The Changing Character of Chinese Urbanization: 2000 - 2021

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Abstract

The scale and pace of urbanization in China over the past few decades is one of the most significant transformations of any human society in history. However, studying urbanization in China encounters an empirical difficulty common to many urban systems: Are there spatial units corresponding to cities as spaces of socioeconomic interaction? To address this question and analyze the transformation of Chinese cities and China's urban system over the last few decades, we analyze a rich set of data comprising of 297 Chinese Prefecture-level Cities (PLCs) from 2000 to 2021. Our analysis fills a number of important gaps by carefully considering the difference in scaling effects result from using total versus registered population, and full PLCs definitions compared to their restriction to Urban Districts (UDs). Our results show that PLCs as well as their UDs exhibit scaling effects when measured with resident population. PLCs have become better urban units of analysis, characterizing functional cities in similar ways to other urban systems, especially after 2015. Their scaling exponents for GDP are also somewhat closer to theory than those obtained in UDs. The substantial redistribution of the population, with a growing concentration in larger and coastal cities and urban districts resulting in the scaling behavior. The future of Chinese urbanization is that these trends will intensify, leading to continued stronger growth of larger cities and relative population decline of many small and more rural places.

Introduction

China's economy has grown spectacularly during the past four decades, with GDP per capita increasing ≈ 7% per year during 1960-2022 and doubling every 10 years. This economic growth coincided with dramatic urbanization. The proportion of China's population living in urban environments increased from just 16% in 1960 to 64% in 2022, with over 800 million people residing in urban areas[1]. China's urbanization has been described as the greatest human resettlement experience in history[2-4]. A remarkable feature of this is that significant policy interventions avoided common ills of fast city growth, such as concentrated poverty, unemployment, and inadequate physical infrastructure[4-6]. Looking ahead, China's urbanization is expected to reach 80% by 2050[7], in line with many high-income nations today, such as the United States[12]. Whether China will become wealthier and more fully developed depends on what it will do with this additional 15-20% of urbanization over the next decades.

Associating economic growth and urbanization in China is not merely a case of noting a strong temporal correlation (Extended Data Fig. 1). Social science now understands that urbanization is one of the major drivers of structural transformation underlying human and economic development[8,9]. By concentrating populations and supporting their interactions, urban environments foster growing specialization and interdependence, leading to increases in production and consumption. This mechanism creates employment and rising incomes, and promotes many other forms of invention and innovation[10,11]. These agglomeration effects speed up the movement of goods, people, and information[12] not only locally in each city but across national systems of cities (urban systems) and internationally. The essence of urbanism is thus not the built environment per se but the expansion of social and economic interactions embedded in a supportive infrastructural space[13]. Observing the telltale signs of urbanization, namely nonlinear scaling (or agglomeration) effects provides insight into the intertwined relationship between urban development and socioeconomic progress[11,14,15].

However, in China as elsewhere the administrative boundaries of cities often fail to capture the true essence of social and economic interactions[16]. Robust definitions of urban areas should be theoretically grounded, adhering to principles that elucidate the nature and functionality of cities. Existing research on agglomeration effects predominantly centers on functional cities, commonly referred to as metropolitan areas, which encompass both residential and economic realms within the same boundary for a majority of their inhabitants[17-19].

In Chinese national statistics, data for cities refers primarily to Prefecture-level Cities (PLCs) and their decomposition into a variety of subcomponents. These subdivisions are categorized as rural or urban based on their economic and demographic characteristics (see Methods). Districts are typically subdivisions of larger cities, such as municipalities or PLCs. Counties can include both urban and rural areas. They are generally more diverse in terms of land use, encompassing towns, villages, and farmland.

The concept of PLCs was first introduced in 1983[20], marking the beginning of their use as the primary spatial units for reporting socio-economic data related to urban areas and urbanization trends in China. Since the early 1980s, as urbanization accelerated—characterized by migration from rural to urban areas—PLCs have experienced significant transformations. The number of PLCs expanded from only 145 in 1983 to nearly 293 by 2021. These PLCs cover 49% of the national land area yet support 94% of the population and generate 97% of China's GDP[21]. In this study, the term "PLCs" also encompasses four municipalities including Beijing, Shanghai, Tianjin, and Chongqing, which are cities with the administrative authority of a province, thus functioning both as cities and as provinces.

The Chinese government has placed a growing value on urbanization and urban development over time and has made efforts to formulate policies to support stable urban transformations. After 2014, significant reforms were introduced to guide urbanization, focusing on revising the Hukou system and implementing the "National New-type Urbanization Plan (NNUP, 2014-2020)". The Hukou system is a household registration system that classifies individuals based on their legal residency status, distinguishing between agricultural and non-agricultural populations. These reforms aimed to eliminate the distinction between agricultural and non-agricultural Hukou holders, creating a unified resident permit system. This change was designed to help integrate 100 million rural inhabitants into urban areas by 2020[22], a key target of the NNUP[23]. The NNUP also included ambitious action to remove settlement restrictions completely in cities with fewer than 3 million people and to relax controls in larger cities with populations between 3 and 5 million[23]. Building on these efforts, the "14th Five-Year NNUP for 2021-2025" continues to advocate for removing settlement barriers in smaller cities and easing urbanization quotas in larger ones. These initiatives represent a shift towards a more human-centered urban planning approach, allowing for more natural population sorting.

In this study, we use the analytical framework of urban scaling to study urban development in China over the past two decades. To keep the data consistent, we investigate the scaling effect of PLCs and their subcomponents during the 1994-2021 period. Urban scaling predicts the relationships between the areal extent, economic output, and population size of cities within an urban system, if the corresponding units of analysis behave like physical spaces of social interactions. We are thus able to assess the geographic extent of urban effects, and the nature of social and economic interactions occurring within PLCs in China. In this way, we can evaluate whether China's urban system, despite its historical, political, cultural, and administrative specificities, is fundamentally similar to urban systems elsewhere in the Global North and the Global South. Chinese policymakers assign important roles to urbanization and urban development in the ongoing efforts to transform China into a "moderately prosperous country"[16,24]. Are these policy adjustments working in utilizing urbanization as an engine of national development? What structural transformations are occurring and can be foreseen, as the Chinese urban system continues to grow and become more integrated?

Results

In China, PLCs are administrative spatial units tiling the entire national territory, but do not constitute a definition of an urban area. In each PLC, there is typically a major city playing the role of a regional capital and central place, but there can also be other cities and towns, and non-urban regions included in its definition. Moreover, each PLC consists of a number of explicitly different geographic subdivisions with distinct urban and nonurban characteristics. Each PLC is the center of government for smaller entities, including urban districts, county-level cities, and (simple) counties. Within each county-level city and county, there are further subdivisions, typically consisting of their own urban centers and rural areas. This administrative structure reflects a hierarchy of governance where the PLC oversees urban districts, counties, and county-level cities, each of which manages its mix of urban and rural regions (see Methods).

National statistical data in China is organized along these administrative regions, allowing us to investigate their properties. However, these definitions do not easily allow us to construct functional urban definitions, based on socioeconomic interactions and mobility flows such as metropolitan areas in the U.S. Previous studies focused on each PLC restricted to its constituent urban districts as an approximate functional urban definition that indeed exhibits archetypal scaling behavior[25] when registered population (Hokou) is used as the measure of scale. However, the Hokou population is likely not a good estimate of the true resident and working population, especially in larger cities.

Here, we use more recent data allows us to resolve these issues. We explore not only issues of urban expansion and the urban character of the PLCs as a whole, now including counties and county-level cities, but also the effect of using actual population counts in scaling analysis, versus its restriction to registered (Hukou) population. In the present study, we refer to the whole PLC as a prefectural-level city and the restriction to its set of urban districts as UD. The latter approximates what is often referred to as urban cores.

Urban Scaling of GDP and Built-up Area in China

We investigate empirically the scaling of GDP, BUA, and other economic quantities in 297 China's PLCs from 2000 to 2021. This analysis updates previous studies in three ways. First, it includes more recent data up to 2021. Second, we expand the urban definition, to consider the full Chinese PLCs, and not just the same units set of UDs, as in ref[25]. Finally, we consider not only registered populations (Hukou) but also resident (complete) census populations, which was a strong limitation discussed in earlier efforts[25]. Expanding on these three issues makes the present study a substantially more complete and robust study of urban scaling in China.

We find that Chinese PLCs exhibit the theoretically expected scaling behavior in 2021, the most recent year for which data is available at the time of this writing. In line with theoretical predictions, the scaling exponent for GDP in PLCs is $\beta = 1.13$ (95% CI [1.07, 1.19]), while that for the BUA is $\beta = 0.86$ (95% CI [0.81, 0.90]). Consistent with previous results[25-27], we also find that the PLCs restricted to their UDs also exhibit scaling effects when measured with both registered (with local *Hukou* status) and resident population. The estimated superlinear scaling exponent for UDs is higher than what is observed for the full PLCs (Fig. 1) and has a narrower 95% confidence. Specifically, for GDP, the scaling coefficients in UDs range from 1.20 ± 0.07 (measured by registered population) to 1.24 ± 0.05 (measured by resident population). However, the estimated sublinear exponents of BUA are essentially the same whether we use the whole PLC (0.86±0.05) or its restriction to urban districts by resident (0.87±0.04) or registered population (0.87±0.05). These results suggest that in larger Chinese PLCs the expected economic activity is more concentrated in its UDs (SI Table S3-S5), as we discuss below.

We also extend our scaling analysis to a range of other economic variables available in Chinese statistics[25]. This allows us to assess whether using the PLC or the more spatially restrictive UD makes a difference for other economic variables also capturing socio-economic interactions in urban settings. These are *sales value in whole- and retail sale trade, total retail sales of consumer goods, budgetary revenue of local government, budgetary expenditure of local government, expenditure of science administration, expenditure for education administration, deposit, and loan*. The general expectation is that these variables should reflect concentrated socio-economic interactions and thus should exhibit superlinear scaling. Similar to GDP, the analysis of these characteristics supports the presence of non-linear scaling behavior in the full PLCs after 2015 (SI Fig. S5), but also indicates that these effects are characterized by larger exponents when the urban definition is restricted to UDs (Fig. 2).

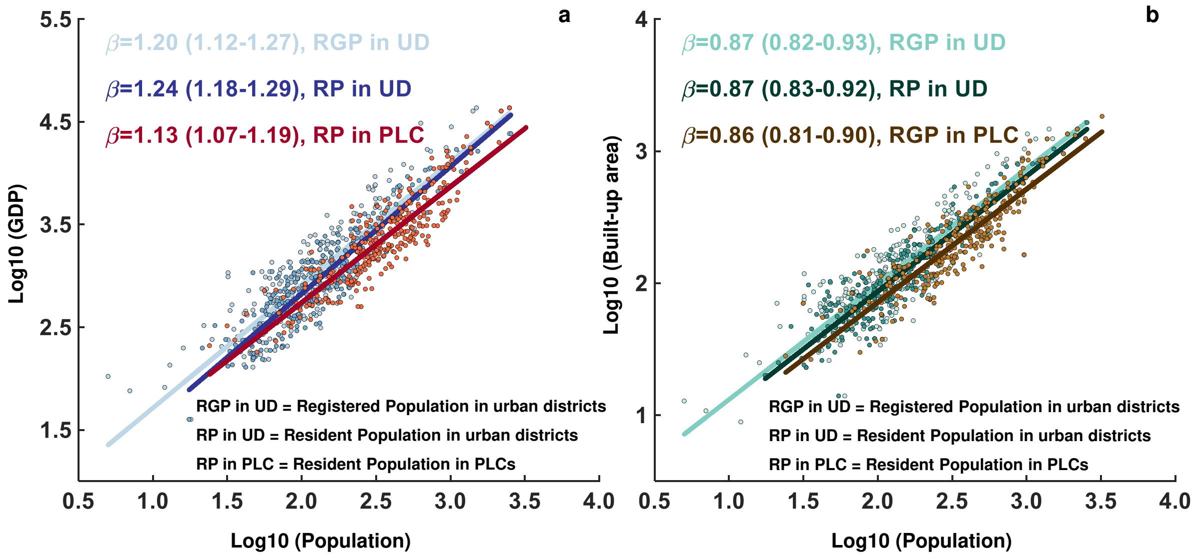


Figure 1. Scaling relations and exponents for Chinese prefecture-level cities and their urban districts in 2021. The superliner scaling behavior (β, 95% CI) for GDP vs. size by registered population in urban districts (light blue, RGP in UD), resident population in urban districts (dark blue, RP in UD), and resident population in prefecture-level cities (red, RP in PLCs) **(a)**. The sublinear scaling behavior (β, 95% CI) for the built-up area vs. size by registered population in urban districts (light green, RGP in UD), resident population in urban districts (dark green, RP in UD), and resident population in prefecture-level cities (brown, RP in PLC) **(b)**.

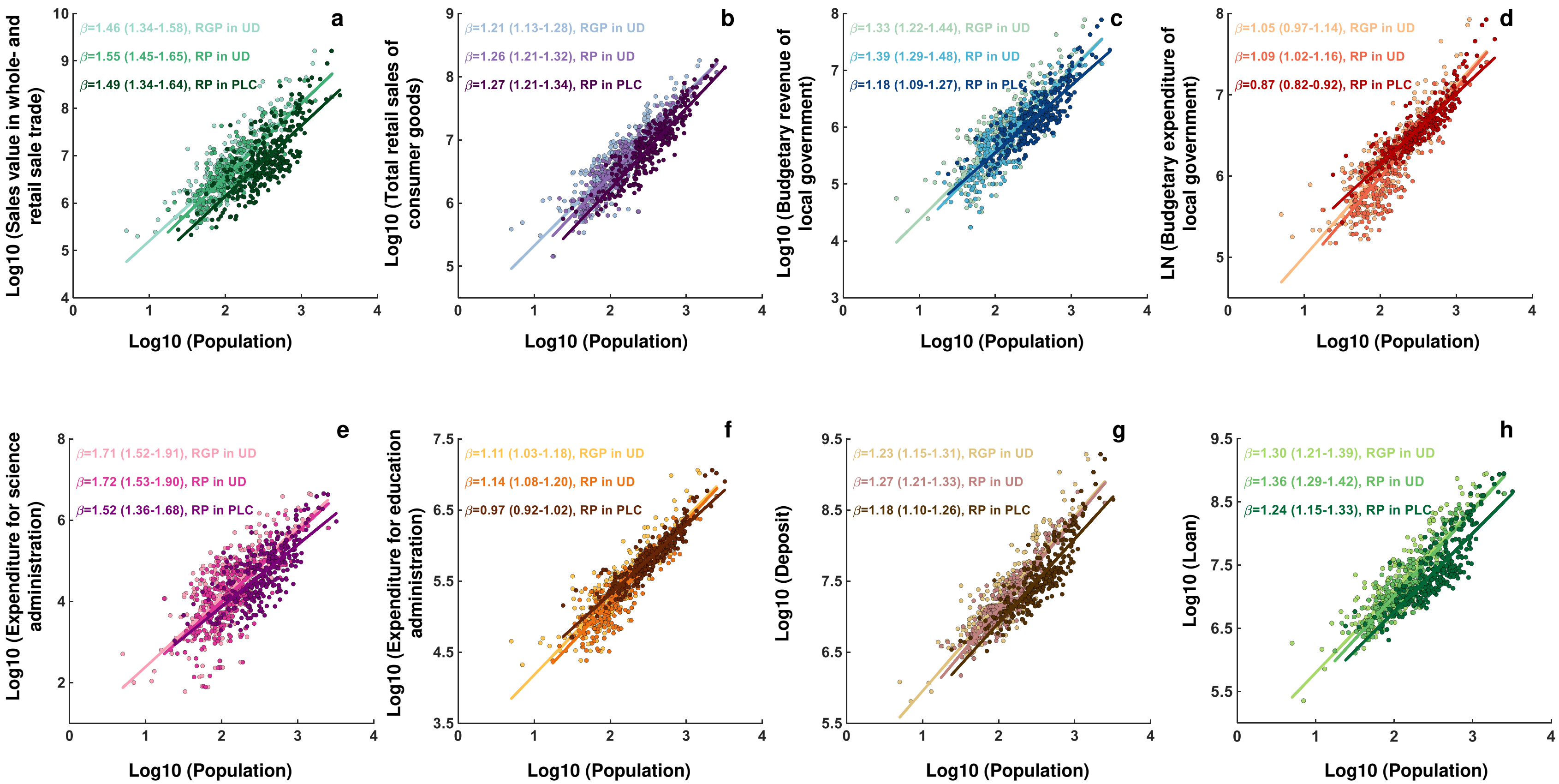


Figure 2. Scaling of different city attributes relative to population size for Chinese prefecture-level cities and their urban districts in 2021. The registered population in urban districts = RGP in UD, the resident population in urban districts = RP in UD, and the resident population in prefecture-level cities = RP in PLC.

Changes in scaling from expanding urban units and their population

To quantify the impact of different spatial units of analysis (PLCs versus UDs) and population counts (registered versus resident) on scaling exponents for Chinese cities, we compare their impact in the logarithmic scaling relation, Eq. (2). Because this is a linear relation, at a fixed time, the scaling exponent estimator is simply the (discrete) derivative of the logarithmic y-variable (GDP, BUA) to the logarithmic x-variable (population) (Eq. 3):

$$\beta_i = \frac{\Delta \ln Y_i}{\Delta \ln N_i}. \tag{3}$$

At a given moment, time and after averaging over the deviations ξ_i, this gives the overall scaling exponents shown in Figs. 1-2. The point of considering this quantity for each city, i.e. before averaging, is that we can then measure the impacts of changing units of analysis and population counts across different types of cities, such as across their size.

Starting with the most restrictive units (UDs and registered populations), the expansion to the PLC increases both the total urban attribute (GDP, BUA) and the total population. The former also changes (typically increases) as we change from registered to resident population (see Fig. 3a). Thus, estimates of the scaling exponent will become larger in the PLCs versus UDs if there is a larger change in $\ln Y$ than in $\ln N$. Conversely, if the population increases more than the attribute, the exponent estimate will become smaller. Because for GDP we observe a reduction of exponents from the UDs to the PLCs, we know that this expansion of the definition corresponds to a larger increase in population than income.

Figure 3 b-c shows the effects of these transformations for all cities. The change from registered (Hukou) to resident population has the pure effect of moving each point horizontally in a scaling plot (light blue and red arrows). Most cities show moves to the right (e.g., Beijing and Shanghai) signaling that their total population is larger than their registered population. A few smaller cities move to the left (e.g., Hegang, Siping, and Erdos), showing the reverse effect signaling outmigration of real population relative to those registered. We also observe, as discussed in previous work[25], that larger cities move substantially more to the right than smaller ones.

The effect of changing the urban definition from UDs to PLCs is to produce a larger GDP and BUA. Combined with the corresponding increases in population, this makes each point move diagonally in Figs. 3 b-c. This effect is much more pronounced in smaller PLCs, where more of the population, productivity, and infrastructure are outside the (less dominant) urban area. However, cities like Beijing, Shanghai, and Tianjin move less than many others because their PLC definitions do not include non-urban districts (Table S2). Upon analyzing the expansion from UDs to PLCs in the year 2020, the most recent year of the population census with comprehensive data, we find that out of the total 297 PLCs, only 63 (green arrows, Fig. 4b) displayed a higher increase in GDP than population ($\beta_i \geq 1$). These 63 cities align with the shrinking cities identified in previous studies[28-30], meaning that in these cases the increase in agglomeration effects in non-UDs is due to increases in productivity even as populations decrease.

Overall, the combined effects of changes in urban units of analysis and population have very little effect on the scaling behavior of BUA. While the population increases in larger PLCs would tend to reduce the average exponent there is a small but consistent effect in smaller PLCs to have substantial infrastructure outside urban districts. The same cannot be said about GDP, with the consequence that the correction of population counts in larger cities does reduce the exponent to a value relative to UDs and a little below theory. This, and the behavior of these exponents in time, which we discuss next, suggest that the entire population of the PLCs may be an overestimate of that associated with its GDP, which is much more concentrated in UDs than infrastructure. Since GDP is measured based on employment in local enterprises rather than residential population, this leads to higher productivity and GDP in densely populated UDs compared to rural areas. As a result, most $\beta_i \leq 1$, and the overall scale value for the PLC is smaller than that of the UDs.

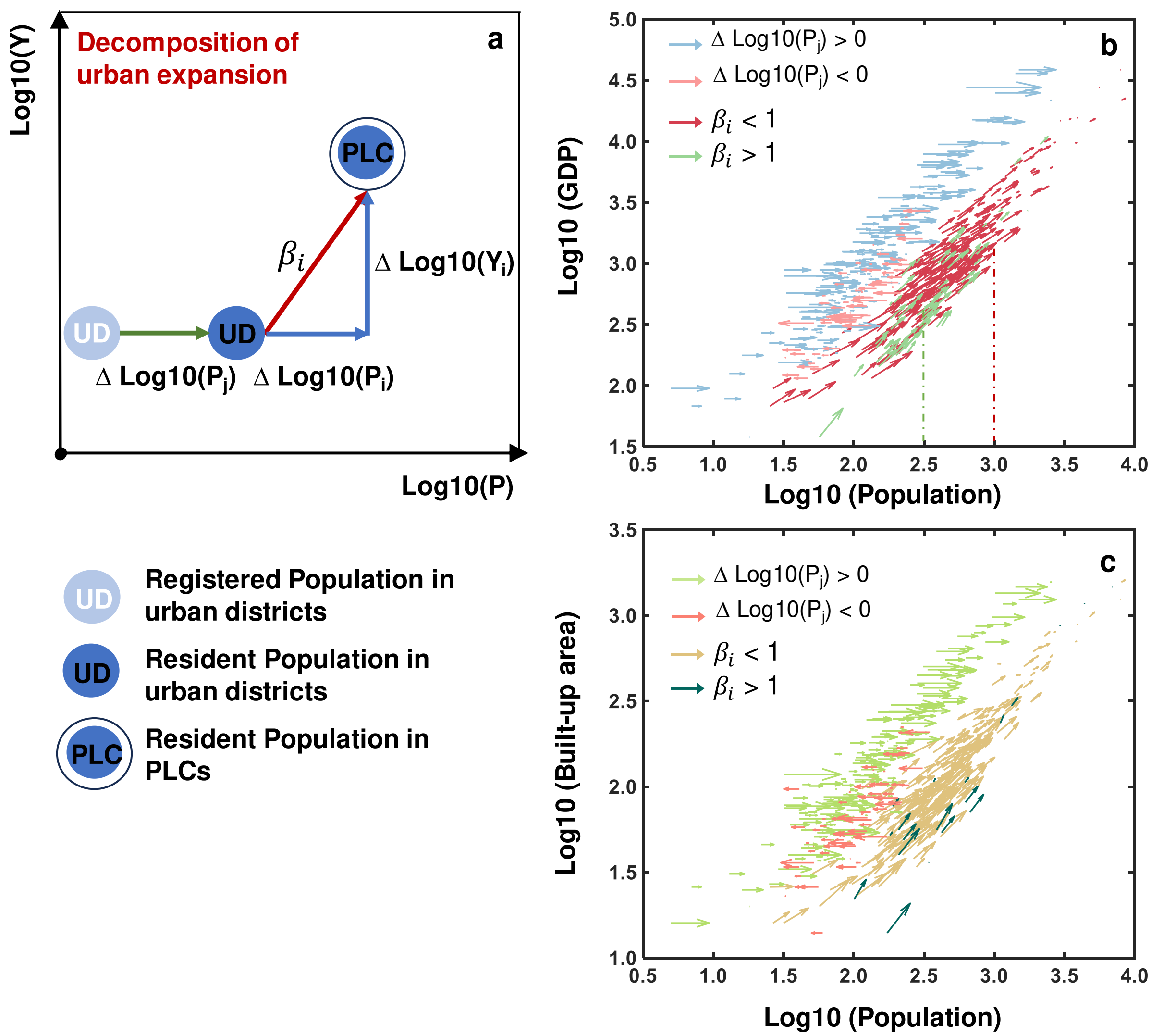


Figure 3. The decomposition of expansion from urban districts to prefecture-level cities in 2020. Theoretically, a prefecture-level city's (PLC) expansion trajectory can be divided into two

phases. The first phase, indicated by the green arrow, involves the transformation of the registered population into the resident population in UDs. During this phase, both GDP and built-up area (BUA) remain unchanged, reflecting a purely demographic shift with parallel movement. The second phase, represented by the blue arrow, marks the expansion from UDs to the PLCs. In this stage, population changes are accompanied by fluctuations in GDP and BUA, highlighting the economic and spatial impacts of urban expansion. The scaling exponent estimator, denoted by β_i, is the derivative of GDP and BUA concerning population changes (the red arrow) **(a)**. Change in each city's GDP and population. Light blue arrows depict the population increase from registered population to resident population in urban districts. Pink arrows depict the population decrease from the registered population to the resident population in urban districts. Red arrows represent instances where the changes in GDP are less than the changes in population from urban districts to the whole PLCs. Green arrows depict instances where the changes in GDP are greater than the changes in population from urban districts to the whole PLCs **(b)**. Similar to (b), the trajectory of each city's BUA development and population size **(c)**.

Changes in agglomeration effects of Chinese cities over time

We now provide a complementary discussion of the effects observed in Fig. 3, by analyzing the temporal dynamics of scaling exponents over a 27-year time span between 1994-2021 for each unit of analysis (Fig. 4). For UDs, as noted before[25], expected urban scaling exponents appear in the data around 2002. It remains unclear if prior to this time, data for Chinese cities was misestimated in available national statistics, or if they had different properties. Using resident counts instead of registered population changes the exponent estimates only slightly, but this change is not statistically significant within 95% confidence intervals. Observed exponents for UDs are slightly higher than theory predicts both for GDP and BUA, but consistent with theory within statistical uncertainty, which is higher than in other nations such as the U.S.[12]. The main novelty in our analysis is the scaling behavior of full PLCs. These units show the expected scaling exponent for BUA, though slightly smaller than for UDs, and more consistent with theory (β=5/6). However, we now see that the scaling exponent estimated for GDP for full PLCs is consistently smaller than for UDs, and has become superlinear only after around 2015. In the most recent data, it agrees more closely with urban scaling theory (β=7/6).

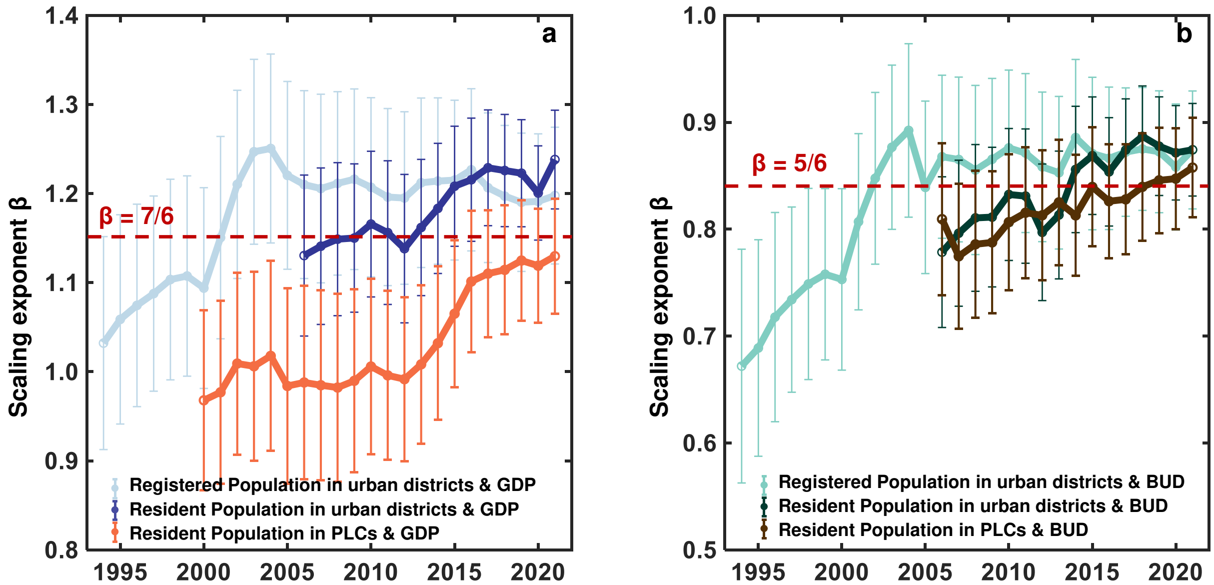


Figure 4. Temporal evolution of the scaling exponents with a 95% confidence interval for GDP (a) and built-up area (BUA) (b) for Chinese prefecture-level cities and their urban districts. The two dotted lines depict the simplest expectation for the theoretical exponents at 7/6 and 5/6, respectively[12].

It is interesting to analyze further this recent change in scaling exponents, and whether it signals that PLCs are becoming better functional urban definitions than their restriction to UDs. This could mean, for example, that GDP in UDs is partly the product of a larger PLC population, living outside UDs. To examine this question, we analyze the dynamics of our key urban metrics and of population in UDs versus non-UDs in each PLC, by city size and geographic location. To do this, we divide PLCs into three categories: Those with a population less than 3 million are considered small cities. Those with a population greater than 6 million are categorized as large cities, and those with a population in between are classified as medium-sized cities.

Analyzing the temporal dynamics of all cities between 2006-21, we find a substantial redistribution of the population with a growing concentration in larger and coastal cities (Fig. 5a-c and SI Fig. S4). Smaller cities experienced a population decline over this period due to outmigration. They also become more "urbanized", as there is a noticeable *increase* in the population share of urban districts versus the rest of their PLC after 2015. Larger PLCs have continued to see population growth but a milder increased concentration also in their UDs. Medium-sized cities share characteristic trends of both smaller and larger cities. They have seen population decreases since 2017, but at milder rates than smaller cities. The concentration of their population in UDs is observable, but also less pronounced. In all cases, the share of GDP and BUA in UDs increased over this period relative to non-UDs (SI Fig. S2).

In addition, we examine changes in scaling exponents between the 12th Five-Year Plan (2011-2015) and the 13th Five-Year Plan (2016-2020). Changes in β_i across time for PLCs, UDs, and rural and suburban districts were evaluated (Fig. 5b-e) following a similar approach as described in Fig. 3. Only 60% of PLCs experienced population growth, while 53% displayed a higher increase in GDP growth compared to population ($\beta_i \geq 1$) (Fig. 5b and SI Fig. S3a). Increases in population in 53% of PLCs were associated with typically large expansion of BUA, signaling investments in infrastructure, with β_i values exceeding the theoretical expectation, and in some cases, surpassing 1 (Fig. 5c and SI Fig. S3b).

Within PLCs, we find a clear shift towards greater population concentration in UDs, which leads to concurrent growth in GDP and BUA (Fig. 5d-e). In contrast, non-UDs experienced significant population loss, with only 40 out of the 297 PLCs demonstrating population growth outside UDs. Among these, only five areas experienced higher GDP than population growth ($\beta_i \geq 1$). These trends are also evident in the expansion of BUA. With the concentration of population within UDs, the BUA of these districts expands correspondingly, resulting in a β_i value surpassing the theoretical threshold ($\beta_i \geq 5/6$). Conversely, in non-UDs, the decrease in population leads to a relative contraction of BUA relative to UDs.

These findings indicate that the general trend in Chinese cities over the last 10 years has been towards greater concentration of population, economic activity, and BUA in urban cores, corresponding to UDs. Most non-UDs, especially in smaller cities, have recently experienced population loss, leading to a pattern of development in the Chinese urban system towards larger and more coastal cities, and within these towards their more urbanized cores. What is perhaps most unexpected is that these structural transformations within each PLC have led to fast increases in GDP per capita in non-UDs (SI Figs S1-3), along with UDs. This has resulted in higher scaling exponents for PLCs than in earlier periods, increasing towards those observed for UDs and approaching what is expected from theory (Fig. 4). These empirical observations leave us with interesting questions as to why this transition has happened so recently and what may have triggered it.

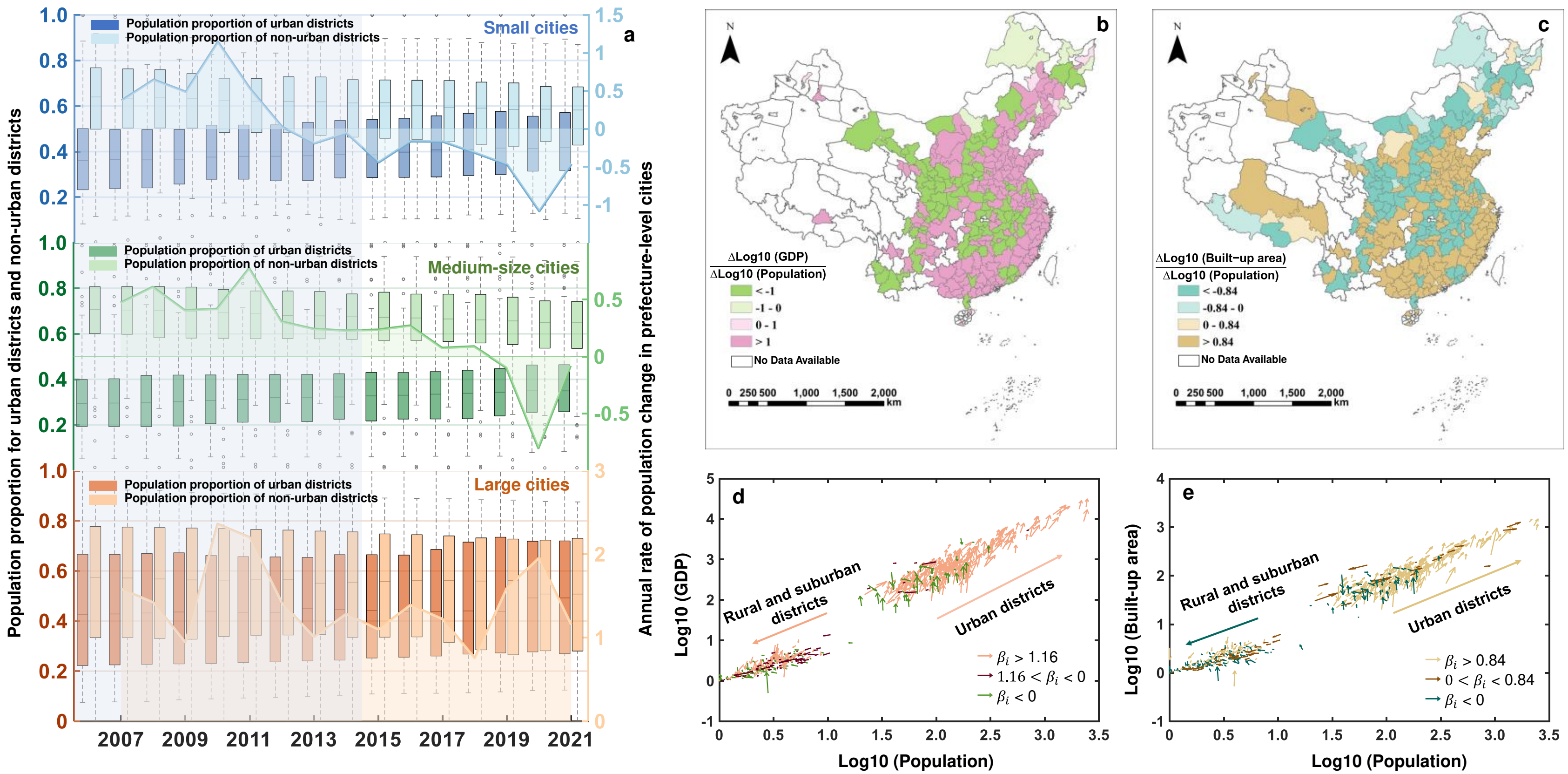


Figure 5. Population dynamics for cities of different sizes and associated scaling behavior change. The annual proportional changes and growth rates of population in large cities (with a population in PLC > 6 million), medium-sized cities (population > 3 million but < 6 million), and small cities (population < 3 million) from 2006 to 2021, considering both urban and non-urban districts. **(a)** shows the proportions of the population (vertical bars) in urban and non-urban districts, along with the overall population growth rate (solid line), which can be negative. **(b)** Changes of logarithm of GDP vs. population for each PLC during the 13th (2016-2020) and 12th (2011-2015) Five-Year Plan periods, and **(c)** of built-up area vs. population for each PLC. **(d)** Arrows show the change in log GDP and population size between the 13th (2016-2020) and 12th (2011-2015) Five-Year Plan periods in urban districts and rural and suburban districts and **(e)** for log built-up area and population size over the same period.

Discussion

We have characterized the evolution of the Chinese urban system and each of its cities over the period 1994-2021. Our analysis fills a number of important gaps in the literature by carefully considering the difference in scaling (agglomeration) effects and geographic distribution of population and urban properties that result from using total versus registered (Hukou) population, and full PLCs definitions compared to their restriction to UDs.

Concerns about data quality and the lack of official "metropolitan" or "functional urban area" definitions make it more difficult to analyze Chinese cities, and in particular to compare Chinese urbanization with that of other urban systems. PLCs and UDs provide an empirical handle on some of these issues. An earlier study found that the growth of Chinese cities shows expected non-linear scaling behavior post-2002[25]. However, this analysis primarily relied on the registered population in UDs. Our results using both full population counts and PLCs show that these larger units also started exhibiting characteristic non-linear scaling beginning in around 2015. Their scaling exponents for GDP are also somewhat closer to theory than those obtained by the restriction to UDs. It should be noted that the contemporary Chinese urban system, one that is originally vary old and which has recently developed in a political and policy setting vary different than in other parts of the globe, is striking similar in its scaling behavior to other contemporary urban systems[12].

To understand some of its more peculiar characteristics, one needs to acknowledge and understand the population movement constraints due to policy within China, and the changes to these regulations that occurred around 2015. The Hukou system, established in 1951, classifies citizens into agricultural and non-agricultural categories at birth[31,32]. This classification was initially intended to discourage the migration of (rural) citizens to cities by denying them residency rights and social benefits. However, even under such conditions, migration to cities did occur resulting in many people not living at their registered locations. As a consequence, registered (Hukou) population counts frequently either overestimate or underestimate the true resident population in PLCs. For instance, in the capital Beijing, the registered population is about 60% of the resident population[33] while in Erdos, it exceeds the resident count by 30%[34].

When discussing the disparities between urban and rural areas, it is crucial to note that PLCs in China generally comprise both densely urbanized centers and adjacent rural regions. UDs are characterized primarily by non-agricultural Hukou holders and saw earlier rapid development due to the concentration of resources and opportunities, while the rural and suburban districts, with a higher proportion of agricultural Hukou holders, lagged behind. China's urbanization strategy has been consistently aimed at integrating urban and rural to mitigate these inequalities, but its approach changed over time.

The Chinese government plays a dominant role in setting policy controlling urbanization through its central planning and social systems[35,36]. For decades after 1951, the Hukou system discouraged urban population growth, inadvertently deepening urban-rural disparities by restricting rural residents' access to urban opportunities and services. As early as 2000, the Chinese government placed special emphasis on regional balance and adopted a development strategy to "actively and steadily promote urbanization" by the "coordinated development of large, medium, and small cities and towns"[37]. From 2000 to 2015, the government implemented national strategies such as the China Western Development Plan, the Revitalization of Northeast China Plan, and the Rise of Central China Plan, aiming to further balance regional development[37-39]. After that, a range of policies have been devised to foster urbanization as the more explicit pathway to growth and national development. Specifically, the Hukou system was relaxed to facilitate the movement of “peasant workers” to cities, addressing labor shortages and reducing distortions in labor markets[39]. The national “New-Style Urbanization” Plan (NNUP) in 2014 promoted population redistribution[22,23] allowing rural Hukou holders to move to UDs and larger cities. This made possible more natural population sorting and resulting processes of urbanization, which coincide in time with our observations of population movements away from smaller and less urban districts while increasing their productivity per capita, and population growth in larger urban areas and UDs. Our results indicate that these transformations are simultaneously increasing the vitality and influence of larger PLCs in the Chinese urban system, but also spreading some of the urban character to “non-urban” districts in many PLCs measured as increasing GDP per capita converging with UDs, even in the face of population loss.

Our expectations for the future of Chinese urbanization based on both theory and the present results are that these trends will intensify, leading to continued stronger growth of larger cities and relative population decline of many small and more rural places. There are three main drivers of these expectations. First, overall demographic decline and aging make living in small rural towns with limited amenities and services increasingly more difficult, with the consequence that smaller and less urbanized areas tend to lead population losses. We have shown that this is already observed in China, as well as in many other nations including Japan, EU nations, and the US. Second, large Chinese cities with populations of ~20-25 million are relatively small for a nation with 1.4 billion people, certainly as the nation further urbanizes. Policies to accommodate larger populations in such cities, which are already expensive, will be crucial so that increases in economic productivity and innovation can be achieved in China, not only in such cities but nationwide. Finally, achieving higher levels of urbanization and prosperity (China is only 65% urban), will produce structural transformations within its cities and across its national urban system, towards larger urban economies less dominated by manufacturing for export and more dedicated to services and innovation, targeted to a larger extent at smaller Chinese cities, thus better integrating systemic national development. Analyzing this structural transition in detail should prove an interesting and important focus for future research.

Methods

Urban scaling

Urban scaling is a framework for studying how the population size of cities (their scale) generates agglomeration effects. The framework quantifies the variation in values of average city-wide attributes with changes in city size (i.e., population). Scaling relations are usually scale-free power functions of city size, so that any city-wide property (e.g., economic output or urbanized land area), Y, is written as

$$Y_i(N,t) = Y_0(t) N_i(t)^{\beta} e^{\xi_i(t)}, \quad (1)$$

where $N_i(t)$ denotes city i population at time t, $Y_0(t)$ is a prefactor common to all cities in an urban system, β is a dimensionless scaling exponent (or elasticity, in the language of economics), and ξ_i(t) are city-specific deviations from the average trend, which are typically normally distributed across cities (with zero mean). Because the prefactor, $Y_0(t)$, is common to all cities, its temporal variation captures nationwide changes. The scaling exponent, β, is assumed to be time-independent and, as such, it is a conserved quantity across time (and development) in any urban system. The value of the exponent arises from the structure of socioeconomic interactions embedded in physical and infrastructural space[40] typical of urban life. Urban scaling theory builds upon extant research traditions which have highlighted the importance of urban population size in the generation of agglomeration effects. The quantitative prediction as to what values β should take, under assumed types of interactions, is a distinguishing feature of urban scaling theory[11,41].

Two variables encapsulate particularly important properties of cities: their *economic output* and their *built-up area*. Economic output (usually measured as *Gross Domestic Product*, GDP) refers to the monetary value of all the goods and services produced (or consumed) over a given period (usually a year) by an urban economy. "Built-up area" (BUA) is defined as the area of a city's surface occupied by buildings and other physical infrastructure. In this sense, BUA measures the total space dedicated to infrastructure, which tends to increase with city size. This is different from the overall extent of a city because urban area can include open spaces without infrastructure or facilities. Both measures are connected to the function of the city as a space facilitating human interactions: GDP reflects economic relations linked to consumption and production, while BUA describes the amount of space available for socio-economic.

Urban scaling theory derives scaling relations for both GDP and BUA as the result of interrelated phenomena, associated with the acceleration of socio-economic interactions to the extent that they become more spatially concentrated as cities become larger. This results in a calculation for scaling exponents, such that $\beta = 1+\delta \simeq 1.16$ for GDP, and $\beta = 1- \delta \simeq 0.84$ for BUA, with $\delta \simeq 1/6$[14,15]. The super-linearity of the scaling of economic output reflects how agglomeration improves the productivity of individuals (through a variety of interactions, including learning) while the sub-linearity of the scaling of BUA reflects efficiencies in the use of infrastructure and the built environment.

As written in Eq. (1), the quantity Y is a stochastic variable, because ξ is a random effect. The properties of ξ have been studied in many different urban systems, including in China[25], resulting in the observation that they are well described by a Gaussian distribution with zero mean and a given variance, σ, which varies with quantity and urban system. These statistical properties justify using the simplest regression fitting procedure for $Y(t)$ versus $N(t)$, under logarithmic transformations, because the resulting variables for a linear relationship whose parameters can be estimated by minimizing ordinary least squares (OLSs):

$$\ln Y_i\,(t) = \ln Y_0(t) + \beta \ln N_i\,(t) + \xi_i(t) \qquad (2)$$

where i index different cities in the urban system. This implies that the exponent β is the slope of the linear regression of $\ln Y(t)$ on $\ln N_i(t)$ and the prefactor, $\ln \mathrm{Y}_0(t)$, is its ordinate at the origin

($N = 1$). This also means that the scaling relation $Y(N,t) = Y_0(t)\, N(t)^{\beta}$ is the expectation value of the approximately lognormally distributed stochastic variable, Y, for a city, given its population size, N.

Spatial Units

We use data on 293 prefecture-level cities (PLCs) and 4 municipalities (Beijing, Shanghai, Chongqing, and Tianjin) in China to analyze the urban scaling behavior (Extended Data Fig. 2a). Municipalities and PLCs are first- and second-level administrative units in China, respectively. Municipalities, having the same power as provinces, are the highest level of classification for cities in China. PLCs are defined as urban cores with at least 250,000 people engaging in non-agricultural industries and a GDP of more than 2.5 billion yuan[16]. The establishment and abolition of PLCs are generally approved by The State Council of China. In this study, we use the terms "PLCs" and "city" to denote prefecture-level cities and municipalities. Moreover, the administrative divisions of PLCs have changed after 1983. To maintain data comparability, we standardize our analysis using the administrative boundaries from 2021[42].

A prefecture-level city in China's administrative hierarchy is positioned between a province and a county, typically comprising several subordinate administrative areas: urban districts, counties, and county-level cities (Extended Data Fig. 2b). Here's a brief explanation of each:

Urban Districts: These are areas where the PLCs government are located and are directly administered by the PLCs government. They generally encompass the most densely populated and urbanized areas of the city.

Counties: These are administrative divisions within the PLCs that can encompass both urban and rural areas. Each county has its own local government and includes several towns and villages.

County-Level Cities: These are cities with enough population and economic development to warrant a degree of self-governance, but they are still administratively and economically linked to the PLCs. County-level cities handle their local administration but are smaller and less autonomous than PLCs. They often include both urban centers and surrounding rural or semi-rural areas.

The vertical administrative hierarchy of China is uniquely tailored to meet its specific governmental needs, and greatly differ from those in Western countries. For example, compared to the U.S., where the primary divisions are states and counties, China introduces an intermediary layer known as PLCs between provinces and counties. Within these PLCs, urban districts manage densely populated areas, similar to U.S. city governments but operating as part of a larger city entity rather than independently. Additionally, Chinese counties and county-level cities have less autonomy, typically being governed under the oversight of PLCs which align local administration with broader provincial and prefectural strategies.

Data sources

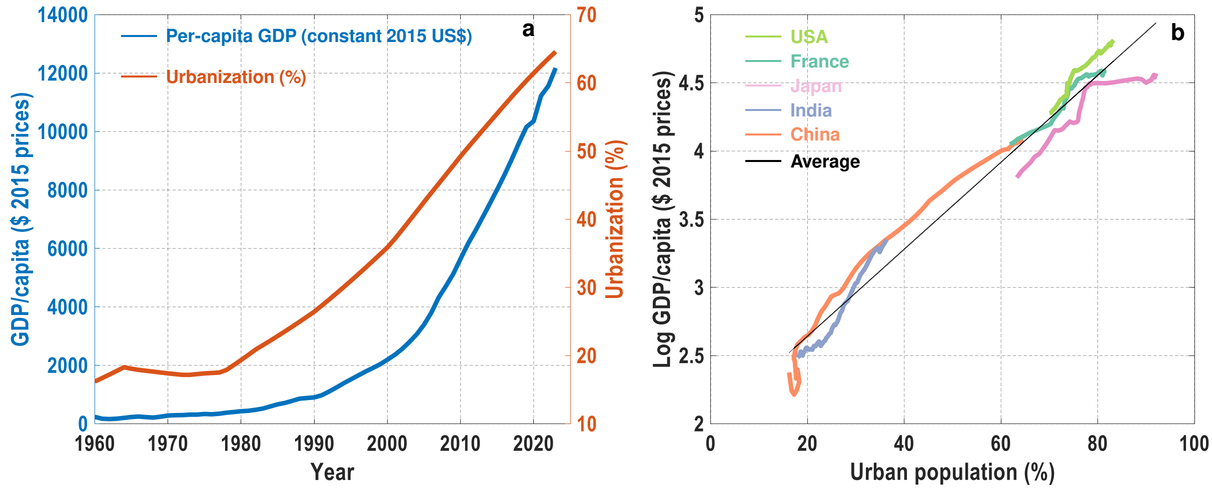
We use data for two spatial units of analysis: PLCs and their UDs (SI Table S1-S2). For UDs, we collected data on registered population, resident population, GDP, built-up area, and other characteristics, including sales value in whole- and retail sale trade, total retail sales of consumer goods, budgetary revenue of local government, budgetary expenditure of local government, expenditure of science administration, expenditure for education administration, deposit, and loan. For PLCs, we collected data on resident population, GDP, BUA, and other characteristics same with that of in UDs.

These data are obtained from the *China City Statistical Yearbook*[43], which is an annual publication presenting the employment, housing, environment, and social service information on urban development, and is compiled by the National Bureau of Statistics of China, and *China Urban Construction Statistical Yearbook*[44] and *China County Seat Construction Statistical Yearbook*[45] which reports the municipal public facilities construction and development in urban, rural, and counties and are annually published by the Ministry of Housing and Urban-Rural Development of China. The resident population of each PLC and UD is derived from the *Statistical Yearbook* for each PLC[46], which is a yearly publication that provides statistical data on economic, industry, agriculture, culture, and social development of each PLC. The registered population (Hukou) of each UD is derived from *China City Statistical Yearbook.*

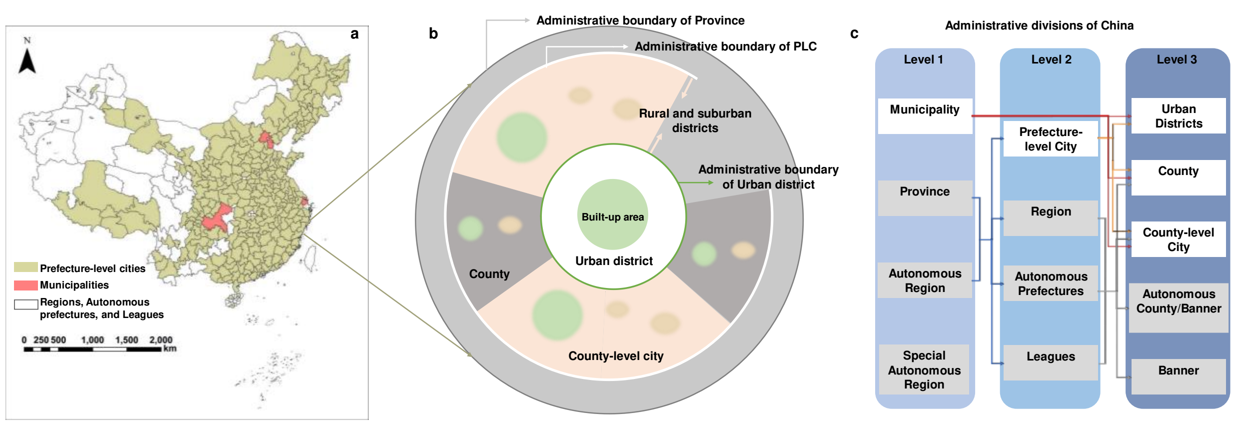
The resident population consists of individuals who have lived in PLCs for over six months and have been away for work or study for less than six months. This population is assessed through a comprehensive census every ten years, while estimates for other years are derived from sampling surveys. The registered (Hukou) population refers to the individuals who are officially recorded by local authorities as residing in a specific area. This population is significant for policy-making, resource allocation, and urban planning, as it reflects the number of individuals who have legal residency status in that area.

GDP and other characteristics of PLCs are derived from the *China City Statistical Yearbook*. The total BUA of the PLC is calculated by adding the BUA of the UDs, county-level cities, and counties. The BUA of county-level cities are derived from the *China Urban Construction Statistical Yearbook*. The BUA of counties are derived from the *China County Seat Construction Statistical Yearbook,* which is an annual publication that provides information on the development of county service facilities in China. The yearbook is intended to help people understand China's urban and rural development.

Extended Data Figure



Extended Data Figure 1. Real GDP per capita and urbanization rate during 1960-2023. After an initial lag, real income per capita has been growing in tandem (and faster) with urbanization **(a)**. Real GDP per capita versus urbanization rate for several nations. On average, a nations GDP per capita increases 4.0% (±0.05) with each percent of urbanization (black line). China's GDP per capita has risen faster, at an average rate of 5.8% (±0.35) with each percent of additional urbanization **(b)**. Real GDP per capita and urbanization in China are derived from World Bank data[1].



Extended Data Figure 2. The spatial units and their composition. The administrative boundaries of 293 Chinese prefecture-level cities (highlighted in yellow) and 4 municipalities (highlighted in red) selected for this study. The white parts on the map are regions, autonomous prefectures, and leagues, which are administrative units equivalent to prefecture-level cities, and are excluded from our study due to missing data **(a)**. Schematic diagram of administrative divisions within a prefecture-level city. Prefecture-level cities are composed of urban districts as well as counties and county-level cities outside of the urban districts. Prefecture-level cities and urban districts are both national-level administrative units that do not necessarily correspond to metropolitan areas **(b)**. Administrative divisions of China. This diagram only illustrates the structures relevant to this study **(c)**.

Data availability

Data used for this research is available from the following link: https://figshare.com/s/1a7b4363108facb668e8.

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Author contributions

J.L., L.M.A.B., W.Q.C., and L.L.S., conceived and designed the research. L.L.S. performed the statistical analysis and produced the figures. L.L.S., L.M.A.B., and J.L. prepared the first draft. All authors reviewed and edited the manuscript.

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