (θ) across all building heights*
- Easier to accommodate real estate demand at intermediate depths



* We predict height using distance from the city center as a demand-side IV Heatmap

Profit Maximization: The Muth Model Revisited

- A representative developer's profit function:

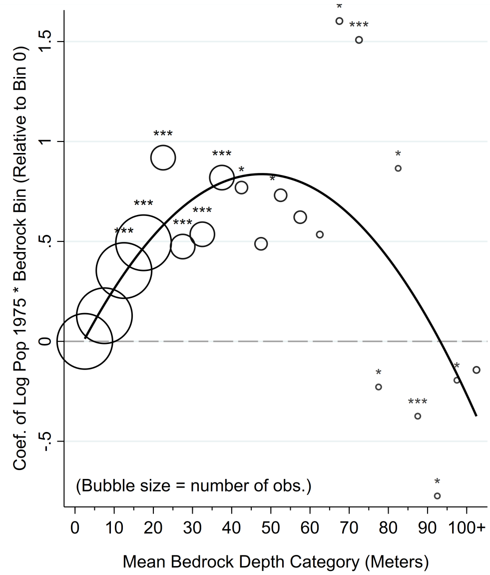
$$\pi_{act}(S, x) = \int_0^S p_{act}(x, s)\, ds - C_{act}(S) - r_{act}(x)$$

  - Assume demand structure $p_{act}(x, s) = p_{act}(x)\, s^{\omega}$
- Resulting equilibrium height supply at location x:

$$\ln S^* = \frac{1}{\theta(B_{ac}, \psi_t) - \omega} \left(\ln \left(\frac{p_{act}(x)}{c_{act}} \right) - \ln \left[\theta(B_{ac}, \psi_t) - 1 \right] \right)$$

  - Think of **1975 population as measure of demand** for height, p/c
  - Bedrock depth B_{ac} shifts cost of height, θ
- **Interaction of bedrock depth B_{ac} and 1975 population** $\frac{\partial \ln S^*}{\partial \ln Pop_{75}} = f(B)$
  - $f(B)$ is concave with a unique maximum (inverse-u-shape)

Elasticities of Tall Building Height Growth (1975–2015)



- **Elasticity of height growth wrt. city size**
  - **by bedrock** depth category b, $0 =$ base

$$\Delta \ln H_{ac} = \gamma_{b(ac)} \ln Pop_{ac75} + \delta \ln Pop_{ac75} + \kappa_c + \phi_{b(ac)} + \epsilon_{ac}$$

  - city c in country a
  - $\Delta \ln H_{ac} = \ln(H_{ac,15} + 1) - \ln(H_{ac,75}+1)$
- **Key insight**
  - Larger cities build more height...
  - ...when bedrock depth in optimal range
- **Intuition**
  - Demand increases quantity more...
  - ...when supply is elastic

Construction dummy | Height level elasticity

Outline

IV strategy: Second stage

- Main estimation equation (N = 12,869 cities a in 179 countries c):

$$
\begin{aligned}
y_{ac} = {} & \beta \Delta \ln(Heights_{ac} + 1) \\
& + \alpha_1 MBD_{ac} + \alpha_2 MBD_{ac}^2 + \alpha_3 \ln(Pop_{ac75}) + \kappa_c + \varepsilon_{ac},
\end{aligned}
$$

  - where κ_c are country fixed effects
- Outcomes: 1975–2015 city-level growth rates of
  - Population
  - Built-up area and urban area
- **IV** for $\Delta \ln(Heights_{ac} + 1)$ First stage
  - $MBD_{ac} \times \ln(Pop_{ac75})$ and $MBD_{ac}^2 \times \ln(Pop_{ac75})$
- **Bedrock-population interaction**
  - **Leads to growth in height** where high demand and low cost of height
  - **Has no direct effect on outcome** change

Main IV Results (1975–2015)

	Δ ln Pop	Δ ln Blt Area	Δ ln Urb Area	Δ ln Pop Dns
	Panel A: All Countries (Observations = 12,849)			
Δ ln(Heights+1)	0.12***	-0.17***	-0.15**	0.27***
	[0.03]	[0.04]	[0.06]	[0.07]
First Stage F	28.42	28.42	28.42	28.42
	Panel B: Developing Economies (Observations = 11,257)			
Δ ln(Heights+1)	0.13***	-0.16***	-0.18**	0.31***
	[0.03]	[0.04]	[0.08]	[0.08]
First Stage F	22.84	22.84	22.84	22.84

- Doubling heights ⇒ population +12%, built area –17% (urban area: –15%),
- Driven by developing countries (88% of sample)
- Radiance-calibrated lights (not top-coded), 1990–2015: +15% (not shown)

Robustness

- **Adding controls** for geography, infrastructure, market potential, etc. More
  - Also when interacting controls with 1975 log population
- **Excluding cities** with geography, infrastructure, and economic features More
  - Excluding cities with high and low values
- **OLS estimates** have same signs but smaller in magnitude
  - LATE from countries with a high Gini of bedrock and attenuation bias
- **Linear spline** instead of quadratic form
  - Can identify effects from deep bedrock or shallow bedrock
- 100m **height threshold** for tall buildings
  - Also works with total building volume (available for 2015 only)
- **Central city bedrock** IV stronger than suburban bedrock IV
  - But 80% of variation in bedrock is between cities
- **Conley standard errors** (200 km or 400 km)
  - Clustered SE on Admin 1 regions (e.g., states) also work

Extensions

- Results driven by **rural-urban migration** (not urban-urban) More
  - Countries with urbanization rate below 20%
  - Market potential appraoch to control for urban migration (Borusyak et al., 2022)
- **Heterogeneity by world region** More
  - Strong effects for developing countries but not developed countries
- **Historic analysis for developed countries** More
  - Developed world similar to today's developing world when it was developing
- Heterogeneity by **country-typical use** More
  - Stronger effects in countries that develop more tall residential buildings
- Implied **impact** of tall building construction More
  - Cities 20% larger in terms of population and 20% smaller in ters of built up area
- **Type of land saved** More
  - Mostly high-value land, tree cover and other vegetation
- Calculation of height gap and **unconstrained elasticities** More
  - 5,315 cities in 38 countries; Population elasticity: 0.21; built area elasticity: -0.39

Outline

Welfare effects

- **Hard to measure** the effect on all aspects that matter for **welfare**
  - Wages, rents, commuting times, views, amenity value
- **Need a quantitative model** to compute **welfare** effects
  - From **observed construction** of tall building
  - From **preventing construction** by regulation
- **Strategy**
  - Build urban GE land use model
  - **Calibrate** canonical parameters
  - **Estimate** crucial density disamenity parameter using **indirect inference**
    - Match reduced-form estimates within model
  - **Invert** height limit (and other fundamentals) to match observables
  - **Simulate** counterfactuals by altering height limits and solving the model

Taking stock

- **Empirics show** that supply of height
  - Increases city population
  - Shrinks city area
- **Canonical models do not fit the bill**
  - Population fixed in standard monocentric city model (Alonso, 1964)
  - City area fixed endowment in QSM (Ahlfeldt et al. 2015)
  - City area *grows* in open-city model (Ahlfeldt & Barr, 2022)
- **Need an imperfectly open-city model**
  - Blend standard land-use model (Duranton & Puga, 2015) and QSM
  - Stylized monocentric city structure with endogenous CBD
  - Designed for quantitative analysis

Monocentric circular city model with endogenous CBD

- **Geography:** Circular city within a region
  - Exogenous historic centre (vs CBD which has a mass)
  - Distance x from the historic centre indexes location within the city
- **Residents:** Choose a location at distance x in the city or rural hinterland;
  - Rural (subsistence) utility exogenously given
  - Urban utility governed by preferences over floorspace and an outside good;
    - Amenity shifts urban utiltiy and depends on vertical distance (views), horizontal distance (commuting), and urban density (congestion)
  - Idiosyncratic utility from locating in city generates migration elasticity
    - *Imperfectly open* city which nests *closed-city* and *open-city* cases
- **Construction:** Marginal cost increasing in building height
  - Imperfectly elastic floor space supply
- **Production:** Uses labor and floorspace (offices) as inputs at location x;
  - Sector also benefits from views (prod. signalling) and agglomeration economies

Primitives and endogenous outcomes

- **Equilibrium:**
  - Utility equalizes within city; expected utility equalizes between city and hinterland
  - Zero profits in goods and floor space production
  - Commercial and residential floor space markets clear; labor market clears
  - Land use allocated to the highest bidder (commercial, residential, agricultural)
- **Primitives:**
  - Calibrated/estimated parameters, height limit, $\bar{S}^U$, some fundamentals
  - Endowments, regional population, $\bar{N}$, regional land within radius $\bar{x}$
- **Endogenous outcomes:**
  - City wage, y, urban population, N, urban utility $\bar{U}$
  - Land-use boundaries: CBD ends at x_0, city ends at x_1
  - Gradients: population density, employment density, wage, rent, height
- **Mapping from primitives to endogenous outcomes**, solved numerically

Residents Production Construction Intuition

Calibrated parameters

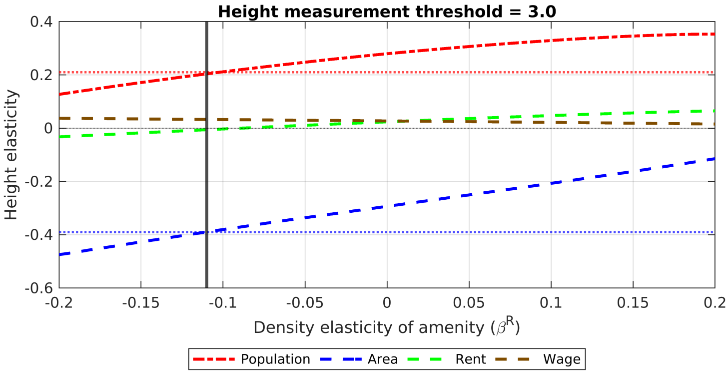
	Parameter	Value
$1-\alpha^C$	Share of floor space at inputs	0.15
$1-\alpha^R$	Share of floor space at consumption	0.33
β^C	Agglomeration elasticity of production amenity	0.03
θ^C	Commercial height elasticity of construction cost	0.5
θ^R	Residential height elasticity of construction cost	0.55
ω^C	Commercial height elasticity of rent	0.03
ω^R	Residential height elasticity of rent	0.07
ζ	Preference heterogeneity	5.4

- $\{\alpha^C, \alpha^R, \beta^C, \theta^C, \theta^R, \omega^C, \omega^R\}$
  - Typical values in literature synthesized by Ahlfeldt & Barr (2023)
- $\zeta = 5.4$ implies migration elasticity of 2.7
  - In line with Brian and Morton (2019), a central estimate in literature

Estimated parameters

- Set **amenity decay values** to match average height gradients in data
  - CoreLogic for Chicago (monocentric city), patterns verified for the world using satellite-based building volumes for unconstrained 1m+ cities (Esch et al 2023)
    - $\tau^C = 0.014$; $\tau^R = 0.016$
- Use **indirect inference** to estimate the **density elasticity of amenity**, β^R More
  - Generate height elasticity of population and area within model More
    - Iterate over cost of height values, θ, and estimate elasticities from equilibrium values
    - Height elasticities originating from floor space supply side, just like in reduced from
  - Find β^R value that **minimizes RMSE in elasticities in model and reduced form**
    - Use **reduced-form estimates from unconstrained sample** More
    - Also need to search for height measurement threshold in model (equiv. to $\geq$ 55m)
    - Use `particle swarm optimization` algorithm, backed up by grid search
  - $\beta^R = -0.11$ (0.06, bootstrap standard error)

Elasticities in model and data



- More **positive density elasticity of amenity** $\Rightarrow$
  - **More workers** move to cities as the cost of height decreases
  - **Less land** is saved as more people need to be accomodated in city
- At $\beta^R = -0.11$, we match reduced-form estimates in model Objective function

Inversion

- Mapping from primitives to endogenous outcomes
  - Primitives:
    - Calibrated/estimated parameters, height limit, $\bar{S}^U$, some fundamentals
    - Endowments, regional population, $\bar{N}$, regional land within radius $\bar{x}$
  - Endogenous outcomes:
    - City wage, y, urban population, N, urban utility $\bar{U}$
    - Land-use boundaries: CBD ends at x_0, city ends at x_1
    - Gradients: population density, employment density, wage, rent, height
- **Invert the model to match characteristics of real-world regions**
  - Urbanization rate, $N/\bar{N}$
  - Height gap = fraction of total not realized due to regulation (Barr & Jedwab, 2023)
- Find values for primitives
  - Rural utility, $\tilde{U}$: lower rural utility $\Rightarrow$ more urbanization (fixed point problem)
  - Height limit, $\bar{S}^U$: lower height limit $\Rightarrow$ larger height gap (simplex algorithm)

Counterfactuals

- **Build 12,873 model cities** that resemble real-world regions in terms of
  - Regional population (from data)
  - Cost of height (from bedrock data via non-parametric estimates)
  - Urbanization rate (model inversion)
  - Height limit (model inversion)
- Simulate the effects of **removing all tall buildings**
  - Set height limit, $\bar{S}^U$ to (estimated) model-equivalent of 55-meter threshold
- Simulate the effects of **removing all height limits**
  - Se height limit to $\bar{S}^U = \infty$ and let developers build out to profit-maximizing height
- Compute **incidence on workers** (expected utility in region)
  - wage, rent, commuting cost, view effect, density disamenity
- Compute **incidence on landlords** (land value)
  - Intensive margin (intensity of land use) and extensive margin (changes in land use)

Effect of height limit on city structure
Effect of height limit by bedrock

Welfare effects

- Removing all tall heights would be bad for workers and landlords
  - Tall buildings are an important source of welfare
- Removing all height limits would be good for workers, but bad for landlords
  - Landlords have incentives to support current regulation
- Effects are generally larger for the developed than the developing world
  - More large cities in developed countries

				Expected utility		Land value	
Group	Pop >1M	θ_{2015}	HG_2015	No tall buildings	No height limit	No tall buildings	No height limit
Developed (D)	50.50%	0.385	79.50%	-1.10%	5.70%	-1.70%	-6.80%
Developing (G)	37.40%	0.5328	42.70%	-0.70%	3.40%	-0.40%	-3.40%
All	39.70%	0.507	49.20%	-0.70%	3.80%	-0.60%	-4.00%

Mechanisms | By world region | No tall heights by height gap and city size | No height limits by height gap and city size

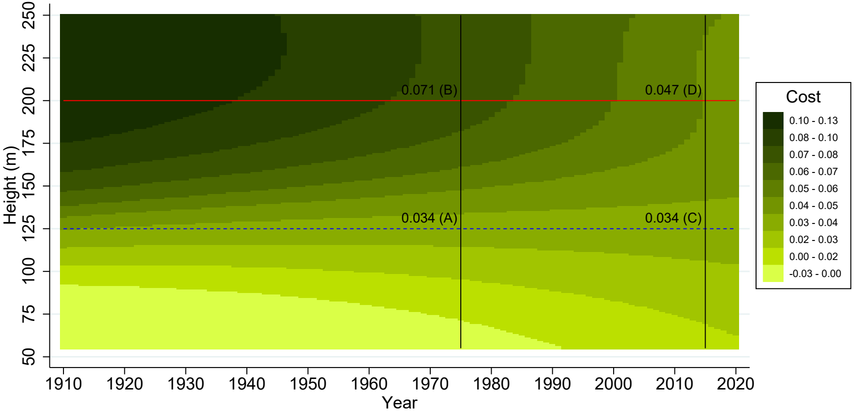
Conclusions

- The **Skyscraper Revolution** has fundamentally changed cities worldwide
  - Especially in developing economies.
- Estimated elasticities with respect to city height:
  - City population: 0.12
  - Built-up area: -0.17
- Tall building construction has:
  - Accommodated a large share of urbanization
  - Facilitated major land savings globally
- **Removing barriers to vertical growth** could lead to
  - **Increase in global worker welfare** $\approx 4\%$
  - Lower aggregate land values
  - **Increasing spatial inequalities**
  - **Welfare effects will grow over time** as cost of height falls

Appendix

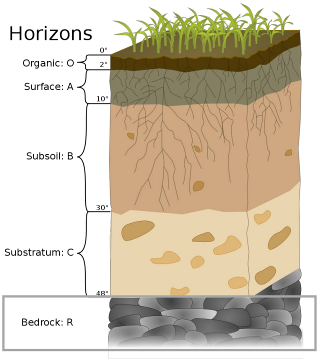
Cost of height decreased over time

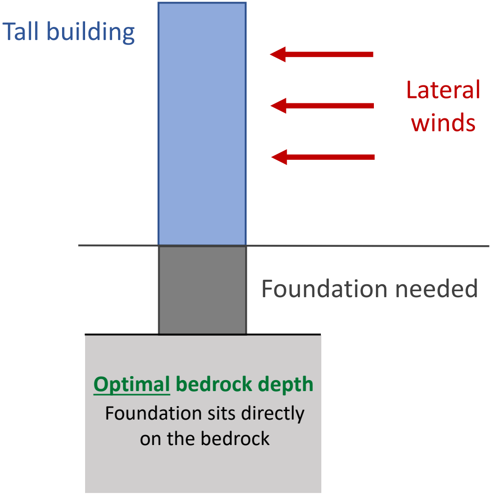
- 600 U.S. tall buildings for which construction cost in Emporis
- Log cost per sq ft residualized for city FE and decade FE



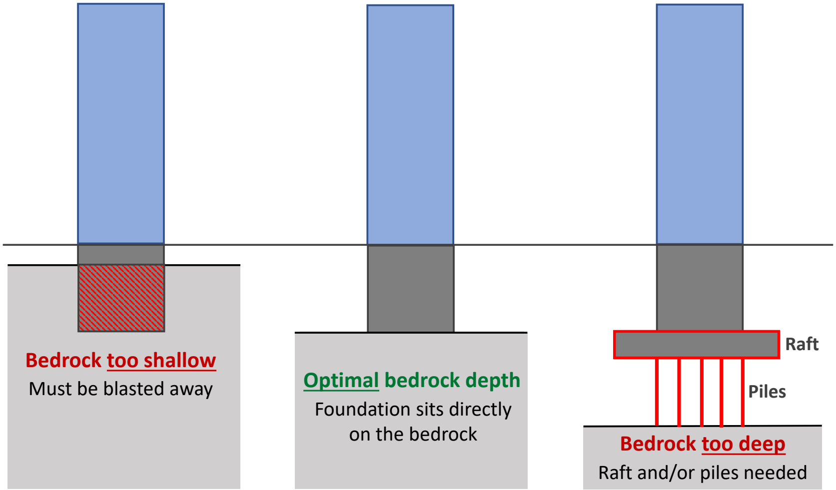
- Cost per sq ft for 200m vs. 125 m ≈ **+4% in 1975 vs. +2% in 2015** Back

Role of Bedrock I (needed to build the identification strategy)





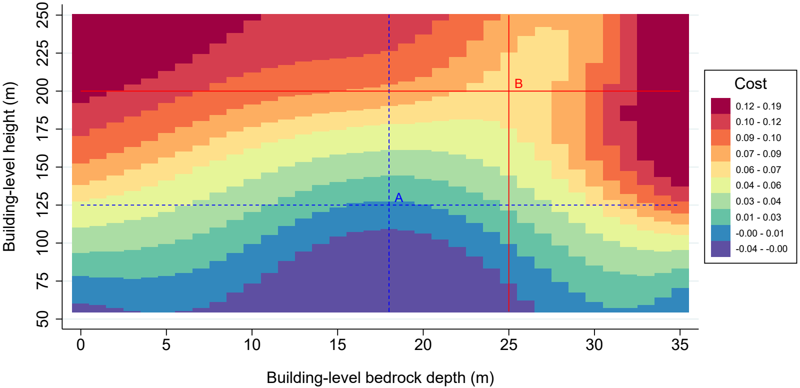
Role of Bedrock II (needed to build the identification strategy)



Back to cost function

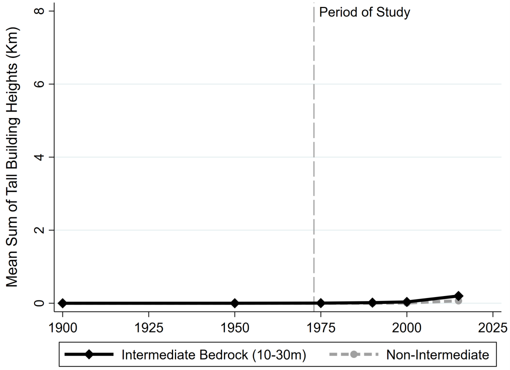
Inverted-U Relation btw Cost of Height & Bedrock Depth

- 1,033 tall buildings with construction cost (206 cities in 55 countries)
- Log cost per sq ft residualized for city FE and country-decade FE

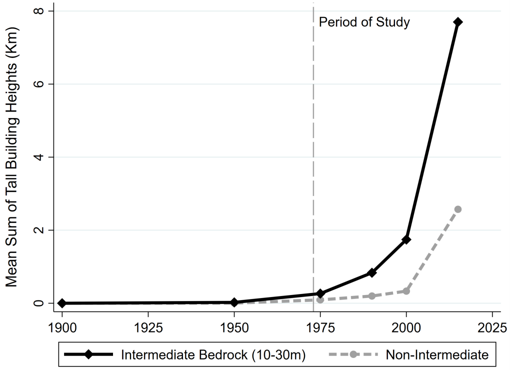


At 125 m, optimal depth saves $> 5\%$ in cost per sq ft relative to surface level or very deep bedrock. Cost savings much larger for 200 m tall buildings ($> 10\%$). Back to LWR Cost

Bedrock Depth & Mean Sum of Heights Over Time



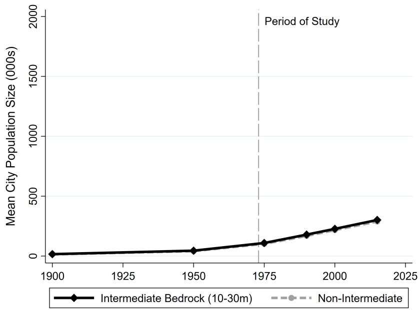
Small Cities: $\leq$ 300K in 1975

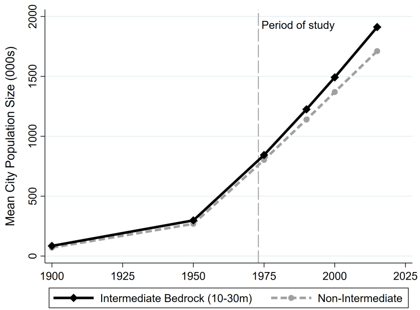


Large Cities: $\geq$ 300K in 1975

- Sample: 1,748 developing country cities from Buringh et al. population database
- 300K threshold $\approx$ 95th percentile in 1975 population distribution
- Selects 418 cities among today's top 500

Bedrock Depth & City Pop Over Time



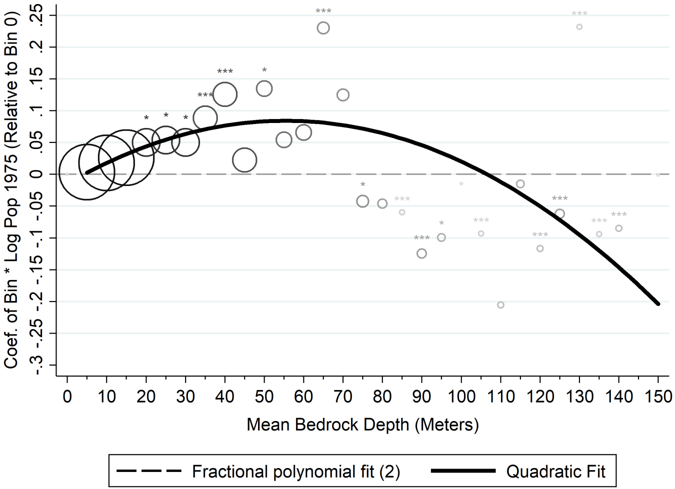


Small Cities $\leq$ 300K in 1975 Large Cities $\geq$ 300K in 1975

Sample: 1,748 developing country cities in pop database of Buringh et al

300K $\sim$95p in pop in 1975, selects 418 cities among top 500 today

Elasticities of Tall Building Constr. Dummy 1975-2015 wrt *1975 City Population by Bedrock Depth*



Back

IV strategy: Fist stage

- Data generating process for heights in city a, country c:

$$\begin{aligned}\Delta \ln H_{ac} &= k_1 MBD_{ac} + k_2 MBD_{ac}^2 + \delta \ln Pop_{ac75} \\ &\quad + \gamma_1 MBD_{ac} \times \ln Pop_{ac75} + \gamma_2 MBD_{ac}^2 \times \ln Pop_{ac75} \\ &\quad + X_{ac75}\xi + \kappa_c + \epsilon_{ac}\end{aligned}$$

- **Triple-difference approach** to identifying variation
  - 2015 vs. 1975, good vs. bad bedrock; high vs. low initial population
- To strengthen validity of IV, we **conditionon**
  - Time-invariant city effects: first difference
  - 1975 city population (larger cities have different demand trends)
  - bedrock depth (cities with different geology may be on different trends)
- Use **only the interaction of bedrock and initial population** to identify variation

First Stage Estimates (3rd Column)

	Δ ln Height 1975-2015		
ln Pop 1975	0.8730***	0.8741***	0.4753***
	[0.0351]	[0.0351]	[0.0653]
Bedrock Depth		-0.0028*	-0.3248***
		[0.0016]	[0.0612]
(Bedrock Depth)^2		0.0000	0.0021**
		[0.0000]	[0.0009]
Bedrock Depth			0.0276***
X ln Pop 1975			[0.0054]
(Bedrock Depth)^2			-0.0002**
X ln Pop 1975			[0.0001]
Country FE	Y	Y	Y
R-squared	0.17	0.17	0.18
Observations	12,869	12,869	12,869

- Faster height growth in initially larger cities
- City-size effect greatest for cities with intermediate bedrock

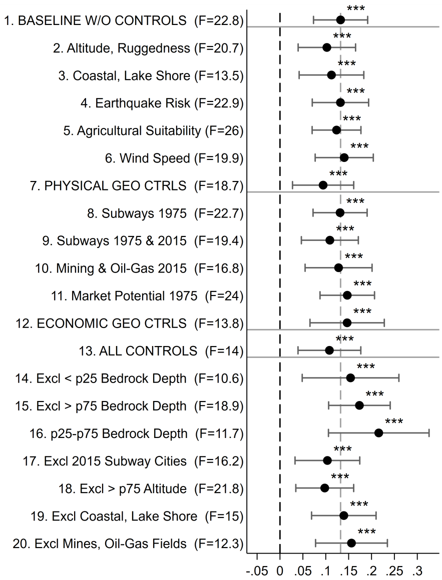
Inverse-u-shape by year and development

- **Developed economies**
  - Inverse-u-shape in 1975 and 2015
  - Becomes stronger
- **Developing economies**
  - Hardly any predictive power in 1975
  - Few tall buildings in 1975
  - Similar inverse-U-shape as in developed countries in 2015
- **Skyscraper revolution** makes bedrock universally relevant

Back to second stage

	1975	2015	Δ 1975-2015
	Panel A: All Countries		
Bedrock Depth	0.0126***	0.0402***	0.0276***
× ln Pop 1975	[0.0032]	[0.0062]	[0.0054]
(Bedrock Depth)^2	-0.0002***	-0.0003***	-0.0002**
× ln Pop 1975	[0.0000]	[0.0001]	[0.0001]
R-Squared	0.18	0.33	0.18
	Panel B: Developing Economies		
Bedrock Depth	0.0030	0.0292***	0.0262***
× ln Pop 1975	[0.0028]	[0.0060]	[0.0056]
(Bedrock Depth)^2	-0.0000*	-0.0002**	-0.0002**
× ln Pop 1975	[0.0000]	[0.0001]	[0.0001]
R-squared	0.14	0.29	0.22

Controls and excluded cities



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Interpretation: Urban Growth vs. Redistribution

Borusyak et al. (2022) shows that with internal migration between cities, regressions like this can be biased: Violation of SUTVA.

- Estimates driven by developing economies where "clean slate" as of 1975 and context of rural-to-urban (not city-to-city) migration
- Similar estimates if developed economies before 1975 when similar context of rural-to-urban (not city-to-city) migration [BELOW]
- Estimates only slightly larger with 1st or 2nd level admin division FE making us compare neighboring cities (China: provinces, prefectures)
- Using sample of countries $<$20% urbanized in 1975, pop estimate unchanged, built area estimate -0.08 (not significantly different)
- Additionally control for (similarly instrumented) Δ ln Market Potential in Δ Heights of other cities (inverse Euclidean distance weights)

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Heterogeneity in Estimates by Region (1975-2015)

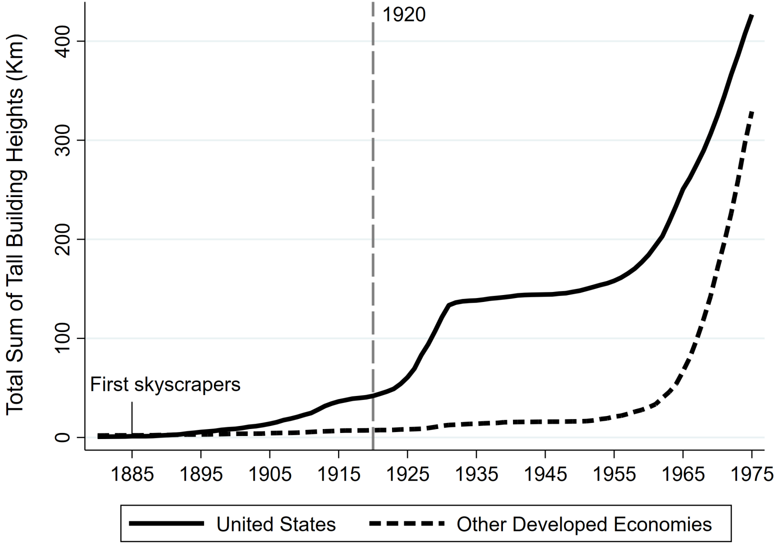
	Developing			Developed		
	Asia xME	Others	Uncons.	Total	USA+Can	Others
	Panel A: Δ ln Population					
Δ ln(Heights+1)	0.17***	0.15**	0.21***	0.00	0.30**	0.01
	[0.03]	[0.07]	[0.04]	[0.03]	[0.12]	[0.02]
	Panel B: Δ ln Built Area					
Δ ln(Heights+1)	-0.20***	-0.26***	-0.39***	-0.04	-0.67*	-0.03
	[0.04]	[0.09]	[0.09]	[0.03]	[0.35]	[0.02]
First Stage F	20.92	7.88	11.36	14.28	5.77	13.68
Observations	6,990	4,267	5,315	1,592	372	1,220

Effects primarily driven by cities in developing economies (88% of cities)

Strong effects in USA-CAN. Nil effects in other developed economies due to central planning in Eastern Europe (and weak IV F-stat in Western Europe and Asia)

→ We focus most of our policy analysis on developing economies. Back

The Skyscraper Revolution in the Developed World



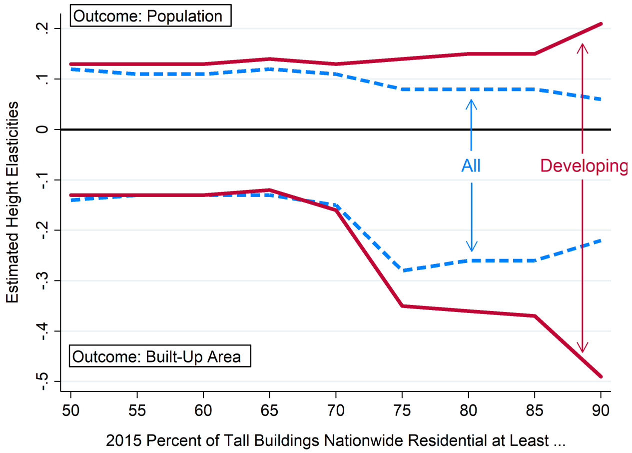
Includes all buildings $\geq$ 55 meters, $\approx$ 14 floors. US: Focus on 1920-1975 period.

Historical Evidence for Developed Economies (...-1975)

Countries:	55 Developed		39 Euro	USA	USA	USA
Initial Year:	1850	1900	1850	1920	1920	1920
Δ ln(Heights+1)	0.14**	0.22***	0.20**	0.21	0.21	0.21†
	[0.06]	[0.07]	[0.10]	[0.17]	[0.15]	[0.13]
First Stage F	10.94	8.44	5.51	4.05	4.82	7.66
Observations	918	918	1,095	324	324	323
Init Yr Ctrl	N	N	N	N	Y	Y
Drop Las Vegas	N	N	N	N	N	Y

- Analogous IVs based on g(bedrock, ln city population) in the initial year
- Population elasticities similar to those for developing economies 1975-2015 Back

Results by Country Tall Building Residential Share



- Developing economies with higher **residential shares** (right side of figure):
  - Greater population response to height
  - Greater land savings from vertical development
- Stronger response for **urban area**
  - Vertical housing and suburbs act as clear substitutes

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Implied Impacts of 1975-2015 Construction

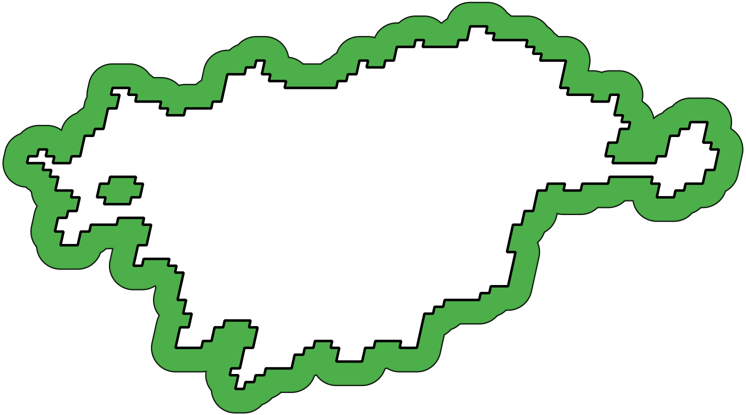
City Pop. 000s (2015)	Number of Cities	1975-2015 ΔHeight km	Share of Height Δ	% of Pop Accomm.	% Area Saved Built	% Area Saved Total
			Panel A: Asian Cities, except Middle East			
0-500	6,514	59	0.02	2	2	1
500-1,000	268	76	0.03	10	9	8
1,000-2,000	114	192	0.07	21	18	15
2,000-5,000	61	527	0.18	47	33	29
5,000+	38	2,001	0.70	58	37	31
All	6,995	2,855	_	23	17	12
			Panel B: Cities in Other Developing Regions			
0-500	3,969	68	0.05	4	5	3
500-1,000	164	123	0.09	20	21	18
1,000-2,000	75	205	0.16	28	28	20
2,000-5,000	54	410	0.31	32	32	24
5,000+	16	501	0.38	38	38	29
All	4,278	1,307	_	18	21	13

Absent construction, 1975-2015 aggregate urban pop change would be ∼20% smaller and aggregate built area change would be ∼20% larger in developing economies Back

Land Savings Outside 2015 Urbanized Boundaries

We investigate whether land-use outside is tree canopy or vegetation

- Use height elasticity of area by city size to predict land expansion
- Assume spatially uniform land expansion



Prediction for São Paulo (had the city not built tall buildings)

Source of Implied Land Savings

City Pop. 000s (2015)	Number of Cities	% Area Saved Built	% Area Saved Total	% Tree Cover	% Other Veg.	% Non Veg.
		Panel A: Asian Cities, except Middle East				
0-500	6,514	2	1	11	77	12
500-1,000	268	9	8	9	75	16
1,000-2,000	114	18	15	10	72	18
2,000-5,000	61	33	29	9	74	17
5,000+	38	37	31	10	76	14
All	6,995	17	12	10	75	15
		Panel B: Cities in Other Developing Regions				
0-500	3,969	5	3	16	76	8
500-1,000	164	21	18	17	74	10
1,000-2,000	75	28	20	17	70	14
2,000-5,000	54	32	24	15	71	13
5,000+	16	38	29	16	59	26
All	4,278	21	13	16	68	16

~10-15% from tree cover, ~70-75% other veg. (incl. cropland), ~15% non-veg. (desert) Back

Calculation of "Height Gaps"

Calculate % gap for each city from the aggregate heights justified by fundamentals:

Predict ln sum of heights with lights, population X (national GDP, earthquake risk, ruggedness, elevation, MBD, year FE) using panel data 1995-2020 (R^2=0.64)

Assume 95^{th} pctile of actual log height in each moving window of 100 cities, ordering by predicted heights, is unconstrained.

Resulting height gap for city *ac* is:

$$Gap_{ac} = \max\left(1 - \frac{Heights_{ac2015}}{H^{95}(\widehat{LHEIGHTS}_{ac2015})}, 0\right)$$

Avg in developed: Europe 85%, North America 77%, Asia 64%

Avg in developing: Asia 41%, Africa 48%, LAC 63%

Calculation of Unconstrained Elasticities

Take first step regression in height gap calculation for 2015

Aggregate residuals with city population weights to the country level

Only keep cities with positive country residuals (excluding former communist countries and developed economies) $\rightarrow$ 5,315 cities in 38 countries

Population elasticity of 0.21 and built area elasticity of -0.39

Used to fit the model below Extensions Indirect inference

Residents

The utility of worker ν:

$$U^o(\nu) = U^o \exp(a^o(\nu))$$

where $o \in \{inside, outside\}$ and $\exp(a^o(\nu))$ is a taste shock

Outside option (hinterland):

$$U^{o=outside} = \widetilde{U}$$

Inside option (representative city):

$$U^{o=inside} = U(x,s) = A^R(x,s)\left(\frac{g}{\alpha^R}\right)^{\alpha^R}\left(\frac{f^R(x,s)}{1-\alpha^R}\right)^{1-\alpha^R},$$

which depends on amenities

$$A^R(x,s) = \bar{a}^R e^{-(\tau^R \times \max(0, x - \underline{x}^R))} s^{\tilde{\omega}^R}$$

Residential Floorspace Bid-Rents

Residents are indifferent across all (x, s) in the city, implying bid-rents

For each location-height:

$$p^R(x, s) = A^R(x, s)^{\frac{1}{1-\alpha^R}} \left(y^R\right)^{\frac{1}{1-\alpha^R}} \bar{U}^{-\frac{1}{1-\alpha^R}}.$$

Averaging across floors puts this in terms of equilibrium height at each location x

$$\bar{p}^R(x) = \frac{1}{S^R(x)} \int_0^{S^R} p^R(x, s) ds = \frac{a^R(x)}{1 + \omega^R} S^R(x)^{\omega^R},$$

where

$$a^R(x) = \tilde{A}^R(x)^{\frac{1}{1-\alpha^R}} \left(y^R\right)^{\frac{1}{1-\alpha^R}} \bar{U}^{-\frac{1}{1-\alpha^R}}$$

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Production

Firms use labor and floorspace to produce:

$$g(x,s) = A^C(x,s)\left(\frac{l}{\alpha^C}\right)^{\alpha^C}\left(\frac{f^C(x,s)}{1-\alpha^C}\right)^{1-\alpha^C}$$

and (agglomeration economies and production amenity decay)

$$A^C(x,s) = \bar{a}^C N^\beta e^{-(\tau^C \times \max(0, x-\underline{x}^C))} s^{\tilde{\omega}^C}$$

Leading to horizontal commercial bid-rents

$$\bar{p}^C(x) = \frac{1}{S^C(x)}\int_0^{S^C} p^C(x,s)ds = \frac{a^C(x)}{1+\omega^C} S^C(x)^{\omega^C},$$

where

$$a^C(x) = \tilde{A}^C(x)^{\frac{1}{1-\alpha^C}} (y^C)^{\frac{\alpha^C}{\alpha^C-1}}$$

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Construction (Again)

Same as before, but separately by Residential (R) or Commercial (C) sector U: We allow production function parameters to differ by sector

Subbing in bid-rents from above,

$$S^{*U}(x) = \left(\frac{a^U(x)}{c^U(1+\theta^U)}\right)^{\frac{1}{\theta^U - \omega^U}}$$

Under perfect competition (0 profits), the use-specific equilibrium bid-rents for land are

$$r^U(x) = \frac{a^U}{1+\omega^U}(\tilde{S}^U)^{1+\omega^U} - c^U(\tilde{S}^U)^{1+\theta^U}$$

which goes to the highest bid use in equilibrium

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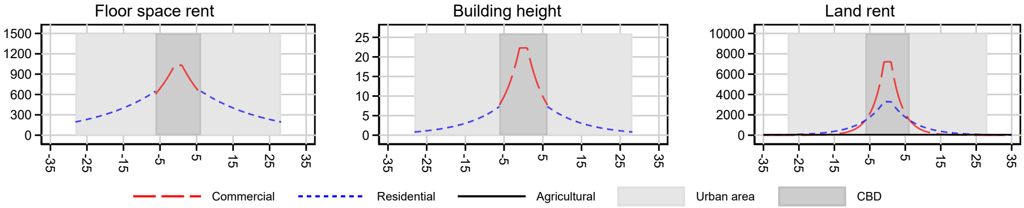
Intuition



- In PE, floor space rents $\Rightarrow$ building height $\Rightarrow$ land rent $\Rightarrow$ land use
- In GE, land (foor space) allocated to urban uses must accommodate workers
  - At workplaces and residences
- Endogenous prices adjust to clear markets
  - Not enough commercial floor space $\Rightarrow$ commercial rent must increase
  - Not enough residential floor space $\Rightarrow$ residential rent must increase
  - Labour supply $>$ labour demand $\Rightarrow$ wage must fall $\Rightarrow$ rents adjust
- Different solutions under different primitives

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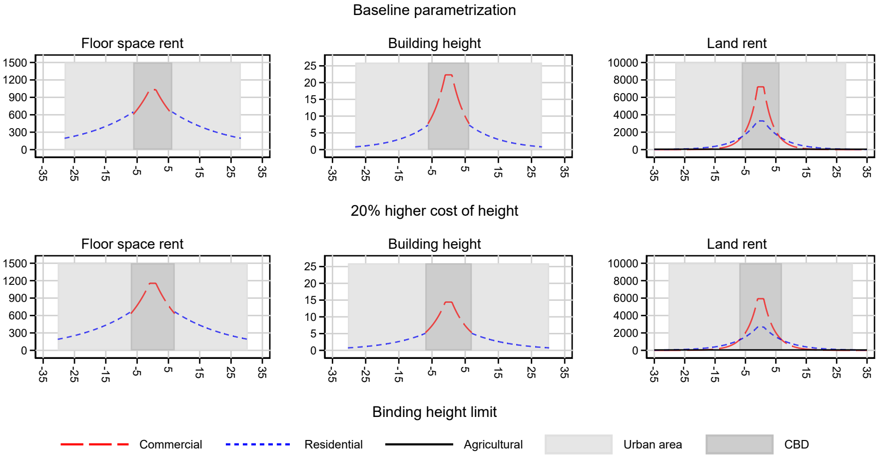
Changing cost of height



- Greater cost of height leads to more horizontal city with smaller population
  - Land values fall in central city, but increase at ciy margin

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SMM I

For each combination of $\{\theta, \zeta, \mathcal{T}\}$, we solve the model and compute the endogenous outcomes city area

$$\mathcal{L}_{\theta}^{\zeta,\mathcal{T}} = \int_{0}^{(x_1)^{\theta,\zeta,\mathcal{T}}} \mathcal{L}(x)dx,$$

city population

$$N_{\theta}^{\zeta,\mathcal{T}} = \int_{(x_0)^{\theta,\zeta,\mathcal{T}}}^{(x_1)^{\theta,\zeta,\mathcal{T}}} (n(x))^{\theta,\zeta}dx,$$

and city tall building height

$$H_{\theta}^{\zeta,\mathcal{T}} = \int_{0}^{(x_1)^{\theta,\zeta,\mathcal{T}}} \mathcal{L}(x)\left((S^C(x))^{\theta,\zeta} - \mathcal{T}\right)dx + \int_{(x_0)^{\theta,\zeta,\mathcal{T}}}^{(x_1)^{\theta,\zeta,\mathcal{T}}} \mathcal{L}(x)\left((S^R(x))^{\theta,\zeta} - \mathcal{T}\right)dx.$$

SMM II

For each combination of $\{\zeta, \mathcal{T}\}$, we run the following regressions on the model-based outcomes to recover our moments in the model $\{\tilde{\beta}^N, \tilde{\beta}^{\mathcal{L}}\}$:

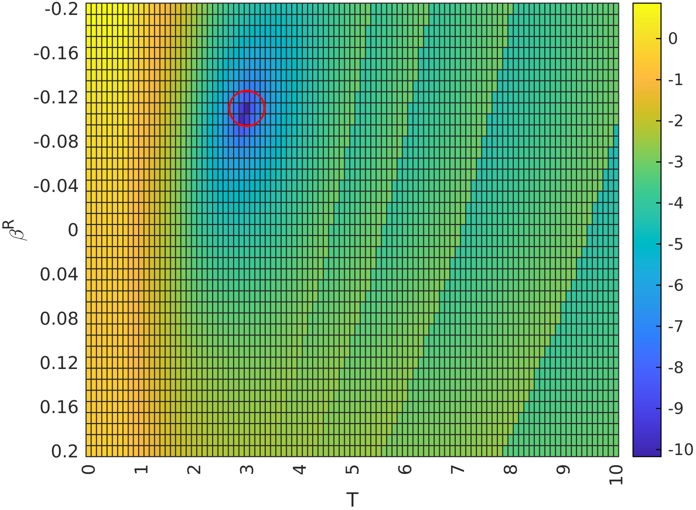
$$\ln \mathcal{L}_{\theta}^{\zeta,\mathcal{T}} = c^{\mathcal{L},\zeta,\mathcal{T}} + \tilde{\beta}_{\zeta,\mathcal{T}}^{\mathcal{L}} \ln H_{\theta}^{\zeta,\mathcal{T}} + \tilde{\epsilon}_{\theta}^{\mathcal{L},\zeta,\mathcal{T}}$$
$$\ln N_{\theta}^{\zeta,\mathcal{T}} = c^{N,\zeta,\mathcal{T}} + \tilde{\beta}_{\zeta,\mathcal{T}}^{N} \ln H_{\theta}^{\zeta,\mathcal{T}} + \tilde{\epsilon}_{\theta}^{N,\zeta,\mathcal{T}}$$

We find our preferred combination of $\{\zeta, \mathcal{T}\}$ by minimizing the value of the residual sum of squares of the moments in model and data:

$$\zeta, \mathcal{T} = \arg \min_{\zeta \in \mathcal{Z}, \mathcal{T} \in \mathcal{R}} \sum_{o \in N, \mathcal{L}} \left(\hat{\beta}^{o} - \tilde{\beta}^{o}\right)^2$$

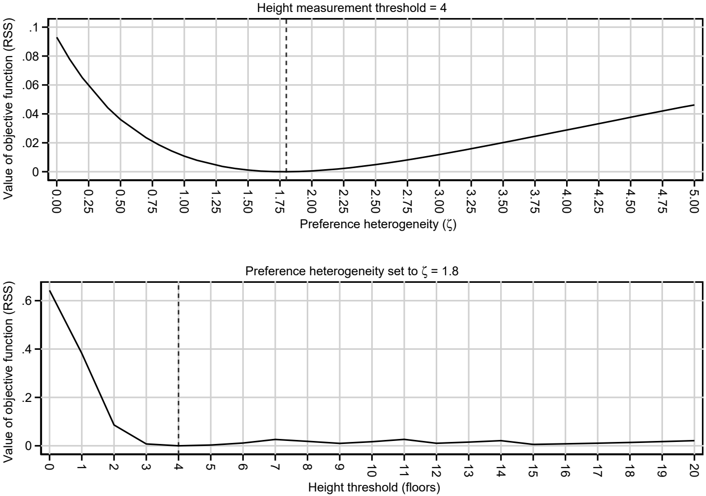
Height elasticities

SMM III



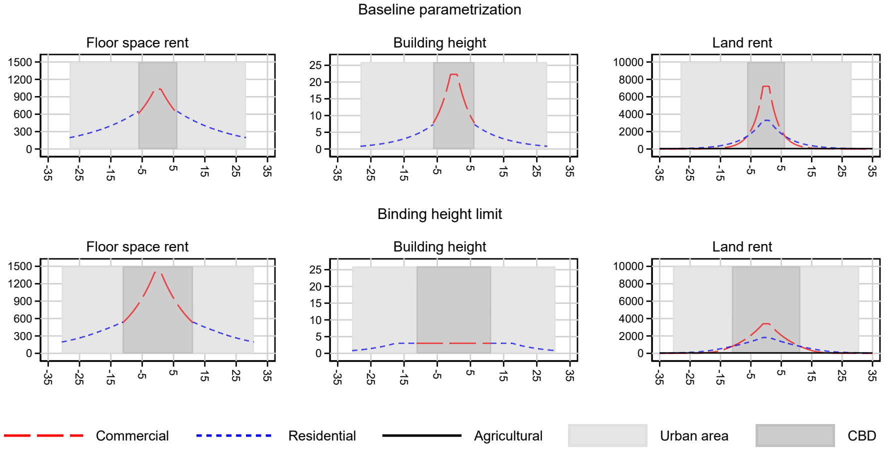
Height elasticities

SMM IV



Height elasticities

Changing height limit



- Height limit leads to more horizontal city with smaller population
  - Wage -8%, commuting cost +8%, population -15 %, urban area +13%, commercial rent +6%, residential rent -15% (real income falls)

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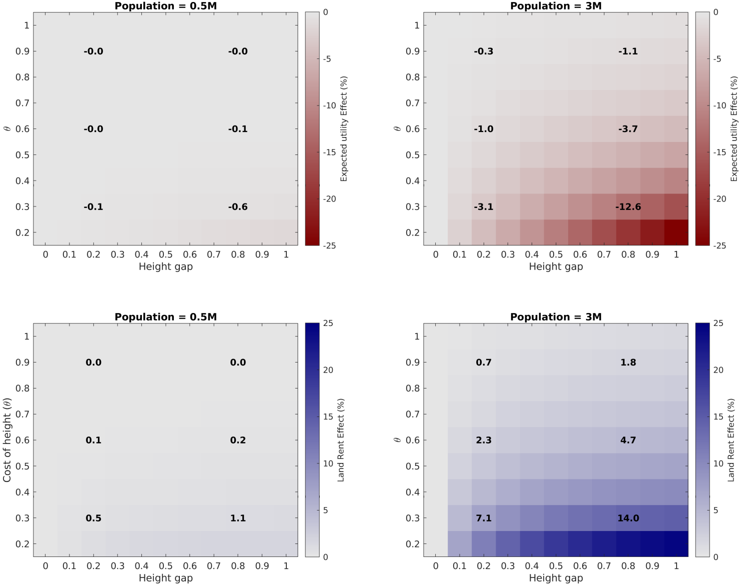
Welfare effects by bedrock and city size



Key Insight:
Height restrictions are *more consequential* when building upward is cheap.

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Mechanisms and size effects

- Effects on the urban population are naturally larger than average effect
  - Expected utility is weighted average of urban and rural utility
- Positive effect of relaxing height limits driven by wage and commuting cost
  - There is also a small positive contribution by the view amenity
  - But there is a cost: Density amenity effect is negative and sizable
- Large effects on population and area
  - But smaller than suggested by quantification within the reduced-form framework

Group	Urban utility		Wage		Rent		Commuting		Density amenity		Population		Area		View amenity	
	No tall build.	No height limit	No tall build.	No height limit	No tall build.	No height limit	No tall build.	No height limit	No tall build.	No height limit	No tall build.	No height limit	No tall build.	No height limit	No tall build.	No height limit
Developed (D)	-2.3%	9.3%	-2.0%	8.6%	-1.3%	12.2%	2.4%	-8.0%	2.0%	-5.9%	-6.8%	25.0%	13.1%	-28.7%	-0.5%	1.8%
Developing (G)	-1.6%	5.5%	-1.9%	4.8%	-2.3%	6.4%	2.2%	-4.4%	2.0%	-3.1%	-5.3%	14.7%	15.6%	-13.5%	-0.4%	1.0%
All	-1.7%	6.2%	-1.9%	5.5%	-2.1%	7.4%	2.2%	-5.0%	2.0%	-3.6%	-5.5%	16.5%	15.2%	-16.2%	-0.5%	1.1%

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By world region

- Effects on the urban population are naturally larger than average effect

Group	Expected utility		Land value	
	No tall build.	No height limit	No tall build.	No height limit
Africa, D	-0.04%	0.50%	0.03%	-0.52%
Africa, G	-0.35%	5.16%	-0.07%	-4.52%
Asia, D	-3.14%	9.96%	0.71%	-10.14%
Asia, G	-0.73%	2.90%	-0.30%	-2.93%
Europe, D	-0.65%	4.78%	-2.42%	-6.03%
Europe, G	-0.49%	0.67%	0.40%	-1.11%
LAC, D	-0.17%	0.69%	0.18%	-0.95%
LAC, G	-1.22%	5.42%	-1.28%	-6.33%
North America, D	-1.08%	6.13%	-2.51%	-7.56%
Oceania, D	-0.24%	7.83%	-0.12%	-7.77%
Oceania, G	-0.14%	-0.00%	0.24%	0.00%

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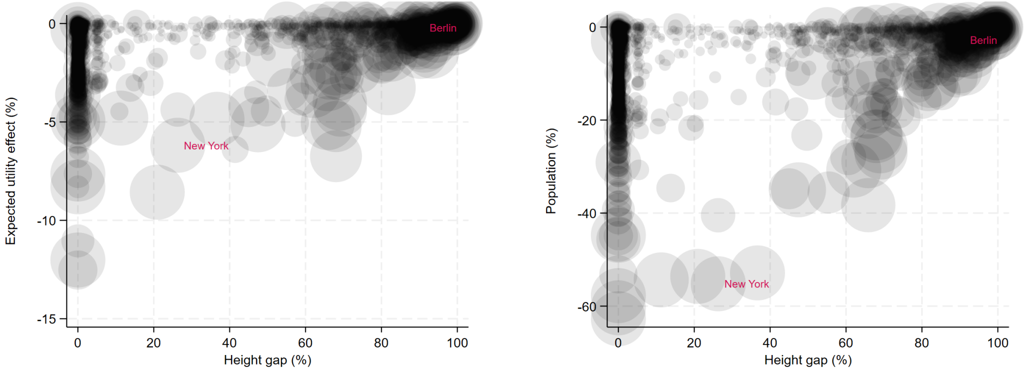
Removing tall heights



- Expected utility and urban population would be lower in large cities
  - And, ceteris paribus, larger effects in places with small height gaps (little regulation)
- Spatial inequalities would be smaller

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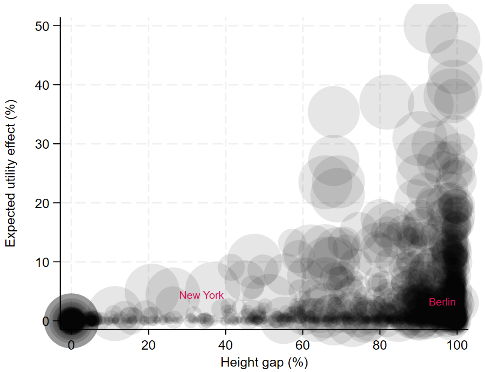
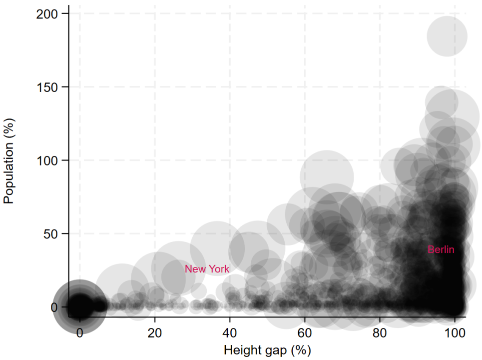
Removing height limits





- Expected utility and urban population would be greater in large cities
  - And, ceteris paribus, larger effects in places with greater height gaps (strong regulation)
- Spatial inequalities would be greater

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