The Skyscraper Revolution:
Global Economic Development and Land Savings

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  Exponential growth in global aggregate building height since 1975

  - Much in developing economies (previous photo: São Paulo)
  - Large variation across world cities
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- Skyscrapers as Central Drivers of Urban Structure

  - Urbanization: Allow cities to accommodate more people
  - Land savings: More land for non-urban uses (agriculture)

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  - Urbanization: Allow cities to accommodate more people
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- Literature: Analogous studies on effects of urban transportation infrastructure (highways, subways, railroads, etc.)
  - Key complication is that skyscraper construction is more closely tied to fundamental local demand and cost factors.

Our Analysis

- Global panel data analysis
  - Novel database: 12,877 world cities (90% world's urban pop) in 1975 (1990 2000) & 2015. RHS: tall building stock; LHS: pop, area
  - Emporis: data on all tall buildings ($\geq$ 55 meters) ever built worldwide, with construction year and (sometimes) cost info

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    ... too close to the surface, must be blasted away

    ... too deep, foundations not anchored, must be reinforced

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- Height elasticities: population 12%, built area -17%, population density 29%, driven by cities in developing economies
- Model: Tall buildings could increase global welfare by 3.3%. But only 1/3 has been realized (due to land-use constraints)

Literature

1. Economics of skyscrapers [we study global economic effects]

   Barr '10, '12, Barr et al '11, Ahlfeldt & McMillen 2018, Liu et al '18, '20, Ahlfeldt & Barr '20, '22, Jedwab et al '20, '21, Jedwab & Barr '22, Jedwab '22

2. Causes of sprawl [we focus on the role of tall buildings]

   Bertaud & Brueckner '05, Burchfield et al '06, Baum-Snow '07, '22, Brueckner & Sridhar '12, Jedwab et al '20, '21, Ahlfeldt & Barr '22

3. Economics of density [we examine the effects of tall buildings]

   Combes & Gobillon '15, Ahlfeldt & Pietrostefani '19, Duranton & Puga '20 for surveys; Rosenthal & Strange '08 and Combes et al '11 for geological IVs

4. Global differences in urbanization [we find heterogeneous effects]

   Jedwab et al '17, '19, '21, Chauvin et al '16, Bryan & Morten '18

Data

- Sample: 12,877 50K+ agglomerations* today (*urban centres* from GHS)
- City-level outcomes:

  From GHS, pop, built-up area and land area 1975 (1990 2000) & 2015

  Radiance calibrated version of the DMSP night lights 1996-2011**

  Global land change data 1982-2015 (deforestation, cropland, etc.)
- Main variable of interest:

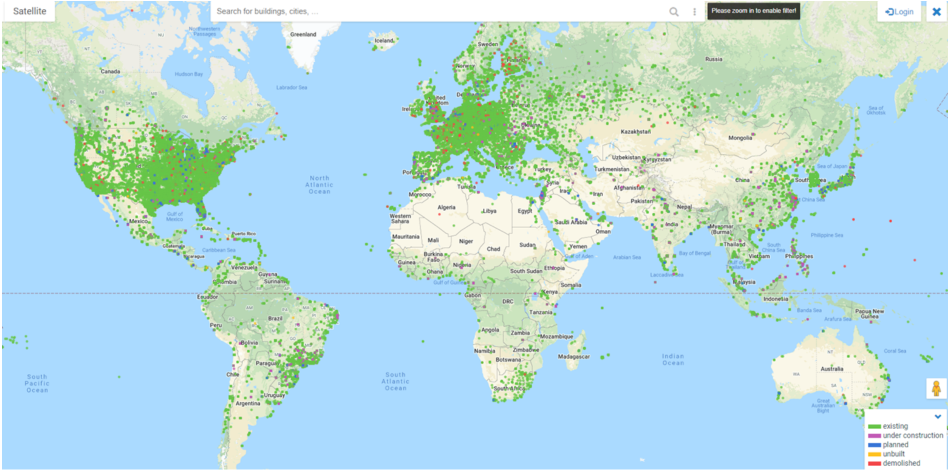
  From *Emporis*, location, height ($\geq$ 55 meters) & year of construction

  Information provided by industry. "*Emporis collects information about the full life-cycle of each building, from idea to demolition*"

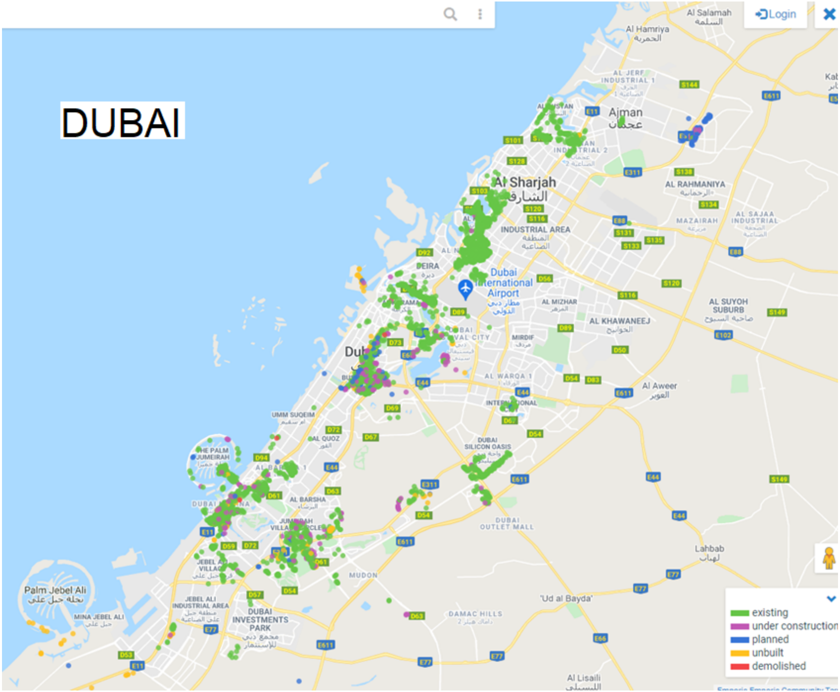
  Tall building stocks for each city 1975 (1990 2000) & 2015

* 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.



Data for 270K tall buildings (buildings $\geq$ 55 meters $\approx$ 180 feet)


DUBAI
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AL SAJAA INDUSTRIAL
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Dubai International Airport
AL MIZHAR
AL KHAWANEEJ
AL SUYOH SUBURB
MIRDIF
AL WARQA 1
Al Aweer
UMM SUQEIM
AL QUOZ
DUBAI SILICON OASIS
AL BARSHA
DUBAI OUTLET MALL
Lahbab
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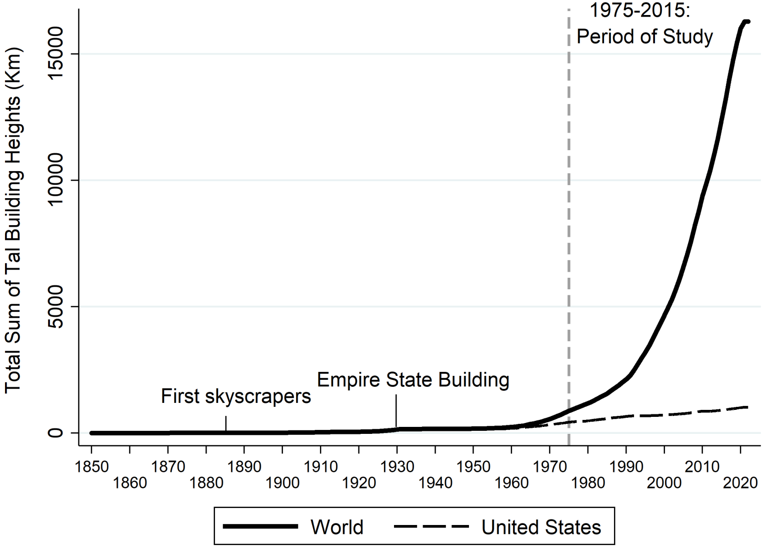
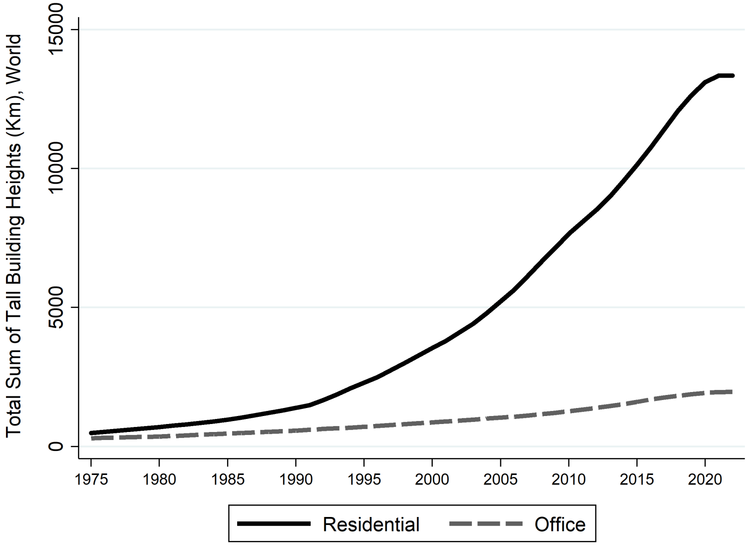
under construction
planned
unbuilt
demolished

The Global Stock of Tall Buildings



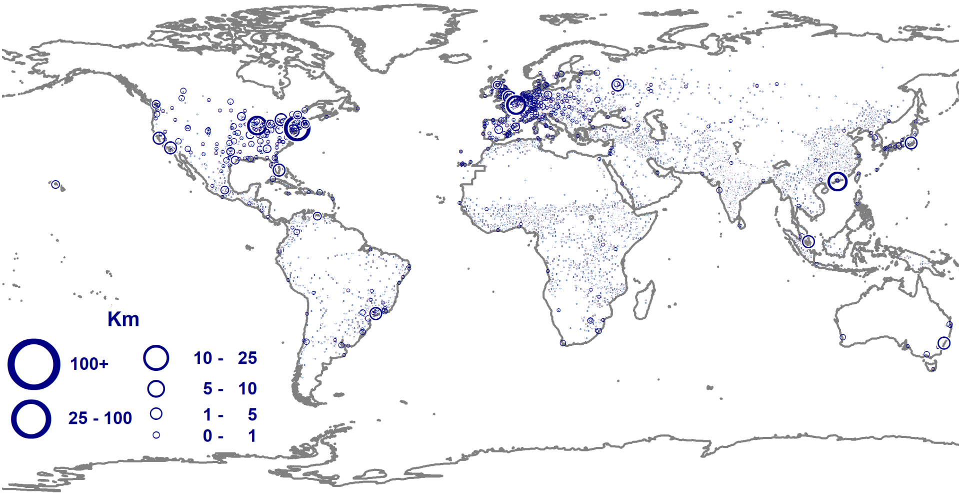
Includes all buildings $\geq$ 55 meters, $\approx$ 14 floors. 1975-2015: +11,500 km $\approx$ 26K Empire State Buildings $\approx$ 3x Euclidean distance between NYC and LA!

Most Recent Tall Building Construction is Residential



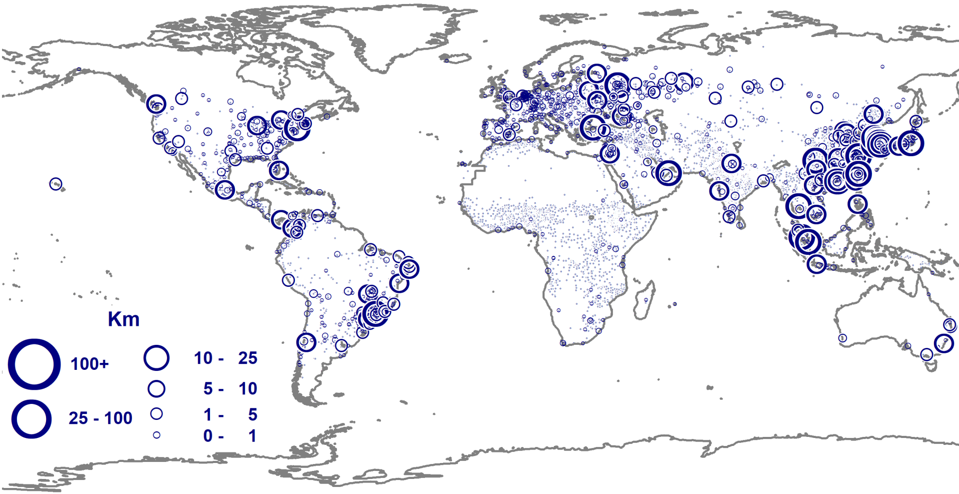
World of residential towers: Increased 7x more for residential buildings (typically in the 55-100 m range) than for commercial/office buildings (100 m+).

The Stock of Skyscraper Heights in 1975



Historically, global skyline dominated by North America & Western Europe

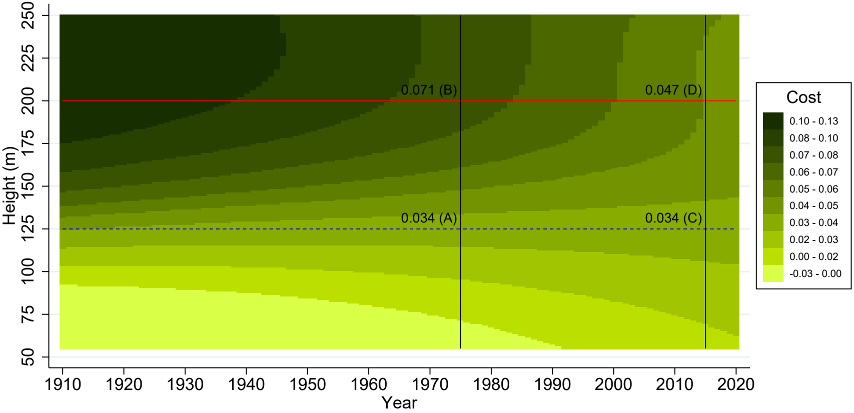
The Flow of Skyscraper Heights 1975-2015



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

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

Sample Means

	Tercile 1	Tercile 2	Tercile 3	Overall
Pop (,000), 1975	18	54	343	138
Heights (m), 1975	0	4	198	67
Heights (m), 2015	34	38	2814	962
Δ ln Heights	0.06	0.14	1.04	0.41
Frac w/ Tall Bldgs, 1975	0.00	0.02	0.11	0.05
Frac w/ Tall Bldgs, 2015	0.01	0.05	0.26	0.10
Δ ln Pop	0.67	0.37	0.35	0.46
Δ ln Built Area	0.47	0.53	0.67	0.55

Terciles calculated using 1975 city pop. (N = 12,877 world cities).

Bedrock Depth as a Source of Exogenous City-Level Variation in Tall Building Construction Cost

- Tall buildings require foundations that go deep into the ground
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- If bedrock is too deep, more costly engineering required for a reinforced floating foundation or additional piles (ibid.)

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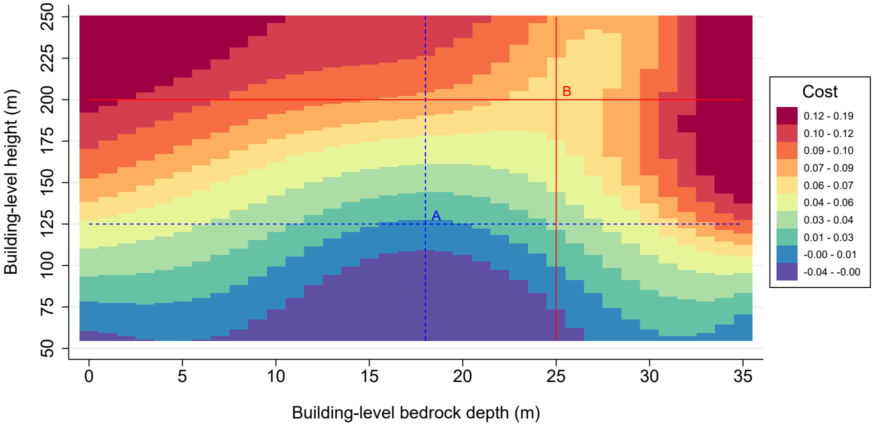
- If bedrock is too deep, more costly engineering required for a reinforced floating foundation or additional piles (ibid.)
- The cost function is non-monotonic in bedrock depth:

  $\rightarrow$ The cost minimizing bedrock depth is that at which the bottom of the optimal foundation rests on the bedrock.

Inverted-U Relation btw Cost of Height & Bedrock Depth

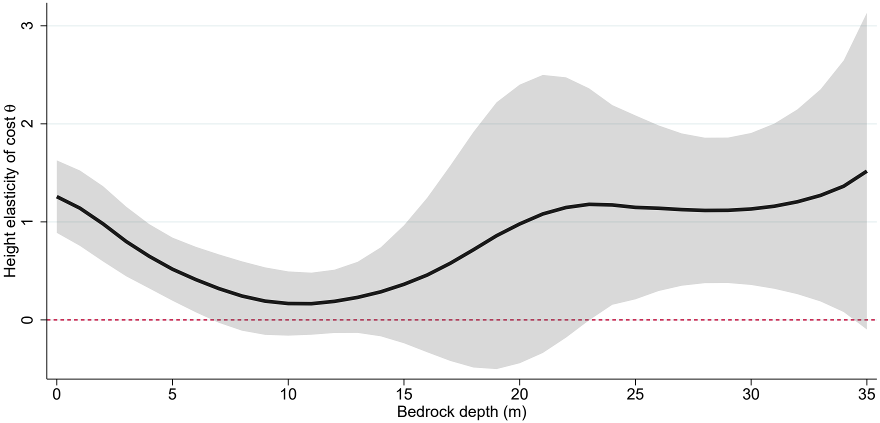
- 1,033 tall buildings with construction cost (206 cities in 55 countries)
- Log cost per sq ft residualized for city FE and country-decade FE



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%).

Marginal Cost Minimized at Depth of 10-15 m

- 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

Construction Conditional on Bedrock Depth

- Conditional on bedrock depth, initially larger cities (as of 1975) have experienced greater 1975-2015 growth in heights
- However, the strength of the relationship between city size and height growth should depend on bedrock depth in the city

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- However, the strength of the relationship between city size and height growth should depend on bedrock depth in the city
- For mean bedrock in each 5 meter depth range b, estimate construction 1975-2015 in 12,869 cities a conditional on 179 country c FE:

$$\text{CONST}_{acb} = \gamma_b \text{LOG POP 75}_{acb} + \delta \text{LOG POP 75}_{acb} + \rho_b + \kappa_c + \mu_{acb}$$

CONST_{acb} is the growth rate in num of tall buildings or in aggregate heights

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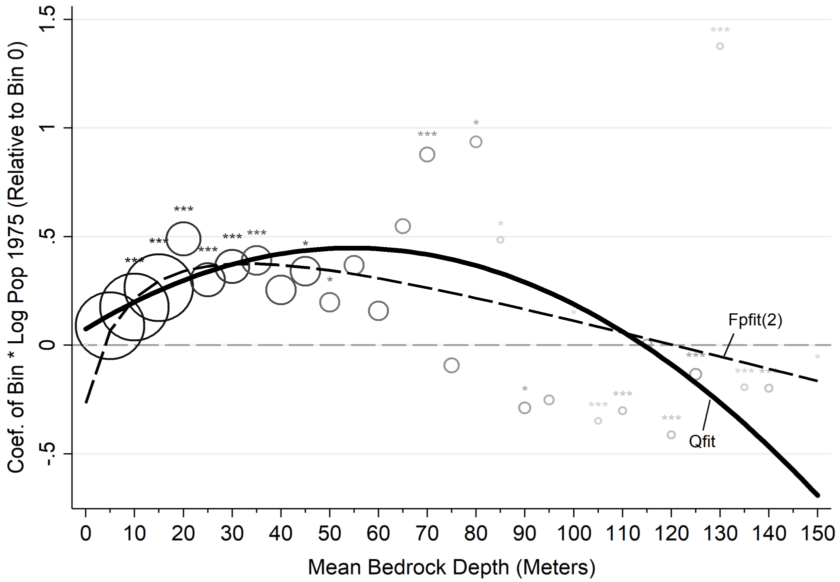
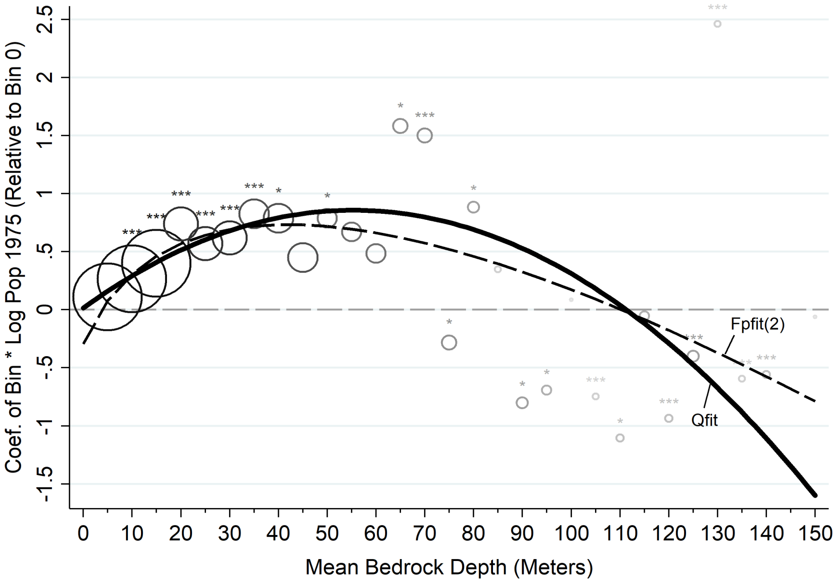
- Consistent with engineering discussion above, we find that estimates of γ_b are highest for the intermediate range of bedrock depth

Elasticities of Tall Building Construction 1975-2015 wrt 1975 City Population by Bedrock Depth



Elasticities of Tall Building Height Growth 1975-2015 wrt 1975 City Population by Bedrock Depth



An IV Strategy for City Height Growth

- Data generation process for height at the city (a) level (country c):

$$\Delta\text{LOG HEIGHTS 75-15}_{ac} = g(\text{MEAN BEDROCK DEPTH}_{ac}, \text{POP 75}_{ac}) + f_1(\text{MEAN BEDROCK DEPTH}_{ac}) + f_2(\text{POP 75}_{ac}) + \kappa_c + \mu_{ac}$$

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- Identifying variation has a diff-in-diff flavor: intermediate vs. extreme (too shallow or too deep) bedrock AND high vs. low initial pop (1975)
- A valid IV must plausibly hold trends in city demand factors constant:
  - Time-invariant city effects captured by first difference
  - As larger cities have different trends in demand for height than smaller cities, we must control for 1975 city population
  - To allow for the possibility that cities with different bedrock depths are on different trends, we must control for bedrock depth

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]
$(\text{Bedrock Depth})^2$		0.0000	0.0021**
		[0.0000]	[0.0009]
Bedrock Depth			0.0276***
X ln Pop 1975			[0.0054]
$(\text{Bedrock Depth})^2$			-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 x intermediate bedrock.

IV Regresssion Specification

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

$$\Delta \text{LOG Y}_{ac75-15} = \beta \ \Delta \text{LOG HEIGHTS}_{ac75-15} + \alpha_1 \text{BEDROCK DEPTH}_{ac} + \alpha_2 (\text{BEDROCK DEPTH}_{ac})^2 + \alpha_3 \text{LOG POP}_{ac75} + \kappa_c + \mu_{ac}$$

- Outcomes are 1975-2015 city level growth rates of
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- First-differences capture city effects. We also add country FE.

- Instrument for $\Delta \text{LOG HEIGHTS}_{ac}$ with a quadratic in city level mean bedrock depth interacted with 1975 log city population
  - Similar results when instrument uses alternative functional forms

Main IV Results (1975-2015)

	Δln Pop	Δln Built Area	Δln Urban Area	Δln Pop Dens
Δ ln Height	0.12***	-0.17***	-0.15**	0.29***
	[0.03]	[0.04]	[0.06]	[0.05]
ln Pop 1975	-0.12***	0.24***	-0.68***	-0.37***
	[0.03]	[0.03]	[0.06]	[0.04]
Bedrock Depth	0.00***	0.00***	0.02***	-0.00*
	[0.00]	[0.00]	[0.00]	[0.00]
(Bedrock Depth)^2	-0.00	-0.00**	-0.00***	0.00
	[0.00]	[0.00]	[0.00]	[0.00]

N = 12,877 observations. Country FE included. First stage F-statistic = 28.4.

- Doubling heights increases city pop by 12%, decreases city built area by 17% (urban area: 15%), increases city pop density by 29% (relative).
- Using growth in (not top-coded) radiance calibrated lights 1990-2015 yields similar results as pop (+15%; lights per pop: +6%, n.s.)
- OLS more muted. Likely due to measurement error, not OVB or LATE.

Robustness Checks for g(Bedrock Depth, Pop 1975) IVs

- **Identifying assumption:** IVs uncorrelated with city level tall building demand growth conditional on f_1(bedrock), f_2(pop 1975), FE

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- **Results hold** if we restrict the sample to cities with a mean bedrock depth below 25th pctile in the data (6 m $\approx$ 20 feet):
  - Topsoil up to 0.25 m; Subsoil up to 0.9 m; Root systems up to 2 m
  - Utility lines typically buried max 1-2 m deep
  - Subgrade (formation level) underneath highways never as deep

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  - Utility lines typically buried max 1-2 m deep
  - Subgrade (formation level) underneath highways never as deep
  - Sometimes deep subway stations as underground bunkers (we drop)
- **Results hold** with (i) 1st or 2nd level admin division FE (China: provinces or prefectures); (ii) physical & econ. geography ctrls*; (iii) other cut-offs (100m); (iv) Conley SEs (500km); (v) low urb rates '75

* Coast, lakes, altitude, ruggedness, ag. suit., temperatures, market access, subways

Heterogeneity (IV) Analysis

- Split sample by ...
  - Country income and region of the world
  - Fraction of 2015 tall building heights that are in residential buildings

    More residential towers countries (Brazil, India and South Korea $\approx$ 90%)

    More office towers countries (Egypt, Pakistan and U.S. $\approx$ 50%)

    Captures preferences and land-use regulations for residential towers
  - By initial city size and focusing on developing economies

    Estimate locally weighted IV regressions using a Gaussian kernel in 1975 ln city population for "Asia w/o MENA" and "others"

Heterogeneity in Estimates - By Region

Table 4: IV Results by Region, 1975-2015

	All Developing	Asia xMENA	Others	All Developed	USA, Canada	Others
			Panel A: Δ ln Pop			
Δ ln Height	0.13***	0.17***	0.15**	-0.02	0.30**	0.01
	[0.03]	[0.03]	[0.07]	[0.03]	[0.12]	[0.02]
			Panel B: Δ ln Built Area			
Δ ln Height	-0.16***	-0.20***	-0.26***	-0.04	-0.67*	-0.04
	[0.04]	[0.04]	[0.09]	[0.03]	[0.35]	[0.03]
Country FE	Y	Y	Y	Y	Y	Y
Observations	11,257	6,990	4,267	1,592	372	1,268
1st Stage F	22.84	20.92	7.881	14.28	5.771	13.64

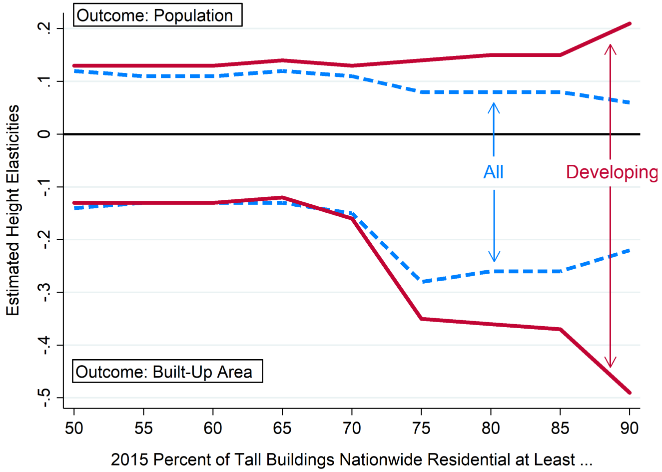
Notes: Each entry is from a separate IV regression using data from cities in world regions indicated in column headers.

Effects primarily driven by cities in developing economies (87% 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)

$\rightarrow$ We will focus most of our policy analysis on developing economies.

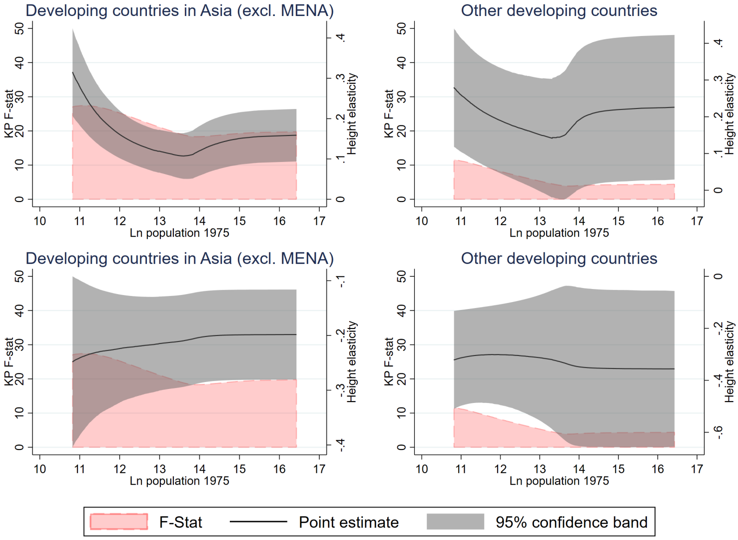
Results by Country Tall Building Residential Share



Developing economies with higher residential shares in tall buildings have greater population *and* land savings responses to height.

Strong response for area (vertical housing and suburbs clear substitutes)

Locally Weighted Regression Results by Initial City Pop.

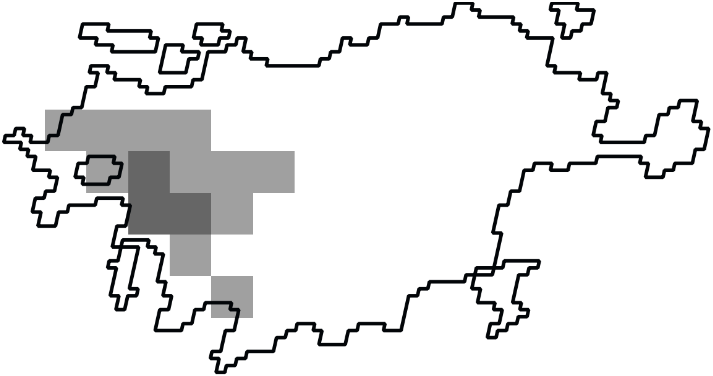


Top panel: U-shaped pop. effects, stronger for smaller cities (in pp terms).

Bottom panel: Built area effects vary less wrt initial city pop. sizes.

Land-Use Changes Inside 2015 Urbanized Boundaries

- We investigate whether land-use changes inside ...
  - Has agricultural suitability
  - Is tree canopy or vegetation (cropland + (sub)urban vegetation)
  - Is cropland or (sub)urban vegetation



Grey pixels: Urban/desert change (sprawl) 1975-2015 in São Paulo

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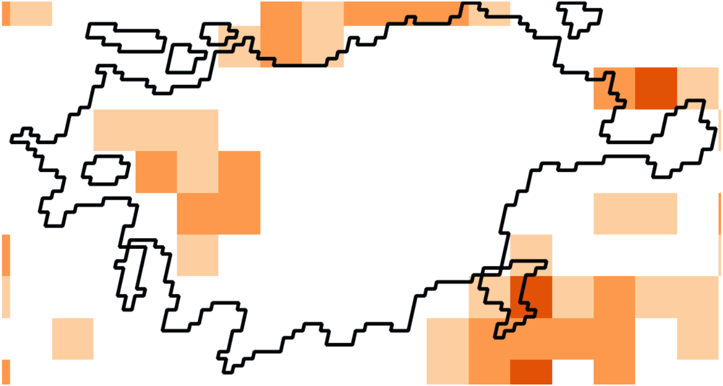

Orange pixels: Vegetation (cropland + urban veg.) loss 1975-2015 in São Paulo

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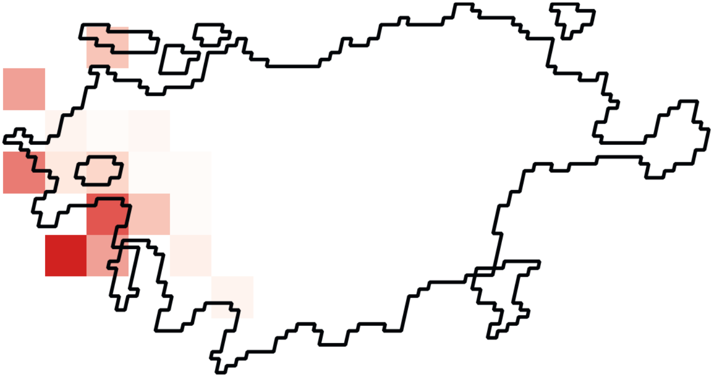


Red pixels: Tree canopy loss (deforestation) 1975-2015 in São Paulo

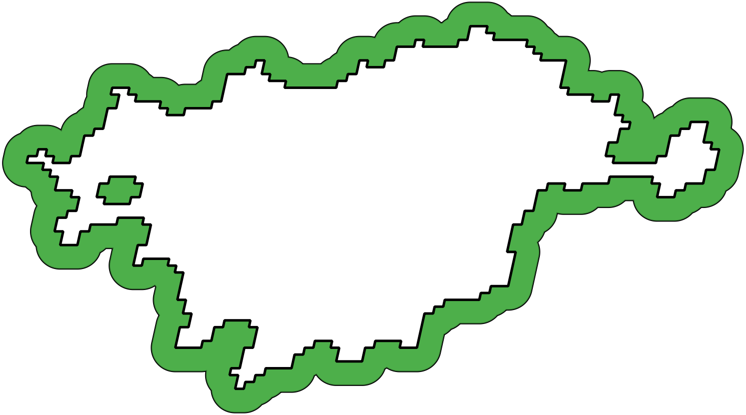
Table 5: Land-Use Changes Inside 2015 Urbanized Boundaries

Time Period	1975-2015	(2)-(4) 1982 - 2015			(5)-(7) 2000 - 2015		
Weight	Agric Suit	None			None		
Dep. Var.: Δ Log ... Area	Built	Urbanized	Tree Cover	Short Veg.	Short Veg.	Cropland	Urban Veg.
	(1)	(2)	(3)	(4)	(5)	(6)	(7)
Panel A: All Economies							
Avg Frac of Area, Base Year	0.56	0.17	0.09	0.72	0.73	0.18	0.55
Coeff. on Δ ln Height	-0.16***	0.16***	-0.22**	-0.02**	-0.07***	-0.07*	-0.06***
	[0.04]	[0.03]	[0.03]	[0.01]	[0.03]	[0.04]	[0.01]
Impact on Frac of Total	-0.090	0.027	-0.019	-0.014	-0.051	-0.013	-0.033
Panel B: Developing Economies							
Avg Frac of Area, Base Year	0.57	0.18	0.08	0.72	0.73	0.25	0.48
Coeff. on Δ ln Height	-0.14***	0.21***	-0.24***	-0.02**	-0.08***	-0.05	-0.07***
	[0.04]	[0.03]	[0.04]	[0.01]	[0.03]	[0.04]	[0.02]
Impact on Frac of Total	-0.080	0.038	-0.019	-0.014	-0.058	-0.013	-0.034
Country FE	Y	Y	Y	Y	Y	Y	Y

(1) Weights = % city land suitable for agriculture. Heights not disproportionately saving bad, or good, land. (2)-(4) Heights promote infill urbanization and land conversion from non-urban to urban use. (5)-(7) Heights reduce cropland and (sub)urban vegetation.

Land Savings Outside 2015 Urbanized Boundaries

- We investigate whether land-use *outside* ...
  - Is tree canopy or vegetation
  - Issue: We do not know the counterfactual urbanized boundary
  - Use estimated height elasticity of land area to predict land expansion



Prediction for São Paulo (assumption: spatially uniform land expansion)

Impacts of 1975-2015 Construction

City Pop. (2015)	Number of Cities	1975-2015 Δ Height (km)	Share of Height Δ	% of Pop Accomm	% of Area Saved	% Tree Cover	% Other Veg	Other Nonveg
Panel A: Asian Cities, except Middle East								
< 162,755	5837	73	0.03	1	1	8	73	19
to 442,413	1282	96	0.03	6	6	10	72	14
to 1,202,604	237	233	0.08	18	15	6	72	22
to 3,269,017	87	865	0.30	75	32	11	76	13
to 8,886,111	16	1,119	0.39	66	39	11	73	15
> 8,886,111	5	471	0.16	59	38	10	77	13
All	7,464	2,855	-	23	17	10	75	15
Panel B: Cities in Other Developing Regions								
< 162,755	3559	39	0.03	2	5	14	78	8
to 442,413	379	138	0.12	16	15	15	75	10
to 1,202,604	90	210	0.18	32	33	18	68	14
to 3,269,017	31	292	0.26	58	35	11	67	22
to 8,886,111	5	55	0.05	39	37	21	58	21
> 8,886,111	3	407	0.36	42	39	18	66	16
All	4,067	1,141	-	18	21	16	68	16

Notes: Estimates in each panel are based on separate sets of locally weighted regressions of Δ ln Pop or Δ ln built area on the change in log heights. Estimated elasticities for each city are applied to the 1975-2015 height growth in each city to determine the associated predicted city-specific population accommodated and built area saved.

Absent construction, 1975-2015 aggregate urban pop change would be 23-18% smaller and aggregate built area change would be 17-21% larger in developing economies

Source of Land Savings

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10-16% from tree cover, 75-68% from other vegetation, 15-16% from non-veg. (desert)

Monocentric City Model - Conceptual Framework

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- **Residents:** preferences over floorspace (housing) and an outside good; amenity depends on vertical distance (views) and horizontal distance (commuting); migration elasticity to the city.
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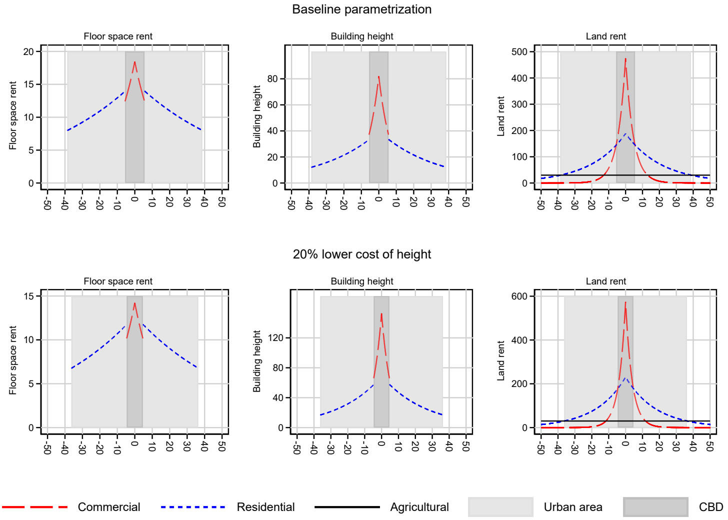
  - *Imperfectly open* city which nests *closed-city* and *open-city* cases
- **Construction:** zero profits; marginal cost increasing in building height
- **Production:** uses labor and floorspace (offices) as inputs; sector also benefits from views (prod. signalling) and agglomeration economies
- **Equilibrium:** land market clears (highest bidder); labor market clears

Table 1: Parameter values

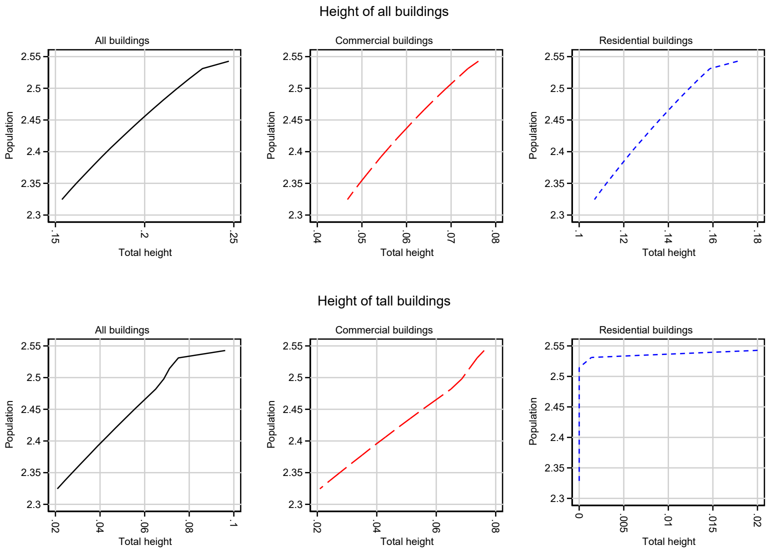
	Parameter	Value	Further reading
$1-\alpha^C$	Share of floor space at inputs	0.15	Lucas and Rossi-Hansberg (2002)
$1-\alpha^R$	Share of floor space at consumption	0.33	Combes et al. (2019)
β	Agglomeration elasticity of production amenity	0.03	Combes and Gobillon (2015)
θ^C	Commercial height elasticity 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)
ζ	Migration elasticity	2	Caliendo et al. (2019)

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 **??**). We set the following scale parameters arbitrarily to to generate a plausible land use pattern: $\bar{a}^C = 2, \bar{a}^R = 1, \tilde{c}^C = 1.4, \tilde{c}^R = 1.4, r^a = 30, \widetilde{U} = 1$. There are no binding height limits in the baseline parametrization ($\bar{S}^C = \bar{S}^R = \infty$).

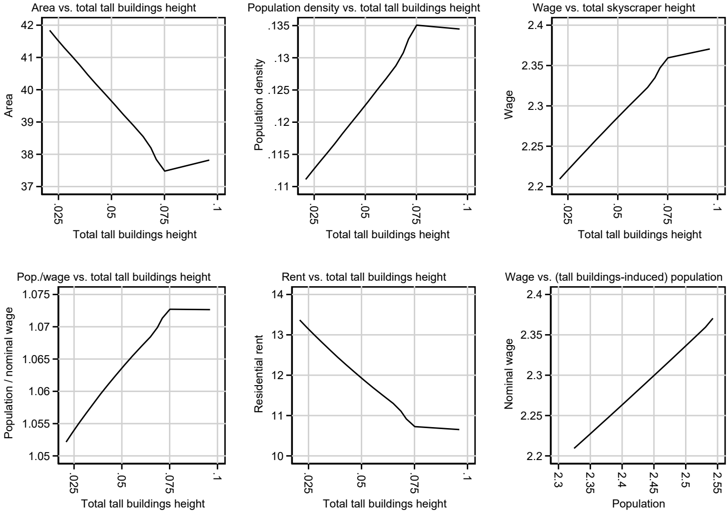
- We solve the model using a numerical procedure.
  - Implied housing supply price ela. = 2.6 (≈ Topel & Rosen '88, Saiz '10)
- Comparative statics exercises in which we reduce the cost of height.
- We do not yet incorporate the estimated (causal) elasticities



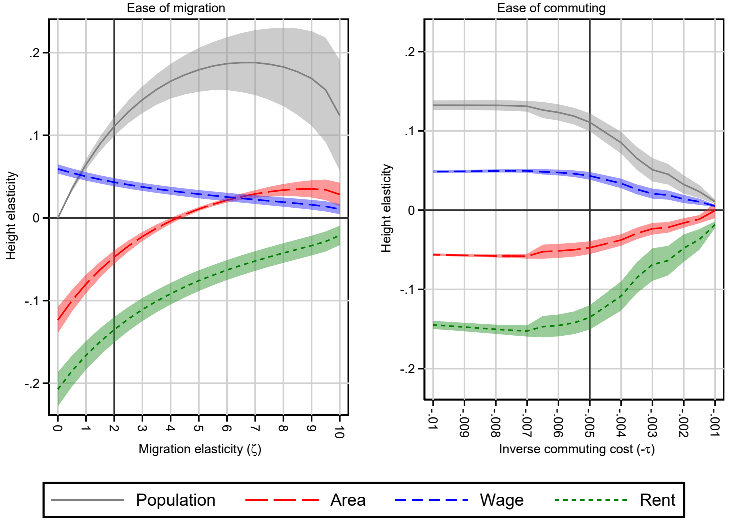
Reducing cost of height by 20% (= *tall building supply shock*). Developers: More profitable to build taller. Reduction in floor space prices. Workers attracted from hinterland. Migration frictions: Floor space prices and area decrease.



Effect of reducing cost of height → increasing heights (for *all* vs. *tall* buildings): larger city pop. (tall residential buildings only appear after some pop threshold).



Mechanisms: (i) lower area due to migration frictions (if open city, it increases); (ii) avg residential rent decreases; (iii) wage increases due to office space & agglomeration economies (as a result, positive relation btw wage and pop).



Positive effects of height on pop & area increase with migration elasticity (ease of migration). Height effects muted as lower commuting costs.

We know causal height elasticities of pop. and area. Will allow us to back out the migration elasticity and commuting cost parameters for different world regions.

Results of Welfare Counterfactuals

- **First exercise:**

  → Compute aggregate effects of height limit of 15 floors vs. no limit

  - Relative to this height limit, market allocations increase worker welfare by 3.3% and total welfare by 1.5% (as landlords lose overall).
  - Working on incorporating city-level measure of land-use regulations (height restrictions) from Barr & Jedwab 2023 (*REE*).

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- **Second exercise:**

  → Compute aggregate effects of removing all existing skyscrapers

  - Reduces worker welfare by 1% and overall welfare by 0.5% (less since landlords capture the resulting increase in property prices).
  - Working on quantifying the effects of technological progress = reduction in cost of height since 19th century (skyscraper revolution).

  → Only 1/3 of welfare potential of tall buildings realized globally.

Conclusions

- The Skyscraper Revolution (SR) has fundamentally changed the nature of cities around the world, especially developing economies.
- Estimated elasticities of city population of 0.12, built up area of -0.17 and city population density of 0.29 with respect to city height.
- Implication is that skyscraper construction has accommodated a large share of urbanization and facilitated large land savings.
- Land savings largest for short vegetation/cropland, then forested land.
- Calibrated model indicates total potential welfare gain of about 1.5 percent, of which about one-third has been realized.

  → SR: economic growth, land savings, and less inequality?