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The Evolution of City Form

Evidence from Satellite Data

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Abstract

This paper describes new global evidence—derived from satellite data—for rates and patterns of urban spatial development since 1990 along three margins: horizontal spread (outward extension), infill development (inward additions in the gaps left between earlier structures), and vertical layering (upward construction). The end product of this growth is floor space, the amount and distribution of which are central to understanding how a city becomes livable and sustainable. Over the quarter century between 1990 and 2015, urban built-up area worldwide grew by 30 percent through horizontal spread and infill. While most cities grow through a combination of horizontal spread and infill, the paper provides the first estimates of the relative prominence of each type of expansion at different stages of economic development. In low-income and lower-middle-income countries, 90 percent of urban built-up area expansion occurs as horizontal spread. The study also finds that increasing incomes are a uniquely necessary condition for a rise in floor space per person through vertical layering: the reason is that building tall is capital intensive. The analysis highlights that if a city's population doubles but incomes stay constant, the city's floor space per person declines by 40 percent; by contrast, if per capita income doubles but population stays constant, the city's total floor space per person increases by 29 percent.

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Produced by the Research Support Team

The Evolution of City Form:
Evidence from Satellite Data

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1. Background and Motivation

The United Nations projects that 2.3 billion people will be added to urban areas between 2020 and 2050, with 90 percent of this increase taking place in Asia and Africa (United Nations 2018). The pace of urban growth is projected to be the fastest in Sub-Saharan Africa, where the state has weak institutional and fiscal capabilities. Urban populations in Sub-Saharan Africa are expected to double from 458 million in 2020 to 1.2 billion in 2050. At the country level, China, India and Nigeria will account for 35 percent of the projected urban population growth. These are significant numbers and proactive planning and investments will be needed to help developing country cities prepare for such growth.

An important part in planning for the large urban population growth expected over the next three decades is to understand how city form has spatially evolved to accommodate people in the recent past and what have been the key drivers of urban spatial evolution. In this paper, we provide the first globally comparable estimates of the evolution of city form over the past three decades. We distinguish changes to city form along three margins: (a) horizontal spread (extensive margin), (b) infill development (inside a city's edge), and (c) vertical layering (building taller structures).

The econometric analysis examines the proximate drivers of city form, showing the extent to which city form responds to the processes of economic development. City forms differ for cities at different stages of development; productivity enhancing agglomeration economies and supporting policies and infrastructure investment influence where people live, where firms locate, and how workers commute. As both the demand for space and economic proximity increase with income, the supply and spatial distribution of floor space is influenced by a city's productivity and the capacity of cities to build higher and their transportation systems (Sturm, Takeda and Venables 2021a).

New transportation and building technologies have historically shaped urban form. Over the last two centuries, new transportation and building technologies have enabled the expansion of cities and increased the amount of living space consumed by households and firms (Glaeser, 2020). Horse-drawn omnibuses and subways enabled the spread of 19th century cities (for example London as discussed in Heblich et al. 2020). Elevators and other engineering innovations have enabled vertical growth which further expanded the supply of floor space (Ahlfeldt & Barr 2020). More recently highways and cars have had a large impact on density and living space as exemplified by sprawling cities in the United States.

Our research makes a significant contribution to the economics literature on the spatial structure of cities. First our analysis is global in scope and employs a new comparable measure – 'the degree of urbanization' (Dijkstra et al 2020) to assess city form. In our analysis, cities are defined as urban centers with at least 50,000 inhabitants in 2015. The universe of cities includes both small cities as well as giant megalopolises and covers cities across all incomes. Having a consistent definition of urban extent allows us to compare cities across countries and over time. While Jedwab et al. (2021) provide income elasticities for land area, population size and density for 1,773 urban agglomerations in 2010, we extend the coverage to about 10,000 cities in the world and construct a panel of data from 1990 to 2015. We also focus on built-up surface rather than total area as done in Jedwab et al. (2021), which is a better proxy for measuring available floor space and allows us to assess whether new built-up surface is done through infill construction or by spreading out.

Second, much of the existing research examines horizontal expansion, and rarely incorporates the vertical dimension. Even when the vertical dimension is considered, the focus has been on North American cities or restricted to very high buildings (Ahlfeldt and McMillen, 2018; Liu et al., 2018, Ahlfeldt & Barr, 2020; Jedwab et al., 2021). While Jedwab et al. (2021) use a data set which restricts the analysis to buildings taller than 80m,[1] we use satellite height data for all buildings within the defined urban extent. We believe our approach provides a more representative measure of heights for the whole city.

Finally, we estimate income and population elasticities of the evolution of city form to understand how the spatial structures of cities change across the different stages of development and across countries and regions. We introduce novel estimates of density using floor area per resident in a city instead of traditional measures that use surface area or built-up area. We find that doubling of a city's income is associated with a 11% increase in its built-up surface and 18% increase in average building height. The share of infill development is significantly higher for upper-middle-income and high-income countries.

Following this motivational section, the rest of the paper is organized as follows. Section 2 describes the satellite and economic data used in the research. Section 3 provides stylized facts on the three margins of city form evolution -- horizontal spread (extensive margin), infill development (inside a city's edge), and vertical layering (building taller structures). Section 4 describes the econometric analysis on the proximate drivers of evolution of city form. Section 5 concludes.

2. Data

2.1 Defining a city

To measure city expansion and infill development, we use the Global Human Settlement Urban Center Database 2015 (GHS-UCDB) developed by the European Commission, Joint Research Centre (JRC). This data set defines urban centers applying the "Degree of Urbanization", which is a new global definition of cities, urban and rural areas developed by the European Union and combines the previously developed Global Human Settlement Layer Built-up (GHS-BUILT) areas and Population (GHS-POP) grids. A city consists of "contiguous grid cells with a density of at least 1,500 inhabitants per km^2 of permanent land or with a built-up surface share on permanent land greater than 0.5 and has at least 50,000 inhabitants in the cluster with smoothed boundaries" (Florczyk et al., 2019).

The GHS-BUILT is derived from satellite imagery to measure the built-up area. The data set is constructed of a series of built-up layers across four different periods (i.e., 1975, 1990, 2000, and 2014). Each year of the data set is based on different collections of Landsat satellite imagery. A total of 33,202 scenes were captured to produce the multi-temporal layers of built-up (Florczyk et al. 2019). The GHS-BUILT uses a 30m spatial resolution, which is higher resolution compared to the Moderate Resolution Imaging Spectroradiometer (MODIS) Land Cover Type (MCD12Q1) and Global Land Cover (Globcover) that are available at 500m and 300m, respectively. Coarser resolution imagery may lead to the omission of small built-up areas (as in low income countries) and poor accuracy at the urban fringe.

The advantages of this data set are twofold. First, it uses a common definition of urban center across the world which is crucial for global level comparison. Although there has been a wide discussion in the literature on how to properly define cities, no definite consensus has been reached. Some studies have used a pre-defined pixel grid as a cookie-cutter and applied that to define each city (Mahtta et al., 2019) while others have used the cities' administrative boundaries or commuting zones (Roberts et al. 2017). Second, it defines the urban extent that corresponds to the most recent available data (2015). Having

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[11] Council on Tall Buildings and the Urban Habitat (CTBUH).

these fixed and recent boundaries is useful because it allows us to analyze changes in the same area aiming to answer the question of how city form has changed through time.

The Global Human Settlements population grid (GHS-POP) uses data from the Gridded Population of the World and reallocates these estimates using the GHS BUILT data set. An alternative would have been to use data from LandScan, which uses a proprietary algorithm to provide population estimates information on elevation, slope, and land cover, as well as locations of road and rail networks, hydrologic features and drainage systems, utility networks, airports, and populated urban places (Henderson et al 2020). While LandScan reports estimates of ambient population averaged throughout the day, GHS POP reports nighttime (residential) population estimates.

The entire data set consists of 13,135 cities with at least 50,000 inhabitants in 2015. The data set focuses on measures of city built-up and city population for four points in time: 1975, 1990, 2000, and 2015. It also includes other economic, geographic and environmental variables such as city GDP, elevation, precipitation and temperature, CO2 emissions, PM 2.5 emissions and concentration levels, for similar points in time. We construct a sample of cities that have recorded positive built-up and GDP since 1990. We drop the 1975 layer as it potentially underestimates built-up areas due to the coarser resolution of the Landsat2 Multispectral Scanner (60m compared to 30m). Using the 1975 data would introduce an upward bias in city growth estimates. To further reduce measurement errors and avoid outliers, we drop cities with population less than 10,000 inhabitants in 1990 and 2000, and those with a population/built-up coefficient larger than 500,000 in 1990. This gives us a final sample of 9,468 cities, which includes cities of all sizes (Table 1). More than half the cities in the sample have less than 200,000 inhabitants.

Table 1: Distribution of Cities by City Size and Region

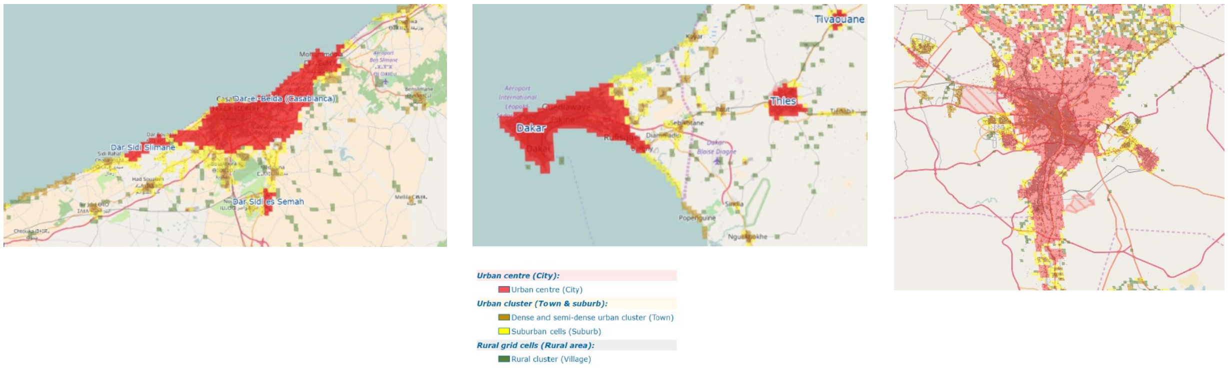
Region	Less than 70k	70k - 100k	100k - 200k	200k - 500k	500k - 1m	1m- 10m	More than 10m
East Asia & Pacific	612	609	819	476	131	116	11
Europe & Central Asia	345	297	324	225	77	56	2
Latin America & Caribbean	267	228	255	158	60	51	3
Middle East & North Africa	221	137	199	113	43	40	2
North America	77	86	92	60	22	33	2
South Asia	312	362	588	390	122	84	7
Sub-Saharan Africa	300	290	439	217	55	52	1

Source: GHS urban centers database

One needs to keep in mind that our analysis uses cities as the unit of analysis and does not include urban agglomerations, which often include adjacent suburbs. However, to enable comparability, a density threshold of 1,500 people per km^2 is used as a cutoff. Figure 1 shows the boundaries for Casablanca, Cairo and Dakar with this approach. To check for robustness of this arbitrary cutoff, we selected the 50 fastest growing cities from 1990 to 2015 to assess the population variations across different sizes of urban areas. Multiple ring buffers (from negative 5km to positive 5km away from the edge of the urban boundary) were added to the urban boundary. Except for two outliers—Guangzhou, China, and Jakarta, Indonesia—

the median values of population estimate with additional buffered urban areas are similar to the population within the urban boundary using the 1,500 persons per km^2 cutoff.[2]

Figure 1: By our definition, a city includes the urban center but excludes the urban cluster (towns and suburbs) and Rural areas


(a) Casablanca (b) Dakar (c) Cairo

Source: Analysis based on GHS urban centers database

Finally, we compare our results using Functional Urban Areas (FUA) boundaries defined as urban centers and neighboring areas belonging to commuting zones. A comparison shows that other than a few exceptions—high-income land-rich countries including the United States, Canada, and Australia -- the GHS-UCDB adequately captures urban built-up areas

2.2 City building heights

We use a novel data set of building heights for a subsample of 397 cities. These data come the WSF 3D data product of the German Aerospace Center (DLR) and this subsample follows a distribution similar to the original sample of cities (Table 2, also Annex 1).

Table 2: Distribution of Cities by City Size and Region – DLR Data

Region	Less than 500k	500k - 1m	1m- 10m	More than 10m
East Asia & Pacific	82	9	24	9
Europe & Central Asia	35	8	12	2
Latin America & Caribbean	28	4	10	3
Middle East & North Africa	19	3	7	2
North America	7	1	8	2
South Asia	55	7	10	5
Sub-Saharan Africa	31	4	9	1

Source: DLR WSF 3D data set

The raw satellite images are collected at a fine grain resolution of 12m*12m pixels. Analysis done by the DLR identifies points at the ground level and generates a digital terrain model (DTM). Ground level heights

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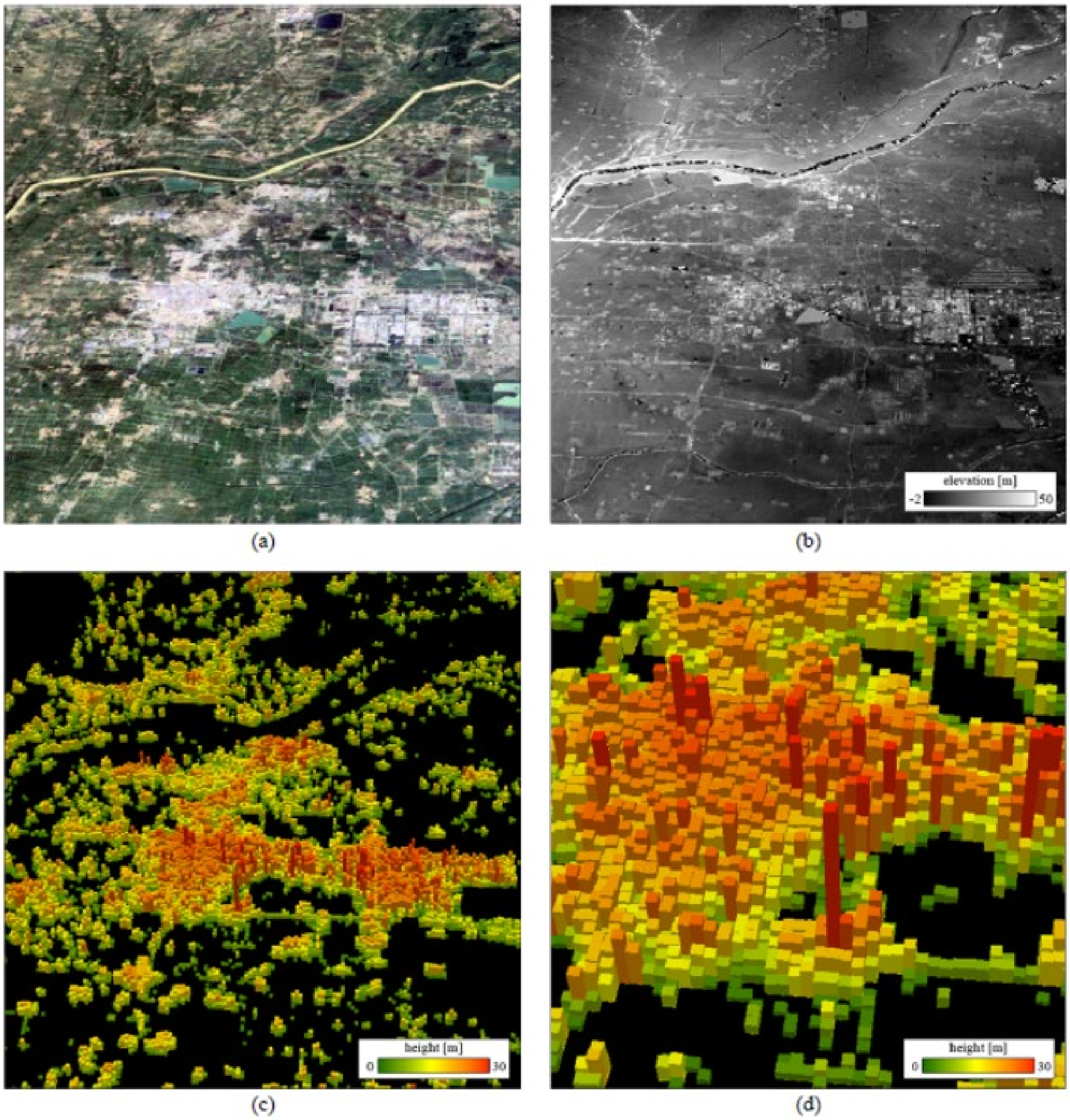
[2] Results from the robustness check can be provided on request.

are subtracted from the original height to obtain the real heights of buildings. To dampen the noise to signal ratio, after identifying ground pixels (12m resolution) and DTM Estimation, the heights are calculated at 30m resolution as an average of the heights of the 12m pixels that fall inside. Figure 2 shows the process for the Dongying area in China.

Figure 2: Estimating building heights from satellite imagery: a four-step process



(a) (b) (c) (d)

Source: DLR Note: Example for a city in China. Panel (a) shows the real picture; (b) Raw data: Elevation using satellite data; (c) Remove ground level height to get the "real" height of buildings; and (d) Generate height maps at 30*30m pixels

For each city, the data set provides the average height of every pixel inside the defined urban extent, with a resolution of 90x90 meters. Although these data do not allow us to identify the building height of individual buildings, it still provides a good measure of the height of the city and how fast or slow that height changes as one moves away from the city center. One caveat is that the data were collected between 2006 and 2011, but corresponds to only one point in time, which does not allow for examination of city height evolution.

As mentioned before, for each city, the data from the DLR provides average height of every pixel inside the defined urban extent, with a resolution of 90x90 meters. Table 3 provides summary statistics on building heights across cities at different income levels. These are average heights, covering the entire urban extent.

Table 3: City Heights Measures - Summary Statistics by Income Group

	Low Income	Lower-Middle Income	Upper-Middle Income	High Income
Ave Height (in m)	2.37 (0.53)	2.34 (0.77)	3.58 (1.32)	3.34 (1.14)
Ave q90 (in m)	3.63 (1.21)	3.72 (1.56)	6.24 (2.73)	5.93 (2.62)
Ave q95 (in m)	4.26 (1.58)	4.35 (2.00)	7.56 (3.43)	7.69 (3.88)
Ave max (in m)	10.52 (6.65)	13.26 (12.26)	25.12 (23.58)	31.78 (16.83)
Ave TFA (in m2)	78.65 (111.24)	140.75 (325.67)	354.58 (1,118.25)	707.37 (1,209.62)
Ave TFA/City Area	0.79 (0.18)	0.78 (0.26)	1.19 (0.44)	1.11 (0.38)

Source: Analysis based on DLR WSF 3D data set

Note: These are average heights for 90m x 90 m blocks, further averaged across the city's extent

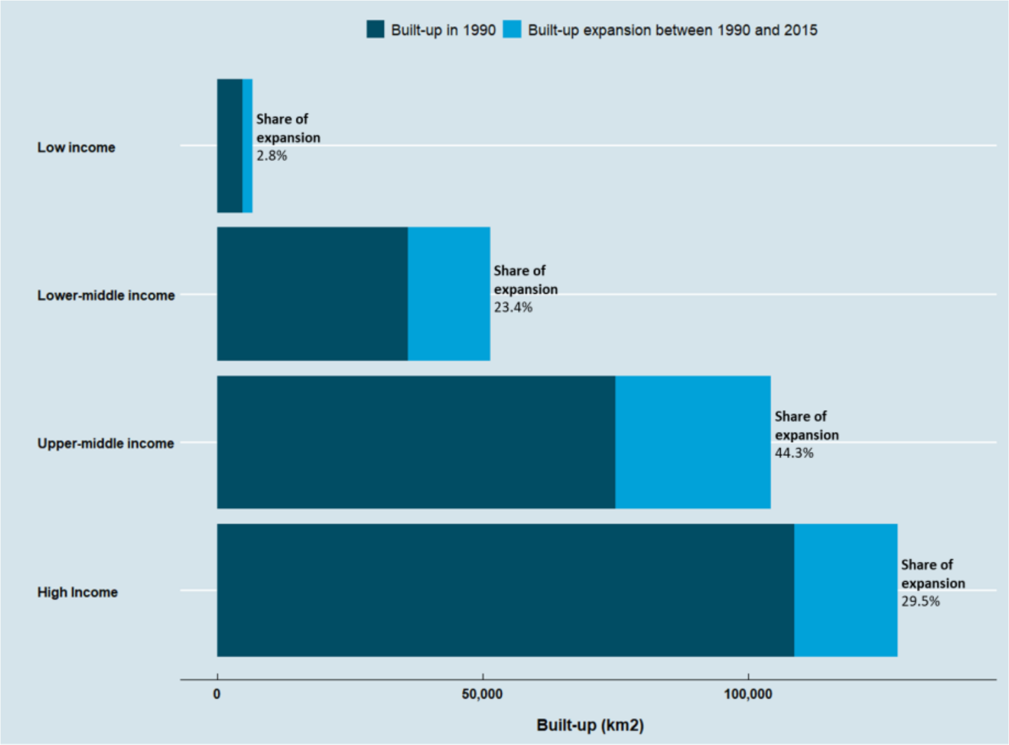
3. Stylized facts

In this section, we provide stylized facts on the magnitude and spatial distribution of built-up area growth and vertical layering in cities. As we have data on heights and can compute floor area, we provide a new measure of floor space adjusted density.

3.1 The growth of urban built-up area is slower than has been thought

Analysis of the satellite data show that between 1990 and 2015 the world's total urban built-up area increased by 66,000 km^2, or the size of Sri Lanka. Urban built-up area increased from 226,768 km^2 to 294,550 km^2, a growth of 30 percent. In developing countries, urban built-up area increased from 117,977 km^2 to 166,231 km^2 over the same time period. That is a 34 percent growth in built-up expansion, an annual growth of 1.36%. While this is significant, it is not quite the explosive spread estimated by many recent studies. For example, the *Atlas of Urban Expansion* (Angel et al, 2016) argued that during this period the area occupied by cities in less developed countries increased by a factor of 3.5—and that if this rate were to continue, the total amount of land taken over by urban land use would be equivalent to the entire country of India by 2050 (Angel et al 2016). Huang et al (2019) project urban land areas to expand by 0.6–1.3 million km^2 between 2015 and 2050, an increase of 78 percent–171 percent over the urban footprint in 2015.

Figure 3: Urban built-up area expansion by national per capita income level (1990–2015)



Source: Authors' analysis using GHS data

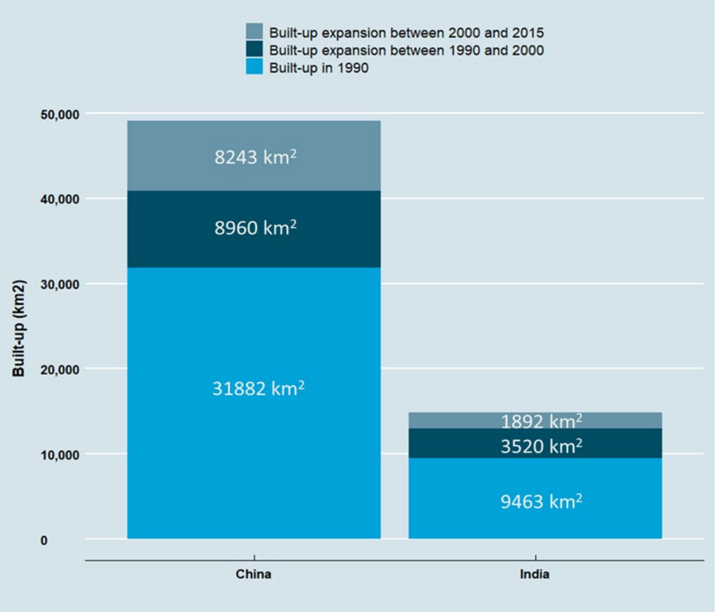
Globally, the expansion of urban built-up area over 1990–2015 was disproportionately concentrated in high-income and upper-middle-income countries. Figure 3 shows that in 1990, cities in high-income countries accounted for 48 percent of global urban built-up area (108,726 km^2). The same rich-country cities contributed 29.5 percent of the world's growth in built-up area between 1990 and 2015.

More striking is the rapid expansion of urban built-up area in upper-middle-income countries. Containing one-third of the world's urban built-up area in 1990, these countries contributed 44 percent to its expansion between 1990 and 2015. Thus, both their total contribution and their rate of urban built-up expansion were about 1.5 times as high as those of high-income countries.

China and India have led globally in expanding urban built-up area over 1990–2015 (Figure 3). China alone contributed 60 percent of all urban built-up area expansion by upper-middle-income countries during this period. In absolute terms, China added more than 17,000 km^2 of such area. India's urban built-up expansion was also impressive: starting from 9,463 km^2 in 1990, it had added 5,421 km^2 by 2015, contributing 8.2 percent of the world's total urban built-up area increase.

While smaller in absolute terms than China's urban expansion, India's was more nearly comparable in its rate of growth: urban built-up area expanded by 45 percent in India over 1990–2015 (Figure 4). These numbers need to be viewed in perspective as China and India are projected to lead global urban population increase over the next three decades.

Figure 4: Urban built-up area expansion in China and India (1990–2015)



Source: Authors' analysis using GHS data

3.2 Horizontal expansion dominates built-up area growth, but rising incomes increase the contribution of infill development

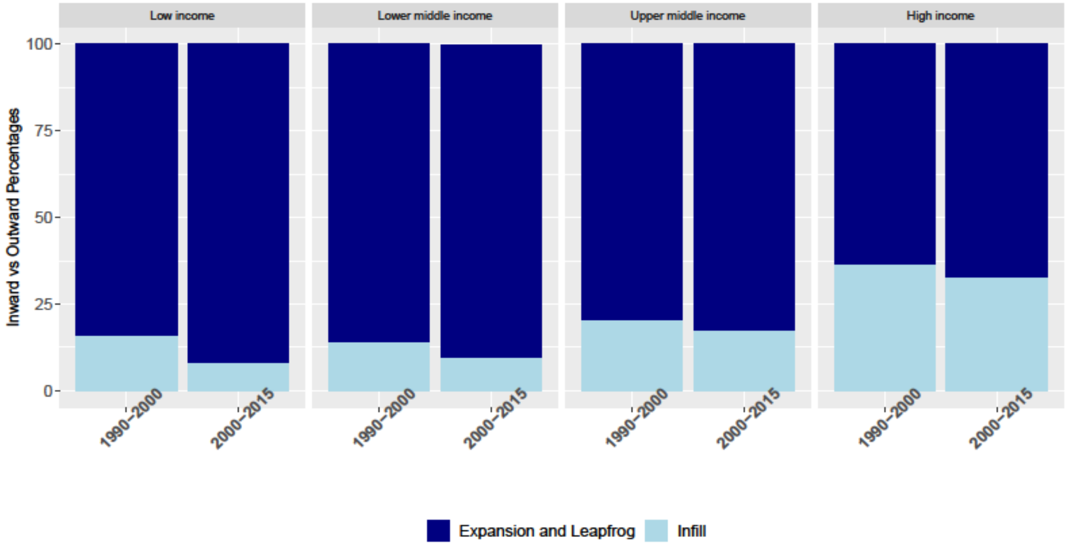
We now examine the spatial distribution of built-up growth, which can take place at a city's extensive margins as the city expands outward as well as through development within the city's boundaries, through what economists call "intensive margin development" or infill development. While most cities grow through a combination of horizontal spread and infill development, the proportions of each are likely to change at different stages of economic development—and with changes in construction technologies, preferences, and local political choices.

To measure the shares of extensive margin development and infill development, we follow the methodology proposed in Liu et al. (2010). They use the percentage of a buffer area of new built-up that intersects the buffer area of existing built-up and estimate an index. This index allows them to identify three types of growth as follows:

- Leapfrog: share of the buffer area of new built-up that intersects existing built-up is less than 0.01%,
- Expansion: share of the buffer area of new built-up that intersects existing built-up is greater than 0.01% or less than 50%,
- Infill: share of the buffer area of new built-up that intersects existing built-up is greater than 50%.

Using the urban extent for 2000 and 2015 from GHSL SMOD data and the GHSL global built-up raster, we combine leapfrog development and expansion as a single measure of horizontal spread. Figure 5 shows the distribution of built-up area changes between horizontal spread and infill development over two periods: 1990-2000 and 2000-2015. Horizontal spread dominates in each period—and its share was even greater in 2000-2015 than in the previous decade. In low-income countries, 90% of built-up area is provided through horizontal spread. Nevertheless, there is a silver lining: in high-income and upper-middle-income country cities, a larger share of new built-up area is provided through infill development.

Figure 5: Horizontal spread and infill development as shares of total additions to built-up area, by income group (1990–2000 and 2000–2015)



Data source: Authors analysis using GHS data

For example, a city in a high-income country that increases its built-up area by 100 m2 will add about 35 m2 through infill development and 65 m2 through horizontal spread. However, a similar city in a low-income country will add about 90 m2 through horizontal spread, with only 10 m2 from infill.

3.3 Increasing incomes are an indispensable driver of vertical layering

Just as infill development is resource intensive, building tall is also capital intensive. This is true for office blocks, and also for the move from informal to formal settlement. It therefore requires income levels, capital wealth, and financial institutions that enable these investments to be made. Even if the levelized lifetime costs of different building types were similar, meeting the upfront capital costs of load-bearing structures would still be more feasible in cities with higher incomes. Using the WSF 3D data, we find that cities in high-income and upper-middle-income countries have higher building heights compared to cities in low-income and lower-middle-income countries. Figure 6 shows a scatter plot between the 95th percentile of city heights (y axis) and city GDP per capita (in logs, x axis).[3] A clear pattern emerges as building heights increase, albeit nonlinearly, with economic development. The scatter plot is based on a sample of 400 cities, which are representative of the global data discussed in section 3.1.

We also examine height distribution within cities. Figure 7 shows that cities in upper-middle-income and high-income countries are built taller higher and more structurally compact near the center: they are more pyramid shaped, with peaked skylines and a higher concentration of downtown floor area for residents and businesses.

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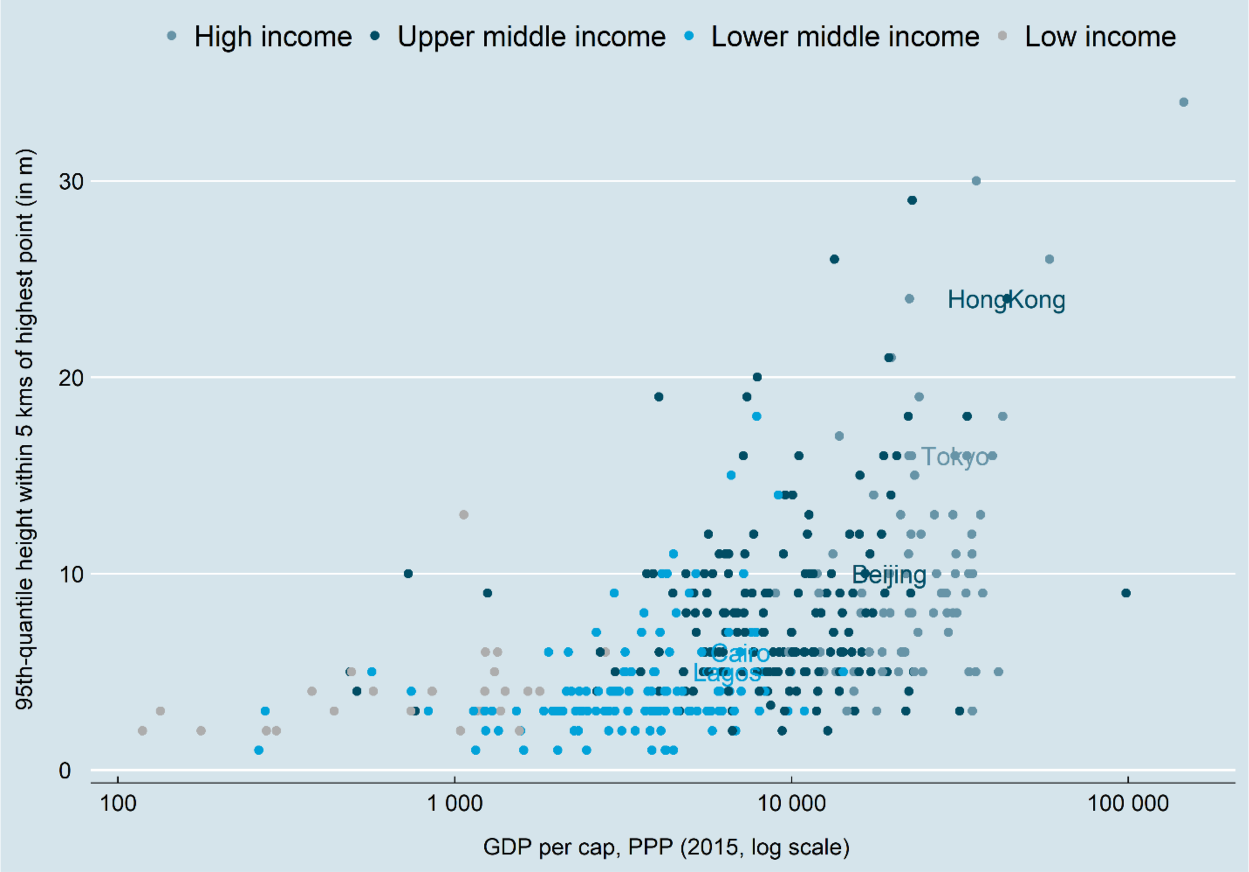
[3] The chart is limited to a radius of 5 km from the highest point in a city.

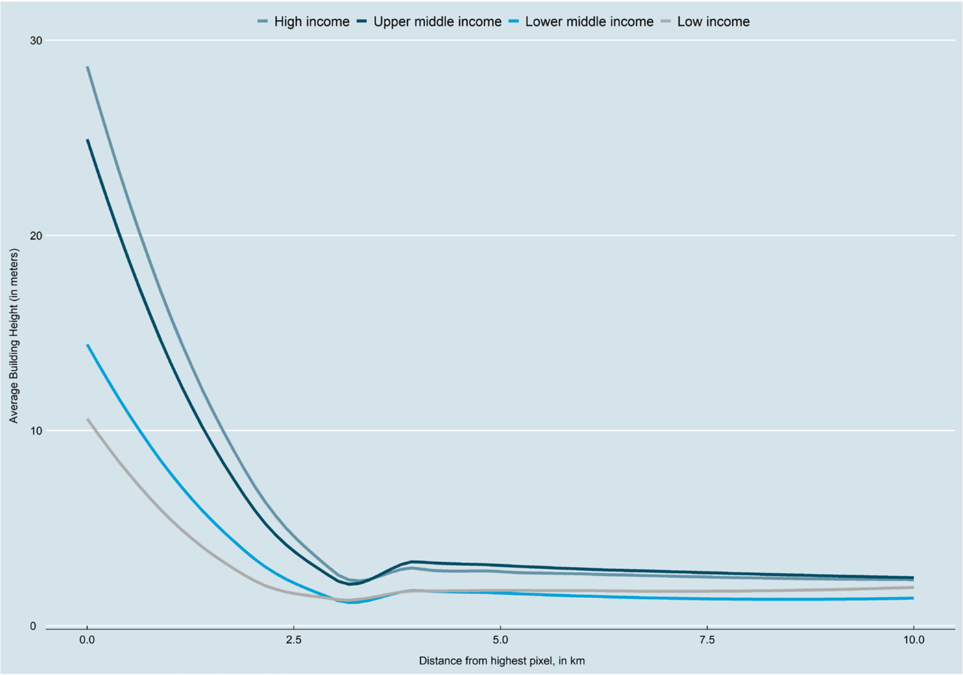
Figure 6: City building heights increase with economic development



Source: Analysis using WSF 3D data. Note: We show the 95th percentile of the height distribution in this scatterplot.

The patterns displayed in Figure 7 reflect economic processes. Higher incomes, driven by rising productivity drive rising demand for commercial floor space and for housing, both of which are normal goods (demand increases with income). Higher income cities meet part of this demand when developers build taller in response to rising land prices. Dasgupta et al (2014) use national accounts statistics to build a data set of residential housing investment for more than 90 countries. They find that housing investment follows an S-shaped trajectory taking off around per capita GDP of around $3,500 (US$2005) and tapering down at per capita GDP around $36,000 (US$2005). Low-income economies have low income elasticities stemming from both demand and supply constraints. Rigidities in the supply of materials, organization of the construction industry, and nascent markets for land transactions constrain housing expansion in urban areas. On the demand side, when incomes are low at early stages of development, the claims of other consumption expenditures such as food tend to be stronger (Lakshmanan et al 1978, Regmi et al 2001).

Figure 7: Richer cities are more pyramid shaped, with peaked skylines



Source: Analysis using WSF 3D data.

Note: The graph reports the smoothed line of average pixel heights per city. Each pixel contains information on both its average height and the calculated distance to the highest pixel of the city. First, in each city, pixel heights are averaged for each interval of distance to the highest point. Second the lowess function is used to report the smoothing lines of average heights for cities per income group. The figure above reports the lowess smooth of average height per distance to the highest city point per income group.

After lagging early in development, the income elasticity of housing expenditures is likely to increase during periods of rapid industrialization and then begins to decline at high levels of per capita incomes. Rising incomes free up room for consumption of housing and related durables, and are typically associated with the building of technical and institutional capabilities that enable housing investment. Asset formation in housing provides a hedge against the erosion of savings driven by inflationary pressures. Finally, as countries approach high incomes, much of the housing and physical infrastructure is in place and residents instead demand many commodities that are substitutes for housing services (e.g., recreation vehicles, boats, etc.) or complements (e.g., household furnishings and equipment). This reduces demand and income elasticity of housing.

The econometric analysis in the next section provides a careful examination of income elasticities of urban expansion, heights, and floor space, and how it varies by stages of development.

3.4 Floor area adjusted population densities can sort between crowded and livable cities

Population density is the most common measure of urban concentration. Most measures of population density take the form of people/urban built-up area or people/total urban area. However, population density is an imperfect measure of urban proximity as it does not account for the quality of built structures.

Figure **8**a shows a scatter plot of population density and city incomes. Population density is measured as people per built-up area of the city, for 400 cities worldwide. Two striking features emerge. First, population densities decline with incomes, as countries move across stages of economic development. Kinshasa, Mumbai and Karachi are four to five time more densely populated than Shanghai, Tokyo or London. Second, naïve measures of population density can conflate crowding with livable densities. Kinshasa, Mumbai and Hong Kong are three cities with similar population density but at very different levels of income.

While Hong Kong's residents can live in tall buildings with adequate floor space, over 50 percent of Mumbai's population lives in slums. Most of Kinshasa's population lives in squalid conditions. In low- and lower-middle-income countries, population densities in the range of 50,000 people per km2 are reflections of squalor and crowding, not livable densities. Such crowding has been associated with high degree of contagion risk during the COVID-19 pandemic, where residents do not have physical space to be socially distant and need to access shared toilets and water kiosks in their neighborhood (Lall and Wahba 2020).

To untangle crowding from livable densities, we introduce a new measure called the Floor-area adjusted population density (FAPD), which we measure using the heights data available from DLRs WSF 3D database. We first compute total floor area using the heights data as follows:

$$TFA = \sum \frac{average\ height\ of\ each\ pixel * pixel\ surface}{average\ floor\ height}$$

Where TFA is the total floor area. The average floor height is assumed to be 3 meters. This measure can be compared across pixels in a city, or aggregates compared across cities. Using the TFA measure, we can compute FAPD as follows:

$$FAPD = \frac{Population}{TFA}$$

Figure 8: Comparing naïve and floor area adjusted population densities (FAPD) across 400 global cities

Figure a. Population density and city income, 2015. (population per km2 of built-up area, log scale)

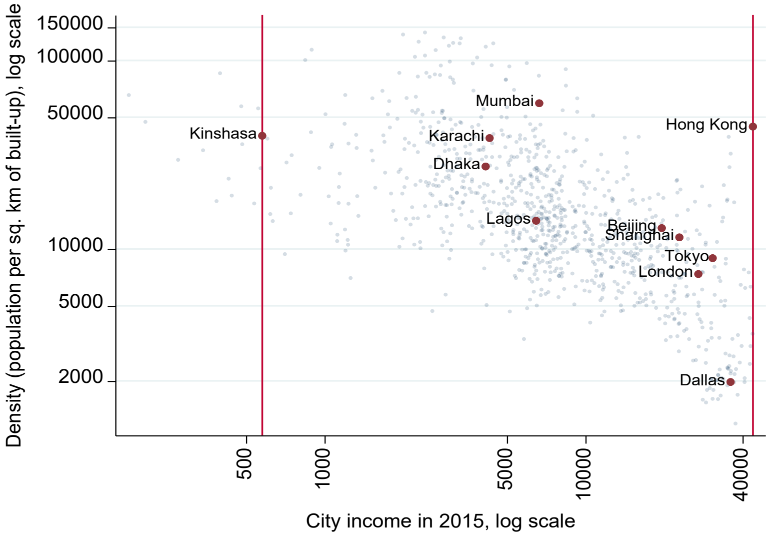
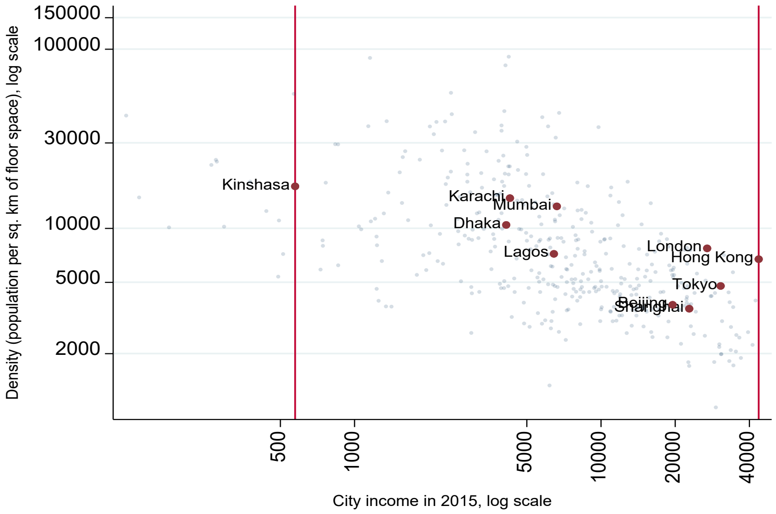


Figure b. Floor Area Adjusted Population Density (FAPD) and city income, 2015 (population per km2 of floor space, log scale)



Source: Analysis based on DLR WSF 3D data set

The FAPD in Figure 8b is a reasonable indicator of livability. Hong Kong's FAPD is in line with that of a high-income city like London or Tokyo. FAPDs for low-income cities such as Kinshasa and Mumbai are also lower than their naïve population densities, with the correction making more of a difference for specific neighborhoods that have taller structures. While the FAPD makes intuitive sense, more work is needed to get better estimates of building heights. The DLR WSF3D data make a first contribution to such measurement. There are many measurement errors in the data coming from the ability of satellite sensors to measure height as well as noise introduced in the aggregation of the data collected at 12mx12m resolution. However, analysis of these data for the city of Dhaka shows remarkable correlation with predictions of heights based on productivity measures estimated through a general equilibrium urban model (Sturm, Takeda and Venables 2021b).

4. Evolution of urban form – econometric evidence

The previous section provided descriptive statistics on built-up area growth, horizontal expansion and vertical layering of cities. In this section we expand on those stylized facts and provide econometric evidence to show how the evolution of urban form follows stages of a city's economic development. There is a broader literature on institutions and economic development that makes the point that human capital, quality of institutions, and government effectiveness are strongly correlated with economic development (La Porta et al. 1999, Glaeser et al. 2004). More recently, Djankov and co-authors (2020) show that quality of institutions of land titling and transferring property across countries are generally much better in more developed countries.

Building and development choices are also shaped by institutions and regulations. Lack of clarity in land tenure creates a bias against sinking capital in formal structures and is a factor in the perpetuation of slum areas (Sturm, Takeda, and Venables 2021a). Building regulations, such as floor-area restrictions (FARs) often restrict density of both commercial and residential development, this lengthening commutes and weakening agglomeration spillovers between firms. Zoning can be done in ways that are damaging – locking in land-use patterns that become inappropriate as a city develops. Potential benefits could arise by regulating negative externalities that affect households, and possibly also by encouraging concentration of commercial activity, and so promoting positive spillovers and externalities between firms. Further, meeting the upfront capital costs of infrastructure and structures is more feasible in cities with higher incomes (Hommann and Lall 2019, White and Wahba 2019).

While we do not have comparable and representative data on institutional quality or regulatory regimes for individual cities, we use city incomes as a proxy for productivity as well as institutional and financial maturity. The econometric analysis examines how the evolution of urban form is closely tied to the processes of economic development. The econometric evidence is organized in three sub-sections. Section 4.1 examines the relationship between incomes and built-up area changes between 1990 and 2015. Section 4.2 examines links between income and city heights. Section 4.3 provides a new approach to look at the combined effect of population growth and income growth on floor space in a city.

4.1 The effects of income and population growth on built-up area

As population and income grow, cities expand by building more and occupying more land. We quantify the income and population elasticities of built-up using a panel of observations from the GHSL Urban Centers database. As described in section 2, built-up surface for all cities with more than 50,000 inhabitants in the world is available for four years: 1975, 1990, 2000, and 2015. City income and population estimates come from the same GHSL database.[4]

Several econometric issues arise when estimating the impacts of a growing population and income on city built-up over the past decades. First endogeneity issues may arise as factors that are not observed may affect both the dependent variable, built-up surface, and the explanatory variables, population and income of the city. Second, there may be omitted variables that are key predictors of built-up but are not observed such as geographic or weather amenities. In each case, a simple OLS estimator will be biased. Therefore, the results from different specifications based on equation (1) are reported with each of them solving an econometric issue. The panel regression analysis is based on the following specification:

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[4] Similar estimates are obtained when using country income.

For city c, at time t ,

$$\ln BU_{c,t} = \alpha + \gamma^{bu} \ln Income_{c,t} + \beta^{bu} \ln Pop_{c,t} + \text{City Controls} + FE + \epsilon_{c,t} \quad (1)$$

With $BU_{c,t}$ the built-up surface at time t for city c. City Controls include built-up surface in 1975. FE include a series of fixed effects at the city or/and year levels.

Our very basic strategy was to use the 'between' estimator to capture variation based on changes across years, adding in country fixed effects. Results from this estimation are reported in table 4, column 1. Year fixed effects control for aggregate changes that have affected all cities at each period. The built-up of the city in 1975 is added as a control for unobserved variables like historical and geographic characteristics that are a main determinant of a city's growth path.

A limitation with this specification is potential omitted variable bias. To address this, we estimate both the 'between' and 'within' estimator, we treat city heterogeneity as another variable, the fixed effect. This allows us to address unobserved city heterogeneity that do not vary with time. This reduces omitted variable bias. Results from this specification are reported in Table 4, column 2.

Table 4: Determinants of built-up surface

Dependent variable: built-up	**Between Estimator**	**Between + Within Estimator**	**Between + Within Estimator with lag**	**IV Between + Within Estimator**	**Between + Within Estimator with NTLs**
Ln Income	0.184^{***}	**0.104^{***}**		0.149^{***}	
	(0.00713)	**(0.00483)**		(0.00439)	
Ln Population	0.509^{***}	**0.347^{***}**		0.373^{***}	0.307^{***}
	(0.00846)	**(0.0176)**		(0.00856)	(0.0179)
Built-up 1975	0.458^{***}				
	(0.00749)				
Ln lagged Income			0.0982^{***}		
			(0.00453)		
Ln lagged population			0.281^{***}		
			(0.0146)		
Ln NTLs per capita					0.0883^{***}
					(0.00553)
FE	Year	**City + Year**	City + Year	City + Year	City + Year
Controls	Country	**No**	No	No	No
R-squared	0.913	**0.583**	0.471		0.572
N. of observations	28332	**28341**	18894	27460	27688

Standard errors in parentheses * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

Another econometric problem is that incomes and population are endogenous to built-up. In addition, built-up might react with delays to changes in income. One way to address these endogeneity concerns is to introduce lagged variables. The first instrument is the lag of population and income. However, it reduces the sample of observations by a third. The second instrument used for income is the country GDP per capita. Column (3) and (4) report these results. Finally, we compare our measure of city income with a commonly-used proxy for income, Nighttime Lights (NTL) per capita.[5] We process DMSP-OLS data for three years (1992, 2000, and 2012) for the areas matching with the GHS-UCDB urban areas used in the rest of the paper. Column (5) reports the results using Nighttime Lights per capita instead of the previous income measure. Our preferred specification is given by the between and within estimator in Column (2). Estimates are similar when using instrumental variables and Nighttime Lights as a proxy for income. Income and population elasticities can be inferred from the results of the regression.[6]

As a city's population doubles, its built-up surface increases by 34.7% when keeping income constant and controlling for unobserved city and year characteristics. This number is lower than previous estimates reported in the literature (Angel, et al., 2016) and shows that cities have not extended their built-up as much as their population growth would have suggested. As a city's income doubles, the built-up surface increases by 10.4% when keeping population constant and controlling for unobserved city and year characteristics.

As a final robustness check, we run the same regression as in Table 4 using population, income and built-up from the Functional Urban Area (FUA) database developed by the OECD and the European Commission. The spatial entities represent the commuting areas of the urban centers in 2015, which are geographically larger than our urban extents as they often contain multiple urban centers. Annex 2 presents a similar table as in Table 4. The new coefficients are similar to the ones estimated using our urban centers.

Table 5 : Determinants of built-up surface across income groups

Dependent variable: built-up	**All countries**	**Low income**	**Lower middle income**	**Upper middle income**	**High income**
Ln city Income	0.104*** (0.00483)	0.0488* (0.0192)	0.0891*** (0.0134)	0.107*** (0.00594)	0.101*** (0.0187)
Ln Population	0.347*** (0.0176)	0.343*** (0.0474)	0.308*** (0.0371)	0.251*** (0.0207)	0.281*** (0.0261)
FE	City + Year	City + Year	City + Year	City + Year	City + Year
Controls	No	No	No	No	No
R-squared	0.583	0.597	0.612	0.611	0.549
N. of observations	28341	2139	10959	11124	4119

Standard errors in parentheses * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

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[5] While Defense Meteorological Satellite Program/Operational Linescan System (DMSP-OLS) was originally designed for military use, DMSP-OLS has been widely used in social science because of its low-light imaging capabilities to detect nighttime artificial lighting (Elvidge et al., 1997). Henderson et al. (2012) empirically prove the concept of using an annual composite of DMSP-OLS as a proxy measurement of economic growth across the national and/or local level. Many studies extensively use nighttime lights to estimate the national and sub-national GDP. These estimates are critically useful for developing countries and/or conflict-affected areas where official statistics are unavailable or limited.

[6] Other possible specifications were considered but not reported in this note. A dynamic panel specification was considered but 3 years of data was not sufficient to report strong results for a dynamic panel.

To examine how urban forms evolve across stages of development, we examine built-up area growth across income groups.

As a final robustness check, we run the same regression as in Table 4 using population, income and built-up from the Functional Urban Area (FUA) database developed by the OECD and the European Commission. The spatial entities represent the commuting areas of the urban centres in 2015, which are geographically larger than our urban extents as they often contain multiple urban centers. Annex 2 presents a similar table as in Table 4. The new coefficients are similar to the ones estimated using our urban centers.

Table 5 reports the results of the between and within estimator following equation (1) for cities per country income group as defined by the World Bank. The coefficients of each column can be interpreted as the income and population elasticities of built-up surface for cities in each income group.

Growing population is associated with a larger increase in built-up surface in poorer countries. As population doubles, cities' built-up increases by 34% in low-income countries, 31% in lower-middle income countries, 25% in upper-middle-income countries and by 28% in high-income countries.[7] Cities in poorer countries grow more horizontally than cities in richer countries. In contrast, rising incomes are associated with slower built-up surface expansion in poorer countries than in richer ones. As urban population doubles, the city's built-up area increases by 5 percent in low-income countries, 9 percent in lower-middle-income countries, 11 percent in upper-middle-income countries, and 10 percent in high-income countries. The significant jump in the income elasticities between low-income and middle-income countries is indicative that the evolution of urban form follows broader stages and processes of economic development.

Next, we examine the extent to which rising incomes and stages of economic development influence the shares of extensive margin and infill development. We build a panel of two periods of built-up growth: 1990-2000 and 2000-2015. We estimate the share of infill as :

$$\ln Infill_{c,t} = \alpha + \beta_1 \ln Inc_{c,t} + \beta_2 \ln Pop_{c,t} + \lambda_t + \gamma_c + \epsilon_{c,t} \text{ (2)}$$

where $Infill_{c,t}$ denotes the share of infill built in the period between two years of our data (1990-2000 and 2000-2015).

Consistent with the stylized facts shown in Figure 5, the share of infill has reduced over time. Also consistent with the stylized facts, the share of infill increases with economic development. Within broad income groups, there is no association between income changes and infill in low-income countries. The positive relationship is strong and statistically significant for middle-incomes countries. We see a negative association between incomes and infill in high-income countries, presumably driven by the United States.

Table 6: Determinants of infill development

Dependent variable: share of infill construction in total built-up area	All countries	Low income	Lower middle income	Upper middle income	High income

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[7] There is no contradiction in the fact that the estimated coefficients per income group are all lower than the estimated coefficient when including all cities.

Ln city Income	0.529*** (0.0458)	-0.181 (0.181)	0.517*** (0.104)	0.687*** (0.0590)	-1.115*** (0.223)
Ln Population	1.132*** (0.143)	1.427*** (0.388)	1.765*** (0.248)	0.675** (0.216)	-0.915* (0.390)
year=2015	-1.235*** (0.0293)	-1.945*** (0.124)	-1.306*** (0.0545)	-1.280*** (0.0467)	-0.655*** (0.0502)
FE	City + Year	City + Year	City + Year	City + Year	City + Year
Controls	No	No	No	No	No
R-squared	0.250	0.324	0.200	0.289	0.469
N. of observations	18787	1423	7233	7377	2754

Standard errors in parentheses * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

The evolution of built-up area also has implications for population density. We estimate Income and population elasticities of naïve density measured as population over built-up area. Using the GHSL panel data, different specifications are estimated including nonlinear effects for the largest cities based on the following regression:

$$\ln Density_{c,t} = \alpha + \beta_1 \ln Inc_{c,t} + \beta_2 \ln Inc^2_{c,t} + \beta_3 \ln Pop_{c,t} + \beta_4 \ln Pop^2_{c,t} + \lambda_t + \gamma_c + \epsilon_{c,t} \quad (3)$$

As shown previously, as cities become richer, they expand responding to a higher demand for space and supply for built-up, and therefore become less densely populated. The income elasticity of density is -0.10 using the between and within estimator; introducing instruments for incomes increases it to -0.15. Table 7 provides estimates of the income elasticity of density using various specifications. Figure 9plots out densities over incomes levels using the nonlinear specification for cities larger than 500,000 people (column 5, Table 7). The chart reveals that density declines rapidly between low and middle incomes, and it stabilizes as cities reach $20,000 per capita. As population keeps growing, some of these large cities will provide space through higher buildings, increasing the livability of its inhabitants while allowing for larger agglomeration gains.

Table 7: Determinants of naïve population density (population over built-up)

Dependent variable: Population density over built-up	**Between + Within Estimator**	**Between + Within Estimator with lag**	**Between + Within Estimator with NTLs**	**Between + Within Estimator with IV for income**	**For Cities > 500k only**	**Nonlinear specification for Cities > 500k**
Ln Income	-0.105*** (0.00484)			-0.149*** (0.00439)	-0.0762*** (0.0103)	-0.397*** (0.0946)
Ln Population	0.649*** (0.0177)		0.692*** (0.0180)	0.627*** (0.00856)	0.784*** (0.0277)	-0.446 (0.380)
Ln lagged Income		-0.181*** (0.00650)				
Ln lagged population		0.478*** (0.0347)				
Square Ln Income						0.0197*** (0.00584)

Square Ln Population						0.0432**
						(0.0132)
Ln NTLs per capita			-0.0880***			
			(0.00553)			
Constant	3.270***	5.699***	1.453***	3.860***	-0.615	9.400***
	(0.218)	(0.424)	(0.204)	(0.119)	(0.402)	(2.768)
FE	City + Year	City + Year	City + Year	City + Year	City + Year	City + Year
Controls	No	No	No	No	No	No
R-squared	0.415	0.328	0.420		0.466	0.477
N. of obs	28352	18856	27636	27460	2495	2495

Standard errors in parentheses * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

4.2 The effects of income and population growth on vertical layering

Cities can add space by expanding their built-up surface as well as by building higher. We use the sub-sample of almost 400 cities, representative of the larger GHSL sample to assess the income and population elasticities of city height.[8] Height is measured as the average height of the city's buildings within 5 kms of the highest point in the city.[9] Similar analysis is conducted using the average over the whole urban extent as defined by GHSL, or using quantiles over the whole distribution. Several specifications are reported in Table 5 adding regional dummies as additional controls and replacing city income by its Nighttime Light proxy or its equivalent at the country level.[10] Using the cross-section data for almost 400 cities, the following specification is estimated for all cities c:

$$\begin{aligned}\ln\ \text{Average Height}_c &\\ &= \alpha + \gamma^{height} \ln \text{Income}_{c,2000} + \beta^{height} \ln \text{Population}_{c,2000} \\ &\quad + Region\ \ Dummies + \epsilon_c \qquad (4)\end{aligned}$$

As city population doubles, the average height increases by 25% when keeping income constant. Such vertical growth adds up to the horizontal built-up growth previously measured. This elasticity is consistent across the different specifications presented in Table 8.

As city income doubles, the average height increases by 18% when keeping population constant. While the population elasticity is lower for height than for built-up, the income elasticity is higher for height. Income is associated with a larger impact on vertical growth relatively to its impact on horizontal growth. This can be rationalized through different economic channels. As households get richer, more of them want to live close to where jobs are to reduce the time spent on commuting and can afford higher rents. Richer cities also tend to produce more tradable services which are intensive in knowledge workers and

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[8] The subsample of 400 cities was built to be as representative as possible at the global level of the GHSL sample of cities. As a first check, the same regression is run using both the universe and the subsample. The within-estimator of the income and population elasticities of built-up is obtained for each sample and are shown to be very similar. These estimates can be shared on request.

[9] Given that most surface is expected to be built around the highest point of the city, the measured height per pixel in this 5-kilometer radius will correspond to both the average over the buildings and the average for the total area of the pixel. DLR data provide height averages over the area of the pixel.

[10] Population and Income from year 2000 are used for two reasons. First, height data have been collected between 2007 and 2011, with the year of collection reported in the data. Second, adding some lag in the explanatory variable can be thought as an instrumental strategy to deal with the endogeneity issues associated with the initial specification.

gain the most from agglomeration gains and density of activities, rising demand for higher buildings. On the supply side, the construction and real estate sectors are better equipped in richer cities to build high buildings which require advanced engineering technologies (Ahlfeldt & Barr, 2020).

Across geographic regions, there is a large heterogeneity in the heights of cities. Compared to cities in East Asia and Pacific, cities in Latin America & Caribbean have shorter buildings. The largest difference is however with cities in South Asia and Sub-Saharan Africa, which have the lowest building heights, when controlling for income and city population.

Table 8: Determinants of city height

Dependent variable: Average height	All with city income [preferred specification]	All with NTLs per capita	+ region dummies	All with country income	+ region dummies
Ln Population 2000	0.251***	0.262***	0.266***	0.267***	0.269***
	(0.0170)	(0.0155)	(0.0173)	(0.0171)	(0.0166)
Ln City Income 2000	0.185***		0.0557		
	(0.0219)		(0.0322)		
Ln NTLs per capita		0.209***			
		(0.0344)			
Ln Country Income 2000				0.222***	0.102**
				(0.0251)	(0.0352)
East Asia & Pacific			0		0
			(.)		(.)
Europe & Central Asia			-0.130		-0.221*
			(0.0780)		(0.0874)
Latin America & Caribbean			-0.139*		-0.195**
			(0.0693)		(0.0706)
Middle East & North Africa			-0.197		-0.248*
			(0.104)		(0.111)
North America			-0.198*		-0.315**
			(0.0876)		(0.0958)
South Asia			-0.978***		-0.973***
			(0.111)		(0.110)
Sub-Saharan Africa			-0.470***		-0.438***
			(0.0751)		(0.0776)
Constant	-4.047***	-1.650***	-2.880***	-4.683***	-3.328***
	(0.286)	(0.254)	(0.289)	(0.352)	(0.362)
FE	No	No	No	No	No
Controls	No	No	Yes	No	Yes
R-squared	0.392	0.440	0.561	0.403	0.564
N. of observations	396	396	396	383	383

Standard errors in parentheses * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

4.3 The combined impacts of built-up growth and vertical layering on floor area

In the previous section, we introduced the concept of Floor Area Adjusted Densities (FAPD), which can help differentiate between crowded and livable cities. Floor area is critical for cities to accommodate families and firms. It can be added through horizontal spread, vertical layering, or infill development. Here, we combine the results from the previous estimates of horizontal and vertical growth to estimate income and population elasticities for the total floor area. Income and population elasticities are inferred using the previous estimates for built-up area and vertical growth.[11] Income and population elasticities of total floor area are defined as the following:[12]

$$\text{Income Elasticities of Floor area} = \frac{\partial Floor\ Area / Floor\ area}{\partial Income / Income} = \gamma^{bu} + \gamma^{height}$$

$$\text{Population Elasticities of Floor Area} = \frac{\partial Floor\ Area / Floor\ area}{\partial Population / Population} = \beta^{bu} + \beta^{height}$$

A measure of area per person is a good proxy of livability for cities. While the slums in Mumbai and the East side of Manhattan have the same population density, the amount of space available per person is the relevant measure to compare these two areas. Based on the previous estimates, income and population elasticities of floor area per person are reported Table 9. The elasticities for total floor area per person with respect to income or population are then derived.[13]

$$\text{Income Elasticities of Floor Area per Capita} = \gamma^{bu} + \gamma^{height}$$

$$\text{Population Elasticities of Floor Area per Capita} = \beta^{bu} + \beta^{height} - 1$$

Table 9: Elasticities of Total Floor Area

ELASTICITIES **Sample of estimation**	**From the data** **Built-up** **GHSL**	 **Height** **DLR**	**Inferred from the previous elasticities** **TFA**	 **TFA per person** **Combination of both**
Population	0.347***	0.251***	0.598	-0.402
Income	0.104***	0.185***	0.289	0.289

Source: Elasticities of income and population reported in earlier tables

Table 9 shows these elasticities and confirms that as cities grow in population, in incomes, or in both, they add floor space by building both upward and outward. These estimates have profound implications for a growing city's supply of floor area, and also for its tendency to sprawl outward—especially in the absence

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[11] We do not directly estimate the elasticities using our measures of total floor area as they only cover cities for which we have height data. Instead we use the estimates of elasticities for built-up calculated with the GHSL sample, which includes almost all cities.

[12] These properties come from the log properties.

$$ln(TFA) = ln(Built - up * Height/3) = ln(Built - up) + ln(Height) - \text{cst}$$

$$\Rightarrow dln(TFA) = dln(Built - up) + dln(Height)$$

The elasticities for total floor area with respect to income or population are then derived.

$$\epsilon_{TFA,inc} = \epsilon_{built-up,inc} + \epsilon_{height,inc}$$

$$\epsilon_{TFA,pop} = \epsilon_{built-up,pop} + \epsilon_{height,pop}$$

[13] The elasticities for total floor area per person with respect to income or population are then derived.

$$\epsilon_{TFA\ percap,inc} = \epsilon_{built-up,inc} + \epsilon_{height,inc}$$

$$\epsilon_{TFA\ per\ cap,pop} = \epsilon_{built-up,pop} + \epsilon_{height,pop} - 1$$

of rising incomes. If incomes do not grow but remain constant, doubling the urban population increases total floor space by only 60 percent. Furthermore, the 60 percent increase in total floor space is achieved more through horizontal spread (built-up area expansion) than through vertical layering (upward construction). Without income gains, a growing population would reduce the livability of the city by providing less space for individuals to live in and work.

Figure 9: Total Floor Area and City Income

Source: Analysis based on DLR WSF 3D data set

Cities with rising incomes fare better. If a city's income doubles, holding population constant, total floor area—and thus per capita floor space—increases by almost 30 percent. As floor area available per person rises with income—though not proportionally so—the city becomes more livable. An intuitively plausible explanation for the income gains not reflected in added floor space is that some are dissipated in higher housing prices. Also, rising incomes are likely to increase demand for housing services, which include the quality and variety (not just the quantity) of floor space. Figure 9 shows a clear link between total floor area and income.

5 Conclusion

In this paper, we provided new estimates of the evolution of city form along three dimensions -- horizontal expansion, infill development and vertical layering. Our main finding is that the evolution of city form follows the broader processes of economic development. As cities go through economic development, they attract people, expand their footprint, and build upwards. Not only do rising incomes increase demand for built-up area and floor space among families and firms, but also rising incomes are associated with stronger land and market institutions, construction capabilities, as well as financial maturity to pay for the lumpy upfront cost of infrastructure.

We have used new sources of satellite data to describe devolution of city form over the past 25 years as well as provide the first glimpse at an exciting new data set that can tell us about the height distribution of cities. We have also provided a new measure of population density which we called the floor area adjusted population density (FAPD) that takes into account floor area based on heights of buildings. We find that distinguishing between FAPD and naive population density is important as one can distinguish between cities that are crowded and those that are livable. More broadly, we find that densities in general decline with economic development as people and firms demand more space and amenities and transportation improvements allow for the city to increase its spatial reach.

Our econometric analysis shows that incomes are a central driver for providing floor space. In fact, the heights of buildings are very sensitive to income growth. In the absence of income growth, cities with rising populations will accommodate people by crowding. The evidence we provide here is a first step towards understanding how new satellite data can help us understand the evolution of city form. These data can form the cornerstone of new and exciting research looking at the impact of urban regulations, construction costs, and transport improvements on city form and its implications for productivity, livability and sustainability.

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Annex 1: Comparing GHS and DLR samples

The table below shows that the DLR subset of 396 cities used to examine building heights is representative of the global population of cities used in measuring built-up area. We compare the elasticities relying the two samples.

All cities: $\ln BU_{c,t} = \alpha + \beta_1 \ln GDPcap_{c,t} + \beta_2 \ln Pop_{c,t} + YearFE + Country\ FE\ +\ \epsilon_{c,t}$

DLR subsample: $\ln BU_{c,t} = \alpha + \beta_1 \ln GDPcap_{c,t} + \beta_2 \ln Pop_{c,t} +\ \ \epsilon_{c,t}$

	Between estimator	
	ALL CITIES	**DLR SAMPLE**
Ln Income	0.184*** (0.00713)	0.191***
Ln Population	0.509*** (0.00846)	0.438***
Built-up 1975	0.458*** (0.00749)	0.476***
FE	Year	No
Controls	Country	No
R-squared	0.913	0.941
N. of observations	28332	396

Annex 2: Robustness check using the Functional Urban Area (FUA) database

We generate the same results as in Table 4 using the FUA database for the following regression:

For city c, at time t ,

$$\ln BU_{c,t} = \alpha + \gamma^{bu} \ln Income_{c,t} + \beta^{bu} \ln Pop_{c,t} + \text{City Controls} + FE + \epsilon_{c,t}$$

with $BU_{c,t}$ the built-up surface at time t for city c. City Controls include built-up surface in 1975. FE include a series of fixed effects at the city or/and year levels.

Dependent variable: built-up	**Between Estimator**	**Between + Within Estimator**	**Between + Within Estimator with lag**	**IV Between + Within Estimator**	**Between + Within Estimator with NTLs**
Ln Income	0.198*** (0.0102)	0.0934*** (0.00804)			
Ln Population	0.480*** (0.0123)	0.379*** (0.0454)		0.361*** (0.0474)	0.351*** (0.0456)
Built-up 1975	0.508*** (0.00791)				
Ln lagged Income			-0.113*** (0.00815)		
Ln lagged population			0.110** (0.0340)		
Ln NTLs per capita				0.171*** (0.0105)	
FE	Year	**City + Year**	City + Year	City + Year	City + Year
Controls	Country	**No**	No	No	No
R-squared	0.912	0.535	0.432	0.550	0.524
N. of observations	24437	24674	16432	23912	23916