Cities Without Skylines: Worldwide Building-Height Gaps and their Implications

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Abstract

There is a relatively 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, and pollution. Taken together, the results suggest that stringent building-height regulations around the world are imposing relatively large welfare losses.

JEL Codes: R3, R5, O18, O50

Keywords: International Buildings Heights; Tall Buildings; Skyscrapers; Land Use Regulations; Housing Supply; Housing Prices; Sprawl; Congestion; Pollution

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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. But in many countries, housing prices are growing more rapidly than incomes (Knoll et al., 2017), and evidence suggests that this price escalation may be partly caused by various physical and regulatory barriers that reduce housing supply (Glaeser et al., 2005; Saiz, 2010). In particular, cities impose various land-use regulations (Gyourko et al., 2008, 2019), including restrictions on building heights and limits on developable land areas via urban growth boundaries. These supply-reducing regulations not only have impacts today but may generate significant effects well into the future, given the durable nature of real estate (Glaeser and Gyourko, 2005). While the extent, and local and aggregate impact, of land use regulations has been extensively studied for the U.S., there are no such studies for the whole world. Offering such a study is the aim of this paper.

In the United States, many studies show that, by restricting supply, regulations raise housing prices (Ihlanfeldt, 2007; Gyourko and Molloy, 2014; Jackson, 2018). In addition, Hsieh and Moretti (2019) quantify the misallocation of labor resulting from land use regulations, which limit access to high-productivity cities. Regulation is thus viewed as generating a variety of undesirable short-run and long-run consequences.

In order to study regulatory impacts, the extent of land-use regulation must first be measured. Its extent in U.S. cities has been captured through a number of different regulatory surveys, which present local government officials with a long list of different types of potential regulations, asking which ones are used in their locality. While some surveys focus on specific localities or specific states (Glickfeld and Levine, 1992; Ihlanfeldt, 2007; Jackson, 2018), Gyourko et al. (2008) and Gyourko et al. (2019) carry out more ambitious national surveys, using the responses to compute a regulatory index for individual cities or states across the country.

Rather than measuring the extent of regulation, other studies attempt to measure its stringency, defined as the degree to which regulations cause development decisions to differ from free-market outcomes. Brueckner et al. (2017) and Brueckner and Singh (2018) develop a method for direct measurement of the stringency of building-height regulations, while Glaeser et al. (2005) take a more indirect approach by measuring the gap between housing prices and input costs, which they call the "regulatory tax".[1]

As important as the works of Gyourko et al. (2008) and Gyourko et al. (2019) are for the United States, no international measures like their exist. Furthermore, their indexes do not directly measure building-height restrictions in the central areas of cities. Rather, they focus on frictions due to the permitting process and on other land-use regulations that are more likely to impact low-rise dwellings in suburban parts of the city. Our work also takes a more direct approach to investigating the causes and economic consequences of building-height variation around the world.

Across countries, some cities appear more willing than others to construct tall buildings in their central cities as a way to accommodate economic and population growth. Cities in China, for example, embrace tall buildings (Barr and Luo, 2018), whereas cities in India have draconian height restrictions (Brueckner and Sridhar, 2012b). Some cities in Europe seem to represent an intermediate case, with tall buildings emerging in London and Frankfurt, although other cities, especially in southern Europe, have few tall buildings. These patterns raise two questions. First, how many tall buildings are possibly "missing" in each country and the world overall? Second, what could be the economic and environmental consequences of these building-height gaps?

Our approach makes use of a remarkable geospatialized data set that inventories all the world's tall buildings (mostly buildings above 80 m, hence 20 floors), with information on their year of construction and height. Using a set of advanced countries as a benchmark, we ask whether the stock of tall buildings in a country outside this set is smaller than expected given the country's characteristics. The resulting gap is viewed as a potential indicator of the stringency of the country's building-height regulation.

More specifically, we start by running a panel regression relating a weighted measure of the tall building stocks in the set of identified benchmark countries to two variables suggested by the standard urban model (the main model used to study urban land use): income and agricultural land rent.[2] Then, for countries outside the benchmark group,

[1]See Bertaud and Malpezzi (2001), Turner et al. (2014) and Albouy and Ehrlich (2018) for additional work on land-use regulation. For other research on building heights, see Ahlfeldt and McMillen (2018), Barr (2010), Barr (2012), Barr (2016), Barr and Cohen (2014), Liu et al. (2018), Bertaud and Brueckner (2005a), Brueckner and Sridhar (2012a), Joshi and Kono (2009), Kono and Joshi (2012), and Moon (2019).

[2]See Brueckner (1987) and Duranton and Puga (2015) for a detailed explanation of the model.

we plug values for these variables into the estimated equation, yielding a predicted size for the tall building stock if the country's regulatory practices followed those in the benchmark group. The difference between the prediction and the country's actual tall building stock is the *building-height gap*. In addition, we carry out a variety of sensitivity tests to ensure that the estimates from the benchmark regression generating the height gap are robust, including estimation using a state-level panel for the United States.

We find that the world should have twice as many tall buildings as observed today if countries outside the benchmark group were to follow the group's practices. We then show that the gaps are relatively larger for richer countries. Poor countries have few tall buildings, but it is not because land-use regulations are binding but because their income level is low. Furthermore, knowing the main function of each building, we document that gaps are larger for residential buildings than for office buildings. Thus, cities appear more open to creating jobs than to receiving residents. Next, we verify that the estimated gaps correlate with other (imperfect) international measures of building regulations.

Consistent with theory, tall buildings are disproportionately found in the central areas of larger cities, which we confirm using city-level data for a world sample of almost 12,000 agglomerations. Logically, building-height gaps are driven by the central areas of larger cities. We then ask if central city gaps are compensated in any way by tall buildings construction in peripheral areas of cities or less stringent limits on outward expansion beyond the existing boundaries of the cities, reaching a negative conclusion.

Furthermore, at the world level, we find that the gaps correlate with measures of housing prices, sprawl, congestion, and pollution. Interestingly, while total urban land area increases with the gaps, we do not find that the gaps disproportionately increase land area in larger cities (relative to smaller cities), thus suggesting that the stringency of building-height restrictions in the largest cities is compensated by sprawl in, and thus migration to, smaller cities.[3] In addition, most of the correlation with congestion and pollution is explained by the correlation with sprawl. Thus, height restrictions are associated with an increase in housing prices throughout the city and to its spatial expansion, with the land and ecological footprints growing in response to the restrictions.

[3]This result directly echoes the work of Hsieh and Moretti (2019) who posit that the largest, and most productive, cities are undersized as a result of land use regulations.

Most of our analysis is cross-country in nature. While recognizing that city-wide analysis can be important, a countrywide analysis like ours is both important and necessary. First, the main objective of this study is to obtain a measure of building-height restrictions for as many countries as possible. By construction, the analysis thus has to be cross-country. Second, only a handful of countries – most of them developed – have consistent city or state-level GDP and land rent data over several decades, ruling out a worldwide, within-country study. Third, we do perform our analysis for U.S. states to assess the validity of the methodology. In particular, our estimated state gaps are strongly correlated with the housing supply elasticities of (Saiz, 2010) and the Wharton Index of Gyourko et al. (2008). They thus capture supply restrictions at the subnational level. Fourth, within-country analyzes miss the fact that stringent building-height restrictions in specific cities or states may be circumvented by migration to less stringent locations in the same country. By focusing on countries, among which mobility is usually restricted, we capture gaps that cannot be as easily offset by migration.

Finally, inspired by the recent analysis of Hsieh and Moretti (2019), we conclude our analysis by performing some relatively simple analysis that shows that removing gaps could lead to an increase in world GDP of 16-17%. More generally, to address housing affordability and traffic congestion issues, governments often spend considerable sums of money to spatially expand their private and public transportation networks. While such policies allow city residents to live farther away from central business district(s) in cheaper housing, removing building-height restrictions might have similar effects at a much lower cost. As city residents do not have to live as far from the center, they may commute shorter distances, thus minimizing sprawl and pollution.

The plan of the paper is as follows. Section 1 provides the conceptual foundations for the regressions that we run. Section 2 discusses the data, and Section 3 discusses the international regression results and the associated building-height gaps. Section 4 shows that the gaps correlate with measures of regulations, housing prices, sprawl, congestion, and pollution. Sections 5 and 6 report a series of robustness and causality checks. Section 7 provides some welfare analysis aimed at generating initial estimates of the economic distortions created by building-height regulations.

1. Conceptual Framework

1.1. The Standard Urban Model

The "standard urban model", as exposited by Brueckner (1987) and Duranton and Puga (2015), depicts the determination of building heights, as measured by output of floor space per acre of land. In the model, consumers value access to jobs in the city center, which leads to both higher housing prices and higher land rents near the center. Faced with expensive land, developers construct taller buildings near the center to limit use of the expensive land input. In the equilibrium of a closed city (where population is fixed), building heights depend on the city's characteristics, which include population P, per capita income y, commuting cost t per mile, and the agricultural rent r_a for the land surrounding the city. A higher P or r_a raises building heights throughout the city. To accommodate the greater demand from a larger P, the city must be denser, with taller buildings, and by increasing the cost of rural-to-urban land conversion and thus making the city more compact, a higher r_a's also generates taller buildings.

A higher y causes urban decentralization as residents find the cheap suburbs more attractive for the bigger dwellings they now prefer.[4] This demand shift tends to raise building heights in the suburbs while decreasing them near the city center, yielding a spatially complex income effect (a higher commuting cost t leads to the opposite impacts).

To make use of these predictions in a cross-country study, the fact that countries become more urbanized as they get richer can be exploited. This tendency implies that city populations in a country tend to rise with the general income level, implying that y and P tend to increase in step with one another moving across countries. Allowing these variables to change together, the result is a tendency for building heights to rise uniformly across space within cities as country income increases, simplifying the complex height effect from above. In particular, with cities tending to be bigger in high-income countries, the positive population-induced effect on building heights offsets the negative height effect in the central city due to income-induced decentralization. As a result, buildings in the high-income country's cities will tend to be taller in the center as well as the suburbs.

[4]The locational equilibrium balances the gains from cheaper housing against the losses from higher commuting cost. If everyone now wants a bigger dwelling because of higher income, the gains from cheaper housing are now more important, creating an incentive to move farther from the CBD.

Therefore, in a regression like ours that relates building heights to a country's income and agricultural rent, the income and agricultural rent coefficients should be positive.

1.2. Additional Elements

The standard urban model above is quite simple in that it assumes no urban amenities. But it is reasonable to assume that as cities achieve higher incomes, they add more urban amenities (cultural venues, shopping options, monuments, etc.), which tend to be downtown. By making city centers more desirable as income rises, amenities can reverse the income-driven tendency toward decentralization, strengthening the tendency of building heights to rise at all locations when income increases.

In addition, if wealthier, larger cities tend to have greater commuting costs due to traffic congestion or because the opportunity cost of commuting time increases with wages, the price premium for central locations will be higher, generating even taller buildings in the center. Combined with growing population and amenities as income rises, the tendency for building heights to rise with income is amplified.

Finally, if we add business land-use to the residential use already in the model, the association between country income and building heights is likely to be magnified. High country incomes tend to be associated with the presence of service sector firms, which may value being located in city centers in order to reduce the costs of accessing inputs (including information) and consumers. Thus, higher incomes should increase the demand for office space in city centers and cause tall building construction there.

In summary, the theories of urban spatial structure suggest an empirical specification in which a measure of the stock of tall buildings is regressed on income and agricultural rent, with the expected coefficient signs both being positive. The analysis, however, applies to a city with perfectly malleable capital, where building heights adjust immediately to reflect current conditions. In reality, tall buildings are long-lived, having been built in response to current conditions at the time of construction and lasting decades. In a model recognizing this longevity, income and agricultural rent would only determine the *increment to the tall-building stock* through an effect on new construction. The existing tall-building stock would also be a determinant of this increment, with a large stock of tall buildings potentially depressing the need for new ones.

These considerations suggest a regression with the existing tall-building stock as dependent variable and the lagged stock, income, and agricultural rent as covariates. In this specification, the depressing effect of a large previous stock on new construction is manifested by a lagged stock coefficient that is positive but less than one. In this case, a given increase in the past stock raises the current stock by a smaller amount via a reduction in the volume of new construction.

Finally, the exact definition of the tall-building stock measure requires discussion. As mentioned above, the stock measure is a weighted one, with each building weighted by its height. Since the stock is measured for the entire country, not for individual cities, it is appropriate to divide the weighted stock variable by the size of the country's urban population. The dependent variable is thus the country's height-weighted stock of tall buildings *per capita*, which we call "urban height density."

2. Data and Background

2.1. Data

To estimate our model, we collected data on building heights, urban populations, urban incomes, and agricultural land rents for as many countries and years as possible. Our main sample comprises 158 countries annually from 1950 to 2017. Here, we briefly summarize the data and sources, but more details are available in Appx. Section 1.

Building Heights. The Council on Tall Buildings and Urban Habitat (CTBUH) maintains a publicly available online database of all *tall buildings* in the world.[5] For each building, we extracted information on the building's height, year of construction, usage, and several other characteristics. According to CTBUH's website, they do not use a consistent definition of tall buildings. However, as described in Appx. Section 1, the database mostly captures buildings above 80 meters. Since some countries have no such buildings, and in order to avoid having their stock of heights equal to 0 when using logs, we consider for each country buildings above 80 meters as well as their 10 tallest buildings even if some of them are below 80 meters. In the end, we use 16,369 tall buildings.[6]

[5] The full online database can be found here: http://www.skyscrapercenter.com/. As one example, the webpage for the Burj Khalifa is found here: http://www.skyscrapercenter.com/building/burj-khalifa

[6] According their website, the data have been "collected by the Council 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 with the help of "an Editorial Board".

Urban Population. United Nations (2018) gives the urban population of each country every 5 years from 1950 to 2020. We interpolate the data for intermediate years.

National Income. Our main source is Maddison (2008), where we obtain per capita GDP for each country annually from 1950 to 2008 (in 1990 Geary-Khamis dollars, which is equivalent to PPP and constant international 1990 $). We use per capita GDP growth rates from World Bank (2018) to reconstruct per capita GDP from 2008 to 2017.

Agricultural Land Rent. We estimate a country's agricultural land rent by dividing agricultural GDP by the total land area. We use as our main source FAO (2018), which shows the agricultural GDP shares for many countries annually from 1960 to 2017. For country-years that are still missing, we use additional sources and interpolations as needed (again Appx. Section 1). We use total land area as the divisor instead of agricultural land area because the latter area is missing for almost all countries before 1960. In addition, a significant share of non-agricultural and non-urban land can potentially be used for agricultural purposes or be converted into urban land.

Land Area. From FAO (2018), we know total land area. We also know agricultural land area annually from 1960 to 2017. We extrapolate the data to the year 1950.

Urban Income. Knowing for each country-year total GDP (PPP and constant international $) and the agricultural GDP share, we can reconstruct urban GDP, which we define as non-agricultural GDP.[7] Knowing urban GDP, we can then estimate urban per capita income as urban GDP divided by urban population.

Urban Height Density. When logged, this is our dependent variable, equal to the sum of the heights of the country's tall buildings in a given year divided by the urban population for that year. We sometimes distinguish residential and commercial tall buildings.

Other Variables. We know from the World Bank the income group of each country in 2017 ("low'," "lower-middle," "upper-middle" or "high income").[8] High income countries are viewed as developed. From The Economist Intelligence Unit (2018), we know whether each country was democratic at any point in the 2006-2017 period (data not available

We will show that measurement error in building height stocks should not impact our results.

[7]The implicit assumption here is that most valuable industrial and service activities take place in urban areas, a stylized fact confirmed for a large sample of countries by Gollin et al. (2015).

[8]datahelpdesk.worldbank.org/knowledgebase/article s/906519-world-bank-country-and-lending-groups.

before). Countries are considered democratic if they are “full” or “flawed” democracies.

2.2. Descriptive Patterns

Figure 1(a) shows the evolution across time of the urban height-density measure for the U.S. along with the evolution of the same measure summed across all the world’s cities. As can be seen, the U.S. contained virtually all of world’s tall buildings up to 1950, with the two curves diverging thereafter. In recent years, the tall-building stock outside the U.S. has grown rapidly. Figure 1(b) shows the world evolution of the total stock of heights separately for residential buildings and commercial buildings from 1920 to 2017. As can be seen, most tall buildings were commercial – i.e., mostly office buildings – until 2000. It is only after 2000 that tall residential buildings were built at a faster pace than commercial buildings. Circa 2017, both residential buildings and commercial buildings each contribute about half of the total stock of heights in the world.

Figure 2 shows the relationship between the country-level log of urban height density in 2017 and the log of national GDP per capita for that year. As expected, the relationship is positive, with a strongly significant slope coefficient of 1.35*** and an R^2 of 0.52 (1.41*** and 0.67 if using urban population weights). Countries above the line have more tall buildings than expected based on their income (e.g., Canada – CAN –), while countries below the line (e.g., Ireland – IRL –) have smaller tall-building stocks than expected.

3. Generation of the Gaps

3.1. Regression Results for the Determinants of Building Heights

With Figure 2 showing that income matters in determining the stock of tall buildings, we now turn to regressions using more years of data. Table 1 shows panel regressions over the period 1950-2017. Up to 2010, the year interval is decades, with 2017 added as the last yearly observation (years are thus 1950, 1960, 1970, 1980, 1990, 2000, 2010, 2017 – which we call 2020 –). The explanatory variables are those identified by the theory, and for which panel data are available: the log of per capita urban GDP (LUPCGDP), the log of agricultural land rent (LAGRENT, derived as explained above), and the lagged value of the dependent variable, log of urban height density (LUHTDENS). We always include country and year fixed effects, with standard errors clustered at the country level.

Column (1) of Table 1 shows a panel regression for the entire set of 158 countries. The per capita GDP coefficient is positive and strongly significant, as is the lagged height-density variable. As expected, the coefficient on this variable is less than one, indicating that an increase in the lagged tall-building stock leads to a less than one-for-one increase in the current stock, given that the increase in the prior stock depresses new construction. The agricultural-rent coefficient while positive, is not statistically significant.

In col. (2), the sample is restricted to 73 countries with a positive residual in a 2017 regression that relates LUHTDENS to LUPCGDP and LAGRENT. These are countries where the tall-building stock is higher than could be expected today given the magnitudes of the covariates, a simple way to select laissez-faire countries. We will show later that other approaches lead to similar selections of countries. Naturally, the GDP coefficient is larger than in col. (1). The effect of agricultural land rent becomes positive and significant.

In column (3), the sample is restricted to 14 democratic upper-middle (henceforth, "UM") or high ("H") income countries whose residual is above the 75th percentile (p75) value (= 0.62). We restrict the sample to more democratic and more developed countries because market forces are likely less free to operate in other countries. In addition, skyscrapers are more likely to be "white elephants" in such countries, thus creating a disconnect between economic conditions and heights. In column (4), we further exclude UM countries, thus focusing 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, Malaysia, North Macedonia, Panama and Thailand. The U.S. is not included in the list. While the U.S. is traditionally associated with skyscrapers, it has very high income and agricultural rent and a large urban population. The U.S. is strikingly close to the regression line in Figure 2, thus suggesting that the U.S. does not have disproportionately tall buildings given its economic conditions. As we will show later, it is mostly because California has relatively few tall buildings, thus offsetting the contributions of New York City or Chicago. Columns (5) and (6) then replicate columns (3) and (4), but with the height variable computed only using residential buildings, while columns (7) and (8) use only commercial buildings.

If we use the UM-H sample (col. (3)), the GDP coefficient is three times larger than in column (1), while the effect of agricultural rent is four times larger and significant. If we use the H sample (col. (4)), the GDP coefficient doubles relative to column (3). In this regression and the other ones, the insignificance of the agricultural rent coefficient is inconsistent with the theory, but this outcome is due to the variable's strong correlation with income at the country level. In a regression where agricultural rent is the only covariate, its coefficient is always positive and significant at the 10% level (not shown).

Lastly, the adjusted R^2 values are 0.87 and 0.91, respectively, in columns (3) and (4), showing the explanatory power of income, agricultural rent, past height density and the year fixed effects.

3.2. Computation of the Building-Height Gaps

To generate the height gaps, we iterate each of the benchmark regressions, respectively, to get predicted heights for 2020, and then compare those heights to the actual 2020 data. The iteration proceeds as follows. Predicted log heights for 1960 are found by evaluating

$$\widehat{\text{LUHTDENS}}_{1960} = \alpha + \beta\text{LUPCGDP}_{1960} + \gamma\text{LAGRENT}_{1960} + \delta\text{LUHTDENS}_{1950}. \tag{1}$$

For simplicity, the year fixed effects are omitted in writing (1).[9] Then, to get predicted log building heights for 1970, we rewrite (1) with 1970 values for the first two covariates and with the 1960 predicted value playing the role of LUHTDENS_{1960}:

$$\widehat{\text{LUHTDENS}}_{1970} = \alpha + \beta\text{LUPCGDP}_{1970} + \gamma\text{LAGRENT}_{1970} + \delta\widehat{\text{LUHTDENS}}_{1960}. \tag{2}$$

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

$$\text{GAP}_{2020} = \widehat{\text{LUHTDENS}}_{2020} - \text{LUHTDENS}_{2020}, \tag{3}$$

or the difference in predicted and actual log height densities.

Once the gaps are estimated, we investigate below how a change in the size of the gap can alter particular outcome variables, such as housing prices. It is thus helpful to derive the connection between a gap change and underlying changes in the country's building

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

stock. Letting Δ denote change, the answer is immediate from differentiating (3):

$$\Delta \text{GAP}_{2020} \approx -\frac{\Delta \text{UHTDENS}_{2020}}{\text{UHTDENS}_{2020}} \tag{4}$$

In deriving (4), note that the predicted height density stays constant as the gap changes. Using (4), if $\Delta \text{GAP} = -0.5$, this change implies a 50% increase in height density, while a unitary decrease in the gap corresponds to a 100% increase in height density.

We also use the corrected antilog of $\text{LUH}\widehat{\text{TDENS}}_{2020}$ to obtain $\text{UH}\widehat{\text{TDENS}}_{2020}$ and compare it to UHTDENS_{2020} to obtain the gap expressed in km of heights per urban capita.[10] Finally, knowing urban population, we obtain the total km gap.

3.3. World Rankings

Table 2 ranks the top 20 countries in terms of the three gap measures just discussed and using the H set as our benchmark set. Col. (1) shows the ranking based on percentage change in actual urban height density required to close any gap. Various European countries are found in the list (e.g., Ireland, Switzerland, Italy, France and Germany). These results certainly concord with common beliefs that European countries tend to be more stringent in regulating heights than other nations with similar income levels (see, for example, Barr and Lyons (2018) for Ireland). However, percentage changes are mechanically larger when the denominator is small. Thus, the percentage gap is mechanically larger in countries with small building height stocks today (e.g., Uzbekistan and Equatorial Guinea). If instead we study the ranking based on the absolute per urban capita gap (km per million of urban inhabitants) (col. (2)), we can see that the list is now dominated by developed countries, and large-stock countries such as the United States (U.S.) and the United Kingdom (UK) are highly ranked. Finally, the total km gap of a country is the product of the per urban capita gap and urban population. Then the U.S. (1,468 km), Taiwan (219), Japan (174), the UK (172) and Germany (168) dominate the list.[11]

In 2020, the data show 2,198 km of total height worldwide. Using the full results of

[10] More precisely, we take the antilog of the predicted values and adjust them by a correction factor to get unbiased predicted heights. Indeed, when generating $exp(ln(\widehat{y}))$ we need to correct this value because of the fact that $E(exp(ln\widehat{y}))$ does not equal $E(\widehat{y})$. We follow the method suggested by Wooldridge (2016).

[11] Web Appx. Fig. A2 shows the per capita gap for each country. Australia, Brazil, Canada, the Gulf States, Hong Kong, Malaysia, Mongolia, North Korea, the Philippines, and Panama are countries with negative gaps, i.e. an excess of building heights relative to the H benchmark set of countries.

column (4) and summing predicted values across countries, we get total predicted heights of 4,828 km, which generates a world gap factor of 2.2, indicating that the total height of the world's tall buildings would be 2.2 times greater if the more stringent countries were similar to the benchmark set. If we use the regression for the UMH benchmark set (col. (3)), we get a predicted total of 2,046 km. What explains the difference in the gaps? When using UMH, income and agricultural rent have positive and significant effects but the effect of income is half of the effect when using H. Thus, when using H, high income countries are more likely to have large gaps, leading to a large total gap value. With UMH, gaps are smaller for such countries and more likely to be negative. The gaps for rich countries are also compensated to some extent by the negative gaps observed in countries where skyscrapers may be built as "white elephants" (e.g., Saudi Arabia).

While the percentage change is useful, we verify that the resulting ranking of countries is correlated with the ranking based on the absolute measure, i.e. the per capita gap in column (2) of Table 2. For the UMH and H benchmark sets, we obtain correlations of 0.65 and 0.66, respectively. However, if we weight the country gaps by the urban population of each country circa 2020, we obtain correlations of 0.77 between percentage and absolute rankings for both sets. Indeed, the weights minimize the issue coming from low-stock countries having mechanically larger percentage gaps. Now, the ranking of countries does not depend much on whether we use UMH or H. Indeed, for a same measure, the ranking between the UMH-based ranking and the H-based ranking is 0.85-0.89.

Richer vs. Poorer Countries. If we compare the gaps across World Bank regions, we find that the gap per urban capita is the highest in North America (5.3 km per million urban residents), next highest in Europe & Central Asia (1.3) and next highest in East Asia & Pacific (0.4). Almost no gap is observed for South Asia (0.1) and Africa (0). Latin America and the Middle East & North Africa both have negative gaps (-0.3 and -0.5, respectively). Historically rich countries are thus the main contributors to the building-height gaps observed in the world. Columns (1) and (4) of row 1 in Table 3 indeed show that the gaps – based on UMH in col. (1) and H in col. (4) – are positively correlated with initial per capita income levels in 1950. Row 2 then shows that gaps are high in countries where income increased between 1950 and 2015. Thus, fast-growing countries post-1950 apparently did not adjust their land use regulations in step with their fast growth.[12]

[12]However, the gaps are constructed using the estimated effect of income as well as decadal income

U.S. Case. These patterns could help to explain the large building-height gaps for the United States, which may seem counterintuitive given the substantial stock of tall buildings in the US. In particular, many of the country's tall buildings were built prior to 1950, and the large current gaps may reflect a failure of US tall-building construction to match income growth to the same extent as in other parts of the world, particularly Asia.[13] As a result, with the gaps that we compute influenced by the experiences of such countries, it may not be surprising that the US gaps are large, particularly in view of the country's high income growth. Lastly, as we will show later, the U.S. gap is driven by California, and if California were like the "best" U.S. states, the U.S. would be ranked around 20th in per urban capita gap instead of 8th (col. (2)).[14]

Residential vs. Commercial Buildings. Row 1 in Table 3 provide further evidence on the sources of the gaps by showing that the gaps in richer countries are driven by residential buildings (col. (2) and (4)). If anything, for the H set, we find significant negative commercial gaps for initially richer countries (col. (6)). Likewise, row 2 shows that if we also include the change in log per capita income between 1950 and 2020, we find that the residential gaps remain stronger than the commercial gaps in richer countries. The commercial gaps increase with income growth, but, again, interpretation is made difficult by the fact that the gaps are constructed using income. Overall, these results suggest that cities might be more open to creating jobs than receiving new residents.

4. Correlates of Country Gaps

4.1. Other Measures of Land Use and Building Regulations

If the gaps are used as an international regulatory-stringency measure, it is important to examine the degree to which they correlate with other measures of building regulations. As explained in the introduction, there are almost no direct international measures of

changes over the period 1950-2020, which make the latter effect difficult to interpret.

[13]The Great Depression halted the very fast tall building construction observed in the 1920s. In particular, urban height density (km per million urban inhabitants) increased by about 1 between 1930 and 2020, roughly matching the increase between just 1900 and 1930.

[14]If we use the same specification as in Table 1 but for the U.S. only (N = 8), the coefficient of urban income is 50% smaller than for UMH (0.99*** vs. 1.54**) whereas the effect of land rent is similar (0.68* vs. 0.55**). If we study the U.S. between 1870 and 1940 (N = 7), thus dropping the World War II decade, we obtain higher effects, at 2.74** and 2.22**. This suggests that skyscrapers in the U.S. were much more responsive to economic conditions before 1950. In fact, many land use regulations were adopted in the 1960s – for example, New York City reformed its zoning ordinance in 1961 –, which corroborates our results.

land use regulations. Nonetheless, Table 4 presents regression results where we regress the gaps on several indirect land-use regulation variables.

In columns 1-3, the independent variables are three measures 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.[15] The UMH-based gaps are reduced if (row 1): (i) fewer procedures are required to obtain approval for building a warehouse (col. (1)); (ii) the cost of obtaining approval is lower (col. (2)); and (iii) building regulations are of higher "quality", hence more stringent (col. (3)). These correlations are weaker in row 2: the effect of procedures is only significant at the 15% level and the effect of total costs disappears. However, these variables do not specifically capture tall buildings in cities.

In column (4), we test how the gaps correlate with a measure of the extent to which the system of landlord and tenant law and practice is pro-landlord.[16]. We find reduced gaps in pro-landlord countries, possibly because the landlord-friendliness of the system captures how pro-urban-development a country's regulatory stance may be.

Next, from Caldera and Johansson (2013), and for 21 OECD – i.e., developed – countries only, we obtain measures of the elasticity of the price responsiveness of housing supply and of the speed of housing supply adjustment. We use these measures in columns (5)-(6). Row 1 results suggest that more housing-supply-elastic countries have lower gaps. The row 2 effects are also negative but are not significant.

Finally, in columns (7)-(8), we use building-height variable from a regulatory database established by Solly Angel. Angel's data set has 195 cities of at least 100,000 residents in 2015. For each city with obtainable data, the index includes the maximum Floor Area Ratio (FAR) (N = 95), the maximum building height (N = 114), and the maximum number of dwellings per acre (N = 35). However, one important limitation of this data set is that information is available only for the peripheral areas of cities. Therefore, to be able to use these variables, we must assume that they can serve as good proxies for the same variables in the central areas of the cities. Combining the information from these variables gives information on building-height regulations for 138 cities in 51 countries, using the

[15]See https://www.doingbusiness.org/en/data/exploretopics/dealing-with-construction-permits.

[16]See 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.

maximum FAR as the main measure. For cities for which we know maximum building height but not the maximum FAR, we can predict the maximum FAR from a simple regression. We also use such a prediction based on maximum number of dwellings to gain more cities for the sample. For countries with multiple cities in the Angel data, we average the maximum FAR values using the population of each city. This yields country values for 49 out of our 158 countries. As can be seen, our building-height gaps show the expected negative relationship to this regulation measure, with a higher maximum FAR (indicating weaker regulation) yielding a lower building-height gap.

Now, for more or less the same cities used to compute the maximum FAR for each country, Angel's database provides information on other land use regulations, which we use to answer two related questions: (1) Do our gap measures capture land use regulations other than building-height restrictions? (2) Do countries with more stringent building-height restrictions "compensate" their urban residents by having more lenient regulations in other dimensions that are not captured when focusing on tall buildings? To a large extent, the answer to both questions is no. First, Appx. Table A1 shows that the correlation between our gap measures and the maximum FAR values actually increases when we control for ten other land use policies. In addition, 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.[17]

Second, if high-gap countries compensate their residents by having more lenient regulations in other dimensions, we should find a strong negative correlation between our gaps and these other measures of land use regulations (when transformed so that higher values imply more stringent regulations). However, the correlation is slightly positive in the majority of cases or weakly negative (the two most negative correlations we obtain are -0.17 and -0.28 for UMH and -0.11 and -0.14 for H; see Web Appx. Table X). In particular, the high-gap countries are not less likely to restrict sprawl through explicit urban containment policies (0.10 for UMH and -0.02 for H).

[17]We know for 47-49 cities if: (i) the city has a strong containment policy; (ii) there is a greenbelt or an urban growth boundary; (iii) there are strong zoning laws; and (iv) if the government acquires land to plan for urban land expansion; (v) if there is a minimum allowable plot size for construction; (vi) the typical numbers of months before a permit is obtained to subdivide land and a permit is obtained to build on that land; and (vii) if streets are delineated and infrastructure is provided by the government or a public-private partnership or whether streets and infrastructure are developed in a more haphazard fashion.

4.2. Building-Height Gaps, Housing Prices, and Urban Sprawl

Housing Prices. International organizations do not systematically collect data on housing prices across countries. However, the *International Comparison Program* of the World Bank reports for the year 2011 the price level of housing and other broad consumption categories (relative to the world = 100).[18] In column (1) of Table 5, we regress the price level of housing on the gaps (based on UMH in row 1 and H in row 2), while simultaneously controlling for log nominal per capita GDP circa 2010 (source: *World Development Indicators* of the World Bank) and using as weights the urban population of each country circa 2010. We control for nominal GDP instead of using the previous PPP-adjusted GDP because higher housing prices would be captured by PPP adjustments. As can be seen, the gaps are highly correlated with housing prices. The magnitude of the effect is large too: A one standard deviation increase in the gap (a value of about 2) is associated with a 0.12-0.15 standard deviation increase in the price level. Alternatively, a unitary decrease in the gap reduces housing prices by 3-4 percent. Recall from above that such a unitary decrease corresponds to a 100% increase in actual height density.[19]

Countries with more stringent land use regulations could compensate their urban residents by subsidizing commuting, for example via public investments in urban transportation infrastructure. In column (2), we use the same specification but regress the price level of transportation on the gaps while also controlling for the price level of housing. While negative effects are observed, the point estimates are not significant. Thus, the higher housing prices are not compensated by cheaper transportation.

Finally, if we use the same specification but examine the effects of residential gaps while controlling for commercial gaps, which also appear in the regression, we find a positive significant effect of residential gaps for the H set (see row 2 of column (3)). Thus, while commercial gaps may matter for housing prices if firms have to take space away from housing, residential gaps may have an additional effect.[20]

[18]According to their website (https://www.worldbank.org/en/programs/icp), "the ICP collects and compares price data and GDP expenditures to estimate and publish purchasing power parities (PPPs)."

[19]The price level is for the whole housing sector. However, differences likely come from urban areas only. With rural land prices being low, rural buildings rarely exceed one storey. Since we control for log per capita income, whose correlation with urbanization tends to be very high (Jedwab and Vollrath, 2018), we compare countries with similar urbanization levels. The price level effect is thus estimated controlling for the composition of the housing sector and should be interpreted as an urban price level effect.

[20]The weaker effects for UMH are explained by the residential and commercial gaps being strongly

Another potentially reliable data set on global property prices is the *World's most expensive cities* list provided by Global Property Guide.[21] For the largest city in 75 countries, the list shows selling prices per sq m (in USD) as well as the price-to-rent ratio. Typically, a high price-to-rent ratio suggests that the costs of housing will increase in the future. The two measures are available for 72 and 70 countries in our sample, respectively. The selling price ranges from 700 USD per sq m in Dar-es-Salaam to 30,000 USD per sq m in Hong Kong, while the price-to-rent ratio ranges from about 10 in Kingston to more than 50 in Vienna. In columns (4)-(5) of Table 5, we regress these two measures on the gaps, while simultaneously controlling for log nominal per capita GDP circa 2017, the log population size of the city circa 2015 and using as weights the urban population of each country circa 2017. As can be seen, the gaps are highly correlated with current and future housing prices. These effects are very large: A one standard deviation increase in the gap (about 2) is associated with a 0.44-0.56 standard deviation increase in housing prices. Alternatively, a unitary decrease in the gap (a 100% increase in actual height density) would decrease property prices in the largest cities by 18-24% lower. Next, in column (6), we examine the effect of residential gaps conditional on the effect of commercial gaps. Residential gaps disproportionately matter but for the H set only.

Another data set is Numbeo, which gives for 90 countries the selling prices per sq m for one- and three-bedroom apartments in the city center and outside the center (Numbeo uses data for the major cities of each country).[22] Assuming average sizes of 70 sq m and 140 sq m for the two types of apartments, we can then estimate price-to-rent ratios for both the city center and outside. Columns (7)-(8) show that the gaps are strongly correlated with the log sales price and the price-to-rent ratio of one-bedroom apartments in the center (similar results are obtained for three-bedroom apartments or housing units outside the center; not shown). The magnitude of the effects is large too: a one standard deviation increase in the gap is associated with a 0.39-0.40 standard deviation increase in housing prices. Alternatively, a unitary decrease in the gap would reduced property prices in major cities would by 16-18% lower. Finally, the effects are significantly stronger for residential gaps than for commercial gaps (see col. (9)).

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correlated for the set of UMH countries (0.64). The correlation is weaker for the H set (0.08).

[21]See https://www.globalpropertyguide.com/most-expensive-cities.

[22]See https://www.numbeo.com/cost-of-living/prices_by_country.jsp.

Overall, with a one-standard deviation increase in the gap, urban housing prices, property prices in major cities, and property prices in the largest city would be 3-4%, 16-18% and 18-24% lower. Now, if we study the effects of the gaps on each set of housing prices while simultaneously controlling for the other two sets of housing prices, in order to isolate the effects of the gaps for each housing subsector, we respectively obtain 5-6% for non-major cities, 13% for major cities except the largest, and 12-20% for the largest city.

Urban Land Expansion: Country-Level Results. If cities cannot expand vertically, they may have to expand horizontally. Therefore, for a given urban population, we expect countries with larger gaps to use more urban land. In columns (1)-(2) of Table 6, we regress two measures of urban land expansion on the gaps, with the gaps based on the UMH set shown in row 1 and the gaps based on the H set shown in row 2. In column (1), we use total urban land area in 2011, which we obtain from the *World Development Indicators* database of the World Bank (2019). For this regression, we also control for log urban population in 2010, in order to examine the effects of the gaps on urban land *per capita*. We also control for log nominal per capita GDP in 2010, since higher incomes should lead to more housing, and thus land, consumption per capita and be associated with better commuting technologies. In addition, we control for log nominal agricultural land rent in 2010, since a higher land rent should constrain land expansion. Finally, we use the country urban populations in 2010 as weights. As can be seen, the effects of the gaps are positive and significant. They are large too: a one standard deviation increase in the gaps (about 2) is then associated with a 0.30-0.32 standard deviation increase in log urban land area. Alternatively, a unitary decrease in the gap (a 100% increase in actual height density) would cause urban areas to consume 19-22% less land.

In addition, 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) urban agglomerations above 50,000 inhabitants today. In columns (2)-(3), we use as the dependent variable log total agglomeration area in year t while adding country and year fixed effects and simultaneously controlling for log agglomeration population in t, log nominal per capita GDP in t and log nominal agricultural land rent in t, with the main variable of interest being the gap in year t. By first restricting our panel analysis to the years 1975 and

2015 (we use the 1970 gap for 1975 and 2020 for 2015), we actually capture how the gaps correlate with the long-difference change in urban land per capita between 1975 and 2015.[23] As can be seen (column (2)), the effects of the gaps are positive and significant. A one standard deviation in the gaps (2) is now associated with a 0.06-0.07 standard deviation increase in log urban land area. Alternatively, a unitary decrease in the gap (a 100% increase in actual height density) would lead urban agglomerations to consume 5-6% less land. If we use the full panel with the four years 1975, 1990, 2000 and 2015, we find elasticities that are about half lower (column (3)).[24] In other words, the long-term effects of the gaps are twice higher than the short-term effects.

Next, we use the same specification as in columns (2)-(3) but include both residential and commercial gap measures and find that urban sprawl is disproportionately associated with residential gaps (the p-value for the H set in column (4) is 0.118).

Finally, the GHS database also reports built-up area for each agglomeration in each year. Using the same specification as in columns (2)-(3) but controlling for log built-up area, we can test if regulations are associated with urban sprawl strictly defined, i.e. non-compact urban land expansion. As can be seen in columns (6)-(7), the gaps show that more land is indeed used conditional on built-up land area.

Urban Land Expansion: City-Level Results. While the previous conclusions are all derived at the country level, we can combine the country-level gaps with city-level information to generate some addition insights, as follows. We take advantage of the fact that the GHS database reports estimates of population and land area for all 11,719 agglomerations circa 1975, 1990, 2000 and 2015. Similarly, we use our building database to obtain the total building height of each city in the same years. Focusing on the year 2015, we can regress the log of city total building heights (km) on six dummies if the city has 55-100K, 100-500K, 500-1,000K, 1,000-5,000K, 5,000-10,000K or 10,000K+ inhabitants (50-55K is the omitted category), while including country fixed effects, with the results illustrated diagrammatically.[25] As can be seen in Figure 3, the relationship is non-linear,

[23]We restrict the sample to 131 countries for which nominal GDP data is available in both years.
[24]Standard errors are clustered at the country level for this multi-period panel regression.
[25]As we will show later, our tall building database is highly reliable. City-years with no tall buildings thus have no, or few, tall buildings. Since we use logs and in order to maximize sample size, we assign city-years with no tall buildings the minimal positive value in the data. Results hold if we use alternative methods to deal with 0s (not shown, but available upon request).

with heights significantly increasing after the 100k threshold is passed. The figure also shows the same relationship for total heights in the central city (e.g., New York City for the New York-Newark-Jersey City MSA) vs. peripheral areas (e.g., Newark and Jersey City). The overall relationship is driven by central areas.

Next, we ask whether the height difference between larger and smaller cities is reduced in countries where gaps are high. Instead of six population categories, 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 changes in city populations are endogenous to post-1975 changes in the country gaps. We then regress for the year 2015 the log sum of heights, with the main variables of interest being the country gap interacted with the three city-population category dummies. As before, we use the population category dummies as controls and include country fixed effects (the gaps are omitted). As can be seen in col. (1) of Table 7, the effects of the gaps are particularly visible for larger cities, thus showing how they are driven by abnormally flat populated agglomerations.

We push this analysis further by exploring how changes in the gaps correlate with changes in the height-population relationship. For the years 1975 and 2015, we run city-level panel regressions where the dependent variable is the log sum of heights of the city and the main variables of interest are the gaps of each country in each year interacted with the three population category dummies (defined in 1975). We include city fixed effects, year effects, country-year fixed effects, and cluster standard errors at the city level. In addition, we control for log national per capita GDP, also interacted with the three population dummies. Indeed, we aim to capture how changes in the gaps occur in larger cities rather than the fact that gaps are becoming larger in richer countries (i.e. countries where the demand for space in larger cities is increasing). As seen in col. (2), a gradient in the effects can still be observed but the effects are less, or not, significant (p-value of 0.131 for the 1000K+ cities). If we use the full panel 1975, 1990, 2000 and 2015 (col. (3)), thus focusing on short-term effects rather than long-term effects, the point estimates are further reduced, but significant for the 1,000K+ cities.

Next, we use the full panel specification to confirm that building-height restrictions are particularly stringent in the central areas of urban agglomerations (not shown). We then test if height restrictions in central areas 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. But if that is the case in these two cities, is it the case overall at the world level? We re-run the same regression using the log sum of heights in peripheral areas and find that the effects of the gaps times the city dummies are nil or negative, not positive (col. (4)). In addition, the negative effects are weaker than for central areas. Thus, a disproportionate share of the gaps comes from central areas in the largest cities, and gaps in central areas are not compensated by vertical development in peripheral areas.

If central area gaps are not compensated by vertical development in peripheral areas, larger cities may expand beyond their initial boundaries. We test that idea using the panel specifications of col. (2)-(3) except that the dependent variable is now the log area of the city in year t (col. (5)-(6)). Effects are overall small and not significant. We find a positive effect for the largest (1000K+) cities for the full panel and UMH (col. (6)). In addition, the magnitude is small: A one standard deviation in the UMH-based gap*100-500K effect is associated with a 0.04 standard deviation in log area (vs. -0.35 for the H-based gap*1000K+ effect in col. (3)). Interestingly, we find a positive significant effect for 100-500K cities but for UMH only (col. (6)). This finding might suggest that medium-sized cities sprawl as a result of stringent height restrictions in larger cities. Now, these regressions compare relative land expansion patterns for different class sizes of cities above 50,000 whereas col. (1)-(3) of Table 6 examined the total expansion of urban areas. Since we found that total urban land expansion is correlated with the gaps, even with the full panel (col. (3)), it must be that *all* class sizes of cities are expanding spatially as a result of height gaps that are binding in the largest cities. In other words, the gaps might increase both rural-to-urban land conversion (e.g., both New York and Austin expand spatially) and between-city land reallocation (e.g., Austin expands faster than New York).

4.3. Building-Height Gaps, Congestion and Pollution

Congestion. As cities sprawl they may become more congested, especially if workers disproportionately rely on motorized vehicles for their commute. To test that notion, we examine a contemporary measure of traffic congestion, available for 391 agglomerations of at least 50,000 inhabitants in 52 countries today. The measure indicates by how many percentage points commuting times increase during rush hours relative to non-rush hours.[26] As expected, congestion strongly increases with log population size (2015; with country fixed effects; coefficient of 3.7***; adj. R2 = 0.75). We then examine how this relationship is affected by the gaps. More precisely, we regress the measure on the gaps interacted with three dummies equal to one if the city has between 100 and 500, 500 and 1000, and more than 1000 thousand inhabitants, respectively (the omitted group comprises cities between 50 and 100 thousand people). We also include country fixed effects and income interacted with the three population category dummies, and use the country urban populations in 2020 as weights. As can be seen in Col. (7) of Table 7, larger cities have higher congestion levels in higher-gap countries. Interestingly, point estimates are slightly lower in the largest cities than in other large cities, possibly because they tend to have better public transportation infrastructure. Finally, knowing the population share of each group of cities in the full GHS database, we can obtain the average effect across the three groups, 1.00** and 1.55*. Thus, a one point increase in the gap raises congestion times by 1-2%. Alternatively, a one standard deviation in the gaps ($= 2$) raises congestion times by 2-3%. Finally, the effects are halved or reduced by a third, and become insignificant if we control for log land area circa 1975 and circa 2015 (0.36 and 0.87, respectively; not shown). Thus, the higher congestion levels in higher-gap country cities today may be due to the sprawl they have experienced in the past decades.

Pollution. With sprawl and road congestion, air pollution may also increase in higher-gap country cities. Air pollution in cities consists of gases – mostly carbon dioxide (CO2) and nitrogen oxides (NO_x) – and particulate matter (PM) measured by their size, such as 10 and 2.5 micrometers. CO2, NO_x and PM have health effects. C02 and NO_x also contribute to global warming. Unfortunately, ground-based measures of CO2 and NO_x are not available for enough urban areas across the world. However, there is data on PM10 and PM2.5. In columns (8)-(9) of Table 6, the dependent variables are the log levels of PM 10 circa 2010 and PM 2.5 circa 2017, respectively (source: *World Development Indicators* of the World Bank).[27] For these regressions, we control for log nominal per capita GDP and log

[26]TomTom constructs the measure using its own data on the travel patterns of 600 million drivers (accessed 02-28-2020: https://www.tomtom.com/en_gb/traffic-index/). The measure is available for 401 agglomerations but we could only match them with 391 agglomerations in the GHS database. Unfortunately, no such data exists for past decades, making us rely on cross-sectional regressions.

[27]PM 10 is measured for urban areas above 100,000 inhabitants only. The mean level exposure of a nation's population to PM 2.5 air pollution is then computed by using the PM 2.5 level and population

urban population in 2010 or 2020, and use the country urban populations in 2010 or 2020 as weights.[28] As can be seen, pollution is correlated with the gaps and the magnitude of the effects is large. A one standard deviation increase in the gaps is associated with a 0.05-0.05 (col. (8)) or 0.07-0.08 (col. (9)) standard deviation increase in PM.[29]

In addition, for 1,473 agglomerations in the GHS database we obtain from the *Global Ambient Air Quality Database* of the WHO the average levels of PM10 and PM2.5 for all available years during the period 2008-2017. We use the same specification as for the congestion regression and find that gaps disproportionately increase pollution levels in the largest cities. Knowing the population share of each group of cities in the full GHS database, we can obtain the average effect across the three groups, 0.04*-0.07** for PM10 and 0.05***-0.08*** for PM2.5. Thus, a one point increase in the gap raises pollution by 4-8%. Alternatively, a one standard deviation in the gaps (= 2) raises pollution by 8-16%. Finally, if we control for land area in 1975 and 2015, and their squares in case congestion varies non-linearly with area, the effects are about halved and insignificant. This suggests that half of the pollution effects could be explained by sprawl.

4.4. Robustness

4.5. Investigation of Causality

The computed building-height gaps depend on the estimated coefficients of income and agricultural land rent for the UMH and H countries. So far, the possibility of bias in these estimated coefficients, which would in turn bias the gaps themselves, has not been considered. In particular, the gaps are over-estimated if the estimated coefficients are upward biased. A downward bias in the coefficients would make us under-estimate the gaps, which would be less consequential. However, note that the bias would most likely affect the total levels of the gaps, not necessarily the ranking of countries.

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of different areas in each country. As such, the measure overly represents populated urban areas.

[28]While the PM measures are available starting in 1990, panel regressions are not reliable because the gaps in 2010 or 2020 are too strongly correlated with the gaps in 1990. For the analysis of urban land areas, we used the gaps for the years 1970 and 2010, for which the correlations are weaker.

[29]We also find that the gaps are disproportionately correlated with the share of the population exposed to PM 2.5 levels exceeding target 2 and target 1 of the WHO (not shown; source: *World Development Indicators* of the World Bank). Nil or weaker effects are found for the WHO guideline or target 3. According to the WHO, target 1 levels are associated with about a 15% higher long-term mortality risk relative to the air quality guideline. This mortality risk is lower, at 6% and 12%, for the target 2 and 3 levels.

Such bias would be a consequence of correlation between the two explanatory variables and the regression error term. This correlation could arise either from omitted variables or from joint determination of building heights and the covariates (in other words, reverse causality). In the omitted variable case, for example, a country's (unobserved) commitment to free-market principles may raise both its urban income level and the height of its buildings (via less willingness to regulate land use), leading to an upward bias. Alternatively, effective urban transit systems may influence both incomes and building heights. While use of country fixed effects mitigates the effect of such unobservables to some extent, bias may still be a concern. Examples of reverse causality could include a positive feedback effect from tall commercial buildings to incomes operating through agglomeration economies, which raise worker productivity as job density increases. [30] Alternatively, the supply-increasing effects of taller buildings may reduce housing prices enough to attract lower income consumers to cities, generating a negative feedback effect on income. Another example might be negative feedback (via reduced sprawl) from building heights to agricultural land values, in which a more compact city relieves price pressure on surrounding farmland.

While we do not believe that there exists a perfect identification strategy that would fully allay these concerns, we discuss another series of results that aims to give greater confidence that the relationship we are measuring may indeed be a causal one. To this end, Table 8 presents the results of an additional seven specifications. Col. (1) replicate the baseline results, and additional columns show that the results tend to hold if:

(i) We include continent-year fixed effects (col. (2)) or World Bank region-year fixed effects (col. (3)), in order to capture time-varying regional economic, institutional and cultural drivers of tall building construction that may simultaneously affect building heights, income and agricultural land rent;[31]

(ii) We include country-specific linear trends (col. (4)) or even country-specific non-

[30]However, if human capital spillovers are as likely on campuses as in office towers, large firms that are the main contributors to economic activity may be indifferent between both (e.g., Apple, Google and Microsoft use campuses as their headquarters). In that case, this positive feedback effect might be limited.

[31]Continents: Africa, America, Asia, Europe, Oceania. Regions: East Asia & Pacific, Europe & Central Asia, Latin America, Middle East & North Africa, North America, South Asia, Sub-Saharan Africa. For example, for a given income level, East Asian cities have more tall residential buildings than in other countries. This preference for residential towers would then be captured by the region-year fixed effects.

linear trends (col. (5)), i.e. country dummies interacted with the year and the square of the year. In that case, identification comes from swift or very swift (and possibly exogenous) growth (or deceleration) within countries, i.e. deviations from country trends.

(iii) We add leads of the two main explanatory variables to address possible reverse causality, with the variables defined as t+10 (col. (6)). The leads have no effects, so tall buildings are not built in anticipation of future income growth. Interestingly, if we use 5-year periods instead of 10-years periods, and also add leads and lags of the two variables of interest in order to better to study the respective timing of tall building construction and growth, we find that urban height density in year t disproportionately increases with income/land rent defined in year t (not shown, but available upon request). The effects of the lags are either small or weak, and the leads still have no effects, suggesting that urban height density might not be driving income and land rent.

(iv) 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 country in year t (source: (Gonzalez-Navarro and Turner, 2018) and (Gendron-Carrier et al., 2018)) as well as the percentage share of country roads (including non-urban roads) that is paved during the period 1990-2017 interacted with a linear year trend (source: *World Development Indicators* of the World Bank). As seen in column (7), the effect of income on height density increases. This change makes sense if richer countries have better transportation infrastructure, and if lower commuting costs reduce the need to build up. Then, a negative correlation between the error term and income arises, creating downward bias in the income coefficient, which is reduced by controlling for commuting infrastructure.[32]

Overall, Table 8 shows that the relationship between urban height density and per capita GDP is fairly robust to changes designed to strengthen a causal interpretation of the results. In addition, the $2 \times 7 = 14$ gap measures that we then obtain for the 158 countries are highly correlated with each other. For the $14 \times 13 \div 2 = 91$ possible combinations, the mean, median and 5th and 95th percentile correlations are 0.90, 0.95, 0.71 and 1.00, respectively. This gives us some confidence in the obtained building-height gaps.

[32]Unfortunately, no panel data exists on urban road stocks across countries over time.

5. Robustness Checks

In this section, we discuss a series of robustness checks performed to ensure that our UMH- and H-based results and the rankings presented above are not sensitive to a particular specification or choice of variables (see Appx. Tables A2 and A3 for details).

Sampling Checks. The estimated gaps are logically sensitive to the benchmark set of countries used. However, the process by which we select benchmark countries appears valid. For the 61 upper-middle and high-income countries in our data, the correlation between the residuals used to select countries – from a 2017 regression that relates LUHTDENS to LUPCGDP and LAGRENT – and the number of Google results when searching for the name of the country & "cities" & "skyscrapers" is 0.61 once we condition on the respective numbers of Google results when searching for the name of the country & "cities" and the name of the country only. The latter two variables are important to control for the economic size of the country and its cities. If we additionally control for whether one official language of the country is English as well as the numbers of famous 20th and 21st century architects from the country (source: Wikipedia) to ensure we do not capture the fact that some countries may have important architects but few skyscrapers (e.g., Italy with Renzo Piano), the correlation becomes 0.72. If we use the corresponding numbers of search results but in the language of the country and add the architecture controls, the correlation increases further to 0.90.

Next, results also hold if we: (i) Include the U.S.; (ii) Use total urban population in t, or its inverse, as weights, to show results are not driven by larger, or smaller, countries; (iii) Drop Hong Kong and Singapore, two city-states with little land available for urban expansion; (iv) Select countries based on residuals from a 1980 regression that relates LUHTDENS to LUPCGDP and LAGRENT. We use 1980 – the mid-point between 1950 and 2020 – because too few countries had tall buildings in 1950; (v) Drop government or religious buildings to capture the private sector only. These buildings account for about 1% of the stock circa 2017; (vi) Drop buildings that were among the 5 tallest buildings in the world at any point in 1950-2017. We do so since the world's tallest buildings may reflect a government's advertising campaign rather than economic conditions; and (vii) Interact the variables of interest with a post-1980 dummy, to isolate their effects in the most recent period since these might be more relevant to compute the gaps today. Finally, results hold if we drop each country one by one (not shown). Therefore, the effects of income and land rent and the gaps are not driven by one particular country.

Measurement Error in Building Heights. The dependent variable is log urban height density, which is the sum of heights (for buildings above 80 or the top 10 buildings) divided by urban population. Classical measurement error in dependent variables affect precision, not the estimates themselves. However, measurement could be non-classical.

To compare results, we collected data from a second source, Emporis (2019), another global provider of building information.[33] Note that Emporis (2019) claims to capture all *high-rise buildings*, which they define as buildings above 35 meters (about 9 floors). They then classify as *skyscrapers* buildings above 100 meters. Finally, they use the number of floors of each 35m+ building to compute for each city a Skyline index. We do not have access to their raw data but their website reports useful information for the 100 top cities in the world.[34] For 90 of these cities also in our data, and using as weights the sum of heights in our data in order to focus on the cities with the most tall buildings, the correlation between the log of their number of skyscrapers and the log of our own number of buildings above 100 meters is 0.90. Next, 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 our data and their formula) is 0.79. Thus, our measure of urban height density is a good proxy for 35m+ buildings.

Now, is our measure also a good proxy for structures below 35m, whether low-rise (four plus one) buildings or houses? Based on Emporis, which also reports the number of low-rise buildings for 7 North American cities, the (mostly 80m+) 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. While it was steel around 1950, the use of concrete has dramatically increased over time, reaching 90% in the 2000s (the mean share over the period 1950-2017 is 73%). We then obtained from the *Minerals Yearbooks* of USGS and for 144 countries and each decade from 1950 the total production of cement – the main ingredient of concrete – which we use as a good proxy for cement consumption.[35] As expected, the correlation between decadal tall building construction

[33]Their website says they rely on their extensive member network to gather information on buildings.
[34]Accessed on 12-11-2019:urlhttps://www.emporis.com/statistics/skyline-ranking.
[35]Because cement is a low-value bulky item, the world trade of cement only accounts for 3% of world

and decadal cement use is high, at 0.77 (N = 870). Adding country and year fixed effects, we obtain a correlation of 0.80 (but 0.99 if we use urban population as weights). Therefore, tall building construction is a good proxy for the overall construction sector.

Next, one could argue that taller skyscrapers are better measured than shorter high-rise buildings, because they stand out more. Among the buildings in our data, the height of the 25th percentile, median and mean is 100, 125 and 135 meters, respectively. Results hold if we restrict our analysis to buildings above such thresholds. For a few buildings, we only know the number of floors. Floors are about 4 meters on average, so we inferred heights based on floors for these buildings. Results hold if we only use observations for which height was not imputed using floors. Results also hold if we modify the height of buildings so that it includes the number of underground floors, which we know for most buildings. Finally, we know the gross floor area (GFA) for one third of existing buildings in 2017. The correlation between log height and log GFA is about 0.6, so lower than 1, due to buildings having different shapes. If we regress for the year 2017 log GFA on log height, log urban per capita GDP and log agricultural land rent and their interactions with log height, we find no interacted effects, thus suggesting that the GFA-height relationship does not vary with our variables of interest (not shown, but available upon request). Thus, not fully capturing GFAs should not dramatically affect our results.

Specification Checks. We show results hold if we: (i) Omit the lagged dependent variable. Indeed, with panel regressions, including a lagged dependent variable might introduce dynamic panel bias (Nickell, 1981); (ii) Interact the lagged dependent variable or also include the square of it in case durability/persistence varies over time or with the existing stock; (iii) Include lags of income and agricultural rent in case their effects take some time to materialize (the combined contemporaneous and lagged effects are similar to the contemporaneous effects); and (iv) Use 15-year or 5-year lags. Our 10-year effects lie between the effects for these other lag definitions. 5-year periods capture short-term effects, so the response to income is lower. The specification with 15-year periods is less precisely identified because the number of observations is smaller.

cement production (see, for example, https://www.worldcement.com/africa-middle-east/29042013/cement_global_trading_patterns_961/). Thus, even if we have limited data on cement imports and exports, cement production is a very good proxy for cement consumption. The *Minerals Yearbooks* can be found here: https://www.usgs.gov/centers/nmic/cement-statistics-and-information.

Classical measurement error in income and land rent should lead us to under-estimate the effects of income and land rent and thus the gaps. In addition, results hold if we: (i) Use log national per capita GDP instead of log urban per capita GDP;[36] (ii) Construct land rent differently. Based on available data, urban land is 6% of total land (circa 1990) and agricultural land is 48% (throughout the 1960-2017 period), making non-agricultural and non-urban land 54%. Results hold if we use agricultural GDP (in t) divided by non-urban land area (1990) or agricultural land area (in t but for the period 1960-2020 only); and (iii) Drop countries above the mean land area across the 158 countries since land rent at the edge of urban areas is more likely to be mismeasured for them.

6. 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 will show 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.[37] 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.[38] Knowing farm income and agricultural land area, we reconstruct agricultural land rent. Note that we use agricultural land area for the U.S. analysis – we used total land area for the international analysis

[36] Since national per capita GDP is the sum of non-agricultural GDP and agricultural GDP, the correlation between income and agricultural rent is then even stronger, making agricultural rent even less relevant.

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

[38] 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 this link: https://en.wikipedia.org/wiki/List_of_U.S._states_and_territories_by_area.

– because it is well measured for the whole period.[39] From Wikipedia, we obtain the population and urbanization rate – and thus the total urban population – of each state in each year.[40]

Results. Table 9 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 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.[41]

Columns (5)-(7) of the table 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

[39]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. Source: www.minneapolisfed.org/community/financial-and-economic-education/cpi-calculator-information/consumer-price-index-1800.

[40]https://en.wikipedia.org/wiki/List_of_states_and_territories_of_the_United_States_by_population and https://en.wikipedia.org/wiki/List_of_states_and_territories_of_the_United_States_by_population.

[41]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.

extensions of highway systems" or "other municipal / urban streets".[42] One advantage of the U.S. regression over the international regression is that consistent data on urban road stocks is now available. As can be seen, the effects are mostly unchanged.

In column (9) 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. Column (10) is similar to column (9) except that 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 (11), 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 effects are mostly unchanged.

State Gaps. For the sample of observations used in columns (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. We then 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 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.[43]

[42] 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.

[43] 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.

Other Measures of Land-Use Regulations. Table 10 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, including the Wharton index.

For the right-hand side variable, columns (1)-(3) use the estimated gaps, i.e. the difference between the predicted and actual log sum of heights. Results are based on states with a laissez-faire value above 0 in column (1), the 75th percentile in column (2), and the 90th percentile in column (3). In short, 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 building-height 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 UMH-based gap measure (for countries above the 75th percentile) and the U.S. state-based gap measures is 0.72-0.89. If we use the H set instead, the correlation remains high, at 0.74-0.76.

7. Welfare Calculations

Were our estimated gaps and effects causal, what would be their economic implications for the world? Without better data to estimate the required parameters to simulate a more complex model, we cannot estimate the true global impact of regulations. However, we can rely on back-of-the-envelop calculations as seen in the following discussion.

Table 6 shows that an increase in a country's building-height gap increases housing prices and urban sprawl. The welfare loss from this greater sprawl can be computed using the approach of Bertaud and Brueckner (2005b), as follows. By restricting housing supply, a tighter height restriction raises the price per unit of housing throughout the city while causing the urban footprint to expand as the city attempts to fit its population. Urban residents thus experience a combination of higher housing prices and longer commutes, making them worse off. For the resident at the edge of the city, housing prices are anchored by agricultural rents, so that this individual's welfare loss comes entirely from a longer commute. With utilities equalized within the city, the welfare loss for each urban resident thus equals the increase in commuting cost for the edge resident. Note that, along with higher commuting costs, this measure captures the welfare effect of the higher housing prices caused by the tighter height restriction (as captured in Table 5), without the need for explicit consideration of prices.

To make use of the results of Table 6 in quantifying this welfare loss, suppose a country has n identical cities and let $urban\_area$ denote the size of each city. Then our dependent variable in the urban sprawl regression (the country's total urban area) 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

$$\frac{n * \triangle urban\_area}{n * urban\_area} = \frac{\triangle urban\_area}{urban\_area} = \beta \triangle \text{GAP} \tag{5}$$

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

$$\frac{\triangle urban\_area}{urban\_area} = \frac{2\pi \overline{x} \triangle \overline{x}}{\pi \overline{x}^2} = 2\frac{\triangle \overline{x}}{\overline{x}} \tag{6}$$

Combining (1) and (2) yields $\triangle \overline{x}/\overline{x} = \beta \Delta \text{GAP}/2$. If GAP increases by one standard deviation, a value equal to 2, then the percentage increase in $\overline{x}$ is just equal to β. Finally, since commuting cost is proportional to distance traveled, β then 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. To compute a country's welfare loss from this increase in GAP, $\beta\lambda$ would be multiplied by total urban income, and for the world welfare loss, the multiplicand would be world urban income.

Various studies suggest λ values for use in this computation. In the simulation analysis of Brueckner (2007), which applies to a US city, the edge resident spends between 14% and 19% of income on the money cost of commuting (time cost is not included). Using this range of values, along with the β values of 0.05-0.06 from column (2) of Table 6, the value of $\beta\lambda$ ranges between 0.007 and 0.01. The implication is thus that the welfare loss from a one-standard-deviation increase in GAP is close to one percent of city and hence global urban income.[44]

To quantify the gap effect on pollution, if we use the estimates from columns (8)-(9) of Table 6, we get a 5% PM2.5 increase and a 7-8% PM10 increase from a unitary increase in the gap. Taking a midpoint value of 6.5%, which is assumed to apply to all types of air pollution, and multiplying by 2 to capture a one-standard deviation increase in the gap, the implied percentage increase in pollution equals 13%. Now, various studies and policy reports estimate the total cost of current levels of air pollution at 4.5-6% of world GDP (source: World Bank 2016). Therefore, a gap increase of 2 could reduce world GDP by 13% x 4.5-6% = 0.6-0.8% of world GDP.[45]

While the calculations just presented view city populations as fixed, 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 the rate of growth of output

[44]Since the 14-19% λ values come from a model with traffic congestion, the one-percent welfare impact includes the losses from higher congestion due to the land use regulations.

[45]Alternatively, Borck and Brueckner (2018) simulate a city containing 1.5 million households, which generates 24,164 kg per household of local and greenhouse gas emissions in the absence of any environmental taxes. Valuing these emissions at $0.04 per kg ($40 per metric ton, a standard value), the city's total emissions damage equals $1.45 billion. The resulting increase in pollution damage from a one-standard deviation in the gap thus equals $188 million = 0.13*$1.45 billion. Given a total urban population of 4.2 billion people and a world GDP of 85,910 billion USD (source: *World Development Indicators* of the World Bank), the cost of air pollution again amounts to 0.6% of world GDP.

and welfare in the US. 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 tightly centered around 0.73, which we take as a representative value, and raising this value to the US median would require an elasticity increase of 0.92 in each of the cities, using data from Saiz's Table VI. [46]

Next, suppose that supply elasticities at the US state level can be expressed as a function of building-height gaps. Then, the elasticity increases required to achieve these growth effects can be restated in terms of a required reduction in the height gap. With columns (1)-(3) of row 1 in Table 10 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 (6) above, ΔUHTDENS/UHTDENS is equal to 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. Assuming that the height-gap/elasticity relationship at the state level, as captured in Table 10, also holds at the city level within a state, these percentage height increases can be applied to the three individual cities, so that building heights need to rise by 50% in San Francisco, San Jose and New York.[47] 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 above 0.50, would produce an even larger GDP gain of about 14.8%.[48]

To summarize, adding the global effects via housing prices/sprawl (0.007-0.01),

[46]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.

[47]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).

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

particulate matter pollution (0.006-0.008) and misallocation (0.148), we obtain a possible global GDP loss of 16-17% from a worldwide one-standard deviation increase in height gaps. Now, these calculations should be viewed with caution, partly because we do not include any positive quality-of-life effects from limiting building heights (e.g., limiting light-reducing building shadows). However, one should then also include the positive economic and amenity effects from increasing density in central city areas. Finally, we ignore the negative environmental effects from other urban pollutants as well as sprawl (including loss of open space). More research is thus warranted to provide a more thorough account of the global welfare impact of building-height restrictions.

8. Conclusion

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, and that the gaps correlate strongly with other measures of land-use regulation and international measures of housing prices, sprawl, and pollution. Taken together, the results suggest that stringent building-height regulations around the world are imposing relatively large welfare losses.

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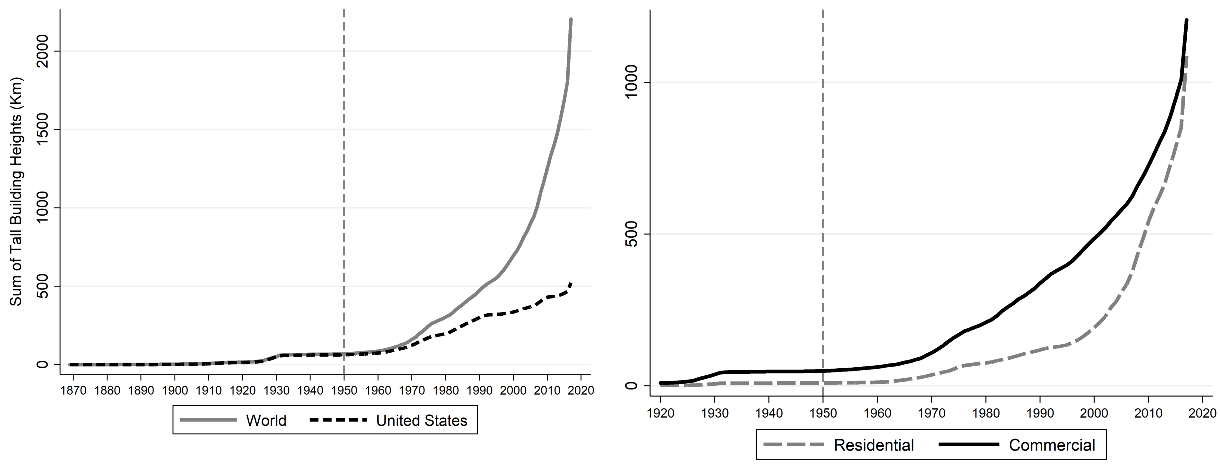
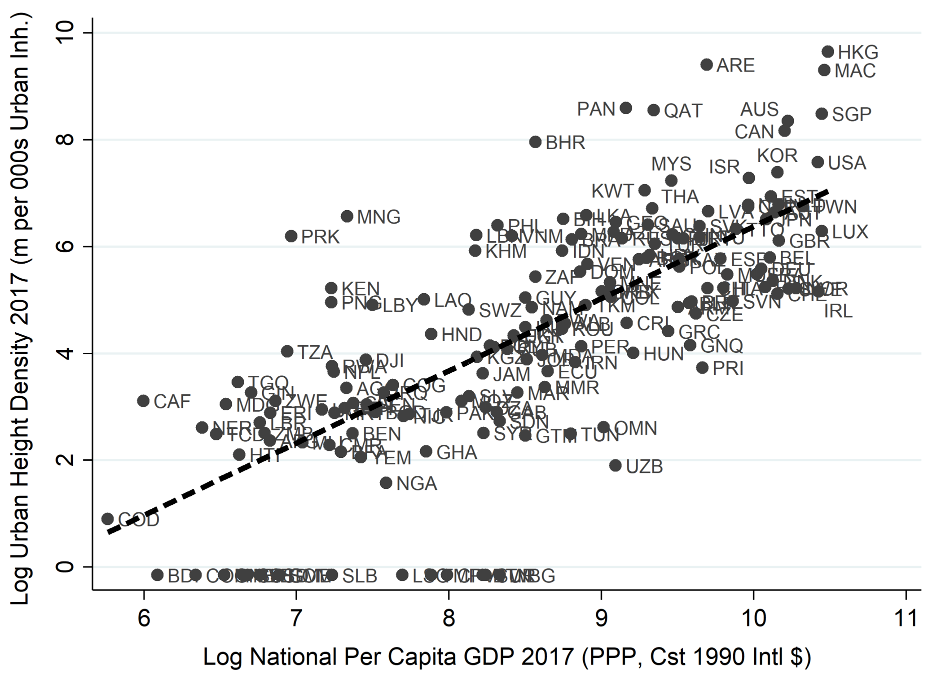
Figure 1: TALL BUILDING HEIGHTS FOR THE WORLD, 1869-2017

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



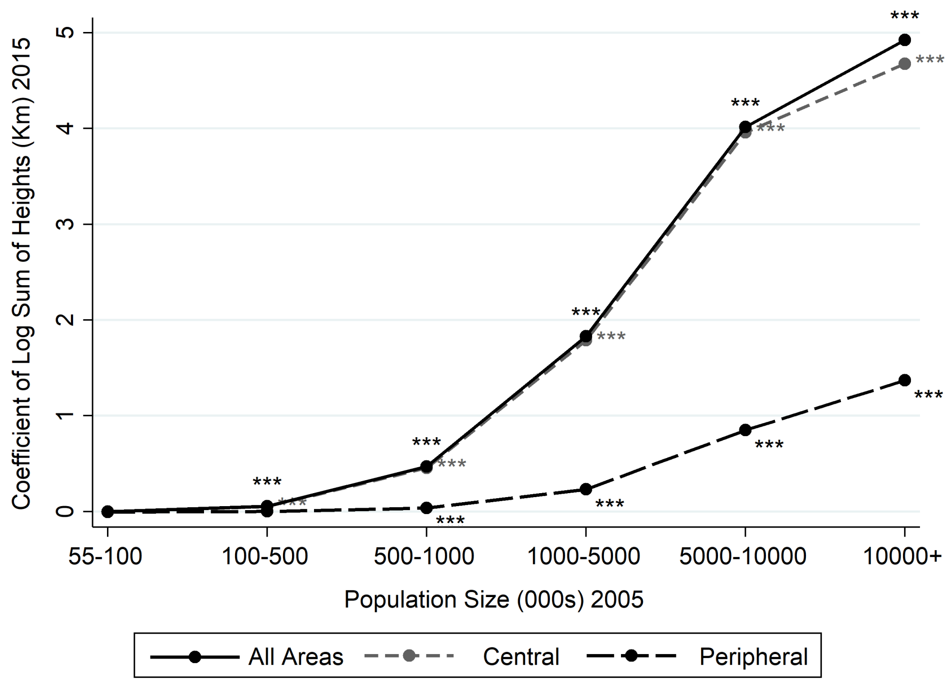
Notes: Subfig. 1(a) shows the evolution of the stock of tall building heights (m) for both the world and the United States from 1869 to 2017. Subfig. 1(b) shows the world evolution of the stock of tall building heights (m) separately for residential and commercial buildings from 1920 to 2017. The dashed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

Figure 2: LOG URBAN HEIGHT DENSITY AND LOG PER CAPITA GDP 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 and constant 1990 international $) for 170 countries circa 2017.

Figure 3: CITY BUILDING HEIGHTS-POPULATION RELATIONSHIP IN 2015



Notes: This figure shows for 11,719 agglomerations of at least 50,000 inh. in 2015 the relationship between the log sum of tall building heights (km) and the pop. size category (the omitted category is 50,000-55,000) ca. 2015. Central areas correspond to the central locality of each agglomeration (e.g., New York City for New York-Newark-New Jersey). The peripheral areas correspond to the other areas of the agglomeration. The 11,719 agglomerations in 2015 belong to 158 countries. There are 829 50-55K agglomerations, 4,543 55-100K agglomerations, 5,304 100-500K agglomerations, 559 500-1000K agglomerations, 410 1000-5000K agglomerations, 43 5000-10000K agglomerations, and 31 10000K+ agglomerations, respectively.

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	≥ p75 & DemUMH	≥ p75 & DemH	Residential ≥ p75 DemUMH	DemH	Commercial ≥ 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 (%, From $UHTDENS_{2020}$))		(2) Per Capita Gap (Km per Mil. Urban Inh.)		(3) Total Gap (Km)	
Rank	Country	Gap	Country	Gap	Country	Gap
1	Ireland	488	Ireland	21	United States	1468
2	Mauritius	451	Mauritius	20	Taiwan	219
3	Slovenia	369	Austria	12	Japan	174
4	Switzerland	361	Taiwan	12	United Kingdom	172
5	Uzbekistan	337	Sri Lanka	8	Germany	168
6	Norway	321	Trinidad	6	China	157
7	Austria	290	Switzerland	6	South Korea	147
8	Taiwan	278	United States	6	France	127
9	Sweden	277	Slovenia	5	Italy	82
10	Sri Lanka	261	Norway	4	Ireland	63
11	Italy	253	South Korea	4	Austria	61
12	Denmark	252	United Kingdom	3	Netherlands	46
13	Trinidad	250	Netherlands	3	Switzerland	35
14	France	249	Estonia	3	Sri Lanka	32
15	Germany	247	Germany	3	Sweden	22
16	Eq. Guinea	243	Sweden	3	Spain	22
17	Finland	223	France	2	Norway	18
18	United Kingdom	215	Denmark	2	India	17
19	Lesotho	212	Italy	2	Belgium	15
20	Portugal	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: INCOME AND THE GAPS, WORLD, 1950-2020

	(1)	(2)	(3)	(4)	(5)	(6)
	Gaps 2020 Based on the UMH Set			Gaps 2020 Based on the H Set		
Buildings:	All	Residential	Commercial	All	Residential	Commercial
1. LPCGDP 1950	0.66**	0.55*	-0.09	1.42***	1.90***	-0.29*
	[0.31]	[0.32]	[0.20]	[0.33]	[0.42]	[0.15]
2. LPCGDP 1950	0.81***	0.69***	-0.03	1.63***	2.15***	-0.27*
	[0.23]	[0.25]	[0.16]	[0.18]	[0.25]	[0.14]
ΔLPCGDP 1950-2020	1.99***	1.85***	0.83***	2.73***	3.34***	0.30**
	[0.20]	[0.23]	[0.16]	[0.18]	[0.24]	[0.14]
Observations	158	158	158	158	158	158

Notes: This table shows the correlation between log per capita GDP in 1950 and the change in log per capita GDP between 1950 and 2020 and the estimated gaps, using the main gap measures based on the UMH and H sets. Robust SE. * $p<0.10$, ** $p<0.05$, *** $p<0.01$.

Table 4: GAPS AND LAND USE REGULATIONS, WORLD, CIRCA 2020

Dep. Var.:	Gap (Predicted Log Heights per Urban Cap.- Actual Log Heights per Urban Cap.)							
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Regulation:	Few Procedures	Cost %Value	Quality Control	Pro Landlord	Johansson-Sanchez: Elasticity	Speed	Max FAR (Angel): Ctrls: N	Ctrls: Y
1. Based on UMH	-0.02***	-0.02***	0.04***	-1.15**	-1.26***	-4.39**	-0.20**	-0.37***
	[0.01]	[0.01]	[0.01]	[0.48]	[0.41]	[2.01]	[0.01]	[0.00]
2. Based on H	-0.01	0.00	0.04***	-1.74***	-0.32	-1.12	-0.12**	-0.32***
	[0.01]	[0.01]	[0.01]	[0.50]	[0.25]	[1.15]	[0.04]	[0.00]
Observations	155	155	155	98	21	21	49	47

Notes: 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 (see text for details). Robust SE. * $p<0.10$, ** $p<0.05$, *** $p<0.01$.

Table 5: GAPS AND HOUSING PRICES, WORLD, CIRCA 2020

Source:	Intl Comparison Program 2011			Global Property Guide 2019			Numbeo 2019		
Dep. Var.:	Price Level (100) Hous	Transp	(1) Resid vs Comm	Log Hous Price	Price-to-Rent	(4) Resid vs Comm	Log Hous Price	Price-to-Rent	(7) Resid vs Comm
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
1. Gap UMH	3.32***	-0.67	1.33	0.18***	2.78***	0.07	0.16***	5.34***	0.28***
	[1.19]	[1.30]	[1.51]	[0.04]	[0.60]	[0.06]	[0.003]	[1.755]	[0.097]
2. Gap H	3.99***	-1.50	2.25*	0.24***	3.51***	0.13***	0.18**	5.47**	0.21***
	[1.33]	[1.34]	[1.15]	[0.04]	[0.84]	[0.03]	[0.024]	[2.350]	[0.054]
Observations	147	147	147	72	70	72	90	90	90
Ctrls, Wgts	Y	Y	Y	Y	Y	Y	Y		

Notes: This table shows the correlation between the estimated gaps based on the UMH and H sets and measures of housing prices for as many countries as possible. We control for log nominal per capita GDP and use the urban population of each country as weights circa 2010 in col. (1)-(3) and circa 2017 in col. (4)-(9). Col. (1): We control for the price index of non-housing consumption. Col. (2): We control for the price level of housing. Col. (3), (6) and (9): We simultaneously include the residential and commercial gap measures but only report the coefficient for the residential gap measure. Col. (4)-(6): We control for the log population of the agglomeration (ca. 2015) for which the housing price data is reported. Robust SE. * $p<0.10$, ** $p<0.05$, *** $p<0.01$.

Table 6: GAPS AND URBAN SPRAWL, COUNTRY ANALYSIS, WORLD, CIRCA 2020

Dep. Var.:	Columns (1)-(7): Log Total Urban Land Area (Km) in ...							Log PM	
Source:	2011 WDI	Columns (2)-(7): Year t (Based on GHS Urban Agglo.)		Resid vs. Comm		Ctrl: Built-Up Area		10 (2010)	2.5 (2017)
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
1. Gap UMH	0.22***	0.06***	0.03**	0.08*	0.02**	0.05*	0.02*	0.05**	0.08***
	[0.04]	[0.02]	[0.01]	[0.04]	[0.01]	[0.03]	[0.01]	[0.02]	[0.02]
2. Gap H	0.19***	0.05**	0.03**	0.06	0.02**	0.04*	0.02*	0.05**	0.07**
	[0.03]	[0.02]	[0.01]	[0.04]	[0.01]	[0.02]	[0.01]	[0.02]	[0.03]
Observations	125	262	524	262	524	262	524	146	156
Countries	125	131	131	131	131	131	131	146	156
Cntry FE, Yr FE	N	Y	Y	Y	Y	Y	Y	Y	Y
Ctrls, Wgts	Y	Y	Y	Y	Y	Y	Y	Y	Y

Notes: This table shows the correlation between the estimated gaps based on the UMH and H sets and measures of total urban land expansion for as many countries as possible (see text for details). Col. (2), (4) and (6): We use panel data for the years 1975 (the gaps and controls are defined in 1970) and 2015 (2010) only. Col. (3), (5) and (7): We use the full panel 1975, 1990, 2000 and 2015. We always control for the log of urban population, the log of nominal per capita GDP and log agricultural nominal land rent, and use the urban population of each country as weights (defined circa 2010 in col. (1), in t in col. (2)-(7)). Col. (4)-(5): We simultaneously include the residential and commercial gap measures but only report the coefficient for the residential gap measure. Col. (6)-(7): We also control for log built-up area. Robust SE (clustered at the country level in col. (3), (5) and (7)): * p<0.10, ** p<0.05, *** p<0.01.

Table 7: GAPS AND URBAN SPRAWL, CITY ANALYSIS, WORLD, CIRCA 2020

Dep. Var.:	Log Sum of Heights in Year t				Log Area in Year t		Cong. 2017	Log PM 2017	
	All	All	All	Peri.				10	2.5
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
Gap_{UMH}*100-500K	-0.03*	-0.02	-0.02	0.00	0.05	0.04**	1.14***	0.02	0.03*
	[0.02]	[0.04]	[0.01]	[0.00]	[0.03]	[0.02]	[0.37]	[0.02]	[0.02]
...*500-1000K	-0.25***	-0.17	-0.13	0.01	0.09	0.05	1.43*	0.06**	0.06***
	[0.05]	[0.32]	[0.12]	[0.04]	[0.06]	[0.03]	[0.77]	[0.02]	[0.02]
...*1000K+	-0.67***	-0.85	-0.68***	-0.01	-0.02	0.01**	1.04	0.07**	0.08***
	[0.14]	[0.56]	[0.17]	[0.13]	[0.05]	[0.01]	[0.64]	[0.03]	[0.03]
Gap_H*100-500K	-0.04	-0.04	-0.03	0.00	0.01	0.01	1.79**	0.04	0.04
	[0.02]	[0.03]	[0.02]	[0.00]	[0.01]	[0.02]	[0.73]	[0.03]	[0.03]
...*500-1000K	-0.36***	-0.25*	-0.11	-0.02	0.00	0.00	2.71*	0.09**	0.08*
	[0.08]	[0.14]	[0.17]	[0.03]	[0.03]	[0.02]	[1.49]	[0.04]	[0.04]
...*1000K+	-1.18***	-0.73**	-0.56**	-0.15*	-0.02	0.00	1.48	0.13**	0.14***
	[0.24]	[0.31]	[0.25]	[0.09]	[0.02]	[0.01]	[1.13]	[0.05]	[0.05]
Observations	11,719	23,438	46,876	46,876	17,040	34,181	391	1,473	1,473
Cities	11,719	11,719	11,719	11,719	11,719	11,719	391	1,473	1,473
Country FE, Ctrls	Y	Y	Y	Y	Y	Y	Y	Y	Y
City FE, Yr FE	N	Y	Y	Y	Y	Y	N	N	N
Country-Yr FE	N	Y	Y	Y	Y	Y	N	N	N

Notes: This table shows the interacted effects of the estimated gaps based on the UMH and H sets and the three pop. category dummies based on the pop. size of each agglo. (defined in 1975 in col. (1)-(6) and 2015 in col. (7)-(9)). Col. (1): Regr. for the year 2015 only. Col. (2) & (5): Panel for the years 1975 and 2015 only. Col. (3)-(4) & (6): Panel for the years 1975, 1990, 2000 and 2015. Col. (4): Heights in peripheral areas. In addition to the FE reported in the table, the regressions include the three pop. category dummies and their interactions with log urban per cap. GDP (PPP, cst 1990 intl $). Robust SE clust. at the country level: * p<0.10, ** p<0.05, *** p<0.01.

Table 8: EFFECTS FOR THE WORLD, INVESTIGATION OF CAUSALITY

Dep. Var.:	Gap (Log Urban Height Density (m per 000s Urban Inh.) in Year t (LUHTDENS$_t$))							
	(1)	(2)	(3)	(4)	(5)	(6)		(7)
Check:	Baseline	Continent -Year FE	Region -Year FE	Country Trend	Country Trend Sq.	Effects of the Vars t	Leads t+10	Ctrls for Commut.
	Panel A: UMH Set (98 Observations; 14 Countries)							
LUPCGDP$_t$	1.54**	1.97**	1.95**	3.32**	3.91*	2.35***	-0.59	1.83*
	[0.67]	[0.82]	[0.75]	[1.32]	[2.06]	[0.65]	[0.83]	[0.88]
LAGRENT$_t$	0.55**	0.63**	0.59*	-0.05	-0.05	0.44	0.31	0.55**
	[0.26]	[0.29]	[0.31]	[0.61]	[0.76]	[0.78]	[0.74]	[0.22]
	Panel B: H Set (56 Observations; 8 Countries)							
LUPCGDP$_t$	3.23***	3.00***	3.28***	6.06**	6.91*	4.96**	-1.43	4.07***
	[0.61]	[0.47]	[0.49]	[2.13]	[2.99]	[1.99]	[0.68]	[0.40]
LAGRENT$_t$	0.19	-0.07	-0.25	-0.45	-0.41	0.08	0.28	0.18
	[0.40]	[0.48]	[0.85]	[0.59]	[0.80]	[0.68]	[0.71]	[0.31]
Cntry FE, Yr FE	Y	Y	Y	Y	Y	Y	Y	Y
LUHTDENS$_{t-10}$	Y	Y	Y	Y	Y	Y	Y	Y

Notes: Col. (2)-(3): We include continent (5)-year FE and World Bank region (7)-year FE, respectively. Col. (4)-(5): We include country-specific linear trends and non-linear trends, respectively. Col. (6): We simultaneously include the variables of interest defined in t+10. Col. (7): We control for whether there is a subway and the log numbers of subway lines and subway stations in the country in year 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. Robust SEs clustered at the country level: * $p<0.10$, ** $p<0.05$, *** $p<0.01$.

Table 9: EFFECTS OF INCOME AND LAND RENT ON HEIGHTS, U.S., 1930-2020

Dep. Var.:	Log Sum of Urban Heights (m) in Year t (LUHT$_t$)					
	(1)	(2)	(3)	(4)	(5)	(6)
States:	All	$\geq$ 0	$\geq$ p75	$\geq$ p90	$\geq$ 0	$\geq$ 0
Test:					Reg.-Yr FE	State Trend
LUGDP$_t$	0.39***	0.57***	0.58***	0.57**	0.48**	0.29
	[0.09]	[0.10]	[0.11]	[0.13]	[0.23]	[0.26]
LAGRENT$_t$	0.08**	0.10	0.16	0.48	0.11*	0.12
	[0.04]	[0.06]	[0.11]	[0.31]	[0.06]	[0.09]
LUHT$_{t-10}$	0.83***	0.76***	0.71***	0.76***	0.80***	0.38***
	[0.03]	[0.04]	[0.06]	[0.08]	[0.05]	[0.07]
	(7)		(8)	(9)	(10)	(11)
States:	$\geq$ 0		$\geq$ 0	$\geq$ p90	$\geq$ 0	$\geq$ 0
Test:	Effects of the		Ctrls	Ctrls	Ctrls	Ctrls
	Vars t	Leads t+10	Commuting	Geography	Land Protect.	Const. Costs
LUGDP$_t$	0.56*	0.11	0.56***	0.60***	0.62***	0.59***
	[0.29]	[0.33]	[0.12]	[0.13]	[0.21]	[0.09]
LAGRENT$_t$	0.13	-0.04	0.08	0.05	0.09	0.10
	[0.08]	[0.07]	[0.05]	[0.04]	[0.07]	[0.06]
LUHT$_{t-10}$	0.75***		0.72***	0.73***	0.74***	0.75***
	[0.05]		[0.04]	[0.06]	[0.06]	[0.04]
State FE, Yr FE	Y	Y	Y	Y	Y	Y

Notes: Sample of 50 U.S. states x 10 years (1930, 1940, 1950, 1960, 1970, 1980, 1990, 2000, 2010, 2020) = 500 obs. 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)). "0", "p75" and "p90" correspond to the following values of the laissez-faire proxy: 0, the 75th percentile and the 90th percentile. See text for details on col. (5)-(11). Robust SEs clustered at the state level: * $p<0.10$, ** $p<0.05$, *** $p<0.01$.

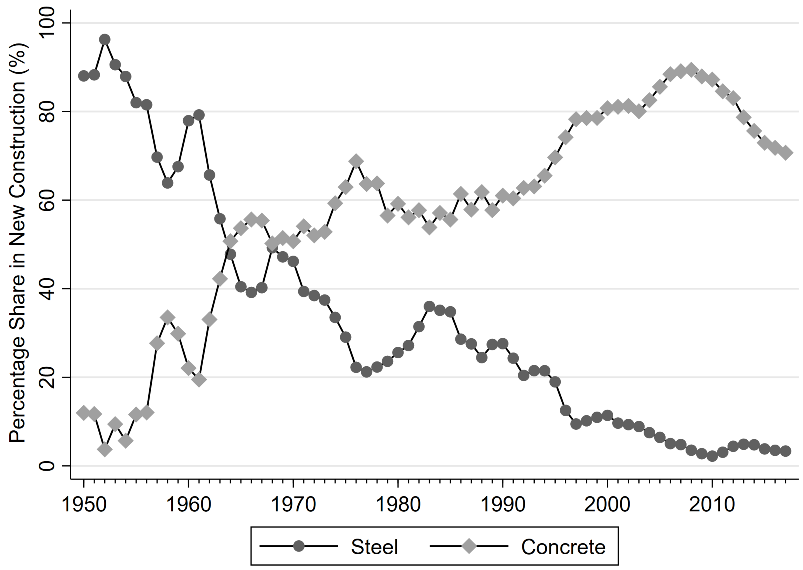
Table 10: **GAPS AND LAND USE REGULATIONS, UNITED STATES, CIRCA 2010**

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

Notes: 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 9) and existing measures of land use regulations circa 2010 (see text for details on each measure). Robust SE: * $p<0.10$, ** $p<0.05$, *** $p<0.01$.

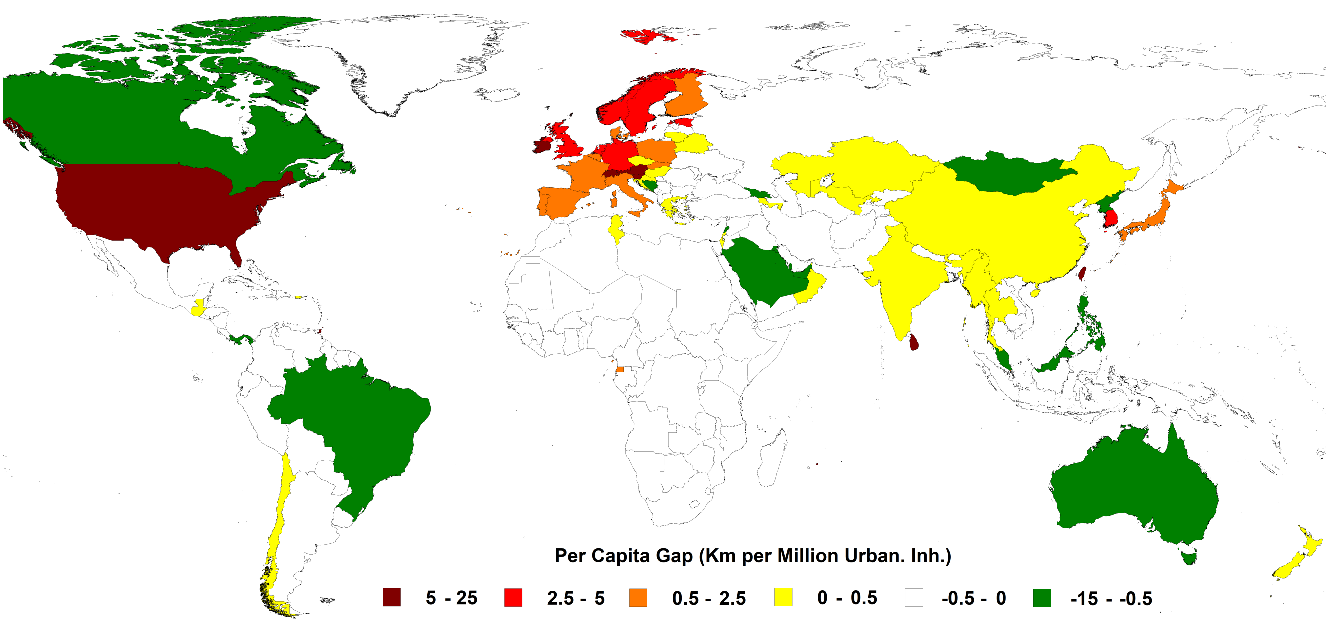
WEB APPENDIX: NOT FOR PUBLICATION

Figure A1: USE OF STEEL VS. CONCRETE IN NEW CONSTRUCTION 1950-2017



Notes: 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 A2: PER CAPITA GAPS FOR ALL COUNTRIES, 2020



Notes: This figure shows the gaps per urban capita (km per million urban inh.) for 149 countries circa 2020. Positive gaps are shown in brown, red, orange or yellow. Negative gaps are shown in green.

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

Notes: This table shows the correlations between the estimated gaps (based on the UMH and H sets) and measures of land use regulations in the database of land use regulations compiled by Solly Angel (see text for details). *Max FAR:* maximum 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: 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

Notes: 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 (in PPP terms). 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 of 158 countries. Robust SEs clustered at the country level: * $p<0.10$, ** $p<0.05$, *** $p<0.01$.

Table A3: 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

Notes: 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 (in PPP terms). 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 of 158 countries. Robust SEs clustered at the country level: * $p<0.10$, ** $p<0.05$, *** $p<0.01$.