The Economics of Skyscrapers: A synthesis

Gabriel M. Ahlfeldt[1] Jason Barr[2]

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[1]London School of Economics, CEPR & CESifo
[2]Rutgers University, Newark

Intro

- Urban economics traditionally concerned with *horizontal* structure of cities
  - Cities have grown vertically since the turn of 19th to 20th century
  - Empirical research only recently gained momentum
- Develop a simple open-city GE model of *vertical* and *horizontal structure*
  - Incorporates vertical costs and benefit in horizontal land use model
  - Endogenous wages, rents, heights, population, horizontal land use
- Use the model to speak to first-order questions of skyscraper economics
  - Rationalize city-internal building height gradients
  - Explore how skyscrapers are *cause* and *effect* of urban growth
  - Distortionary effects of height regulation (in open-city)

Stylized evidence

Height decisions

- Skyscrapers emerge when there are innovations in construction technology
  - Elevator ans steel frame
  - Mainframe computing and buttressed core Record buildings
- Skyscrapers emerge where there is high demand Determinants Diffusion Count
  - Population, GDP per capita, GDP growth are determinants of verticlal growth
  - Shift in gravity of vertical growth from North America to Asia
- Evidence for 'too tall' buildings limited #1, #2, #3 tallest ESB
  - #2 (#3) building (very) good predictor for #1 (#2) building height
  - ESB—led hight rankings longer than any other building—was profitable

Consistent with profit-maximization driving height decisions

Model

- Linear city with exogenous historic center at $x = 0$
- Consumption amenity varies in horizontal (x) and vertical (s) space

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

- Productivity depends on x and s and agglomeration (population N)

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

- Developers face per-unit construction costs that increase in height (S)

$$\pi^U(x,S^U(x)) = \bar{p}(x)S^U(x) - \tilde{c}^U(S^U(x))S^U(x) - r^U(x)$$

Model II

- Workers **maximize utility**, firms and developers maximize **profits**
- **Zero** firm **profits** and **perfect mobility** → bid-rents
- Bid-rents and convex construction cost → optimal building height
- **Zero** developer **profits** → use-specific land rent
- Land goes to the **highest bidder** → horizontal land use pattern
- General equilibrium conditions
  - Commercial and residential **markets clear** (at all locations)
  - Labour **market clears**
  - **Population** must **adjust** to maintain reservation utility

Floor space rents, land rent, commercial and residential area, height, wage, population are endogenous

Parameter values

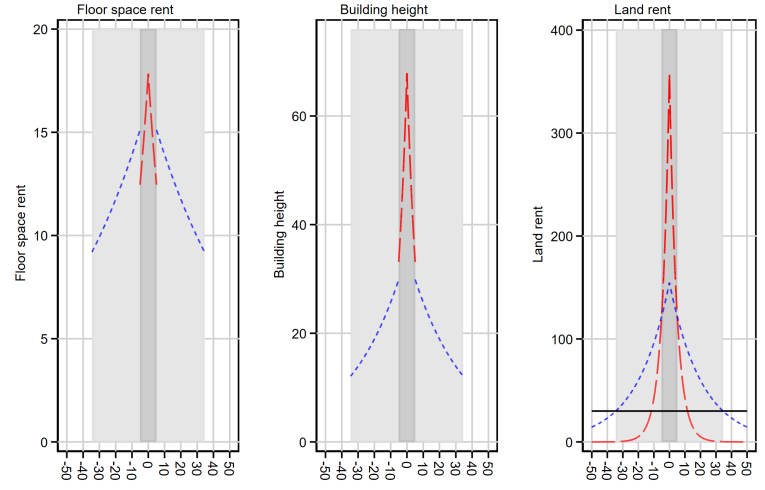
	Parameter	Value	Further reading
$1-\alpha^C$	Share of floor space at inputs	0.15	Lucas and Rossi-Hansberg (2002)
$1-\alpha^R$	Share of floor space at consumption	0.33	Combes et al. (2019)
β	Agglomeration elasticity of production amenity	0.03	Combes and Gobillon (2015)
θ^R	Commercial height elasticity of construction cost	0.5	Ahlfeldt and McMillen (2018)
θ^R	Residential height elasticity of construction cost	0.55	Ahlfeldt and McMillen (2018)
ω^C	Commercial height elasticity of rent	0.03	Liu et al. (2018)
ω^R	Residential height elasticity of rent	0.07	Danton and Himbert (2018)
τ^C	Production amenity decay	0.01	Ahlfeldt et al. (2015)[a]
τ^R	Residential amenity decay	0.005	Ahlfeldt et al. (2015)

Notes: These parameter values are not taken from individual papers and do not necessarily correspond to our own estimates. Instead, they represent what we view as canonical values that are suitable for stylized presentations and simple counterfactual analysis. The last column provides a references for the interested reader for further reading, but not necessarily the source of a point estimate. [a]The parameter value is consistent with the commercial rent gradient estimated for a large set of global cities, assuming $\alpha^C = 0.15$ (see Appendix Section N.1.1). We set the following scale parameters arbitrarily to to generate a plausible land use pattern: $\bar{a}^C = 2, \bar{a}^R = 1, \bar{c}^C = 1.4, \bar{c}^R = 1.4, r^a = 30, \bar{U} = 1$. There are no binding height limits in the baseline parametrization ($\bar{S}^C = \bar{S}^R = \infty$).

Cost of height Return to height

Internal city structure

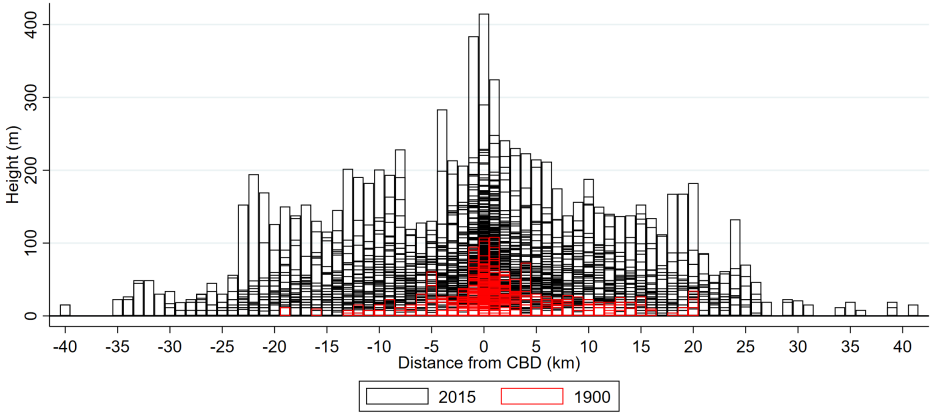
Gradients


Floor space rent
Floor space rent
20
15
10
5
0
-50 -40 -30 -20 -10 0 10 20 30 40 50
Building height
Building height
60
40
20
0
-50 -40 -30 -20 -10 0 10 20 30 40 50
Land rent
Land rent
400
300
200
100
0
-50 -40 -30 -20 -10 0 10 20 30 40 50
Commercial
Residential
Agricultural
Urban area
CBD

Empirics

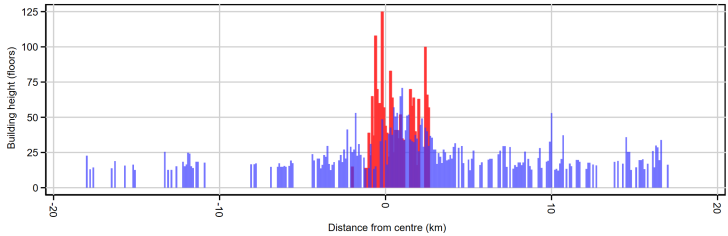
- Slope of height gradient across *global cities* **constant over time**
  - Distance elasticity about -0.29 in 1900 and 2000
- **Commercial height gradient steeper** than residential gradient Table
  - Driven by substitution in use an construction (in model)
- North American height gradients steeper than European or Asian gradients
  - Role for regulation?
- Evidence for **height discontinuity** at land use border Discontinuity
  - Discontinuous change of 0.2 log points at CBD boundaries of North Am. cities

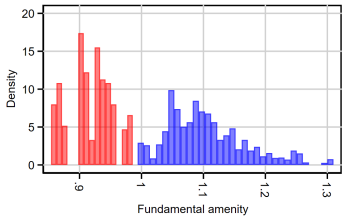
Height gradient in data

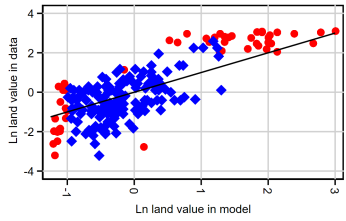


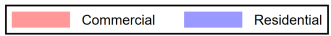
dln(y)/dln(|x|) = -.29***
dln(y)/dln(|x|) | year ≤ 1900 = -.282***

Fuzzy height gradient







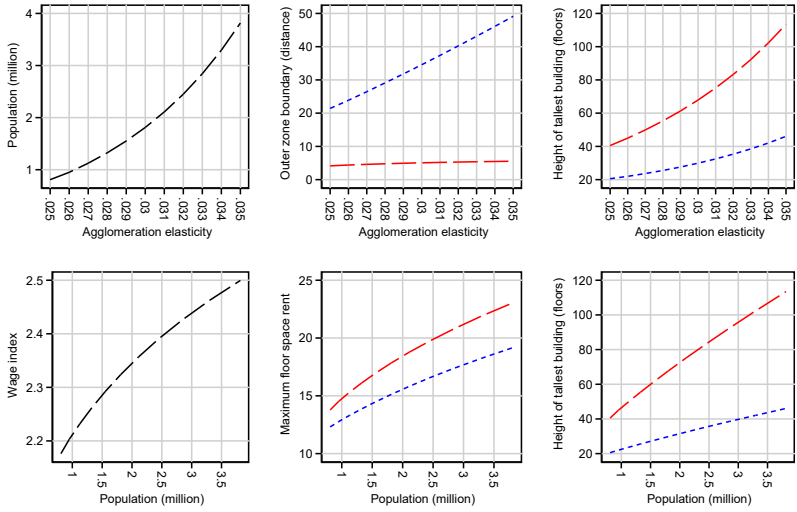


Skyscrapers as cause and effect of urbanization

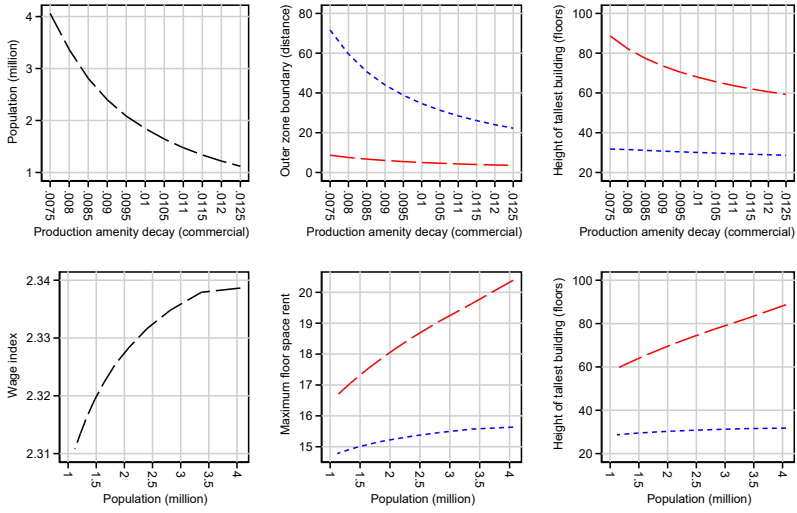
Counterfactuals

- Solve for endogenous objects given primitives
  - Exogenous parameters: $\{\alpha^U, \beta, \omega^U, \theta^U, \tau^U, \bar{a}^U, \tilde{c}^U, \bar{S}^U, \bar{U}, r^a\}$
  - Location-specific endogenous objects $\{L(x), n(x), \bar{p}^U(x), r^U(x), \tilde{S}^U(x)\}$
  - City-specific endogenous objects $\{y, N\}$
- Pick one exogenous parameter and consider a **series of alternative values**
  - Change all use-specific values at a time, maintaining relative size
  - Generate a vector of equilibrium values for each endogenous outcome
- Explore vector of equilibrium values of endogenous outcomes
  - Outcomes vs. "forcing" parameter
  - Endogenous outcome vs. other endogenous outcomes (e.g. population)

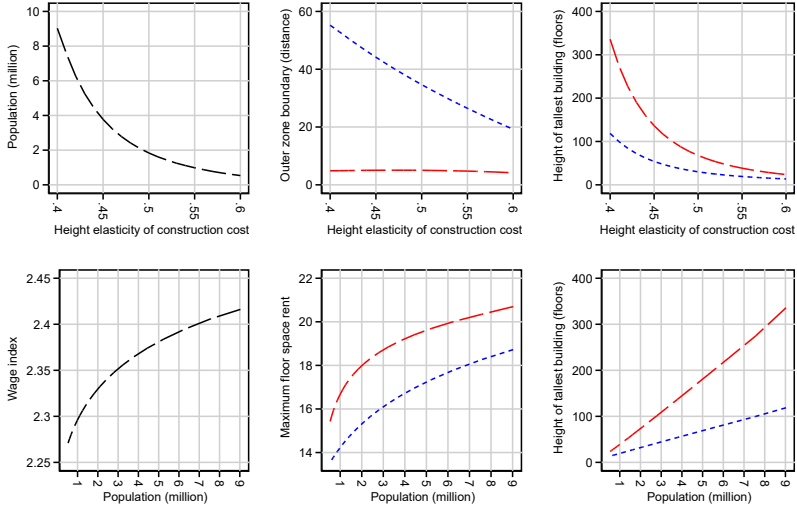
GE effects of variation in agglomeration elasticity



GE effects of variation in transport cost



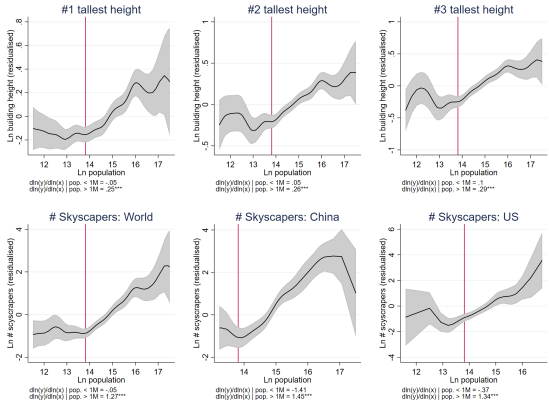
GE effects of variation in cost of height



Summary

- Height positively correlated with various outcomes
  - Rent, productivity, wage, population
- Skyscrapers are cause and effect of urbanization
  - **Demand channels**, e.g. agglomeration gains, reduction in transport cost
    - Urbanization causes skyscraper development
  - **Supply channel**, reduction in cost of height
    - Skyscrapers cause urbanization, deserves more attention in literature
- Model generates **empirically relevant elasticities** that **vary by channel**
  - Population elasticity of rent: 0.1-0.3 (in line with Ahlfeldt & Pietrostefani, 2019)
  - Population density elasticity of height: 0.1-1

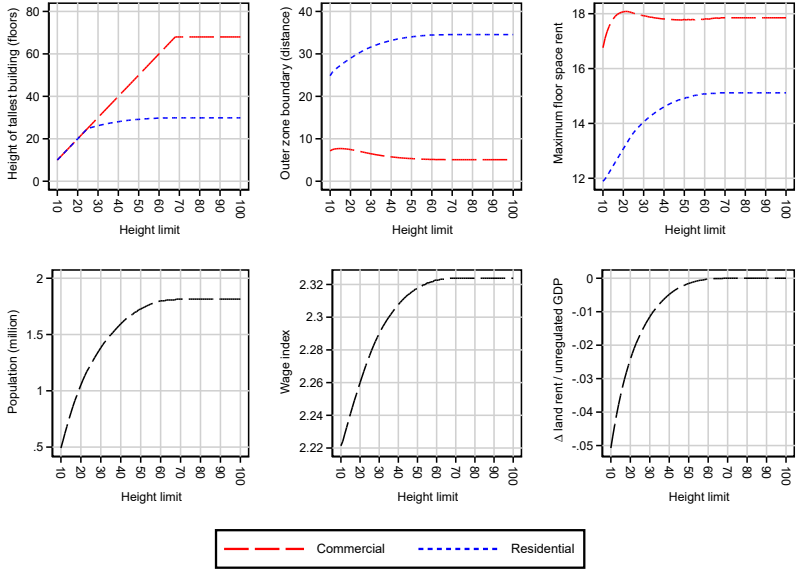
Height and city size



Population elasticity of height ≈ 0.25 | pop. $>$ 1m
Likely from a mix of demand and supply channels

Regulation

GE effects of height regulation



Summary

- Regulation causes **large incidence (cost)** on immobile factor (land)
  - 5.8% of GDP of a city similar to Houston, TX, equiv. to $23 bn per year
  - $210k per-capita terms
- Implications **differ** from standard **closed-city** model
  - Regulation increases horizontal size of CBD, but reduces size of residential zone
  - Population shrinks, wages fall (lower agglomeration gains)
  - **Rents must fall** to restore equilibrium (reservation utility)
  - Migration offsets affordability gains from liberal land use regulation

Mind positive effects of height regulation
(less shadowing, congestion, coherence of fabric, etc.)

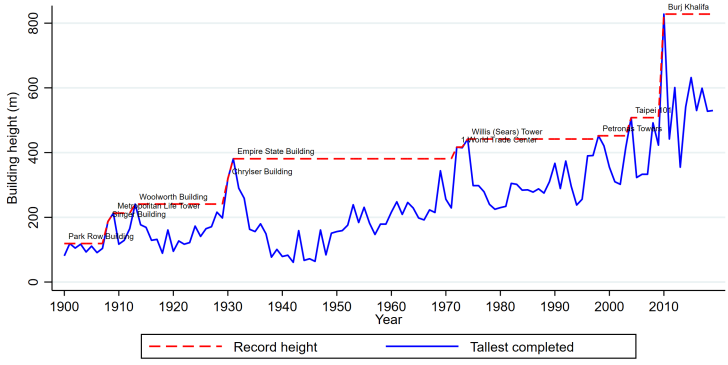
Scope for future research

- Positive and negative externalities of skyscrapers
  - Agglomeration effects, signaling, tourism, etc.
  - Shadowing, congestion, loss of coherent (historic) fabric
- Costs and returns to height
  - Explore heterogeneity, non-linear and threshold effects more fully
  - Use-specific costs to be incorporated into quantitative models
- Non-economic motives
  - Evidence for height competition?
  - Direct systematic evidence on profitability of skyscrapers

Worth accounting for use-specific vertical costs and heights in QSMs

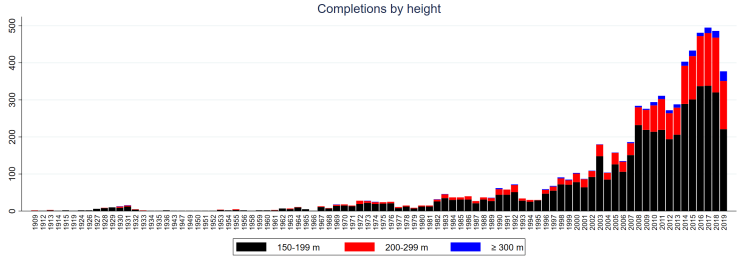
Additional material

Tallest buildings in history

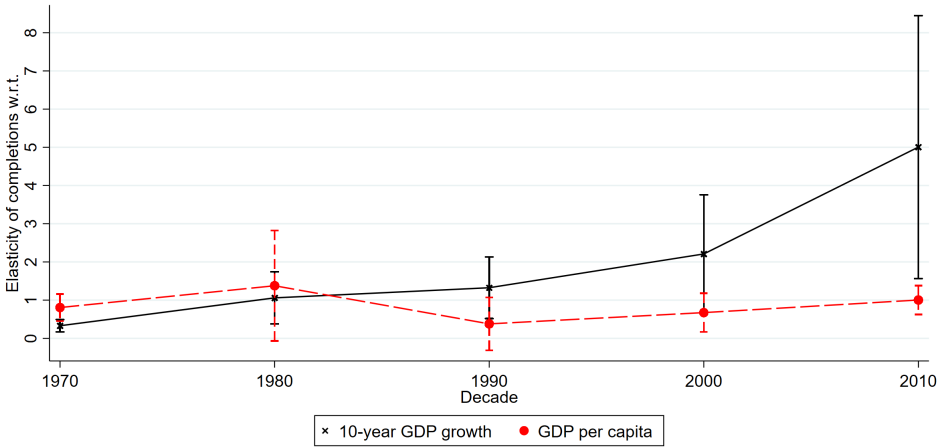


Height decisions

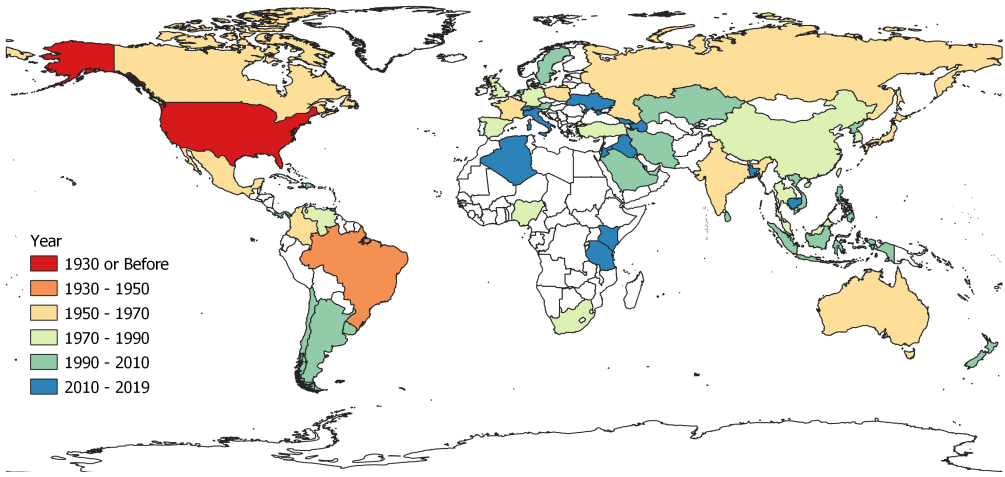
Vertical growth



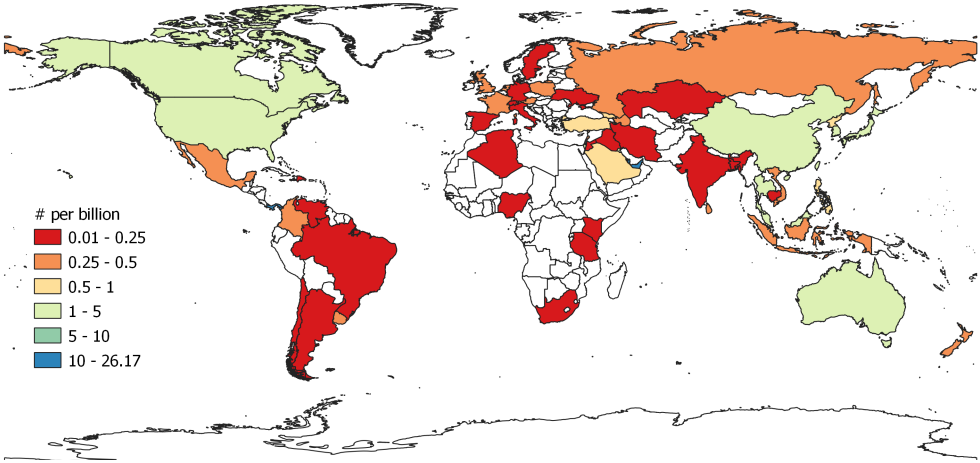
Determinants



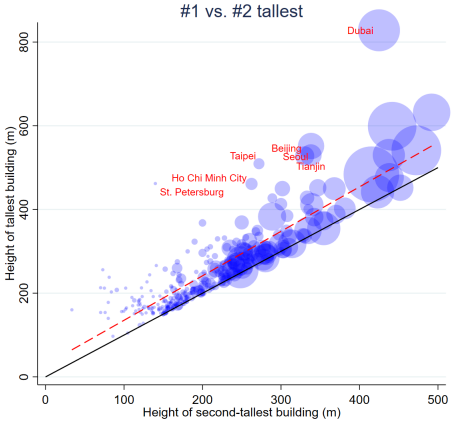
Diffusion

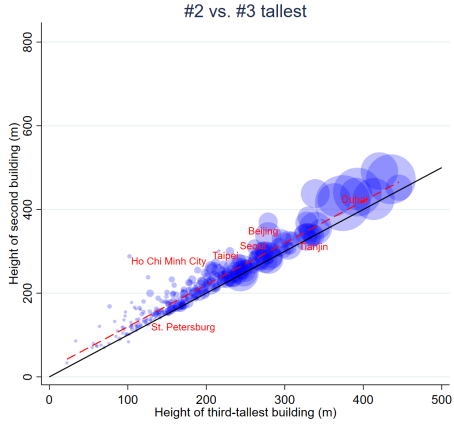

Year
1930 or Before
1930 - 1950
1950 - 1970
1970 - 1990
1990 - 2010
2010 - 2019

Skyscraperization



Tallest buildings in cities

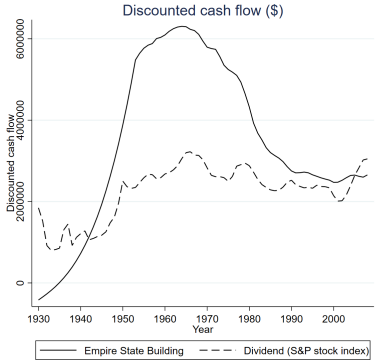


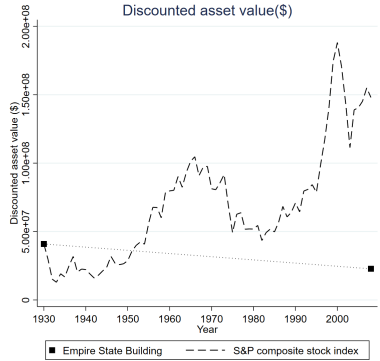


Height decisions

Few tall buildings are suspiciously tall

Empire State Building

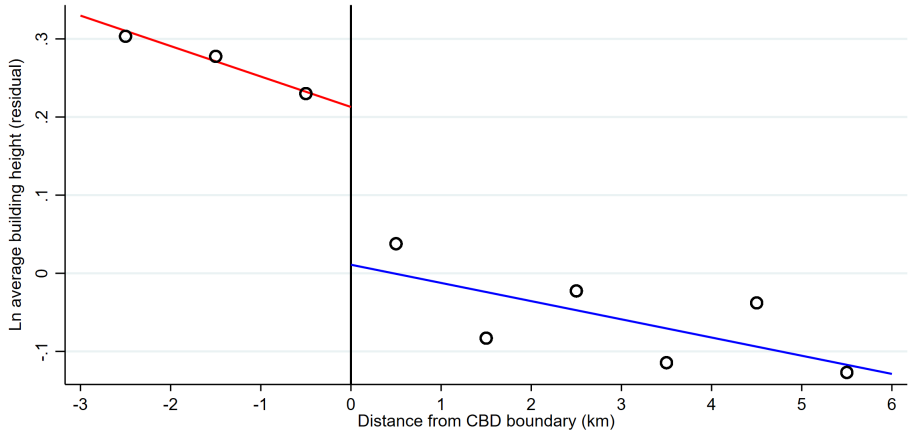




Height decisions

ESB beats stock market over its (first lifetime)

Discontinuity



dln(y)/d(x)|x<0 = -.039***, dln(y)/d(x)|x>0 = -.023***, boundary effect = .202***

Height gradients

	(1) Ln(height)	(2) Ln(height)	(3) Ln(height)	(4) Ln(height)	(5) Ln(height)	(6) Ln(height)	(7) Ln(height)
Distance from CBD center (km)	-0.069*** (0.01)	-0.042*** (0.00)	-0.052*** (0.00)	-0.036*** (0.00)	-0.024*** (0.00)	-0.023*** (0.00)	-0.048*** (0.00)
City fixed effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes
$d\ln(y)/d\ln(x)$	-.23	-.27	-.33	-.26	-.12	-.12	-.35
Building Sample	$t^a \leq 1900$	All	Comm.^{b}	Residential	Asia	Europe	North A.^{b}
Observations	344	3469	1294	1185	2081	662	419
R^2	.494	.559	.679	.647	.427	.331	.376

Notes: ^{a}: Completion year. ^{b} Commercial. ^{c}: North America. Unit of observation is city-distance bin (1 km). Height is the height of the tallest building within a one-km distance bin. Building data from Emporis. CBD definitions (global prime locations) for 125 global cities from Ahlfeldt et al. (2020). Elasticities computed at the sample means. Data from Empiris (see Ahlfeldt et al. (2020) for details). * p < 0.1, ** p < 0.05, *** p < 0.01.

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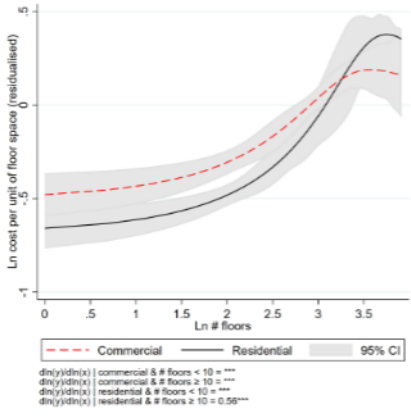
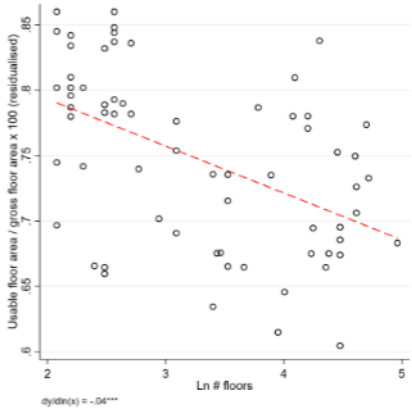
Cost of height

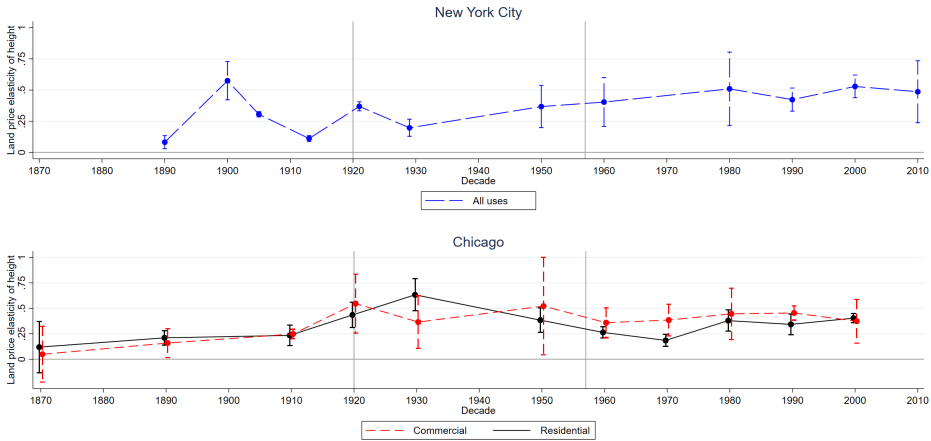


(a) Unit cost vs. height

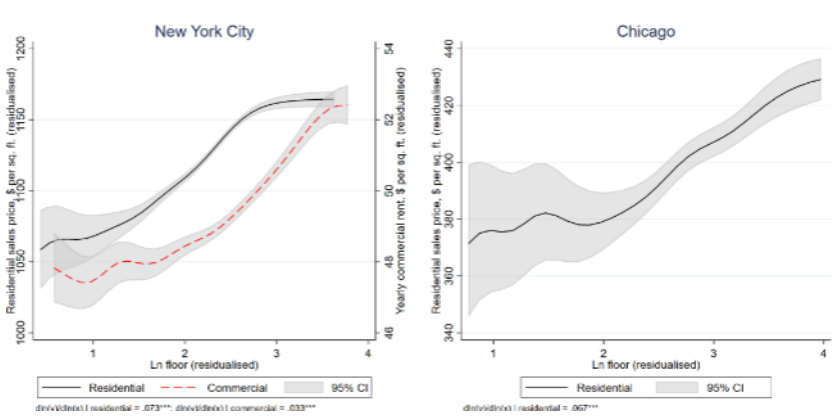


(b) Usable floor area vs. height

Cost of height over time



Return to height



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Return to height over time