Don't Look Up?

Durable Skyscrapers and Future Climate Change

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(Very) Preliminary Project

I thank the World Bank for funding the project. The findings, interpretations and conclusions expressed in this paper are entirely those of the authors. They do not necessarily represent the views of the World Bank and its affiliated organizations, or those of the Executive Directors of the World Bank or the government they represent.

Motivation

- **Gulf cities:** Where the world has built the most in the recent past.
- But questions about future livability of these cities ($> 60^\circ$C $= 140^\circ$F), hence their global competitiveness and future economic development.
- Why is it an issue? To adapt to climate change (CC), humans can move (migration) and capital can also "move" (or depreciates).
- BUT (very expensive) tall buildings depreciate very slowly.
- Global dynamic spatial misallocation for durable skyscrapers that are very expensive AND "built to last"?

What I Do

- Use novel data to investigate whether tall buildings being built “away” from *future bad locations* (FBLs) in terms of future extreme heat.

  Both within-country (viewpoint of domestic dynamic social planners) and globally (viewpoint of a global dynamic social planner).

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  Emporis database on location, height, and year of construction of nearly all tall buildings (buildings $\geq$ 55m) in the world.

- Both globally and within countries, tallest, and most durable, buildings not built away from FBLs. Same post-Kyoto '97, Doha '12, Paris '15

- Less democratic countries build more durable skyscrapers in FBLs.

Literature

1. Global consequences of clim chg [we focus on (very) durable real estate]

   Spatial-dynamic models: Desmet & Rossi-Hansberg '15, Conte et al '20, Desmet et al '21. Costs = f(depreciation of real estate K): Bunten & Kahn '17

2. Clim chg and cities [we focus on future temperatures & real estate]

   Clim chg: Barrios et al '06, Henderson et al '17, '22, World Bank '22. Coastal flooding: Kocornik-Mina et al '20, Desmet et al '21, Lin et al '21

3. Economics of skyscrapers [we focus on the role of (future) clim chg]

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

Sample & Data

- Sample: 12,877 (50K+) agglomerations* today (UCs from GHS**)

  Full period: 1910-2020. Main period of study: 1975-2020.

  From GHS, city pop & city land area 1975, 1990, 2000, 2015

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  - Full period: 1910-2020. Main period of study: 1975-2020.
  - From GHS, city pop & city land area 1975, 1990, 2000, 2015
- Future climate change for each city:
  - Source: *Climate Change Knowledge Portal* of the World Bank
  - CMIP6 projections (IPCC, 2021), resolution: $1^\circ \times 1^\circ$ ($\approx$ 100km x 100km)
  - Temperatures 1995-2014, 2020-39, 2040-59, 2060-79, 2080-99
  - Pessimistic scenario (RCP 8.5) = current scenario (Schwalm et al '20)

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  Pessimistic scenario (RCP 8.5) = current scenario (Schwalm et al '20)

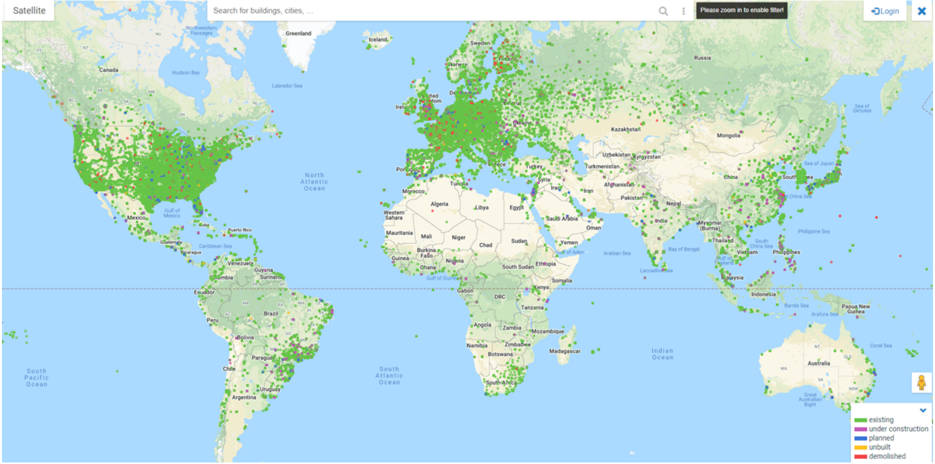
- Stocks of tall buildings for each city in each year:

  Source: *Emporis* (information provided by industry)

  Location, height ($\geq$ 55 meters $\approx$ 14 floors) & year of construction

* Urban centres = commuting zones. New York UC includes Newark; Jersey City, etc.

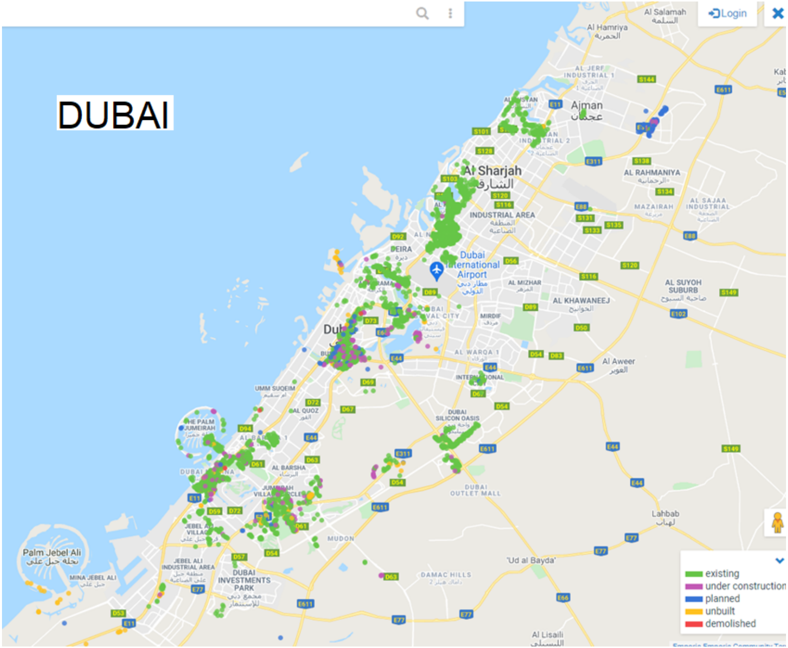
** GHS: *Global Human Settlements - Urban Centre Database* (GHS-UCDB)



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

Esch, Deininger, Jedwab & Palacios Lopez 2022: satellite (SAR) + Emporis
$\rightarrow$ tall buildings $\approx$ 8% of global total city volume! More in selected cities:

Hong Kong (50%), Seoul (41%), Singapore (28%), Mumbai (27%), Moscow (24%), Dubai (22%), Kuala Lumpur (20%), São Paulo (20%), Hanoi (19%), New York (12%).


DUBAI
Login
Al Sharjah
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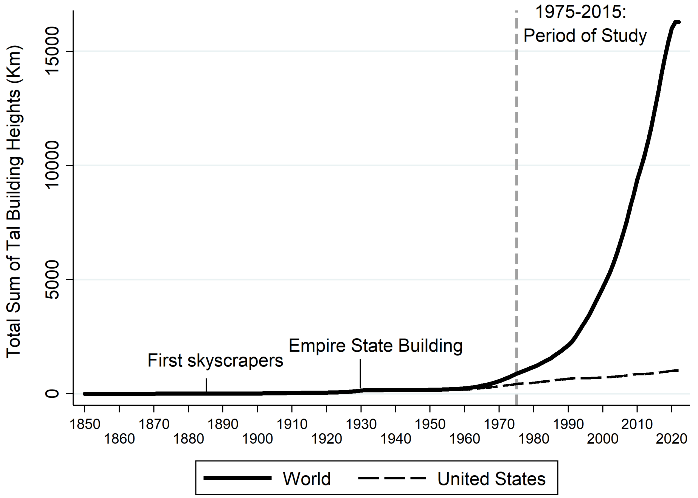
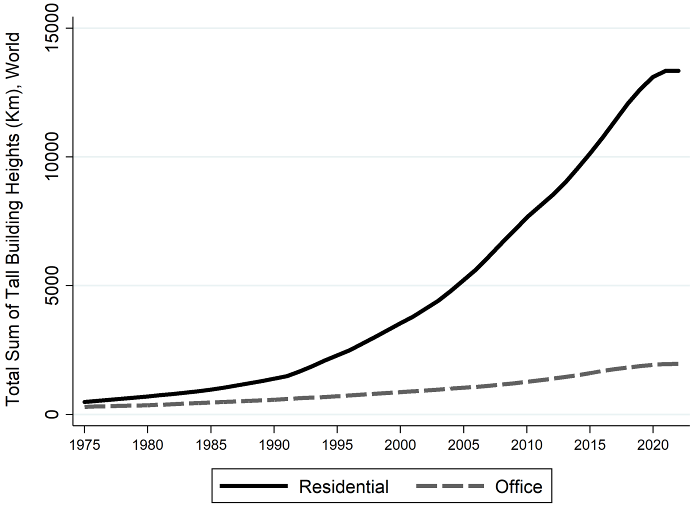
DEIRA
AL RAHMANIYA
INDUSTRIAL AREA
AL KHAWANEEJ
AL WARQA 1
DUBAI SILICON OASIS
AL QUOZ
AL BARSHA
UMM SUQEIM
DUBAI OUTLET MALL
MUDON
DAMAC HILLS
Palm Jebel Ali
MINA JEBEL ALI
JEBEL ALI INDUSTRIAL AREA
DUBAI INVESTMENTS PARK
Al Aweer
Lahbab
Al Lisaili
existing
under construction
planned
unbuilt
demolished

The Global Stock of Tall Buildings



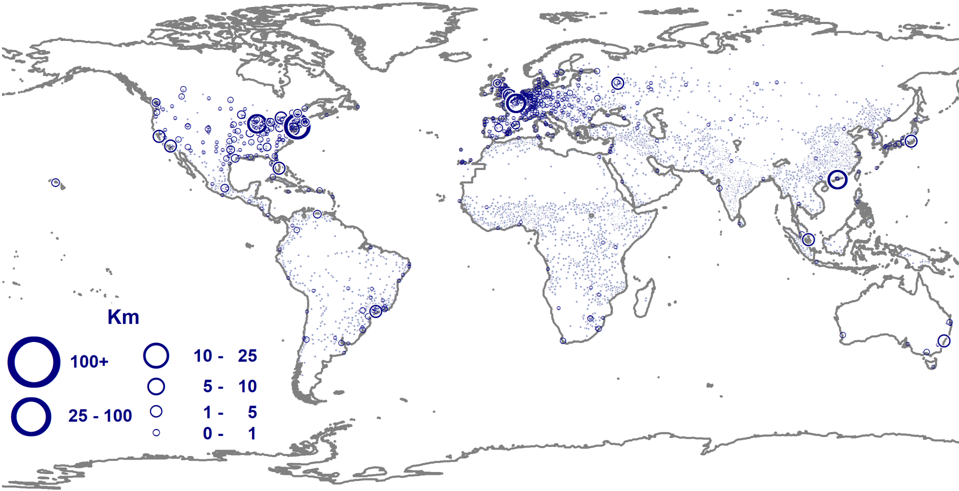
Includes all buildings $\geq$ 55 meters, $\approx$ 14 floors. 1975-2015: +11,500 km $\approx$ 26K Empire State Buildings $\approx$ 3x Euclidean distance between NYC and LA!

Most Recent Tall Building Construction is Residential



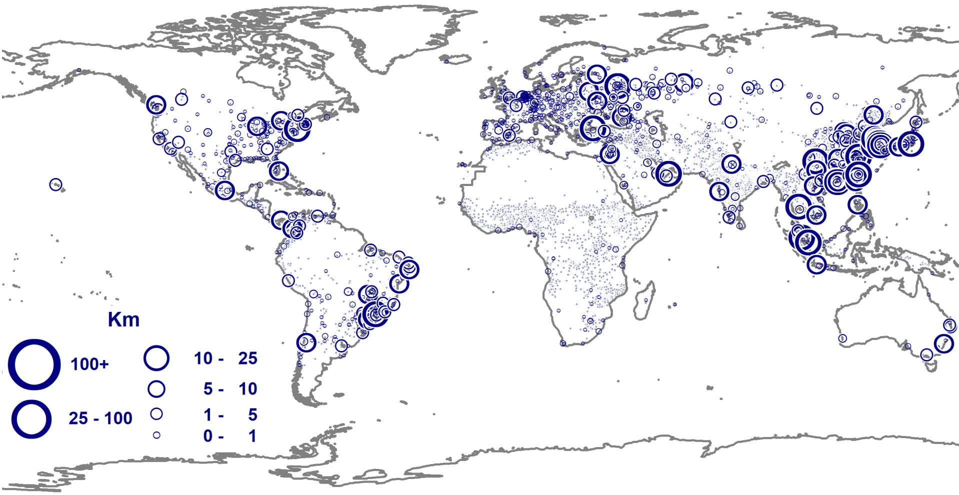
World of residential towers: Increased 7x more for residential buildings (typically in the 55-100 m range) than for commercial buildings (100 m+).

The Stock of Skyscraper Heights in 1975



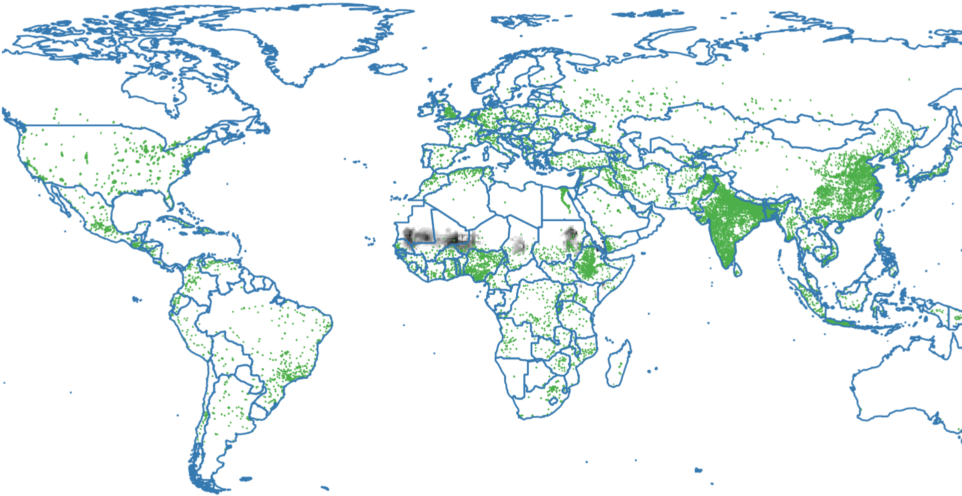
Historically, global skyline dominated by North America & Western Europe

The Flow of Skyscraper Heights 1975-2015



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

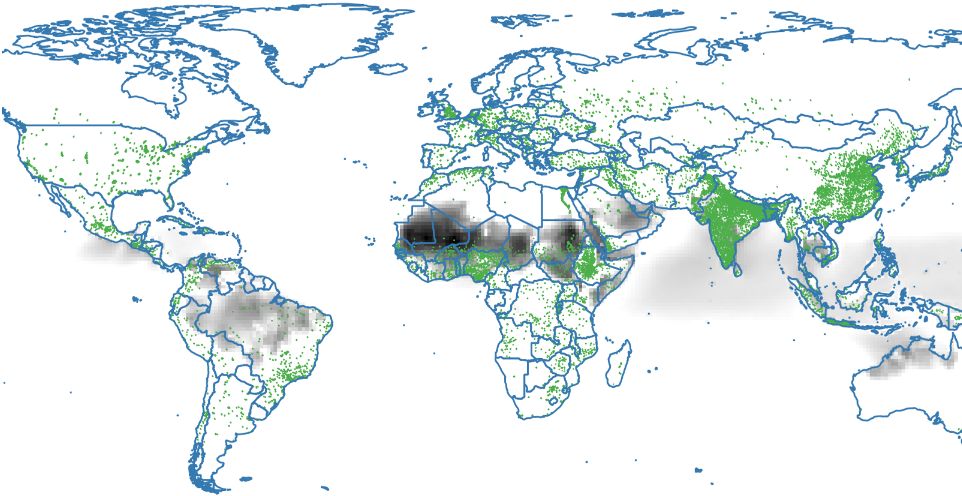
Hottest Places on Earth Today (1995-2014)



The Sahel ranks as the hottest place on earth (see the dark areas).

The 12,877 urban agglomerations used in the analysis are shown in green.

Hottest Places on Earth in 50 Years (2060-2079)



Sahel-like conditions in many regions. Fewer durable skyscrapers there?

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Possible Effects of Future Extreme Temperatures

- Productivity:
  - Agriculture and other outdoor activities (construction, tourism, etc.)
  - Also manufacturing (machines, worker productivity) and services less.
  - Tech breakdowns: electrical grid, AC units*, machinery, etc.
- Prices:
  - Food, housing, utility costs, and commuting costs
- Quality-of-life amenities:

  Mortality, health, and "living in a mall" part/most of the year
- Connectivity:
  - Planes can operate at temperatures up to 53C (127F)

* Most AC systems designed to function with outside temps of 100F or less. When higher than 100 degrees Fahrenheit, AC system can begin to malfunction or fail.

Conceptual Framework

- Optimality when durable skyscrapers and climate change (CC)?
  - Option value costs of durable structures in *future bad locations* (FBLs)
  - *Developers & buyers*: limited horizon, as long as not last one to sell
  - *Government*: somewhat less limited horizon, but political incentives

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  - *Domestic social planner*: hedge domestic *durable* construction against CC

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  - *Global social planner*: hedge global *durable* construction against CC

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  - *Domestic social planner*: hedge domestic *durable* construction against CC
  - *Global social planner*: hedge global *durable* construction against CC
- Tall buildings (55m+), skyscrapers (100m+) & supertall towers (300m+):
  - Very durable (few demolitions in our data; lifespan > one century)
  - Very expensive (real estate = world's largest asset class)
  - Global competition: skyscrapers owned by international real estate funds, occupied by internationally mobile firms, workers, and residents
  - But can help adapt to CC (work and live in same structure to avoid heat)

Econometric Framework

- Use our global tall building construction data to test:
  - if the world is *over-building* in future bad locations (FBLs) (caveat: since we do not future tech, impossible to know if/how much over-building).
  - if global patterns change as more information is provided about clim chg, costs, and location-specific hazard rates (e.g., Kyoto '97)

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- For 12,877 cities a in 182 countries c & years t (1915, 1920 ... 2020):

$$\text{LOG HEIGHTS}_{act} = a + b_t * \text{FBL INDEX}_{ac} + \gamma_a + \kappa_{ct} + \mu_{act}$$

LOG HEIGHTS log of (sum of tall building heights + 1)

FBL INDEX of how early transitions to unsustainable temperatures

City FE (γ_a), country-year FE (κ_{ct}), SEs clust. at city level

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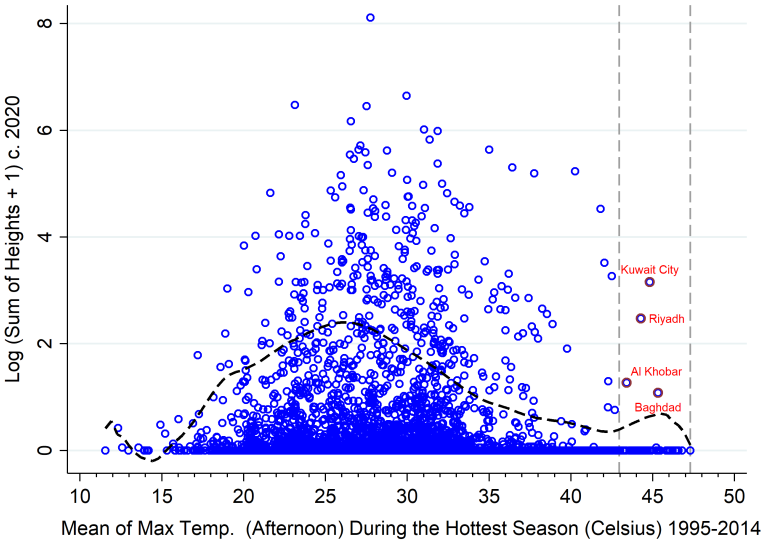
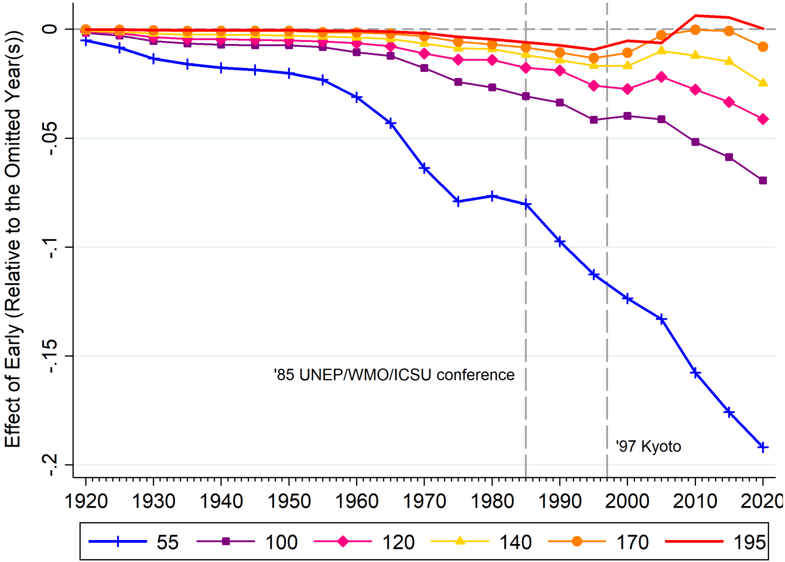
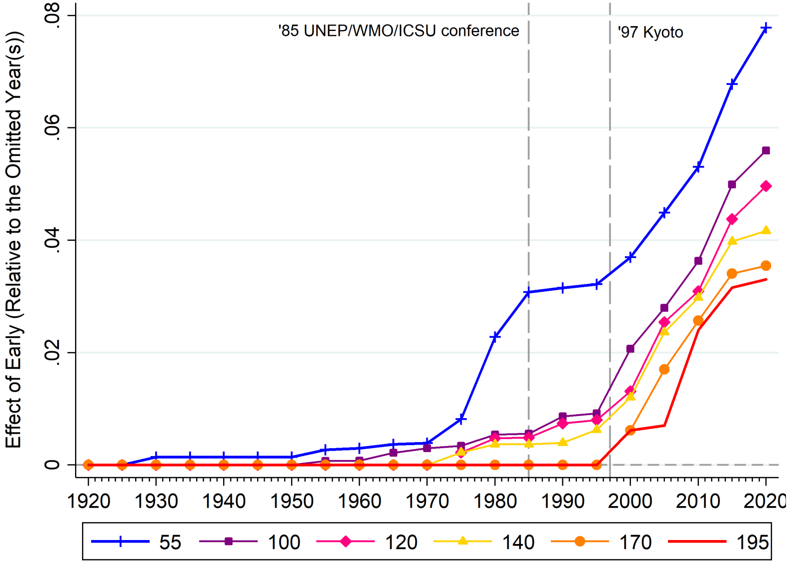
If focus on *global misallocation*, replace country-year FE by year FE



Inverted U-shape. FBL Index: 5, 4, 3, 2, 1 and 0 if the city passes unsustainable threshold (99p, max) in 1995-2014, in 2020-39, in 2040-59, in 2060-79, in 2080-99, and after 2100.



Globally (year FE instead of country-year FE), world building away from FBLs (55 = buildings $\geq$ 55m). BUT not as much as for *most durable skyscrapers* (195, 170, 140)



Domestically (with country-year FE), very tall (durable) buildings increasingly located in FBLs. Invention of the AC (1930s) + rise of the Sunbelt. But heat is nice, until it is not.

Role of Information Updating

- **Kyoto '97**: info updating on CC, costs, and location-specific hazard rates → durable skyscrapers moving away from FBLs?
- 12,877 world cities a and years '75 '90 '00 '15 (N = 51,508):

$$\text{LHEIGHTS}_{act} = a + b\,\text{FBL-I}_{ac} \times 1(t > 1997) + \gamma_a + \kappa_{ct} + \mu_{act}$$

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FBL INDEX interacted with post-Kyoto (1997) dummy

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Caveat: If Kyoto reduces CC, FBL-ness less relevant.

Dependent Variable:	Log Pop. t	Log Built t	Columns (3)-(8): Log Sum of Heights in Year t 55m+	100m+	120m+	140m+	170m+	195m+
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
1. FBL-I_a*$\mathbb{1}(t > 1997)$	0.04***	0.04***	-0.06***	-0.02**	-0.01	-0.00	0.00	0.01
	[0.00]	[0.00]	[0.01]	[0.01]	[0.01]	[0.01]	[0.01]	[0.01]
City FE, Year FE	Y	Y	Y	Y	Y	Y	Y	Y
2. FBL-I_a*$\mathbb{1}(t > 1997)$	0.14***	0.17***	0.03***	0.03***	0.02***	0.02***	0.02***	0.02**
	[0.00]	[0.00]	[0.01]	[0.01]	[0.01]	[0.01]	[0.01]	[0.01]
City FE, Cntry-Year FE	Y	Y	Y	Y	Y	Y	Y	Y
Observations	51,508	51,508	51,508	51,508	51,508	51,508	51,508	51,508

Notes: 12,877 cities x 4 years (1975, 1990, 2000, 2015) = 51,508 obs. SEs clustered at the city level. * p<0.10, ** p<0.05, *** p<0.01.

Durable skyscrapers *not moving away* from FBLs post-Kyoto. Caveat: We do not control for skyscraper demand factors (but no need to if future heat becomes too extreme).

Dependent Variable:	(1)-(6) Log Sum of Heights in Year t					
	55m+	100m+	120m+	140m+	170m+	195m+
	(1)	(2)	(3)	(4)	(5)	(6)
1. FBL-I_a*$\mathbb{1}(t > 1997)$	-0.07***	-0.03***	-0.02**	-0.01	-0.00	0.00
	[0.01]	[0.01]	[0.01]	[0.01]	[0.01]	[0.01]
City FE, Year FE	Y	Y	Y	Y	Y	Y
Pop, Built Area Controls	Y	Y	Y	Y	Y	Y
2. FBL-I_a*$\mathbb{1}(t > 1997)$	-0.05***	-0.02**	-0.02**	-0.01	-0.00	0.00
	[0.01]	[0.01]	[0.01]	[0.01]	[0.01]	[0.01]
City FE, Country-Year FE	Y	Y	Y	Y	Y	Y
Pop, Built Area Controls	Y	Y	Y	Y	Y	Y
Observations	51,508	51,508	51,508	51,508	51,508	51,508

Notes: 12,877 cities x 4 years (1975, 1990, 2000, 2015) = 51,508 obs. *Pop, Built Area Controls*: The controls include log city

Controls for local tall building demand: log city pop t and log city built-up area t.

Dependent Variable:	(1)-(6) Log Sum of Heights in Year t					
	55m+	100m+	120m+	140m+	170m+	195m+
	(1)	(2)	(3)	(4)	(5)	(6)
1. FBL-I_a*$\mathbb{1}$(t > 1997)	-0.05***	-0.02**	-0.01*	-0.00	0.00	0.00
	[0.01]	[0.01]	[0.01]	[0.01]	[0.01]	[0.01]
City FE, Year FE	Y	Y	Y	Y	Y	Y
Pop, Built Controls & Lags	Y	Y	Y	Y	Y	Y
2. FBL-I_a*$\mathbb{1}$(t > 1997)	-0.06***	-0.02***	-0.02**	-0.01	-0.00	0.00
	[0.01]	[0.01]	[0.01]	[0.01]	[0.01]	[0.01]
City FE, Country-Year FE	Y	Y	Y	Y	Y	Y
Pop, Built Controls & Lags	Y	Y	Y	Y	Y	Y
Observations	38,631	38,631	38,631	38,631	38,631	38,631

Notes: 12,877 cities x 3 years (1990, 2000, 2015) = 38,631 obs. The controls include log city population and log city

More controls: log pop & log built-up area t, lags (t-1) of log pop, log built-up area & log heights. These also potentially control for the local state of the technology.

Role of Information Updating

- **Role of additional COP conferences?**
- 12,877 world cities a and every 5 years 1975-2025 (N = 141,647):

$$\text{LHEIGHTS}_{act} = a + b_1 \text{FBL-I}_{ac} \times 1(t >' 97) + b_2 \text{FBL-I}_{ac} \times 1(t >' 12)$$
$$+ b_3 \text{FBL-I}_{ac} \times 1(t >' 15) + \gamma_a + \kappa_{ct} + \mu_{act}.$$

LOG HEIGHTS log (heights + 1). 2025 recreated based on 2022 data

FBL INDEX x post-Kyoto ('97), Doha ('12), Paris ('15) dummies

City FE (γ_a), country-year FE (κ_{ct}), SEs clust. at city level

Controls for pre-trends in heights: two lags in log heights

If focus on global misallocation, replace country-year FE by year FE

Dependent Variable:	(1)-(6) Log Sum of Heights in Year t					
	55m+	100m+	120m+	140m+	170m+	195m+
	(1)	(2)	(3)	(4)	(5)	(6)
1. FBL-I_a*$\mathbb{1}(t > 1997)$ (Kyoto)	-0.01***	-0.00	0.00	0.00	0.01	0.01*
	[0.00]	[0.00]	[0.00]	[0.00]	[0.00]	[0.00]
FBL-I_a*$\mathbb{1}(t > 2012)$ (Doha)	-0.01	-0.00	-0.01	-0.00	-0.00	-0.01
	[0.01]	[0.01]	[0.01]	[0.01]	[0.00]	[0.00]
FBL-I_a*$\mathbb{1}(t > 2015)$ (Paris)	0.00	-0.00	-0.00	-0.00	-0.00	-0.00
	[0.00]	[0.01]	[0.01]	[0.01]	[0.00]	[0.00]
City FE, Year FE	Y	Y	Y	Y	Y	Y
Two Lags of Heights	Y	Y	Y	Y	Y	Y
2. FBL-I_a*$\mathbb{1}(t > 1997)$ (Kyoto)	0.00**	0.01**	0.01**	0.01**	0.01**	0.01**
	[0.00]	[0.00]	[0.00]	[0.00]	[0.00]	[0.00]
FBL-I_a*$\mathbb{1}(t > 2012)$ (Doha)	0.01**	0.01	0.01	0.00	0.00	0.00
	[0.00]	[0.01]	[0.01]	[0.00]	[0.00]	[0.00]
FBL-I_a*$\mathbb{1}(t > 2015)$ (Paris)	-0.01	-0.01	-0.01	-0.00	-0.00	-0.00
	[0.00]	[0.01]	[0.01]	[0.00]	[0.00]	[0.00]
City FE, Country-Year FE	Y	Y	Y	Y	Y	Y
Two Lags of Heights	Y	Y	Y	Y	Y	Y
Observations	141,647	141,647	141,647	141,647	141,647	141,647

Notes: 12,877 cities * 11 years (data every 5 years from 1975-2025) = 141,647 obs. The controls include log heights in

Countries and the World not building durable structures away from FBLs.

Robustness Checks

- Results generally hold if:
  - Max of mean max temp (afternoon) in hottest season 1995-2014 = 49C (120.2F) instead of the 99th percentile in the baseline = 43C (109.4F)
  - Mean max temperature throughout the year
  - Number of *extremely hot* days ($\geq$ 45C = 113.2F)
  - Number of *dangerous* days (heat index $\geq$ 39C).
  - More intermediate RCP scenarios.
  - "Planned" buildings: construction "expected to start in the future"
  - "Vision" buildings: tall buildings for which "a design was released without any expectation of being realized" [some may be eventually realized]

Dep. Var.:	Log Sum of Heights in Year t				
Type of Heights:	All (55m+)	Residential	Office	Hotel	Government
	(1)	(2)	(3)	(4)	(5)
1. FBL-I_a*$\mathbb{1}(t > 1997)$	-0.05***	-0.04***	-0.02**	-0.02***	-0.00
	[0.01]	[0.01]	[0.01]	[0.00]	[0.00]
City FE, Year FE	Y	Y	Y	Y	Y
Pop, Built Controls & Lags	Y	Y	Y	Y	Y
2. FBL-I_a*$\mathbb{1}(t > 1997)$	-0.06***	-0.05***	-0.02***	-0.02***	-0.00
	[0.01]	[0.01]	[0.01]	[0.00]	[0.00]
City FE, Country-Year FE	Y	Y	Y	Y	Y
Pop, Built Controls & Lags	Y	Y	Y	Y	Y
Observations	38,631	38,631	38,631	38,631	38,631

Notes: 12,877 cities x 3 years (1990, 2000, 2015) = 38,631 obs. SEs clustered at the city level. * p<0.10, ** p<0.05, *** p<0.01.

Considering *all* 55m+ buildings only, we had a negative, but small, effect. Not for gvt buildings, although could have expected gvts to be less myopic than private agents.

Table 8: ROBUSTNESS TO EXCLUDING GULF COUNTRIES, COUNTRY-YEAR FE

Dep. Var.:	Log 55m+ Heights t		Log 100m+ Heights t		Log 195m+ Heights t	
Countries:	All	No Gulf	All	No Gulf	All	No Gulf
	(1)	(2)	(3)	(4)	(5)	(6)
1. FBL-I_a*$\mathbb{1}$(t > 1997)	-0.06***	-0.08***	-0.02***	-0.05***	0.00	-0.02***
	[0.01]	[0.01]	[0.01]	[0.00]	[0.01]	[0.00]
City FE, Country-Year FE	Y	Y	Y	Y	Y	Y
Pop, Built Controls & Lags	Y	Y	Y	Y	Y	Y
Observations	38,631	38,157	38,631	38,157	38,631	38,157

Notes: 12,877 cities x 3 years (1990, 2000, 2015) = 38,631 obs. SEs clustered at the city level. * p<0.10, ** p<0.05, *** p<0.01.

40 countries have FBL cities.* Among 10 countries with highest (city) pop-weighted FBL index, 4 located in the Gulf. Coefs typically more negative for non-Gulf countries. However, coef 195m+ still less < 0 than coeff 55m+ (expected reverse due to durability)

* Large non-Gulf countries with FBL & non-FBL cities: Algeria, Brazil, Egypt, India, Iran, Jordan, Kazakhstan, Mexico, Morocco, Nigeria, Pakistan, Sudan, Turkey, the U.S., etc.

Dep. Var.:	Log Sum of Heights in Year t								
Heights:		55m+			100m+			195m+	
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
FBL-I_a*$\mathbb{1}(t > 1997)$	-0.06***	-0.12***	-0.12***	-0.02***	-0.08***	-0.09***	0.00	-0.02***	-0.03***
	[0.01]	[0.01]	[0.01]	[0.01]	[0.01]	[0.01]	[0.01]	[0.01]	[0.01]
x Non-Democratic 75-15		0.07***			0.07***			0.03***	
		[0.01]			[0.01]			[0.01]	
x Anocratic 75-15			0.06***			0.05***			0.01**
			[0.01]			[0.01]			[0.00]
x Autocratic 75-15			0.07***			0.08***			0.04***
			[0.01]			[0.01]			[0.01]
City FE, Country-Year FE	Y	Y	Y	Y	Y	Y	Y	Y	Y
Pop, Built Ctrls & Lags	Y	Y	Y	Y	Y	Y	Y	Y	Y
Observations	38,631	38,556	38,556	38,631	38,556	38,556	38,631	38,556	38,556

Notes: 12,877 cities x 3 years (1990, 2000, 2015) = 38,631 obs. A country is non-democratic if its mean polity V score during the period

Interaction with democracy variables (based on mean Polity V score 1975-2015). Less democratic countries build towards FBLs. Stronger for autocraties than for anocraties (imperfectly democratic). Democracy effect not just driven by the Gulf (not shown).

Dep. Var.:	Log Sum of Heights in Year t								
Heights:	55m+				100m+			195m+	
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
FBL-I_a * $\mathbb{1}(t > 1997)$	-0.06***	-0.10***	-0.10***	-0.02***	0.06	0.05	0.00	0.14**	0.13**
	[0.01]	[0.02]	[0.02]	[0.01]	[0.06]	[0.06]	[0.01]	[0.06]	[0.06]
x Developing Status 2020		-0.02			-0.15**			-0.17***	
		[0.02]			[0.06]			[0.06]	
x Upper-Middle Income			-0.02			-0.15**			-0.17***
			[0.02]			[0.06]			[0.06]
x Lower-Middle Income			-0.03			-0.15**			-0.17***
			[0.02]			[0.06]			[0.06]
x Low-Middle Income			-0.05**			-0.16**			-0.18***
			[0.02]			[0.06]			[0.06]
City FE, Country-Year FE	Y	Y	Y	Y	Y	Y	Y	Y	Y
Pop, Built Ctrls & Lags	Y	Y	Y	Y	Y	Y	Y	Y	Y
Ano-/Auto-cracy Ctrls	Y	Y	Y	Y	Y	Y	Y	Y	Y
Observations	38,631	38,556	38,556	38,631	38,556	38,556	38,631	38,556	38,556

Notes: 12,877 cities x 3 years (1990, 2000, 2015) = 38,631 obs. SEs clustered at the city level. * p<0.10, ** p<0.05, *** p<0.01.

Interaction with WB income status '20 (+ ctrls for interactions with democracy variables).
>0 effects in richer nations. Only developed economies with FBLs = Gulf and the U.S.
Two interpretations: (i) confident that tech will mitigate FBL-ness; (ii) political incentives.

Role of Political Incentives?

- Do Gulf nations have "developer autocrats"?
  - Interest as rulers to develop their country, to project prestige and power
  - Leaders are largest landowners and developers in their own country

    Their land values and dvt companies gain from construction boom
  - In long run, better to invest in *international non-FBLs* (e.g., London)?
- The U.S. is a "decentralized democracy"
  - FBLs: Las Vegas, cities in Arizona including Phoenix, etc.
  - Incumbent state politicians may have incentives to overdevelop FBLs.
  - In more centralized democracy, incentives to hedge whole urban system?