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Cities without Skylines: Worldwide Building-Height Gaps and Their Implications

Abstract

There is a large literature in the U.S. measuring the extent and stringency of land-use regulations in urban areas and how these regulations affect important outcomes such as housing prices and economic growth. This paper is the first to present an international measure of regulatory stringency by estimating what we call building-height gaps. Using a novel geospatialized data set on the year of construction and heights of tall buildings around the world, we compare the total height of a country's actual stock of tall buildings to what the total height would have been if building-height regulations were relatively less stringent, based on parameters from a benchmark set of countries. We find that these gaps are larger for richer countries and for residential buildings rather than for commercial buildings. The building-heights gaps correlate strongly with other measures of land-use regulation and international measures of housing prices, sprawl, congestion and pollution. Taken together, the results suggest that stringent building-height regulations around the world might be imposing relatively large welfare losses.

JEL-Codes: R300, R500, O180, O500.

Keywords: international buildings heights, tall buildings, skyscrapers, land use regulations, housing supply, housing prices, sprawl, congestion, pollution.

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1. Introduction

Today, the majority of the world's population lives in cities, and this global urbanized population will continue to grow over the rest of the century (UN-Habitat, 2020). Cities throughout the world must expand their stock of real estate in order to accommodate urban growth (Glaeser, 2011). But housing prices are growing more rapidly than incomes (Knoll et al., 2017), which may be partly caused by physical and regulatory barriers reducing housing supply (Glaeser and Gyourko, 2003; Glaeser, Gyourko and Saks, 2005, 2006; Saiz, 2010; Gyourko and Molloy, 2015). In particular, cities impose various land-use regulations (Glaeser and Ward, 2009; Gyourko, Saiz and Summers, 2008; Gyourko, Hartley and Krimmel, 2019). Such regulations not only have impacts today but may generate significant welfare effects well into the future (Glaeser and Gyourko, 2005, 2018; Hsieh and Moretti, 2019).[1] While the extent and impact of land-use regulations has been extensively studied for the U.S. (Ihlanfeldt, 2007; Saks, 2008; Jackson, 2018; Brueckner and Singh, 2020), there are no such studies for the whole world.

Using a novel data set on the year of construction and heights of tall buildings around the world, we compare the total height of a country's actual stock of tall buildings to what the total height would have been if building-height regulations were relatively less stringent, based on panel regression parameters from a benchmark set of countries.

We find that the world should have twice as many tall buildings (about 6,000 Empire State Buildings) as observed today. Building-height gaps are larger for richer countries and for residential buildings rather than for commercial buildings. The gaps correlate strongly with other measures of land-use regulation and, conditional on income, measures of housing prices, sprawl, congestion, and pollution.

Taken together, the results suggest that stringent building-height regulations around the world might be imposing large welfare losses. We contrast various explanations for why richer countries adopt such explanations and find correlations more consistent with countries preserving historical patrimonies than homevoters constraining construction.

[1] See Liu, Rosenthal and Strange (2018) for evidence on the effect of building heights on rents.

2. Conceptual Framework

In the "standard urban model" (SUM) (Brueckner, 1987), individuals value access to the city center, which leads to higher housing and land prices there. Faced with expensive land, developers construct taller buildings.

In the equilibrium of a closed city, building heights depend on population, income, commuting cost, and the agricultural rent for the land surrounding the city. To accommodate the greater demand from a larger population, the city builds "up". By increasing the cost of rural-to-urban land conversion, a higher agricultural rent generates taller buildings. A higher income causes decentralization as residents find the cheap suburbs more attractive for the bigger dwellings they prefer. This demand shift decreases heights near the center (high commuting costs have the opposite impacts). However, countries urbanize as they get richer, and this positive effect on heights offsets the negative height effect in the central city as incomes grow.

The SUM ignores amenities. By making city centers more desirable as income rises, amenities reverse the income-driven tendency toward decentralization, so that central heights rise. Moreover, if wealthier, larger cities have greater commuting costs due to congestion or because the opportunity cost of commuting time increases with wages, the price premium for central locations is higher, generating taller buildings there. Finally, high-country incomes are associated with the presence of service sector firms, which value being located in city centers, thus raising the demand for office space.

Given that tall buildings are long-lived, income and agricultural rent determine the *increment to the tall-building stock* through an effect on new construction. Finally, since the stock is measured for the entire country, we can divide the stock variable by total urban population. The dependent variable is the country's height-weighted stock of tall buildings per capita, or *urban height density*.

3. Data

Our sample comprises 158 countries decadally from 1950 to 2017.

CTBUH (2018) maintains an online database of all *tall buildings* in the world. The data have been "collected [...] for more than 40 years [...] The Council relies on its extensive member network [of academics, land developers, architectural firms, builders, city administrations, and banks] to maintain" the database. We extracted information on each building's height, year of construction and usage. The database mostly captures buildings above 80 meters (Appx. Section 1). Some countries have no such buildings. To avoid having their stock equal to 0 when using logs, we consider for each country 80m+ buildings and their 10 tallest buildings even when below 80m (N = 16,369).

United Nations (2018) gives urban population every 5 years from 1950 to 2020. Maddison (2008) shows per capita GDP for each country in 1950-2008 (PPP, constant international 1990$). We use World Bank (2018) data to reconstruct per capita GDP post-2008.

We estimate agricultural land rent by dividing agricultural GDP by total land area. FAO (2018) shows agricultural GDP shares from 1960 to 2017. For 1950, we use additional sources. We use total land area as the divisor instead of agricultural land area (FAO, 2018) because the latter area is missing before 1960. Furthermore, non-agricultural/non-urban land can be used for agricultural purposes or be converted into urban land.

Knowing total GDP and the agricultural GDP share, we reconstruct urban GDP (non-agricultural GDP). Urban per capita income is urban GDP divided by urban population.

Urban height density is the sum of the heights of the country's tall buildings in a given year divided by the urban population for that year.

We know the World Bank income group of each country (2017). From The Economist (2018), we know whether each country was democratic at any point in 2006-2017.

4. Background

The U.S. contained virtually all of world's tall buildings up to 1950. In recent decades, the tall-building stocks outside the U.S. have grown rapidly, by about 3,900 Empire State Buildings (Appx. Fig. 1(a)). Most tall buildings were commercial until 2000. After 2000, tall residential buildings have been built at a faster pace (Appx. Fig. 1(b)).

Figure 1 shows the strongly positive relationship between log urban height density and log national GDP per capita (2017). Countries above (below) the regression line have more (fewer) buildings than expected based on their income.

5. The Gaps

Table 1 shows panel regressions for the years 1950, 1960, 1970, 1980, 1990, 2000, 2010, and 2017 (henceforth, "2020"). The explanatory variables are those for which panel data are available: log per capita urban GDP (LUPCGDP), log agricultural land rent (LAGRENT), and the lag of the dependent variable, log urban height density (LUHTDENS). We include country and year fixed effects (standard errors clustered at the country level).

Column (1) of Table 1 uses 158 countries. The GDP coefficient is positive and significant, as is lagged height-density.

Column (2) restricts the sample to 73 countries with a positive residual in a 2017 regression that relates LUHTDENS to LUPCGDP and LAGRENT. These are *laissez-faire* countries where the building stock is higher than expected today given economic conditions. The GDP coefficient is now larger. The agricultural rent coefficent becomes significant.

Column (3) restricts the sample to 14 democratic upper-middle (henceforth, "UM") or high ("H") income countries whose residual is above the 75th percentile value. We restrict the sample to more democratic and more developed countries because market forces are less free to operate in other countries. Column (4) focuses on 8 H countries: Australia, Canada, Hong Kong, Israel, the Netherlands, Singapore, South Korea, and Uruguay. The 6 UM countries excluded are Brazil, the Dominican Republic, Macedonia, Malaysia, Panama and Thailand.

The U.S., being close to the regression line in Fig. 1, is not in the list. As shown later, California has few tall buildings, which offsets the contributions of New York or Chicago.

Col. (5)-(6) replicate col. (3)-(4), but with the height variable computed using residential buildings, while col. (7)-(8) use commercial buildings.

With the UMH sample (col. (3)), the GDP coefficient is three times larger than in col. (1), while the effect of agricultural rent is four times larger. With the H sample (col. (4)), the GDP coefficient doubles relative to col. (3). The agricultural rent coefficient is non-significant due to its strong correlation with income at the country level.

To generate the gaps, we iterate each benchmark regression, respectively, to get predicted heights for 2020, and then compare those heights to the actual 2020 data (see

Appx. Section B). The gap is equal to

$$\text{GAP}_{2020} = \widehat{\text{LUHTDENS}}_{2020} - \text{LUHTDENS}_{2020}. \quad (1)$$

It is helpful to derive the connection between a gap change and underlying changes in the building stock. Letting Δ denote change, the answer is immediate from differentiating (7):

$$\Delta\text{GAP}_{2020} \approx -\frac{\Delta\text{UHTDENS}_{2020}}{\text{UHTDENS}_{2020}} \quad (2)$$

If the *gap* measure (GAP) = 2, the absolute value of the *percentage change gap* (ΔGAP) implies that a 200% increase in height density is needed to "close" any gap. Following Wooldridge (2016), we use the corrected antilog of $\widehat{\text{LUHTDENS}}_{2020}$ to obtain $\widehat{\text{UHTDENS}}_{2020}$ and compare it to UHTDENS_{2020} to obtain the *per capita gap* (km per urban inh.). Knowing urban population, we obtain the *total gap* (km).

6. Rankings

Table 2 ranks the top 20 countries in terms of H set-based gaps.

Col. (1) shows the ranking based on the *percentage change gap*. Various European countries are found in the list, which concords with common beliefs that they are more stringent in regulating heights than other nations (Barr and Lyons, 2018).

The percentage gap is mechanically larger in countries with small height stocks (e.g., Uzbekistan). If we study the *per capita gaps* (col. (2)), the list is dominated by developed countries, and large-stock countries such as the U.S. and the UK are highly ranked. Finally, focusing on the *total gap* (col. (3)), the U.S., Taiwan, Japan, the UK and Germany dominate the list.[2]

In 2020, the data show 2,198 km of total height worldwide. Summing predicted values across countries, we get total predicted heights of 4,828 km, which generates a difference of 2,630 km – 6,000 Empire State Buildings (ESBs) – and a world gap factor of 2.2. However, negative gaps are observed in 45 countries where skyscrapers might be "white elephants" (e.g., the Gulf states, North Korea and Russia). For 44 countries with a positive gap, the total gap is 3,143 km (7,250 ESBs). If we use the UMH regression, we get a smaller predicted world total of 2,046 km. However, 31 countries still have a

[2] Appx. Fig. A3 shows the gap for each country.

positive gap and their total gap is 919 km (2,100 ESBs). Also, with UMH, income and agricultural rent have positive effects but the effect of income is half of the effect when using H. Moreover, with UMH, more richer (including H) countries mechanically have small positive, or even negative, gaps.

The percentage gap ranking is correlated with the per capita gap ranking (0.77; urban populations as weights). Rankings do not depend on using H or UMH (0.89).

Col. (1) of Table 3 shows higher gaps in historically richer countries (1950) and in countries where income increased between 1950 and 2020. Fast-growing countries post-1950 apparently did not adjust their regulations in step with their fast growth. Col. (2)-(3) show that the gaps in richer countries are driven by residential buildings, not commercial buildings. Thus, cities might be more open to creating jobs than receiving new residents (the rest of Table 3 is discussed below).[3]

These patterns could explain the U.S. gap. Many tall buildings were built before 1950 and subsequent construction may have failed to match income growth to the same extent as in other regions. To assess the validity of the methodology, we perform our panel analysis for 50 U.S. states (1930-2020; decadally) (Appx. Section C). State gaps strongly correlate with the housing supply elasticities of Saiz (2010) and the Wharton Index of Gyourko et al. (2008). California then accounts for 48-61% of the U.S. gap. If California were like the "best" U.S. states, the U.S. would be ranked 20th in per capita gap instead of 8th. Also, if we use the "best" U.S. state estimates to construct the gaps for all countries, the correlation between the H-based gaps and the U.S. state-based gaps is 0.75.

7. Land-Use Regulations

Do the gaps correlate with other land-use regulations?

We use a regulatory database established by Shlomo Angel. Angel's data set has 195 100K+ cities in 2015. The database includes maximum Floor Area Ratio (FAR) (N = 95), maximum building height (114), and the maximum number of dwellings per acre (35). Unfortunately, this information is available only for peripheral areas.

We focus on maximum FAR. For cities for which we know maximum building height but not maximum FAR, we predict the latter from a simple regression, proceeding

[3]See Appx. Table A10 for the UMH-based gaps.

similarly for the number of dwellings. For countries with multiple cities, we average the maximum FAR values using city populations. As seen in column (1) of Table 4, a higher maximum FAR (indicating weaker regulation) yields a lower gap.

Angel's database provides information on other land use regulations. Do the gaps capture land-use regulations other than building-height restrictions? Do countries with stringent building-height restrictions "compensate" their urban residents by having lenient regulations in other dimensions? The answer to both questions is no.

First, col. (2) shows that the correlation between our gaps and maximum FAR increases when we control for other land-use policies (e.g., urban containment and zoning). Furthermore, the gaps are not particulary correlated with other regulations (Appx. Table A1). Second, if high-gap countries have more lenient regulations in other dimensions, we should find a strong negative correlation between our gaps and other measures. The correlation is positive in most cases (Appx. Table A2).

Appx. Table A3 shows the gaps correlate with measures of the ease of building a warehouse (World Bank) or landlord-friendliness.

8. Urban Outcomes

Table 4 presents correlations between the H-based gaps and measures of housing prices, sprawl, congestion and pollution (Appx. Table A7 for UMH).

Housing Prices. World Bank (2019a) reports the price level of broad consumption categories in 2011 (relative to the world = 100). In col. (3), we regress the price level of housing on the gaps while controlling for log nominal per capita GDP (2010) (World Bank, 2019b) – because richer countries have larger gaps – and using as weights urban population (2010). We control for nominal, not PPP-adjusted, GDP because higher prices would be captured by PPP adjustments. A unitary decrease in the gap is associated with 4% lower housing prices. One standard deviation increase in the gap (≈ 2) is associated with a 0.15 standard deviation increase in prices.

Countries could compensate their residents by subsidizing commuting. In col. (4), we use the same specification but regress the price level of transportation on the gaps while also controlling for the price level of housing. The correlation is not significant.

GPG (2019) shows selling prices and price-to-rent ratios (PRR) for the largest city in 75 countries. High PRRs suggest prices will increase in the future. In col. (5)-(6), we regress these measures on the gaps while controlling for log nominal per capita GDP (2017), log city population size (2015) and using as weights urban population (2017). The gaps strongly correlate with current and future housing prices (captured by PRR). A unitary decrease in the gap is associated with 24% lower housing prices. A one standard deviation increase in the gap is associated with a 0.56 standard deviation increase in prices.

Knoll et al. (2017) show that housing prices have increased faster than overall prices for 14 countries post-1950. We show that the evolution of the total km gap of the 14 countries follows the evolution of mean real house prices in their sample (Appx. Fig. A2). Col. (7)-(8) show using panel regressions for the 14 countries (1960-2010) the strong correlation between the gaps and real house prices (country and year fixed effects included; standard errors clustered at the country level). In col. (7), we keep 1960 and 2010 to study the long-difference effect of the gaps. A unitary decrease in the gap is associated with 29% lower prices. A one standard deviation increase in the gap is associated with a 0.60 standard deviation increase in prices. The short-difference effect, estimated using all years, is halved, implying that gaps might have effects in the following decades. Lastly, proportionate reduction of error analysis suggests the gaps might explain 22% of the global house price boom.

Finally, although expensive high-gap countries might exclude the urban poor unless housing is subsidized, the share of housing that is publicly provided (HOFINET, 2020) is not correlated with the gaps (col. (9); using the specification of col. (4)).

Cross-sectional results suggest housing prices in urban areas and major cities could be 4% and 24% lower with an unitary decrease in the gap. Stronger correlations in larger cities could be because that is where gaps are binding.

Urban Land Expansion. If cities cannot expand vertically, they may expand horizontally. Thus, high-gap countries could use more urban land per urban capita.

In col. (10), we regress total urban land area (2011) (World Bank, 2019b) on the gaps. We control for log urban population (2010), log nominal per capita GDP (2010) (since higher incomes increase housing/land consumption and imply better commuting technologies), and log nominal agricultural land rent (2010) (since a higher land rent should constrain land expansion). We use urban populations (2010) as weights. Land expansion is positively correlated with the gaps. A unitary decrease in the gap is associated with urban areas consuming 19% less land. A one standard deviation increase in the gaps is associated with a 0.23 standard deviation increase in urban land area.

Moreover, we use the *Global Human Settlement* (GHS) database of European Commission (2018) to obtain for each country in 1975, in 1990, in 2000 and in 2015 the total population and total land area of all (11,719) 50K+ urban agglomerations today. In col. (11)-(12), we use as the dependent variable log total agglomeration area while adding country and year fixed effects and controlling for log agglomeration population, log nominal per capita GDP and log nominal agricultural land rent, with the variable of interest being the gap. By restricting our panel analysis to the years 1975 and 2015, we capture how the gaps correlate with the long-difference change in urban land per capita. A unitary decrease in the gap is associated with urban areas consuming 5% less land. A one standard deviation in the gaps is associated with a 0.07 standard deviation increase in urban land area. With the full panel, elasticities are halved (col. (12)).

Using the same specifications but controlling for log built-up area, col. (13)-(14) show regulations correlate with sprawl (more land used conditional on built-up land area).

Next, we combine the country-level gaps with city-level information to generate additional insights. We first ask if the height difference between larger and smaller cities is reduced in higher-gap countries. We use three dummies for whether the city has 100-500K, 500-1,000K and 1,000K+ inhabitants in 1975, respectively. We use 1975 because post-1975 population changes are endogenous to post-1975 gap changes. For the years 1975 and 2015, we run city-level panel regressions where the dependent variable is the log sum of heights and the variables of interest are the country gaps interacted with the three population category dummies. We include city and year fixed effects, country-year fixed effects, and cluster standard errors at the country level. Moreover, we control for log per capita GDP interacted with the three population dummies to capture how changes in the gaps occur in larger cities rather than the fact that gaps are becoming larger in richer countries. The effects of the country gaps are particularly visible for larger cities (col. (17)), thus suggesting that they are associated with abnormally constrained big agglomerations.

If we use the full panel (col. (18)), thus focusing on short-term effects, the point estimates are reduced, but significant above 1,000K.

Using the full panel specification, we confirm that building-height restrictions are stringent in the central areas of urban agglomerations (not shown). We then test if such gaps are compensated by vertical development in peripheral areas. For example, most tall buildings in the Paris and Washington DC agglomerations are located in the peripheral La Défense and Arlington areas, respectively. We re-run the same regression using the log sum of heights in peripheral areas and find, however, that the effects of the gaps interacted with the city dummies are nil or negative, not positive (col. (19)).

Larger cities may then expand beyond their initial boundaries. We test that idea using the panel specifications except that the dependent variable is now log city area (col. (20)-(21)). No effect is found. These regressions compare relative land expansion patterns for different class sizes of cities whereas col. (11)-(12) examined the total expansion of urban areas. Since urban land expansion is correlated with the gaps, *all* class sizes of cities might be expanding spatially due to binding gaps in the largest cities.

Congestion. Traffic congestion is available for 391 50K+ agglomerations today (TomTom, 2019). The measure indicates by how many percentage points commuting times increase during rush hours relative to non-rush hours. Congestion increases with log population size (2015; with country FE; coef. = 3.7***; adjR2 = 0.75). We examine how this relationship is affected by the gaps. We regress congestion on the gaps interacted with three dummies if the city has between 100 and 500, 500 and 1000, and more than 1000 thousand inhabitants, respectively (50-100K is the omitted category). We include country fixed effects and income interacted with the three population category dummies, and use urban populations (2020) as weights. Larger cities are disproportionately more congested than 50-100K cities in higher-gap countries (col. (22)).[4] Finally, knowing the population share of each group of cities, we compute the average effect across the three groups, 1.55*. Thus, a one point increase in the gap is associated with 1.5% more congestion. A one standard deviation in the gaps raises congestion by 3%. Finally, the effect is halved and insignificant when controlling for sprawl 1975-2015 (not shown).

[4]Point estimates are lower in the largest cities than in other large cities, possibly due to public transportation infrastructure.

Pollution. With sprawl and congestion, pollution may also increase. Air pollution in cities consists of gases and particulate matter (PM) measured by their size, such as 10 and 2.5 micrometers. In columns (15)-(16), the dependent variables are the log levels of PM 10 (2010) and PM 2.5 (2017) in more populated areas, respectively (World Bank, 2019b). We control for log nominal per capita GDP and log urban population (2010 or 2020), and use urban populations (2010 or 2020) as weights. A one point increase in the gap is associated with 0.05-0.07% more pollution. A one standard deviation increase in the gaps is associated with a 0.05-0.08 standard deviation increase in PM.

Furthermore, for 1,473 GHS agglomerations we obtain from WHO (2019) the average levels of PM10 and PM2.5 in 2008-2017. Given the same specification as for congestion, gaps are associated with increased pollution in the largest cities (col. (23)-(24)). If we control for sprawl (1975-2015), the effects are halved and insignificant (not shown).

9. Causality

The gaps are over-estimated if the coefficients of income and agricultural land rent in Table 1 are upward biased. A downward bias would make us under-estimate the gaps, which is less consequential. However, the bias would most likely affect the levels of the gaps, not country rankings.

Appx. Table A6 shows results hold if we: (i) Include continent- or World Bank region-year fixed effects, in order to capture time-varying regional drivers of tall-building construction; (ii) Include country-specific linear or non-linear trends. Identification comes from (possibly exogenous) swift growth within countries; (iii) Add leads of the two main explanatory variables. The leads have no effects, so buildings are not built in anticipation of income growth the following decade; (iv) Capture commuting costs by controlling for whether there is a subway and the logs of the number of subway lines and stations in the country (t) (Gonzalez-Navarro and Turner, 2018; Gendron-Carrier et al., 2018) and the percentage share of roads that is paved (1990-2017) interacted with a linear year trend (World Bank, 2019b). The effect of income on height density increases. Indeed, richer countries have better transportation infrastructure and lower commuting costs reduce the need to build up; (v) Control for time-invariant geographical factors interacted with year fixed effects: the logged number of significant earthquakes ever experienced (per sq km), the logged (population-weighted) average bedrock depth and ruggedness in urban areas, and the (population-weighted) share of urban land below sea level.[5]

We then obtain 11 gap series. For $11 \times 10 \div 2 = 55$ combinations, the mean and 5th percentile correlations are 0.96, and 0.90, respectively. Rankings are thus little sensitive to the coefficients used. We analyze how rankings change as we lower the income and land rent coefficients used. For most country gaps to disappear the coefficients would need to be halved. Rankings are unaffected unless coefficients are reduced by two thirds.

While there were historically important geographical constraints, they were, thanks to technological progress, overall weak post-1960. During earthquakes, structural techniques allow buildings to sway without damaging the structure (Wang, 2016). While bedrock depth influences skyscraper locations very locally (Barr et al., 2011), it is unlikely to systematically impact building construction at the country level. Furthermore, piles have been used to anchor skyscrapers for one century (Bradford and Landau, 1996). While being below sea level makes foundation work costlier if soils are porous (Ibid.), this only concerns 0.2% of global urban land. Finally, foundation costs are low compared to construction costs and land is the most expensive factor in central city areas.

Moreover, the gaps (col. (1) of Table 2) are not driven by countries with high earthquake risk (Japan, New Zealand or Turkey), a deep bedrock (the Gulf States or Central Asian countries) or ruggedness (Chile, Colombia or Lebanon).

10. Robustness

We discuss various robustness checks (see Appx. Tables A8-A9 for details).

Sampling. The process by which we select laissez-faire countries appears valid. For 61 UM-H countries, the correlation between the selection residuals and the number of Google search results for the country name & “cities” & “skyscrapers” is 0.61 (conditioning on the respective numbers of search results for the country name & “cities” and the country name). The correlation is 0.72 if we also control for whether English is an official language and the numbers of famous architects (Wikipedia, 2020b), as some countries have renown architects but few skyscrapers. With search results in the country’s language, it becomes 0.90.

Results hold if we: (i) Include the U.S.; (ii) Give more weight to large, or small,

[5]The U.S.-state regressions allow us to add more refined controls (Appx. Section C).

countries; (iii) Drop Hong Kong and Singapore; (iv) Select countries based on 1980 residuals (too few countries had tall buildings in 1950); (v) Drop government/religious buildings (1% of the stock); (vi) Drop buildings among the 5 tallest buildings in the world at any point in case they reflect a government's advertising campaign; and (vii) Interact the variables with a post-1980 dummy to isolate more recent effects.

Measurement Error. Classical measurement error in dependent variables only affect precision. However, measurement could be non-classical.

We collected data from Emporis (2019), another global provider of building information. Emporis claims to capture *high-rise* (35m+) buildings and classify as *skyscrapers* 100m+ buildings. Finally, they use the number of floors of each high-rise to compute a Skyline index. Their website reports useful information for the 100 top cities. For 90 of these, using as weights the sum of heights in our data to focus on cities with taller buildings, the correlation between the log of their number of skyscrapers and the log of our own number of 100m+ buildings is 0.90. The correlation between the log of their Skyline index and the log of their number of skyscrapers is 0.83. The correlation of their Skyline index with our own reconstructed index (using their formula) is 0.79. Thus, urban height density is a good proxy for 35m+ buildings.

Is our measure a good proxy for structures below 35m? Based on Emporis, which reports the number of low-rise buildings for 7 North American cities, the buildings in our data account for between half and two thirds of total heights including low-rises. In addition, for each building, we know the main material used. The use of concrete has dramatically increased over time, reaching 90% in the 2000s (Appx. Fig. A4; mean share 1950-2017 = 73%). We then obtained from the *Minerals Yearbooks* of USGS and for 144 countries and each decade from 1950 the total production of cement.[6] The correlation between building construction and cement use is 0.77. Adding country and year fixed effects, the correlation is 0.80 (0.99 with urban populations as weights).

Taller buildings are better measured. The height of the 25th percentile, median and mean is 100, 125 and 135 m, respectively. Results hold restricting our analysis to buildings above such thresholds. We know gross floor area (GFA) for one third of buildings. The correlation between log height and log GFA is 0.6 (buildings have different shapes). If

[6] Cement being a low-value bulky item, trade only accounts for 3% of consumption.

we regress for the year 2017 log GFA on log height, LUPCGDP and LAGRENT and their interactions with log height, we find no interacted effects, suggesting the GFA-height relationship does not endogenously vary with our variables of interest (not shown).

Specification. Results hold if we: (i) Omit the lagged dependent variable, to avoid introducing dynamic panel bias (Nickell, 1981); (ii) Interact the lagged dependent variable with year fixed effects or include the square of it in case persistence varies over time or with the stock; (iii) Include lags of income and agricultural rent in case their effects take time to materialize; and (iv) Use 15-year or 5-year lags.

Classical measurement error in income and land rent leads us to under-estimate their effects and the gaps. Results hold if we construct income and land rent differently or drop countries above mean land area since land rent at the edge of cities is then mismeasured.

11. Welfare

Were the effects causal, what could be their economic implications?

Theoretically, by restricting housing supply, height restrictions raise the price per unit of housing throughout the city while causing the urban footprint to expand. Residents experience a combination of higher housing prices and longer commutes. For the resident at the edge of the city, the welfare loss comes entirely from a longer commute. With utilities equalized within the city, the welfare loss for each resident equals the increase in commuting cost for the edge resident (Bertaud and Brueckner, 2005).

Suppose a country has n identical cities and let $urban\_area$ denote the size of each city. Then our dependent variable in the urban area regression is $n * urban\_area$, so that the regressions relate $\log(n*urban\_area)$ to GAP and other variables, with the GAP coefficient denoted β. Letting ΔGAP denote the change in GAP, differentiation of this relationship shows that

$$\frac{n * \triangle urban\_area}{n * urban\_area} = \frac{\triangle urban\_area}{urban\_area} = \beta \triangle \text{GAP} \tag{3}$$

With $urban\_area$ equal to $\pi\overline{x}^2$ for a circular city, where $\overline{x}$ is the distance to the edge,

$$\frac{\triangle urban\_area}{urban\_area} = \frac{2\pi\overline{x} \triangle \overline{x}}{\pi\overline{x}^2} = 2\frac{\triangle\overline{x}}{\overline{x}} \tag{4}$$

Combining 3 and 4 yields $\triangle\overline{x}/\overline{x} = \beta\Delta\text{GAP}/2$. If GAP increases by one standard deviation ($\approx$ 2), then the percentage increase in $\overline{x}$ is equal to β. Finally, since commuting cost is proportional to distance traveled, β equals the percentage increase in the edge resident's commuting cost.

The final step is to assume that the edge resident's commuting cost is a fixed proportion λ of individual gross income y. Then, the absolute increase in the edge resident's commuting cost from the greater GAP equals $\beta\lambda y$. Thus, $\beta\lambda y$ equals the individual welfare cost of a one standard deviation increase in GAP.

In Brueckner (2007), the edge resident spends 14-19% of income on commuting. Given β = 0.05 (col. (11) of Table 4), $\beta\lambda$ = 0.007-0.01. Thus, the welfare loss from a one-standard-deviation increase in GAP is close to one percent of urban income.

We found a 6% PM increase from a unitary increase in the gap. Multiplying by 2 to capture a one-standard deviation increase in the gap, the implied percentage increase in pollution equals 12%. Now, the cost of air pollution is 4.8% of world GDP (World Bank, 2016). Thus, a gap increase of 2 could reduce GDP by 0.6%.

Finally, Hsieh and Moretti (2019) compute the aggregate output effects of raising housing supply elasticities in three large, high-productivity but also highly-constrained US cities. Using their numbers along with our US results on the link between supply elasticities and the gap, we compute the output effects of a one-standard-deviation decrease in the gaps for these cities. The results are implausibly large (14.8%; Appx. Section D), but the calculation shows how to link our findings with their findings.

12. Concluding Discussion

We showed that richer countries have stringent height-restrictions. Why is that so?

The homevoter hypothesis stipulates that homeowners worried by increasing supply reducing property values lobby local governments to impose regulations (Fischel, 2005). We interact 1950 income and income growth 1950-2020 with the home ownership share today (Wikipedia, 2020a,f; HOFINET, 2020). No effect is found (col. (4) of Table 3), consistent with Fischel's conjecture that his hypothesis might not apply to larger cities.[7]

Urban planning became popular in the 19th century as a response to uncontrolled urbanization and with the aim of providing residents with open space and light. We

[7]Results hold excluding ex-communist countries given their high ownership share (not shown).

interact the income variables with the logged numbed of renowned urban planners per capita (Wikipedia, 2020h). We find positive significant interacted effects (col. (5)). Thus, in richer countries, urban planning might be contributing to stringent height-restrictions.

Historically populated cities have more historical buildings in their central areas. We interact the income variables with the logged 1800 population of the largest city today (Chandler, 1987; Wikipedia, 2020g). We find a positive significant interacted effect for 1950 income (col. (6)).[8]

Such countries may not adopt regulations because of old buildings *per se* but because such buildings are considered "valuable". We interact the income variables with the log number of cultural World Heritage Sites per capita (UNESCO, 2020). These include the "historic centres" of Paris, Rome and Vienna. We find a positive significant interacted effect for 1950 income (col. (7)). Including all interactions (col. (8)), this is the only effect to survive. Urban planners may thus act as defenders of historical patrimonies.[9]

Now, the gaps are not particularly correlated with a higher GDP contribution of tourism (Appx. Table A3). Thus, the historical patrimony effect might be due instead to richer countries valuing historical amenities for cultural reasons.

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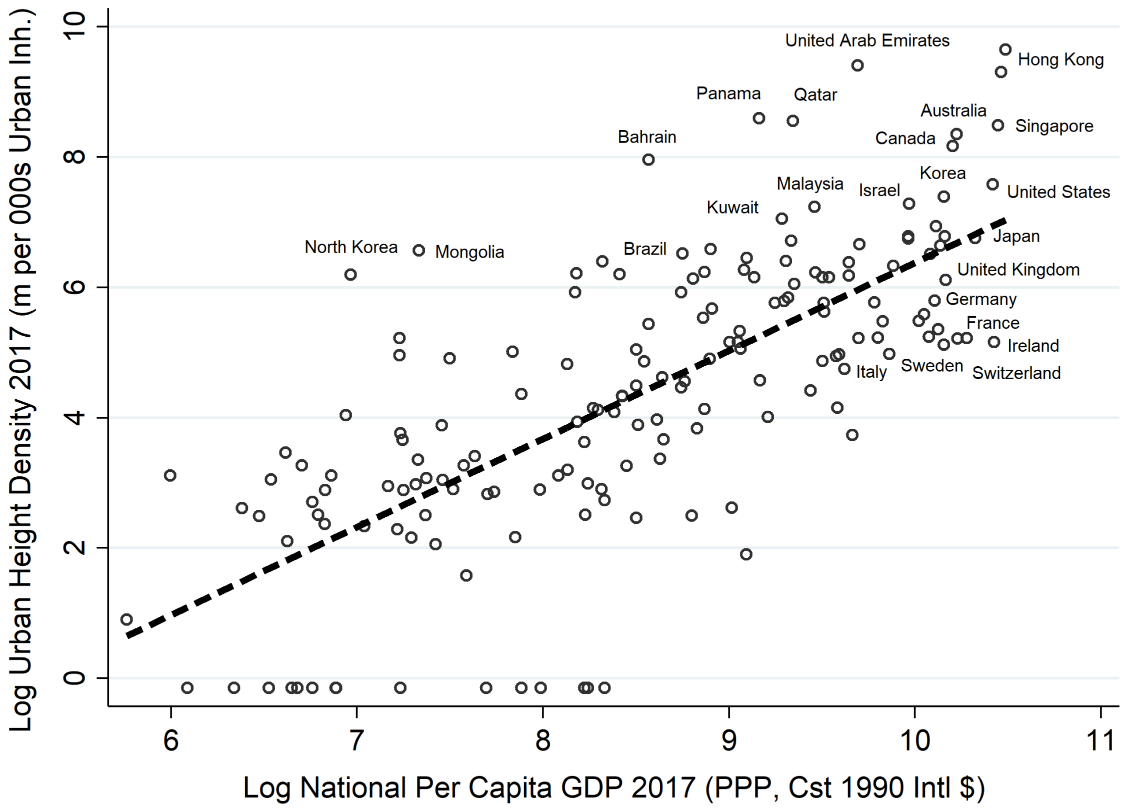
Figure 1: URBAN HEIGHT DENSITY AND NATIONAL INCOME IN 2017



Notes: This figure shows the relationship between the log sum of tall building heights per urban capita (m per inh.) and log per capita GDP (PPP, constant 1990 international $) for 170 countries circa 2017.

Table 1: EFFECTS OF INCOME AND LAND RENT ON HEIGHTS, WORLD, 1950-2020

Dep. Var.:	Log Urban Height Density (m per 000s Urban Inh.) in Year t ($LUHTDENS_t$)							
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Countries	All	≥ 0	$\geq$ p75 & DemUMH	$\geq$ p75 & DemH	Residential $\geq$ p75 DemUMH	DemH	Commercial $\geq$ p75 DemUMH	DemH
$LUPCGDP_t$	0.49***	0.68***	1.54**	3.23***	1.54***	2.66***	1.27***	1.07
	[0.10]	[0.16]	[0.67]	[0.61]	[0.34]	[0.47]	[0.40]	[0.69]
$LAGRENT_t$	0.13	0.30**	0.55**	0.19	0.58**	0.40	0.28	-0.03
	[0.09]	[0.13]	[0.26]	[0.40]	[0.22]	[0.42]	[0.16]	[0.28]
$LUHTDENS_{t-10}$	0.48***	0.46***	0.46***	0.18	0.47***	0.45***	0.25**	0.23
	[0.03]	[0.04]	[0.11]	[0.12]	[0.09]	[0.11]	[0.10]	[0.14]
Cntry FE, Yr FE	Y	Y	Y	Y	Y	Y	Y	Y
Observations	1,106	511	98	56	119	56	84	56
Countries	158	73	14	8	17	8	12	8
Adjusted R2	0.79	0.80	0.87	0.91	0.80	0.86	0.87	0.86

Notes: Sample of 158 countries x 8 years (1950, 1960, 1970, 1980, 1990, 2000, 2010, 2020) = 1,264 obs. Since we control for the dependent variable in t-10, we lose one round of data, hence N = 1,106 (col. (1)). "Dem" countries are "full democracies" or "flawed democracies" at any point in 2006-2017. "UM" and "H" countries are upper-middle income countries and high-income countries circa 2017, respectively. "0" and "p75"correspond to the following values of the laissez-faire proxy: 0 and the 75th percentile. Col. (5)-(6) & (7)-(8): We study residential buildings and commercial buildings, respectively. Robust SEs clustered at the country level: * $p<0.10$, ** $p<0.05$, *** $p<0.01$.

Table 2: COUNTRIES WITH THE LARGEST BUILDING-HEIGHT GAPS, 2020

	(1) Percentage Change Gap_H ($\lvert\Delta Gap\rvert$ Expressed in %)			(2) Per Capita Gap_H (Km per Mil. Urban Inh.)		(3) Total Gap_H (Km)	
Rank	Country	Gap	$\lvert\Delta Gap\rvert$	Country		Country	
1	Ireland	4.88	488	Ireland	21	United States	1468
2	Mauritius	4.51	451	Mauritius	20	Taiwan	219
3	Slovenia	3.69	369	Austria	12	Japan	174
4	Switzerland	3.61	361	Taiwan	12	United Kingdom	172
5	Uzbekistan	3.37	337	Sri Lanka	8	Germany	168
6	Norway	3.21	321	Trinidad	6	China	157
7	Austria	2.90	290	Switzerland	6	South Korea	147
8	Taiwan	2.78	278	United States	6	France	127
9	Sweden	2.77	277	Slovenia	5	Italy	82
10	Sri Lanka	2.61	261	Norway	4	Ireland	63
11	Italy	2.53	253	South Korea	4	Austria	61
12	Denmark	2.52	252	United Kingdom	3	Netherlands	46
13	Trinidad	2.50	250	Netherlands	3	Switzerland	35
14	France	2.49	249	Estonia	3	Sri Lanka	32
15	Germany	2.47	247	Germany	3	Sweden	22
16	Eq. Guinea	2.43	243	Sweden	3	Spain	22
17	Finland	2.23	223	France	2	Norway	18
18	United Kingdom	2.15	215	Denmark	2	India	17
19	Lesotho	2.12	212	Italy	2	Belgium	15
20	Portugal	2.02	202	Slovakia	2	Poland	12

Notes: The table shows the 20 countries with the largest gaps in 2020. Col. (1): The gap is the percentage change in urban height density required to make the height stock similar to the benchmark set of countries. Col. (2): The gap is expressed in km of heights per urban capita. Col. (3): The gap is the total gap in km. The gaps are estimated using as our set of benchmark countries 8 democratic high-income countries whose laissez-faire value is above the 75th percentile (p75) value (col. (4) in Table 1).

Table 3: DETERMINANTS OF THE GAPS, 2020

Dependent Variable:	H-Based ... Building-Height Gap 2020							
Considered Gap$_H$:	Overall	Resid.	Comm.	Overall	Overall	Overall	Overall	Overall
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
LPCGDP 1950	1.63***	2.15***	-0.27*	1.48	-30.98*	1.56***	1.08***	14.58
	[0.18]	[0.25]	[0.14]	[1.18]	[15.75]	[0.19]	[0.22]	[20.84]
ΔLPCGDP 1950-2020	2.73***	3.34***	0.30**	1.81*	-35.86*	2.69***	2.52***	8.81
	[0.18]	[0.24]	[0.14]	[0.96]	[20.16]	[0.21]	[0.23]	[22.97]
Home Ownership Sh. (HO)				-0.03				-0.02
				[0.12]				[0.11]
HO*LPCGDP 1950				0.00				0.01
				[0.02]				[0.02]
HO*ΔLPCGDP 19502020				0.01				0.00
				[0.01]				[0.01]
Log Num. Renown Urban Planners pc (LUPpc)					-46.03**			20.17
					[22.60]			[29.88]
LUPpc*LPCGDP 1950					4.68**			-2.05
					[2.28]			[2.98]
LUPpc*ΔLPCGDP 19502020					5.57*			-1.03
					[2.91]			[3.31]
Log 1800 Pop. of Largest City Today (LPL1800)						-0.88***		-0.08
						[0.31]		[0.45]
LPL1800*LPCGDP 1950						0.12***		0.02
						[0.04]		[0.06]
LPL1800*ΔLPCGDP 19502020						0.01		0.00
						[0.04]		[0.05]
Log Cultural World Heritage Sites pc (LWHSpc)							-20.80***	-18.52**
							[7.78]	[7.36]
LWHSpc*LPCGDP 1950							2.50***	2.37***
							[0.87]	[0.80]
LWHSpc*ΔLPCGDP 19502020							1.39	0.73
							[1.01]	[0.90]
Observations	158	158	158	105	158	158	158	105
R-squared	0.66	0.58	0.04	0.64	0.68	0.68	0.69	0.70

Notes: Col. (1)-(7): PCGDP 1950 is log national per capita GDP (PPP, cst 1990 intl $) in 1950 and ΔLPCGDP 1950-2020 is the log change in national per capita GDP between 1950 and 2020. Col. (2)-(3): We consider the gaps based on residential buildings (resid.) or commercial buildings (comm.) only. Col. (4): We use Wikipedia (2020a) as our main source for the home ownership share in the 2010s. When the share is still missing, we rely on Wikipedia (2020f) and then HOFINET (2020) (data available for 105 countries only). Col. (5): For the number of renown urban planners (per capita), we use the list from Wikipedia (2020h). Col. (6): For the 1800 population of the largest city of each country today, we use Chandler (1987) and then Wikipedia (2020g). Col. (7): For the number of cultural World Heritage Sites (WHS) (per capita), we use the list from UNESCO (2020). For example, cultural WHS for Italy include the historic centres of Florence, Naples, Rome, Sienna and Venice. Robust SEs: * $p<0.10$, ** $p<0.05$, *** $p<0.01$.

Table 4: BUILDING-HEIGHT GAPS AND ECONOMIC OUTCOMES, WORLD

Panel A: Country-Level Analysis

Source:	Angel's Regu. '19		World Bank '11		Global Prop.Guide'19		Knoll et al 2017	
Dep. Var.:	Max FAR:		Price Level (100)		Log Hous	Price-	Real Hous. Price t	
	Ctrls: N	Ctrls: Y	Hous.	Transp.	Price ($)	to-Rent	LongDiff	ShortDiff
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Gaps$_H$	-0.12**	-0.32***	3.99***	-1.50	0.24***	3.51***	28.78*	14.78**
	[0.04]	[0.00]	[1.33]	[1.34]	[0.04]	[0.84]	[14.38]	[6.48]
Cntry FE, Yr FE	N	N	N	N	N	N	Y	Y
Ctrls, Wgts	N	Y	Y	Y	Y	Y	N	N
Observations	49	47	147	147	72	70	28	83
Cntries, Yrs	49, 1	47, 1	147, 1	147, 1	72, 1	70, 1	14, 2	14, 6

Dep. Var.:	Share	Col. (10)-(14): Log Total Urban Land Area (Km) in ...					Log Particulate	
	Public	World	Col. (11)-(14): GHS t		Ctrl: Built-Up Area t		Matter Level (PM)	
	Housing	Bank '11	LongDiff	ShortDiff	LongDiff	ShortDiff	10	2.5
	(9)	(10)	(11)	(12)	(13)	(14)	(15)	(16)
Gaps$_H$	-0.08	0.19***	0.05**	0.03**	0.04*	0.02*	0.05**	0.07**
	[0.87]	[0.03]	[0.02]	[0.01]	[0.02]	[0.01]	[0.02]	[0.03]
Cntry FE, Yr FE	N	N	Y	Y	Y	Y	N	N
Ctrls, Wgts	Y	Y	Y	Y	Y	Y	Y	Y
Observations	48	125	262	524	262	524	146	156
Cntries, Yrs	48, 1	125, 1	131, 2	131, 4	131, 2	131, 4	146, 1	156, 1

Panel B: Urban Agglomeration-Level Analysis

Dep. Var.:	Log Sum of Heights in Year t			Log Area		Congestion	Log PM 2017	
			Peri.Areas	in Year t		2017	10	2.5
	(17)	(18)	(19)	(20)	(21)	(22)	(23)	(24)
$\mathbb{1}$(100K-500K)*Gap$_H$	-0.04	-0.03	0.00	0.01	0.01	1.79**	0.04	0.04
	[0.03]	[0.02]	[0.00]	[0.01]	[0.02]	[0.73]	[0.03]	[0.03]
$\mathbb{1}$(500K-1000K)*Gap$_H$	-0.25*	-0.11	-0.02	0.00	0.00	2.71*	0.09**	0.08*
	[0.14]	[0.17]	[0.03]	[0.03]	[0.02]	[1.49]	[0.04]	[0.04]
$\mathbb{1}$(1000K+)*Gap$_H$	-0.73**	-0.56**	-0.15*	-0.02	0.00	1.48	0.13**	0.14***
	[0.31]	[0.25]	[0.09]	[0.02]	[0.01]	[1.13]	[0.05]	[0.05]
City FE, Year FE	Y	Y	Y	Y	Y	N	N	N
Country-Year FE, Ctrls	Y	Y	Y	Y	Y	Y	Y	Y
Observations	23,438	46,876	46,876	17,040	34,181	391	1,473	1,473
Number of Cities	11,719	11,719	11,719	11,719	11,719	391	1,473	1,473
Number of Years	2	4	4	2	4	1	1	1

Col. (2): We control for other land use regulations. Col. (3)-(6), (9)-(10), (15)-(16) and (22)-(24): See text for details. Col. (7)-(8): Panel regressions for 14 countries in 1960-2010 (1960, 1970, 1980, 1990, 2000, 2010). Col. (11)-(14): Panel regressions for 131 countries in 1975-2015 (1975, 1990, 2000, 2015). Col. (17)-(21): Panel regressions for 11,719 50K+ urban agglomerations in 1975-2015 (1975, 1990, 2000, 2015). We interact the country-level gaps with three population category dummies defined in 1975 (50-100K is the omitted category). Robust SE (clustered at the country level in col. (7)-(8), (11)-(14) and (17)-(21)): * $p<0.10$, ** $p<0.05$, *** $p<0.01$.

WEB APPENDIX: NOT FOR PUBLICATION

A Details on the Building Heights Data

The original data set of CTBUH (2018) (accessed between January 2017 and January 2018) has 27,652 *tall buildings*. Once we keep "buildings" and "tower-buildings" that are completed or about to be completed, we are left with 19,132 tall buildings.

Heights. According to the website of CTBUH (2018), they do not use a consistent definition of tall buildings across all cities. We thus study how heights vary across the data set. To do so, we need to obtain height for as many buildings as possible.

For most buildings, we know height to tip of the building (no matter the function of the highest element) and/or height to the architectural top of the building (which may include spires but excludes antennaes) and/or height to the highest occupied floor and/or height of the observatory of the building if there is one and/or the number of floors above ground. Height to the highest occupied floor may be the best measure but it is only available for 11.6% of buildings whereas architectural height is available for 84.7% of them, height to the tip 60.6% of them, height to the observatory 1.1% of them, and the number of floors 98.2% of them. We thus use architectural height as our main measure.

Since it is missing for 15.3% of buildings, we impute it when possible with data on height to the tip (correlation between architectural height and this height = 0.99), then data on height to the highest occupied floor (correlation = 0.98), then data on height to the observatory (correlation = 0.96). We then regress our measure of height on the number of floors and find a coefficient of 3.8***, which indicates that a floor corresponds to 4 meters for most buildings in the world (95% conf. interval = [3.77; 3.87]). We can then impute heights for the remaining buildings. In the end, we obtain a consistent measure of heights (m) for 99.6% of buildings (N = 19,132). We nonetheless verify results hold if we use architectural height or height not using information on number of floors.

As can be seen in Web Appendix Figure A5 (on the next page) which plots the Kernel distribution of building heights in the data set, the mode of the distribution is 80 m. Since cities are likely to have more buildings below 80 m than above 80 m, and since the distribution of buildings is relatively smooth after 80 m, this suggests that the data set mostly captures buildings above 80 m. Thus, the data set is likely unreliable for buildings below 80 m. However, since some countries may have few tall buildings above 80 m, and since some height data may be available for some relatively important local buildings below 80 m, we keep the 16,369 buildings above 80 m and/or buildings in the top 10 in the country today. This guarantees that few countries have no building data at all.

Year of Construction. For most buildings, we know the year of completion and/or the year construction started and/or the year construction was proposed. We use the year of completion as our main measure (available for 96.6% of buildings). For the remaining buildings, we impute the year of completion using information on the year construction started (corr. with the year of completion = 0.99), then the year construction was proposed (0.97). On average, a building is completed 5.5 years after construction is proposed and 3.3 years after it starts. We obtain the year of completion for 96.8% of buildings.

Function. The function(s) of the buildings is available for 98.9% of buildings. Many buildings have multiple functions. Among buildings for which we know the function, 49.9% of them are used for *residential* purposes and 41.8% of them include offices. Other important functions include hotels (11.8%) and retail (3.9%). In our analysis, we define as *commercial* buildings with the function "office", "hotel" and/or "retail".

B Computation of the Building-Height Gaps

The iteration proceeds as follows. Predicted log heights for 1960 are found by evaluating

$$\widehat{\text{LUHTDENS}}_{1960} = \alpha + \beta \text{LUPCGDP}_{1960} + \gamma \text{LAGRENT}_{1960} + \delta \text{LUHTDENS}_{1950}. \quad (5)$$

with LUHTDENS being log urban height density, LUPCGDP log per capita urban GDP and LAGRENT log agricultural land rent. (α, β, γ, δ) are obtained from Table 1.

For simplicity, the year fixed effects are omitted in writing (5).[10] To get predicted log building heights for 1970, we rewrite (5) with 1970 values for the first two covariates and with the 1960 predicted value playing the role of LUHTDENS_{1960}:

$$\widehat{\text{LUHTDENS}}_{1970} = \alpha + \beta \text{LUPCGDP}_{1970} + \gamma \text{LAGRENT}_{1970} + \delta \widehat{\text{LUHTDENS}}_{1960}. \quad (6)$$

The procedure continues until a LUHTDENS predicted value emerges for 2020. The building-height gap measure in 2020 is then equal to

[10]By construction, we ignore the country effects to compute the gaps.

$$\text{GAP}_{2020} = \widehat{\text{LUHTDENS}}_{2020} - \text{LUHTDENS}_{2020}, \tag{7}$$

or the difference in predicted and actual log height densities.

C U.S. State Analysis and U.S. State and World Gaps

In this section we perform a similar gap analysis using U.S. state-level data, which offers an opportunity to validate our methodology. The specification that we use for this analysis differs from the one used for the international analysis. Indeed, due to interurban mobility within a country as well as agglomeration effects, population and income per capita are very strongly correlated across cities and urban areas. Therefore, on the left hand side, we do not divide the sum of heights by total urban population, and on the right hand side, we use total urban income instead of urban income per capita. However, we show below that world rankings are little affected if we use the U.S.-based coefficients.

Data. Our sample comprises 50 states almost annually from 1929 to 2017.[11] For building heights, we use CTBUH. From Bureau of Economic Analysis (2019), we then obtain for the 1929-2017 period total income, farm income, and non-farm income, a proxy for urban income. Next, from United States Census Bureau (1975), we know state farmland area from 1929 to 1940. From United States Department of Agriculture (2017) and Wikipedia, we know agricultural land area and total land area.[12] Knowing farm income and agricultural land area, we reconstruct agricultural land rent. We use agricultural land area for the U.S. analysis – we used total land area for the international analysis – because it is well measured for the whole period.[13] From Wikipedia, we obtain the population and urbanization rate – and thus the total urban population – of each state in each year.[14]

Results. Table A5 shows the baseline regression in column (1), where all three coefficients are significant. The GDP coefficient is smaller than in the country-level regressions, while the lagged height-density coefficient remains less than one. Columns (2), (3) and (4) then

[11] We drop the District of Columbia because agricultural rent is unavailable for most of the period.

[12] To obtain a consistent series of state agricultural land area from 1929 to 2017, we use cropland/pasture area from 1945 to 2017 as our benchmark. We then use the growth rate of farmland expansion in each state before 1940 to extend that variable to 1929. Total land area is obtained from Wikipedia (2020e).

[13] we use the consumer price index of the United States to express the income variables and the agricultural land rent variables in constant 2017 dollars (Minneapolis Federal Reserve, 2020).

[14] Sources are Wikipedia (2020c) and Wikipedia (2020d).

eliminate states with residuals below 0, the 75th percentile, and the 90th percentile in a 2017 regression using GDP and agricultural rent as covariates. The GDP coefficient increases, as happened at the country level, and the agricultural-rent coefficient also increases but loses significance. Restricting the sample to the states with residuals above the 75th or 90th percentile (col. (3)-(4)) has little effect on the GDP coefficient compared to restricting the sample to states with residuals above 0 (col. (2)). In order to keep more observations, we thus privilege the sample of states with residuals above 0.[15]

The other columns present robustness checks similar to those in the country-level analysis. Following that analysis, in column (5), the year fixed effects are replaced by nine census region dummies × year fixed effects; adding them has little effect on the GDP coefficient relative to column (2). In this regression, the agricultural land-rent coefficient regains significance. Use of state time trends in place of region × year fixed effects yields positive, yet insignificant, coefficients (col. (6)). Indeed, unlike in the international sample, no state has experienced a period of growth fast enough that the coefficients survive the inclusion of state time trends. Column (7) shows the effect of adding ten-year leads of the GDP and agricultural-rent variables, whose coefficients are insignificant.

In column (8) we capture commuting costs by controlling for whether there is a subway and the logs of the number subway lines and subway stations in the state in year t (source: Gonzalez-Navarro and Turner (2018) and Gendron-Carrier et al. (2018)) and the log of the total mileages of paved roads corresponding to "municipal / urban extensions of highway systems" or "other municipal / urban streets".[16] One advantage of the U.S. regression over the international regression is that consistent panel data on urban road stocks is now available. As can be seen, the effects are mostly unchanged.

In columns (9)-(12), we control for time-invariant geographical factors interacted with year fixed effects: the logged number of significant earthquakes ever experienced (per sq km; col. (9)), the logged (population-weighted) average bedrock depth ((10)) and ruggedness in the state's urban areas ((11)), and the (population-weighted) share of urban

[15] Using the 75th percentile (p75) cutoff gives the following 13 states: Delaware, Georgia, Hawaii, Illinois, Kansas, Louisiana, Minnesota, Nevada, New York, Oklahoma, Rhode Island, Utah, Washington. Using the 90th percentile (p90) cutoff gives the following 5 states: Hawaii, Illinois, Nevada, New York, Rhode Island.

[16] The sources are *A Quarter Century of Financing Municipal Highways, 1937-61* (Bureau of Public Roads) and the annual *Highway Statistics* reports of the U.S. Department of Transportation.

land below sea level ((12)). Results appear to hold across all specifications.[17]

While these were historically important geographical constraints, especially in the 19th century when U.S. cities experienced fast population growth, they were, thanks to technological progress, overall weak post-1960. During earthquakes, structural techniques allow buildings to sway without damaging the structure (Wang, 2016). While bedrock depth can influence skyscraper locations very locally (Barr et al., 2011), it is unlikely to systematically impact building construction at the country level. Furthermore, piles have been used to anchor skyscrapers for one century (Bradford and Landau, 1996). While being below sea level makes foundation work costlier if soils are porous (Ibid.), this only concerns 0.1% of urban land. Finally, foundation costs are low compared to construction costs and land is the most expensive factor in central city areas.

In column (13) we add geographical controls, each interacted with a year trend. These controls are total land area and the shares of land unavailable for development due to excessive slope, the presence of wetlands, or the presence of bodies of water (source: Lutz and Sand (2017)). If anything, this change increases the effect of land rent. In column (14), the geographical controls are replaced by time-interacted variables measuring the amounts of land under various types of government ownership (source: NRCM (2017)): federal government, state government, Bureau of Land Management, U.S. Forest Service, National Park Service, National Wildlife Refuge, Army Corps of Engineers, Military Bases, Tribal lands. Again, the results are similar to those in column (2).

Finally, in column (15), we control for the RSMeans construction cost in the state in the same year. Indeed, as income increases, construction costs could increase, thus depressing construction. Controlling for construction costs then allows us to capture the direct effect of income. As can be seen, the estimated effects are mostly unchanged.

State Gaps. For the sample of observations used in col. (2)-(4), we take the antilog of the predicted heights and adjust it by a correction factor (see Wooldridge (2016)). We then obtain for each state in 2020 the predicted sum of heights based on the regressions and compare these values with the actual stocks. In the U.S., the total stock in 2020 was 508 km of height. Using the estimates based on states above 0, the 75th percentile and the

[17]See table notes for details on the underlying sources used and how the population-weighted averages of the variables are constructed for each state's urban areas.

90th percentile, we get 1137, 1474 and 2317 km, respectively. In other words, had most states been like the less stringent ones, the total stock today would be 2.2-4.6 times higher.

The U.S. gaps are mostly driven by California. Across the three benchmark sets, California accounts for about 48-61% of the U.S. gap. If we use "above 0" benchmark set, other states that contribute to the gap are New York, Pennsylvania, Texas and Florida. Altogether, they account for about 24-32% of the total gap.[18]

Other Measures of Land-Use Regulations. Table A4 gives the results of regressions of measures of building regulations on the gaps. For the dependent variables, row 1 uses a measure of housing supply elasticity from Saiz (2010), but at the state level. Saiz obtains elasticities for 269 metropolitan areas, and we create our state-level elasticities by taking a MSA-population weighted value for cities in each state, based on population counts from the 2000 census. Row 2 uses an unweighted average of the Wharton Residential Land Use Regulation Index (Gyourko et al. (2008)), which measures the extent of building regulations for towns and cities across the U.S. The data set in Saiz (2010) also includes MSA-level values for the Wharton Index. We generate state-level weighted averages for this index, which are used as right-hand side variables in row 3. Finally, row 4 uses an index created by Saks (2008), which is the average of several building regulation indexes.

For the right-hand side variable, col. (1)-(3) use the estimated gaps. Results are based on states with a laissez-faire value above 0 in col. (1), the 75th percentile in col. (2), and the 90th percentile in col. (3). Across all gap measures, and all measures of building and land-use regulations across states, we find statistically significant relationships. These results provide evidence that the gap measures are useful indicators of land-use stringency.

World Gaps. Overall, the qualitative similarity of the state-level regressions reported in this section to the above country-level regressions increases our confidence in the country-level benchmark regression as a tool for computing building-height across the world. In particular, if we use the U.S. state estimates to obtain predicted heights and the gaps for all countries in the world, the coefficient of correlation between the H-based gap measure (for countries above the 75th percentile) and the U.S. state-based gap measures is 0.74-0.76. If we use the UMH set instead, the correlation remains high, at 0.72-0.89.

[18] If we use the p75 benchmark set, we get California, New York, Florida, Pennsylvania and New Jersey. If we use the p90 benchmark set, we get California, New York, New Jersey, Massachusetts and Connecticut.

D Possible Welfare Loss from Spatial Misallocation

Hsieh and Moretti (2019) investigate losses from land-use regulation that come from a distortion in the allocation of the workforce across cities. They show that reducing regulation so as to increase housing supply elasticities in the highly productive but land-use-constrained cities of New York, San Francisco and San Jose would increase output and welfare growth. Their Table 4 shows that increasing the supply elasticities in these three cities to the median value among all US cities would raise the annual growth rates of output and welfare (both equal to 0.8%) by 86% and 52%, to annual rates of 1.5% and 1.2%, respectively. The supply elasticities from Saiz (2010) that they use for the three cities are centered around 0.73, which we take as a representative value. Raising this value to the US median would require an elasticity increase of 0.92, using data from Saiz's Table VI.[19]

Using our results on the link between the elasticities and the building-height gap, along with some additional assumptions, we can compute by how much building-height gaps must fall to raise the elasticity by 0.92. With columns (1)-(3) of row 1 in Table A4 showing that a unit increase in the Saiz elasticity (measured at the state level) is associated with at least a 0.54 reduction in the state height gap, the height gaps in California and New York must fall by 0.50 (0.54 times 0.92) to achieve the desired elasticity increases. From equation (4) above, ΔUHTDENS/UHTDENS then must equal 0.50, implying that a 50% increase in building heights in California and New York is required to achieve the desired increase in the supply elasticity.[20] Height increases of this magnitude would raise the growth in output and welfare by the substantial magnitudes stated above.

Finally, Hsieh and Moretti (2019) claim that, with these higher growth rates, U.S. GDP in 2009 would have been 3.7% higher than its actual value. Thus, a one-standard-deviation gap change of 2, which is four times 0.50, would produce an even larger GDP gain of about 14.8%.[21] This number appears to be implausibly large, but the calculation is at least illustrative.

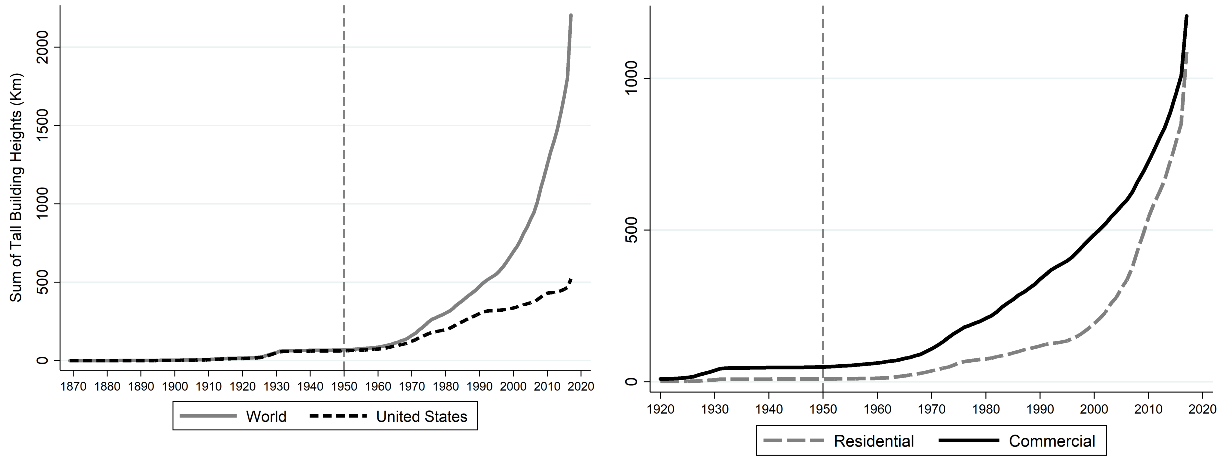
[19] Hsieh and Moretti's (2019) calculations are based on a set of 220 cities, with the median elasticity value not reported. Instead, our calculation uses the median elasticity from the smaller set of 95 cities in Saiz (2010), which likely understates Hsieh and Moretti's median. Therefore, the numbers above are likely to slightly understate the required elasticity increase along with the required increases in building heights.

[20] The New York height increase is similar in size to the one required to raise heights to the free-market level, as computed in Brueckner and Singh (2020).

[21] Although other countries may not exhibit the same urban productivity differentials as the U.S., similar calculations would apply in principle.

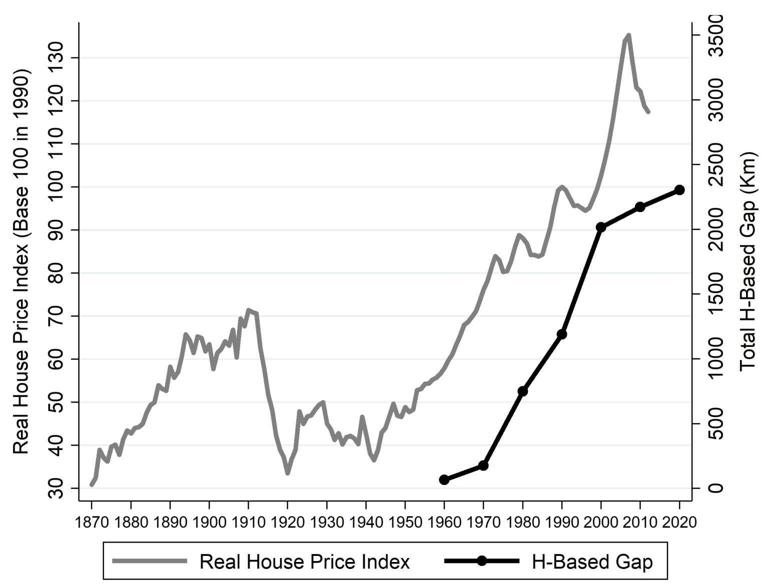
Figure A1: TALL BUILDING HEIGHTS FOR THE WORLD, 1869-2017

(a) Tall Building Heights **(b)** Residential vs. Commercial Heights, World



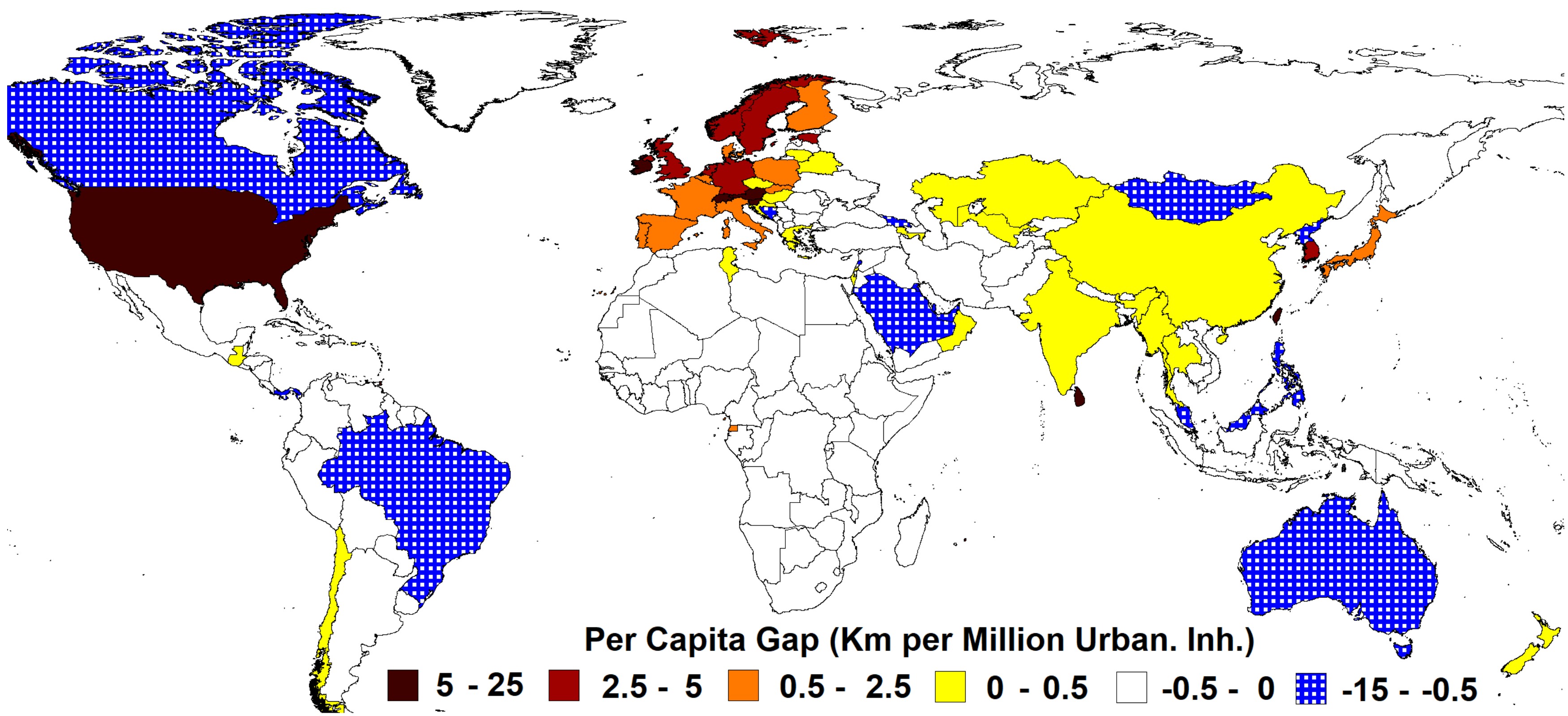
Subfig. 1(a) shows the evolution of the stock of tall building heights (m) for both the world and the United States from 1869 to 2017. Subfig. 1(b) shows the world evolution of the stock of tall building heights (m) separately for residential and commercial buildings from 1920 to 2017. The dashed vertical line shows the year 1950, the start year of our main period of study (1950-2020). See text for details.

Figure A2: HOUSE PRICES & BUILDING-HEIGHT GAPS, 14 COUNTRIES, 1870-2020



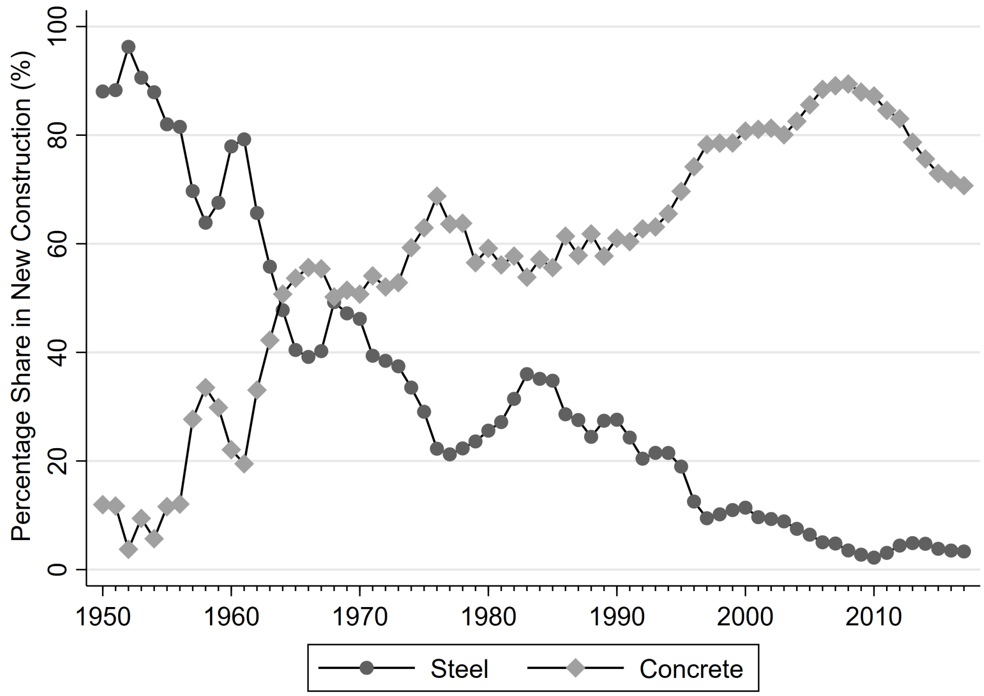
This figure shows that real house prices have dramatically increased in developed countries since the 1950s (we use the data from Knoll et al. (2017)). It also shows that the estimated total km (H-based) gap of the 14 countries has increased since 1960. More precisely, Knoll et al. (2017) reports a real house price index (base 100 in 1990) for 14 OECD countries annually from 1870 to 2012. We then obtain the average real house price index for the 14 countries in each year using the population of each country as weights.

Figure A3: PER CAPITA GAPS FOR ALL COUNTRIES, 2020



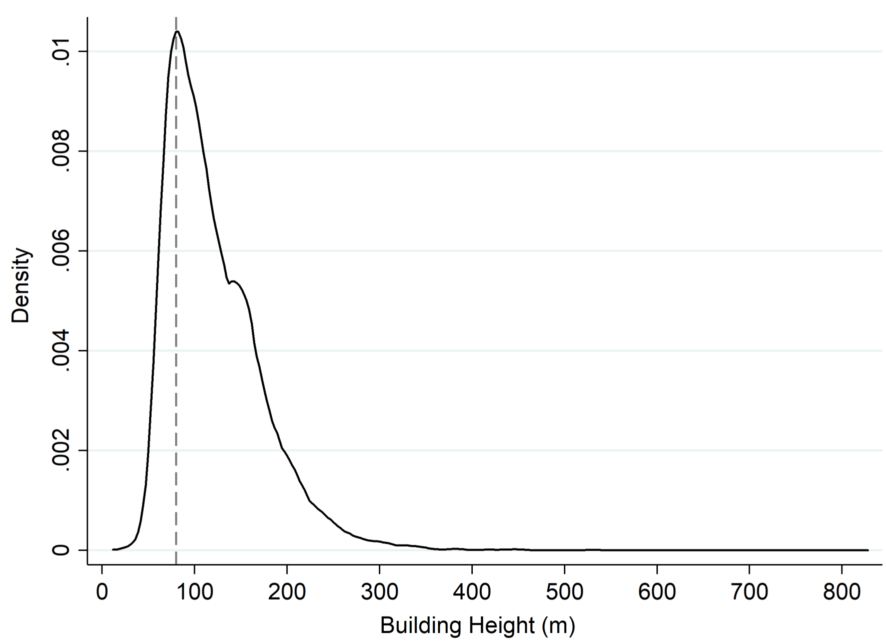
This figure shows the H-based gaps per urban capita (km per million urban inhabitants) for 158 countries circa 2020. Positive gaps are shown in dark brown, dark red, orange or yellow. Negative gaps (= excess) are shown in blue (dotted patterns).

Figure A4: USE OF STEEL VS. CONCRETE IN NEW CONSTRUCTION 1950-2017



For each building, we know the main material used. While it was steel around 1950, the use of concrete has dramatically increased over time, reaching 90% in the 2000s (mean share in 1950-2017 = 73%). More precisely, this figure shows for each year the share of new construction (weighted by building heights) that comes from buildings whose main material is steel vs. concrete. These shares are obtained using available information for 10,809 out of the 16,369 buildings in our data. We report two-year moving averages.

Figure A5: KERNEL DISTRIBUTION OF TALL BUILDING HEIGHTS



The mode of the Kernel distribution of all building heights in the CTBUH data set is 80 m.

Table A1: GAPS AND LAND USE REGULATIONS, WORLD, CIRCA 2020, DETAILS

Dep. Var.:	Col. (1)-(4): Gap Based on UMH Set				Col. (5)-(8): Gap Based on H Set			
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Max FAR	-0.20**	-0.20**	-0.32***	-0.37***	-0.12**	-0.15**	-0.24***	-0.32***
	[0.013]	[0.014]	[0.002]	[0.002]	[0.037]	[0.016]	[0.002]	[0.000]
Urban Containment		0.98		0.42		-0.29		-0.55
		[0.344]		[0.752]		[0.802]		[0.647]
Via Green Belt		-0.87		-1.47		-1.35		-1.36
		[0.584]		[0.418]		[0.401]		[0.408]
Via Urban Growth Boundary		-1.61		-1.05		-0.65		-0.45
		[0.101]		[0.352]		[0.452]		[0.635]
Full or Partial Zoning		1.37		0.68		2.44***		1.22
		[0.205]		[0.428]		[0.002]		[0.200]
Gvt Land Acquisition		0.53		-0.94		0.64		-1.40
		[0.685]		[0.370]		[0.624]		[0.147]
Min Plot Size Y/N			-1.96	-2.06			-1.50	-1.87
			[0.111]	[0.153]			[0.285]	[0.279]
Mths Permit Subdivid.			-0.04	0.04			-0.02	0.07
			[0.446]	[0.552]			[0.636]	[0.302]
Mths Permit Build.			0.12	0.15			0.11	0.16**
			[0.218]	[0.165]			[0.118]	[0.044]
Street Layout Gvt/Mixed			1.70	1.59*			1.13	1.10
			[0.113]	[0.095]			[0.252]	[0.160]
Infrastructure Gvt/Mixed			-1.20	-0.45			-2.17**	-1.21
			[0.241]	[0.717]			[0.050]	[0.264]
Obs./Countries	49	49	47	47	49	49	47	47
R-squared	0.08	0.18	0.30	0.41	0.03	0.14	0.28	0.43

This table shows that the correlation between our gap measures and the maximum FAR values (*max FAR*) increases when we control for ten other land use policies. The effects of the other variables are for the most part not significant, showing that the gaps are not particulary correlated with other types of land use regulations. To obtain these country-level measures, we rely on the (pop.-weighted) city-level database of land use regulations (ca. 2017) compiled by Solly Angel (N = 195). *Max FAR:* max FAR allowed. *Urban Containment:* Dummy if containing the expansion of the city is an explicit goal of the zoning and land use plan. *Via Green Belt:* Urban containment done via a green belt. *Via Urban Growth Boundary:* Urban containment done via an urban growth boundary. *Full or Partial Zoning*: Partial or full zoning. *Gvt Land Acquisition*: Extensive or common government land acquisition to plan for future urban land expansion. *Min Plot Size Y/N:* Restrictions on plot size. *Mths Permit Subdivid.:* Number of months needed to obtain a permit to subdivide land. *Mths Permit Build.:* Number of months needed to build structures on that subdivided land. *Street Layout Gvt/Mixed:* The layout of streets is decided by the government or through public-private partnerships. *Infrastructure Gvt/Mixed:* Infrastructure is provided by the government or through public-private partnerships. Robust SEs: * $p<0.10$, ** $p<0.05$, *** $p<0.01$.

Table A2: CORRELATION BTW THE GAPS AND OTHER LAND USE REGULATIONS

Land-Use Regulation ca. 2020 (Angel) (Higher values = more stringent regulations):	UMH-Based Gaps 2020	H-Based Gaps 2020
Dummy Urban Containment	0.10	-0.02
Dummy Containment Via Green Belt	0.00	-0.11
Dummy Containment Via Urban Growth Boundary	-0.17	-0.08
Dummy Full or Partial Zoning	0.14	0.20
(-) Dummy Gvt Land Acquisition	-0.03	0.00
Dummy Min Plot Size Regulation	-0.15	-0.04
Number of Months before Permit Subdivision	0.10	0.21
Number of Months before Permit Building	0.19	0.26
(-) Dummy Street Layout Gvt or Mixed	-0.28	-0.14
(-) Dummy Infrastructure Gvt or Mixed	0.02	0.29
Mean Correlation	-0.01	0.06
Two Lowest Correlations	-0.28; -0.17	-0.14; -0.11
Observations (Countries)	48	48

This table shows that high-gap countries do not compensate their residents by having more lenient regulations in other dimensions. In most cases, we do not find a strong negative correlation between our gaps and other measures of land use regulations (when transformed so that higher values imply more stringent regulations). The two most negative correlations are -0.11 and -0.14 for H-based gaps (mean = 0.06). See the notes of Web Appx. Table A1 for details on the measures.

Table A3: GAPS, LAND-USE REGULATIONS & TOURISM, WORLD, CIRCA 2020

Dep. Var.:	Gap (Predicted Log Heights per Urban Cap.- Actual Log Heights per Urban Cap.)				
Source:	World Bank: Ease of Building a Warehouse'19			Glob.Prop.Guid.	Tourism's
RHS var.:	Few Procedures	Cost Relative to Value (%)	Quality Ctrl Stringent	Pro-Landlord Regime'19	Contribution GDP (%; 90s-10s)
Dep. Var.:	(1)	(2)	(3)	(4)	(5)
1. $Gap_{UMH,2020}$	-0.02***	-0.02***	0.04***	-1.15**	0.18*
	[0.01]	[0.01]	[0.01]	[0.48]	[0.10]
2. $Gap_{H,2020}$	-0.01	0.00	0.04***	-1.74***	0.09
	[0.01]	[0.01]	[0.01]	[0.50]	[0.09]
Observations	155	155	155	98	155

Col. (1)-(4) that the gaps are correlated with other indirect international measures of land-use regulations, whether World Bank measures that capture "procedures, time and cost to build a warehouse" or the extent to which the system of landlord and tenant law and practice is pro-landlord. Col. (5) shows that the gaps are only weakly correlated with the average contribution of tourism to GDP (%) in 1990-2017. More precisely, this table shows the correlation between the estimated gaps based on the UMH and H sets and indirect measures of land use regulations for as many countries as possible. The three measures in col. (1)-(3) are taken from the *Doing Business* website that capture the "procedures, time and cost to build a warehouse", which constitute the only measures of land-use regulations that could be obtained from World Bank data (source: https://www.doingbusiness.org/en/data/exploretopics/dealing-with-construction-permits). The measure in col. (4) measures the extent to which the system of landlord and tenant law and practice is pro-landlord. The source is the Global Property Guide website (https://www.globalpropertyguide.com/landlord-and-tenant). We classify as pro-landlord any country that is classified as either pro-landlord or strongly pro-landlord. The contribution of tourism to GDP in each year 1990-2017 comes from World Bank (2019b). Robust SE. * p<0.10, ** p<0.05, *** p<0.01.

Table A4: GAPS AND LAND USE REGULATIONS, UNITED STATES, CIRCA 2010

	Effect of the Estimated State Gap (circa 2010) Based on ...								
	(1) States $\geq$ 0			(2) States $\geq$ p75			(3) States $\geq$ 90		
Dep. Var.:	Coef.	Obs.	R2	Coef.	Obs.	R2	Coef.	Obs.	R2
1. Saiz Elasticity	-0.54*	47	0.13	-0.61**	47	0.13	-1.30***	47	0.19
	[0.29]			[0.30]			[0.46]		
2. Wharton Index	0.81**	48	0.14	1.08**	48	0.2	2.12***	48	0.24
	[0.40]			[0.41]			[0.64]		
3. Wharton (Saiz)	0.69*	47	0.11	0.91**	47	0.14	1.89***	47	0.19
	[0.37]			[0.39]			[0.65]		
4. Saks: Combined	0.63**	33	0.27	0.74**	33	0.29	1.45***	33	0.36
	[0.30]			[0.32]			[0.45]		

This table shows the correlation between the estimated U.S. state gaps based on states with a laissez-faire value above 0 (col. (1)) or the 75th (col. (2)) or 90th (col. (3)) percentile of the laissez-faire value in the data (see Table A5) and existing measures of land use regulations circa 2010 (see text for details on each measure). Robust SE: * p<0.10, ** p<0.05, *** p<0.01.

Table A5: INCOME, LAND RENT & BUILDING HEIGHTS, U.S. STATES, 1930-2020

Dep. Var.:	Log Sum of Urban Heights (m) in Year t ($LUHT_t$)							
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	
States:	All	Resid.'17	Resid.'17	Resid.'17	≥ 0	≥ 0	≥ 0	≥ 0
Test:		≥ 0	$\geq$ p75	$\geq$ p90	Region Year FE	State Trend	Effects of Vars t	t+10 (Leads)
$LUGDP_t$	0.39***	0.57***	0.58***	0.57**	0.48**	0.29	0.56*	0.11
	[0.09]	[0.10]	[0.11]	[0.13]	[0.23]	[0.26]	[0.29]	[0.33]
$LAGRENT_t$	0.08**	0.1	0.16	0.48	0.11*	0.12	0.13	-0.04
	[0.04]	[0.06]	[0.11]	[0.31]	[0.06]	[0.09]	[0.08]	[0.07]
$LUHT_{t-10}$	0.83***	0.76***	0.71***	0.76***	0.80***	0.38***	0.75***	
	[0.03]	[0.04]	[0.06]	[0.08]	[0.05]	[0.07]	[0.05]	
Observations	447	222	116	44	222	222	222	222
State FE, Yr FE	Y	Y	Y	Y	Y	Y	Y	Y

	(8)	(9)	(10)	(11)	(12)	(13)	(14)	(15)
States:	≥ 0	≥ 0	≥ 0	≥ 0	≥ 0	≥ 0	≥ 0	≥ 0
Test:	Ctrls Commut. Costs	Log. Num Quakes x Yr FE	L.Bedrock Depth (m) x Yr FE	Share Elev. <SeaLevel x Yr FE	Rugged. SD Elev. x Yr FE	Geography U.S. Spec. x Yr FE	Land Protect. x Yr FE	Construct. Costs Year t
$LUGDP_t$	0.56***	0.64***	0.62***	0.59***	0.57***	0.60***	0.62***	0.59***
	[0.12]	[0.11]	[0.12]	[0.10]	[0.10]	[0.13]	[0.21]	[0.09]
$LAGRENT_t$	0.08	0.07	0.08	0.10*	0.10	0.05	0.09	0.1
	[0.05]	[0.06]	[0.06]	[0.06]	[0.07]	[0.04]	[0.07]	[0.06]
$LUHT_{t-10}$	0.72***	0.76***	0.75***	0.77***	0.76***	0.73***	0.74***	0.75***
	[0.04]	[0.05]	[0.06]	[0.04]	[0.04]	[0.06]	[0.06]	[0.04]
Observations	222	222	222	222	222	222	222	222
State FE, Yr FE	Y	Y	Y	Y	Y	Y	Y	Y

This table shows for 50 U.S. states x 10 years (1930, 1940, 1950, 1960, 1970, 1980, 1990, 2000, 2010, 2020) = 500 observations the effects of log total urban income ($LUGDP_t$), log agricultural rent ($LAGRENT_t$) and the log of the past urban height stock ($LUHT_{t-10}$). Col. (2),(3) and (4) eliminate states with residuals below 0, the 75th percentile, and the 90th percentile in a 2017 regression using log total urban income and log agricultural rent as covariates. Col. (5)-(15): We keep states with residuals above 0. The columns show that results hold when we include additional controls (see table notes just below for details on each specification). Since we control for the dependent variable in t-10, we lose one round of data. In addition, a few states have missing income data before 1950, hence N = 447 (col. (1)). **Col. (5)-(6):** We include 9 census region-year FE and state-specific linear trends, respectively. **Col. (7)** shows the effect of adding ten-year leads of the GDP and agricultural-rent variables, whose coefficients are insignificant. **Col. (8):** We capture commuting costs by controlling for whether there is a subway and the logs of the number subway lines and subway stations in the state in year t (source: Gonzalez-Navarro and Turner (2018) and Gendron-Carrier et al. (2018)) and the log of the total mileages of paved roads corresponding to "municipal / urban extensions of highway systems" or "other municipal / urban streets". The sources are *A Quarter Century of Financing Municipal Highways, 1937-61* (Bureau of Public Roads) and the annual *Highway Statistics* reports of the U.S. Department of Transportation. **Col. (9):** We control for the logged number of significant earthquakes that ever took place (per sq km) interacted with year FE. **Col. (10):** We control for the log of average (pop.-weighted) bedrock depth in the state's urban areas interacted with year FE. More precisely, we use the 30 seconds version of the bedrock depth data of Shangguan et al. (2017). We then use city boundaries from CIESIN (2017) (incl. all cities $\geq$ 1,000) to obtain the mean pop.(2000)-weighted average of bedrock depth (m). **Col. (11)-(12):** In col. (11), we control for the average (pop.-weighted) share of urban land that is located below sea level interacted with year FE. In col. (12), we control for the average (pop.-weighted) standard deviation of elevation in the state's urban areas interacted with year FE. We use the 15 arc-seconds version (breakline emphasis) of the elevation data from USGS (2010) and construct pop.-weighted averages for all cities in CIESIN (2017). **Col. (13):** We add U.S.-specific geographical controls, each interacted with a year trend: total land area and the shares of land unavailable for development due to excessive slope, the presence of wetlands, or the presence of bodies of water (source: Lutz and Sand (2017)). **Col. (14):** The geographical controls are replaced by time-interacted variables measuring the amounts of land under various types of government ownership (source: NRCM (2017)): federal government, state government, Bureau of Land Management, U.S. Forest Service, National Park Service, National Wildlife Refuge, Army Corps of Engineers, Military Bases, Tribal lands. **Col. (15):** We control for the RSMeans construction cost in the state in the same year. Indeed, as income increases, construction costs could increase, thus depressing construction. Controlling for construction costs then allows us to capture the direct effect of income. Robust SEs clustered at the state level: * p<0.10, ** p<0.05, *** p<0.01.

Table A6: EFFECTS FOR THE WORLD, INVESTIGATION OF CAUSALITY

Dep. Var.:	Gap (Log Urban Height Density (m per 000s Urban Inh.) in Year t (LUHTDENS$_t$))					
Check:	Baseline	Continent -Year FE	Region -Year FE	Country Trend	Country Trend Sq.	Ctrls for Commuting
	(1)	(2)	(3)	(4)	(5)	(6)
	Panel A: H Set (56 Observations; 8 Countries)					
LUPCGDP$_t$	3.23***	3.00***	3.28***	6.06**	6.91*	4.07***
	[0.61]	[0.47]	[0.49]	[2.13]	[2.99]	[0.40]
LAGRENT$_t$	0.19	-0.07	-0.25	-0.45	-0.41	0.18
	[0.40]	[0.48]	[0.85]	[0.59]	[0.80]	[0.31]
	Panel B: UMH Set (98 Observations; 14 Countries)					
LUPCGDP$_t$	1.54**	1.97**	1.95**	3.32**	3.91*	1.83*
	[0.67]	[0.82]	[0.75]	[1.32]	[2.06]	[0.88]
LAGRENT$_t$	0.55**	0.63**	0.59*	-0.05	-0.05	0.55**
	[0.26]	[0.29]	[0.31]	[0.61]	[0.76]	[0.22]
Check:	Effects of the Variables		Log. Num Earthquakes x Year FE	Log Bedrock Depth (m) x Year FE	Share Elev. < Sea Level x Year FE	Ruggedness SD of Elev. x Year FE
	t	t+10 (Leads)				
	(7)		(8)	(9)	(10)	(11)
	Panel A: H Set (56 Observations; 8 Countries)					
LUPCGDP$_t$	4.96**	-1.43	2.88***	2.87***	3.44***	3.13***
	[1.99]	[0.68]	[0.40]	[0.60]	[0.67]	[0.57]
LAGRENT$_t$	0.08	0.28	0.08	0.40	0.15	0.10
	[0.68]	[0.71]	[0.41]	[0.29]	[0.48]	[0.58]
	Panel B: UMH Set (98 Observations; 14 Countries)					
LUPCGDP$_t$	2.35***	-0.59	1.44**	1.66*	1.52*	1.53**
	[0.65]	[0.83]	[0.56]	[0.79]	[0.72]	[0.70]
LAGRENT$_t$	0.44	0.31	0.77**	0.43**	0.51	0.55*
	[0.78]	[0.74]	[0.26]	[0.18]	[0.29]	[0.28]

Col. (1) replicate the baseline results. Additional columns show that the results tend to hold for additional ten specifications. Col. (2)-(3) include continent (5)-year FE and World Bank region (7)-year FE, respectively. Col. (4)-(5) include country-specific linear trends and non-linear trends, respectively. Col. (6): We control for whether there is a subway and the log numbers of subway lines and subway stations in the country in t as well as the mean percentage share of country roads (incl. non-urban roads) that is paved during the period 1990-2017 interacted with a linear year trend. Col. (7) include the variables of interest defined in t+10. Col. (8): We control for the logged number of significant earthquakes that ever took place (per sq km) interacted with year FE. Col. (9): We control for the log of average (pop.-weighted) bedrock depth in the country's urban areas interacted with year FE. More precisely, we use the 30 seconds version of the bedrock depth data of Shangguan et al. (2017). We then use city boundaries from CIESIN (2017) (incl. all cities $\geq$ 1,000) to obtain the mean pop.(2000)-weighted average of bedrock depth (m). Col. (10)-(11): In col. (10), we control for the average (pop.-weighted) share of urban land that is located below sea level interacted with year FE. In col. (11), we control for the average (pop.-weighted) standard deviation of elevation in the country's urban areas interacted with year FE. We use the 15 arc-seconds version (breakline emphasis) of the elevation data from USGS (2010) and construct pop.-weighted averages for all cities in CIESIN (2017). Robust SEs clust. at the country level: * $p<0.10$, ** $p<0.05$, *** $p<0.01$.

Table A7: UMH-BASED GAPS AND ECONOMIC OUTCOMES, WORLD

Panel A: Country-Level Analysis

Source:	Angel's Regu.Data		World Bank '11		Global Prop.Guide'19		Knoll et al 2017	
Dep. Var.:	Max FAR:		Price Level (100)		Log Hous	Price-	Real Hous. Price t	
	Ctrls: N	Ctrls: Y	Hous.	Transp.	Price ($)	to-Rent	LongDiff	ShortDiff
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Gaps_{UMH}	-0.20**	-0.37***	3.32***	-0.67	0.18***	2.78***	13.27	8.33
	[0.01]	[0.00]	[1.19]	[1.30]	[0.04]	[0.60]	[16.62]	[6.01]
Cntry FE, Yr FE	N	N	N	N	N	N	Y	Y
Ctrls, Wgts	N	Y	Y	Y	Y	Y	N	N
Observations	49	47	147	147	72	70	28	83
Cntries, Yrs	49, 1	47, 1	147, 1	147, 1	72, 1	70, 1	14, 2	14, 6

Dep. Var.:	Share	Col. (10)-(14): Log Total Urban Land Area (Km) in ...					Log Particulate	
	Public	World	Col. (11)-(14): GHS t		Ctrl: Built-Up Area t		Matter Level (PM)	
	Housing	Bank '11	LongDiff	ShortDiff	LongDiff	ShortDiff	10	2.5
	(9)	(10)	(11)	(12)	(13)	(14)	(15)	(16)
Gaps_{UMH}	0.29	0.22***	0.06***	0.03**	0.05*	0.02*	0.05**	0.08***
	[0.61]	[0.04]	[0.02]	[0.01]	[0.03]	[0.01]	[0.02]	[0.02]
Cntry FE, Yr FE	N	N	Y	Y	Y	Y	N	N
Ctrls, Wgts	Y	Y	Y	Y	Y	Y	Y	Y
Observations	48	125	262	524	262	524	146	156
Cntries, Yrs	48, 1	125, 1	131, 2	131, 4	131, 2	131, 4	146, 1	156, 1

Panel B: Urban Agglomeration-Level Analysis

Dep. Var.:	Log Sum of Heights in Year t			Log Area		Congestion	Log PM 2017	
			Peri.Areas	in Year t		2017	10	2.5
	(17)	(18)	(19)	(20)	(21)	(22)	(23)	(24)
$\mathbb{1}$(100K-500K)*Gap_{UMH}	-0.02	-0.02	0	0.05	0.04**	1.14***	0.02	0.03*
	[0.04]	[0.01]	[0.00]	[0.03]	[0.02]	[0.37]	[0.02]	[0.02]
$\mathbb{1}$(500K-1000K)*Gap_{UMH}	-0.17	-0.13	0.01	0.09	0.05	1.43*	0.06**	0.06***
	[0.32]	[0.12]	[0.04]	[0.06]	[0.03]	[0.77]	[0.02]	[0.02]
$\mathbb{1}$(1000K+)*Gap_{UMH}	-0.85	-0.68***	-0.01	-0.02	0.01**	1.04	0.07**	0.08***
	[0.56]	[0.17]	[0.13]	[0.05]	[0.01]	[0.64]	[0.03]	[0.03]
City FE, Year FE	Y	Y	Y	Y	Y	N	N	N
Country-Year FE, Ctrls	Y	Y	Y	Y	Y	Y	Y	Y
Observations	23,438	46,876	46,876	17,040	34,181	391	1,473	1,473
Number of Cities	11,719	11,719	11,719	11,719	11,719	391	1,473	1,473
Number of Years	2	4	4	2	4	1	1	1

This table shows that the results of Table 4 hold if we use the UMH-based gaps instead of the H-based gaps. See text for details. Robust SE clustered at the country level in col. (7)-(8) and (11)-(14) of Panel A as well as in Panel B.

Table A8: ROBUSTNESS CHECKS FOR THE H SET REGRESSIONS

Dep. Var.:	Log Urban Height Density (m per 000s Urban Inh.) in Year t ($LUHTDENS_t$)					
	(1) Baseline	(2) Incl. U.S.	(3) Wt UrbPop	(4) Wt 1/UrbPop	(5) No HKG SGP	(6) Resid. 1980
LUPCGDP	3.23***	3.23***	2.75***	4.20***	2.59***	2.18**
	[0.61]	[0.63]	[0.33]	[0.45]	[0.41]	[0.96]
LAGRENT	0.19	0.24	0.07	0.46	-0.34	0.06
	[0.40]	[0.39]	[0.32]	[0.55]	[0.25]	[0.24]
	(7) No Gvt/Relig	(8) No Top 5	(9) Post-1980	(10) ≥25p(100)	(11) ≥Med(125)	(12) ≥Mean(135)
LUPCGDP	2.89***	3.22***	2.68***	2.53***	2.32*	2.39**
	[0.56]	[0.61]	[0.76]	[0.66]	[1.05]	[1.00]
LAGRENT	0.08	0.19	0.41	0.31	0.78	0.67
	[0.39]	[0.39]	[0.52]	[0.56]	[0.69]	[0.69]
	(13) No Floors	(14) Undergr.	(15) NoLagUHT	(16) LagUHT*YrFE	(17) LagUHTsq	(18) Lags Vars
LUPCGDP	3.07***	3.17***	3.73***	2.67***	3.25***	3.27**
	[0.67]	[0.61]	[0.32]	[0.44]	[0.70]	[1.14]
LAGRENT	0.55	0.20	-0.10	-0.10	0.21	0.51
	[0.41]	[0.39]	[0.45]	[0.30]	[0.44]	[0.57]
	(19) 5Yr Periods	(20) 15Yr Periods	(21) TotalGDP	(22) NoUrbLand	(23) Ag Land	(24) Drop Large
LUPCGDP	2.21***	4.10***	2.29**	3.23***	3.56***	3.28***
	[0.49]	[1.10]	[0.79]	[0.61]	[0.73]	[0.66]
LAGRENT	0.55	0.42	0.01	0.19	-0.45*	0.25
	[0.35]	[0.49]	[0.36]	[0.40]	[0.23]	[0.48]
Cntry FE, Yr FE	Y	Y	Y	Y	Y	Y
Lag LHUT	Y	Y	Y	Y	Y	Y

This table shows that the baseline results based on the H-based gaps tend to hold if we implement various robustness checks related to specification or choice of variables. The main sample has 56 observations (8 countries) from 1950-2020. Col. (2): Adding the U.S. to the set. Col. (3)-(4): Using urban pop. or (1/urban pop.) in t as weights. Col. (5) Excl. Hong Kong and Singapore. Col. (6): Using 1980 residuals to select the countries in the set. Col. (7): Excl. government or religious buildings. Col. (8): Excl. buildings among top 5 tallest at any point in 1950-2017. Col. (9): We interact the variables with a post-1980 dummy and reports the post-1980 effects only. Col. (10)-(12): Keeping buildings above the 25th percentile (100m), median (125m) or mean (135m) height in the data. Col. (13): Not using heights imputed based on the number of floors. Col. (14): Adding heights coming from underground floors. Col. (15): Not adding a lag of log urban height density. Col. (16): Interacting the lag of log urban height density with year FE. Col. (17): Adding the square of log urban height density. Col. (18): Adding lags of the two variables of interest and reporting the combined contemporaneous and lagged effects. Col. (19)-(20): Using 5-year or 15-year periods. Col. (21): Using log national per capital GDP (PPP). Col. (22)-(23): Land rent defined as agricultural GDP (t) divided by non-urban land (1990) or agricultural land area (t). Col. (24): Excl. countries with total land area above the mean in the sample. Robust SEs clust. at the country level: * $p<0.10$, ** $p<0.05$, *** $p<0.01$.

Table A9: ROBUSTNESS CHECKS FOR THE UMH SET REGRESSIONS

Dep. Var.:	Log Urban Height Density (m per 000s Urban Inh.) in Year t ($LUHTDENS_t$)					
	(1) Baseline	(2) Incl. U.S.	(3) Wt UrbPop	(4) Wt 1/UrbPop	(5) No HKG SGP	(6) Resid. 1980
LUPCGDP	1.54**	1.53**	2.02***	1.27*	1.21**	1.00**
	[0.67]	[0.68]	[0.44]	[0.60]	[0.53]	[0.40]
LAGRENT	0.55**	0.59**	0.20	0.58	0.37	0.29
	[0.26]	[0.25]	[0.28]	[0.58]	[0.29]	[0.22]
	(7) No Gvt/Relig	(8) No Top 5	(9) Post-1980	(10) ≥25p (100)	(11) ≥Med.(125)	(12) ≥Mean(135)
LUPCGDP	2.02**	1.54**	1.42***	1.92*	2.02*	2.09**
	[0.68]	[0.67]	[0.43]	[0.94]	[0.96]	[0.96]
LAGRENT	0.64**	0.55*	0.14	0.53	0.71*	0.81**
	[0.24]	[0.25]	[0.39]	[0.32]	[0.35]	[0.34]
	(13) No Floors	(14) Undergr.	(15) NoLagUHT	(16) LagUHT*YrFE	(17) LagUHTsq	(18) Lags Vars
LUPCGDP	1.75**	1.53**	2.51***	1.29*	1.64**	1.28*
	[0.72]	[0.66]	[0.70]	[0.64]	[0.62]	[0.64]
LAGRENT	0.63**	0.55**	0.53	-0.01	0.12	0.77***
	[0.27]	[0.25]	[0.33]	[0.35]	[0.40]	[0.23]
	(19) 5Yr Periods	(20) 15Yr Periods	(21) TotalGDP	(22) NoUrbLand	(23) Ag Land	(24) Drop Large
LUPCGDP	1.10***	2.20	1.42**	1.54**	1.32**	1.48*
	[0.36]	[1.27]	[0.59]	[0.67]	[0.55]	[0.68]
LAGRENT	0.65***	1.19***	0.27	0.55**	0.15	0.61*
	[0.17]	[0.26]	[0.20]	[0.26]	[0.32]	[0.29]
Cntry FE, Yr FE	Y	Y	Y	Y	Y	Y
Lag LHUT	Y	Y	Y	Y	Y	Y

This table shows that the baseline results based on the UMH-based gaps tend to hold if we implement various robustness checks related to specification or choice of variables. The main sample has 98 observations (14 countries) from 1950-2020. Col. (2): Adding the U.S. to the set. Col. (3)-(4): Using urban pop. or (1/urban pop.) in t as weights. Col. (5) Excl. Hong Kong and Singapore. Col. (6): Using 1980 residuals to select the countries in the set. Col. (7): Excl. government or religious buildings. Col. (8): Excl. buildings among top 5 tallest at any point in 1950-2017. Col. (9): We interact the variables with a post-1980 dummy and reports the post-1980 effects only. Col. (10)-(12): Keeping buildings above the 25th percentile (100m), median (125m) or mean (135m) height in the data. Col. (13): Not using heights imputed based on the number of floors. Col. (14): Adding heights coming from underground floors. Col. (15): Not adding a lag of log urban height density. Col. (16): Interacting the lag of log urban height density with year FE. Col. (17): Adding the square of log urban height density. Col. (18): Adding lags of the two variables of interest and reporting the combined contemporaneous and lagged effects. Col. (19)-(20): Using 5-year or 15-year periods. Col. (21): Using log national per capital GDP (PPP). Col. (22)-(23): Land rent defined as agricultural GDP (t) divided by non-urban land (1990) or agricultural land area (t). Col. (24): Excl. countries with total land area above the mean in the sample. Robust SEs clust. at the country level: * $p<0.10$, ** $p<0.05$, *** $p<0.01$.

Table A10: DETERMINANTS OF THE UMH-BASED GAPS, 2020

Dependent Variable:	UMH-Based ... Building-Height Gap 2020							
Considered Gap$_{UMH}$:	Overall (1)	Resid. (2)	Comm. (3)	Overall (4)	Overall (5)	Overall (6)	Overall (7)	Overall (8)
LPCGDP 1950	0.81***	0.69***	-0.03	0.91	-40.82*	0.55**	0.14	15.72
	[0.23]	[0.25]	[0.16]	[1.55]	[22.27]	[0.23]	[0.27]	[20.91]
ΔLPCGDP 1950-2020	1.99***	1.85***	0.83***	0.81	-48.58**	1.75***	1.82***	4.00
	[0.20]	[0.23]	[0.16]	[1.53]	[23.49]	[0.23]	[0.25]	[22.82]
Home Ownership Share (HO)				0.01				-0.06
				[0.15]				[0.13]
HO*LPCGDP 1950				-0.00				0.01
				[0.02]				[0.02]
HO*ΔLPCGDP 19502020				0.01				0.01
				[0.02]				[0.01]
Log Urb. Planners pc (LUPpc)					-59.79*			22.90
					[31.81]			[29.59]
LUPpc*LPCGDP 1950					5.98*			-2.43
					[3.22]			[2.97]
LUPpc*ΔLPCGDP 19502020					7.30**			-0.52
					[3.40]			[3.29]
Log 1800 Pop. Largest City (LPL1800)						-0.74**		0.25
						[0.36]		[0.61]
LPL1800*LPCGDP 1950						0.12***		-0.01
						[0.05]		[0.08]
LPL1800*ΔLPCGDP 19502020						0.01		-0.00
						[0.05]		[0.06]
Log World Heritage Sites pc (LWHSpc)							-24.91**	-23.07**
							[10.69]	[10.03]
LWHSpc*LPCGDP 1950							3.07**	3.00***
							[1.18]	[1.06]
LWHSpc*ΔLPCGDP 19502020							1.27	0.31
							[1.31]	[1.29]
Observations	158	158	158	105	158	158	158	105
Adjusted R-squared	0.38	0.26	0.13	0.27	0.42	0.41	0.43	0.44

This table shows that the results of Table 3 hold when we use the UMH-based gaps instead of the H-based gaps. Col. (1)-(7): PCGDP 1950 is log national per capita GDP (PPP, cst 1990 intl $) in 1950 and ΔLPCGDP 1950-2020 is the log change in per capita GDP between 1950 and 2020. Col. (2)-(3): We consider the gaps based on residential buildings (resid.) or commercial buildings (comm.) only. Col. (4): The home ownership share is available for the 2010s (N = 105). Col. (5): We use the log of the number of renown urban planners per capita today. Col. (6): We use the log of the 1800 population of the largest city today. Col. (7): We use the log of the number of cultural World Heritage Sites per capita today. Robust SEs: * $p<0.10$, ** $p<0.05$, *** $p<0.01$.