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Spatial and Temporal Dimensions of Urban Expansion in China

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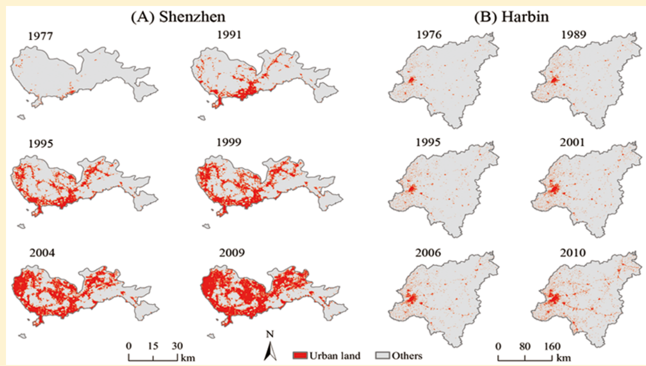
ABSTRACT: The scale of urbanization in China during the past three decades is unprecedented in human history, and the processes are poorly understood. Here we present an effort to map the urban land expansion processes of 32 major cities in China from 1978 to 2010 using Landsat satellite data to understand the temporal and spatial characteristics. Results showed that the urban extent of the 32 cities expanded exponentially with very high annual rates varying from 3.2% to 12.8%. Temporal fluctuation in urban expansion rates in these 32 cities was obvious, with unexpected and alarming expansion rates from 2005 to 2010 that drastically exceeded their expectation, which was calculated from the long-term trend between 1978 and 2005, by 45%. Overall, we found that the growth rates of cities during the entire study period were inversely related to city size, contradicting the theory or Gibrat's law, which states that the growth rate is independent of city size. More detailed analysis indicated that city growth in China has transitioned from contradicting to conforming to Gibrat's law since 1995. Our study suggests that the urban expansion theory (i.e., Gibrat's law) does not fit Chinese expansion consistently over time, and the exact causes are unknown. Exploring the causes in future research will improve our understanding of the theory and, more importantly, understand the feasibility of the theoretical relationship between city size and expansion rate in guiding contemporary urban expansion planning.



INTRODUCTION

We live in an increasingly urbanized world, with more than half of the world's population residing in cities at present.[1] Urban areas offer both problems and solutions to a sustainable future for human societies.[2] Urban areas are the centers of wealth creation, social services, culture, and politics, being the engine of society's innovation and prosperity.[3,4] However, urbanization, characterized primarily by a dramatic demographic shift from rural to urbanized areas and physical urban land expansion, is generally associated with crowding and environmental degradation.[5] The worldwide trend toward urbanization presents a grand challenge for a future sustainability transition.[6] Therefore, the spatial and temporal characteristics, causes, and consequences of urbanization must be scientifically understood before cities can be sustainably planned and managed.

The scale of urbanization in China during the past 30 years is unprecedented in human history, along with its fast economic growth. Urban population in China has increased from 17.9% in 1978 to 51.3% in 2011, a net increase of 518.3 million.[7] As the most populous country on the planet, China differs from either developed or other developing countries in its urbanization process. Most previous studies on urbanization processes in China have focused on the socioeconomic aspects including migration, demographic expansion, and economic development,[8−10] or were restricted to one or a few cities.[11,12] A few studies have mapped and examined the general urban land expansion processes in China in a national or global context.[13−17] However, according to two recent insightful reviews, urbanization in China calls for more in-depth studies at the national level and more theoretical understanding.[18,19]

Gibrat's law was first observed many years ago and states that the size and growth rate of firms was independent.[20] It has become one of the most-documented empirical regularities in urban growth because the mean and variance of growth rate of cities are independent of city size.[21−24] However, this theoretical understanding of urbanization is mostly based on observations of population growth, not on urban land expansion. The applicability of Gibrat's law to urban land expansion has rarely been investigated so far. Does urban land expansion follow Gibrat's law? Does the applicability of Gibrat's law change over time in response to regional and national policies and economic conditions?

Here, we mapped and analyzed the rates, spatial patterns, and temporal courses of urban land expansion for 32 major cities across China from the late 1970s (nominally 1978) to 2010 using multitemporal Landsat data of ca. 1978, 1990, 1995, 2000, 2005, and 2010. The objectives of this study were to (1) quantify the spatial and temporal characteristics of urban land expansion across China over the past three decades, and (2)

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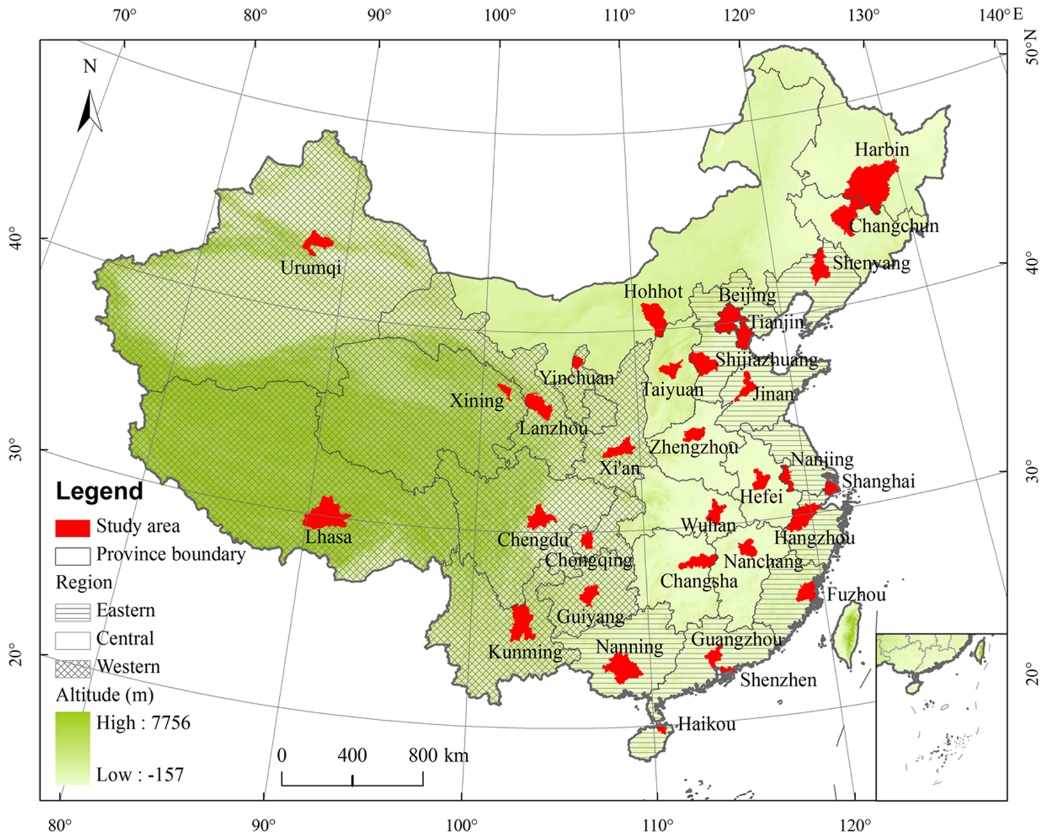

Figure 1. Administrative boundaries of 32 major cities in China. The background map shows the topography of China. The three geographic divisions in China (Eastern, Central, and Western regions) are illustrated.

investigate the applicability of Gibrat's law in China using urban land expansion data.

■ MATERIALS AND METHODS

Data. Our study covered 32 major cities including municipalities, provincial and autonomous regional capitals, and the city of Shenzhen. Shenzhen, the first Special Economic Zone established in 1978 by the Chinese government, was included because it is now considered one of the fastest growing cities in the world. The boundaries of these 32 major cities were defined according to China's official definition of their administrative areas (i.e., city or *shi*)[25] (Figure 1). The urban land was defined as all nonvegetative areas dominated by human-made surfaces (e.g., roads and buildings) including residential, commercial, industrial, and transportation space within the administrative boundary.[26]

Cloud-free Landsat Multispectral Scanner System (MSS), Thematic Mapper (TM), and Enhanced Thematic Mapper (ETM) remote sensing imagers were used to obtain the information on urban land expansion for those 32 cities over the past three decades. We collected over 1000 images, and around 500 with relatively high quality were used to extract the extent of urban land for all the cities in this study. The acquisition time of these images spanned 1973−1981, 1988−1992, 1994−1996, 1999−2001, 2004−2006, and 2009−2010, nominally representing six time periods of ca. 1978, 1990, 1995, 2000, 2005, and 2010, respectively. The timespan corresponds to the period of rapid urbanization in China since the initialization of the national policy of "reform and opening-up" in the late 1970s.[27] Detailed procedures on how to derive the extent of urban area can be found in our previous works.[12,26,28−30]

Calculation of Urban Growth Rate. The average annual compound growth rate or the annual urban growth rate (AGR) of each city for each time period between 1978 and 2010 was calculated, converting urban growth into a standard metric and removing the size effect of urban land to facilitate the comparison across various cities:

$$\mathrm{AGR} = 100\% \times \left(\sqrt[n]{\frac{A_{\mathrm{end}}}{A_{\mathrm{start}}}} - 1 \right) \tag{1}$$

where A_{start} is the urban area at the initial time of the period, A_{end} is the urban area at the end time of the period, and n is the time span of the period in years. In other words, A_{end} can be calculated as

$$A_{\mathrm{end}} = A_{\mathrm{start}} \times (1 + \mathrm{AGR})^n \tag{2}$$

An alternative way to measure the speed of urban growth is the number of years to double the city in area. The shorter the doubling time, the faster the land growth speed. The time or the number of years that is needed to double a city in area can be derived from eq 2 and calculated as

$$n = \frac{\ln 2}{\ln(1 + \mathrm{AGR})} \tag{3}$$

Test of Gibrat's Law. We examined the size and growth rate relationship by fitting the data to the following equation:

$$\mathrm{AGR} = k{A_{\mathrm{start}}}^{\gamma} \tag{4}$$

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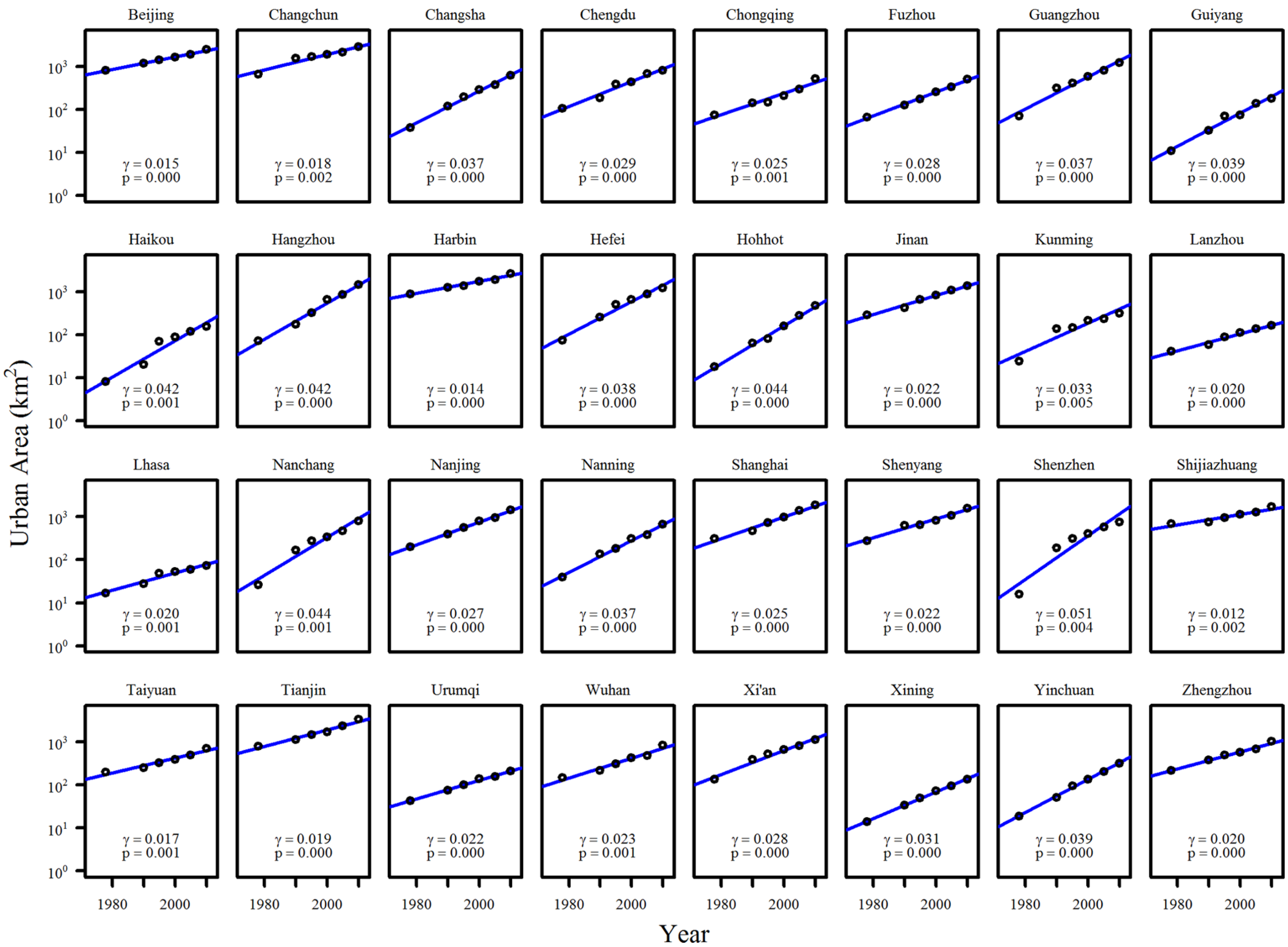

Figure 2. Exponential growth of urban land in the 32 major cities in China. The relationship was $y = y_0 \cdot e^{\gamma t}$, where y is the urban area (km^2), t is time (year), and y_0 and γ are regression coefficients. The γ values were derived by city using least-squared linear regression, and all regressions were significant at $p = 0.005$.

where AGR is the growth rate, and k and γ are regression coefficients. If Gibrat's law holds (i.e., the distribution of the growth rate is identical with respect to size), the constant γ does not significantly differ from zero. Otherwise, the growth rate is an increasing (or decreasing) function of size if the constant γ is greater (or less) than zero. In this study, the constant γ and its 95% confidence bounds were calculated by taking logarithms of both sides of eq 4. The constant γ was considered significantly different from zero (i.e., Gibrat's law does not hold) if its 95% confidence bounds did not include zero. The normality of the data was tested by the Shapiro–Wilk statistic.

We used two approaches to test the adequacy of Gibrat's law. First, our data set characterized the expansion of 32 cities over time and therefore can be analyzed using panel data analysis tools.[31] The "plm" package[32] in the R[33] environment was used for our analysis. The least-squares dummy variable model, pooled time-fixed effects model, random effects model, and variable coefficients time-fixed effects model were developed and compared, and the effects of $\log(A_{start})$ were analyzed. To test the existence of Gibrat's law is essentially to test whether the time-fixed effects exist or if the slope of $\log(A_{start})$ is significantly different from zero. Cross-sectional dependence or contemporaneous correlation was tested using the Breusch–Pagan/LM statistic (i.e., to test whether the residuals across cities were correlated); the Breusch–Godfrey/Wooldridge test was used for serial correlation in panel models (i.e., to test whether the residuals are correlated over time); The Breusch–Pagan test was used to reveal the presence of heteroscedasticity in both cross-sectional and longitudinal directions. A robust heteroscedasticity- and autocorrelation-consistent covariance matrix of $\log(A_{start})$ was calculated for the fixed or random effects models if dependence and heteroscedasticity were found. Second, we applied the ordinary least-squares (OLS) linear regression to eq 4, following Laitinen (1999),[34] to each time period independently, and the results were compared with those from panel analysis.

Gibrat's law also states that the variance of growth rate is independent of size. To test the independence of variance on city size, we grouped the cities into four quartiles according to their sizes and then tested the significance of the variance difference between each pair of the quartiles for a given time period using the F-test.[35] If the p value of the F-test was smaller than 0.05, the variances of the pair would be significantly different, and the variance would be dependent on size, therefore rejecting Gibrat's law regarding the stable distribution of variance on city size.

Temporal Change of Rate between Time Periods. Gibrat's law describes the distribution of rate with size at any given time, and it is a cross-sectional or contemporaneous comparison. We can ask similar questions longitudinally or temporally. Do city growth rates and the variance of urbanization rates change between time periods? In this study, we used Student's *t*-test for dependent samples (panel data are dependent longitudinally) to test the significance of the difference between two means if the samples passed the Shapiro–Wilk test for normality ("Shapiro's test" in R) and the F-test for variance homogeneity ("var.test" in R). Otherwise, the nonparametric procedure Kruskal–Wallis test was used. The means and variances of urban expansion rates across time periods were analyzed from three perspectives:

(a) We used the rates of all cities to answer the question: did overall mean and variance of rate change across time?
(b) We grouped the rates into quartiles according to the magnitude of rate and performed longitudinal comparisons by quartile. The question was: did mean and variance of rate change across time for a given quartile of growth rate?
(c) We grouped the rates into quartiles according to size of city and performed longitudinal comparisons by quartile. The question was: did mean and variance of rate change across time for a given quartile of city size?

Comparison of Regional Differences. To analyze the geographic patterns (variability and similarity) of urban growth rates and growth characteristics, we used a broad regionalization scheme that devides China into the Eastern, Central, and Western regions (Figure 1). This regionalization is widely considered to represent the general patterns of the population, economy, climate, and terrain of China.[27]

All calculations and analysis in this study were performed using R packages.[33] A value of α = 0.05 was used for all significance tests throughout the paper.

■ RESULTS

Urban Growth Rate over Time and across Region. The urban land area of individual cities expanded exponentially and significantly from 1978 to 2010 at varying rates (Figure 2). Shenzhen, one of the earliest and also the most successful Special Economic Zones, experienced the fastest growth among all cities, with an annual rate of 12.8% (area doubled in every 5.8 years), while both Shijiazhuang and Harbin witnessed the slowest growth rate of 3.2% (area doubled in every 22 years). The total urban land area of the 32 cities increased exponentially from 1978 to 2005 (Figure 3). Surprisingly, an accelerated increase in area was observed in the period of 2005–2010, when the annual growth rate increased from 5% to 7.2%, and the average city-doubling time reduced from 14.3 years (prior to 2005) to 9.9 years. The actual growth (9860 km^2) exceeded the expected growth (6802 km^2), which was calculated according to the historical (1978–2005) growth pattern, by 3058 km^2 or 45%.

Collectively, urban growth rates observed from these 32 cities showed significant changes over time (Figure 4A). Examining the growth rates by period, it can be seen that the highest and the lowest average rates were 8.3% and 5.3%, respectively appearing in the periods of 2005–2010 and 2000–2005, and they were significantly different. In addition, the average growth rate in the period of 1990–1995 was 8.2%, which was also significantly different from the lowest rate in the period of 2000–2005. The growth rates between 1995–2000 and 2005–2010 and between 1990–1995 and 2000–2005

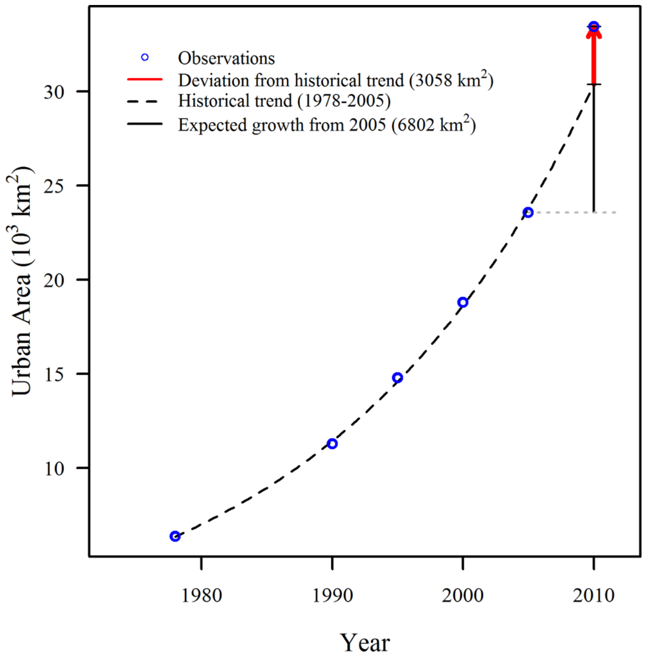

Figure 3. Exponential growth of the total urban land area from 1978 to 2005 in 32 major cities in China and the accelerated growth from 2005 to 2010. The expected urban growth from 2005 to 2010 was estimated by extending the historical growth path (1978–2005) to 2010. The exceeded growth beyond expectation was calculated as the difference between the observed and expected area growths from 2005 to 2010.

were also significantly different. The rates between other time periods were not significantly different.

Comparing the growth rates by rate percentile and area percentile revealed more details on the temporal structural change of the overall growth rate (Figure 4B–I). The average growth rate in the lowest or the 0–25% rate bracket elevated significantly in the period of 2005–2010, changed from below 3% in previous periods to 5.1% (Figure 4B). The rates in the 25–50% percentile range experienced dramatic changes as well, especially during the periods of 2000–2005 (decreased significantly) and 2005–2010 (increased significantly) (Figure 4C). The growth rate during the 2000–2005 period in the 50–75% bracket was significantly lower than those in any of the other periods, and during 2005–2010, it was significantly higher than those in other periods except that from 1990 to 1995 (Figure 4D). However, the average rates did not show significant changes in the 75–100% percentile bracket except for the difference between the periods 1990–1995 and the subsequent three periods (Figure 4E). The growth rates that were binned according to city size (i.e., area percentile) (Figures 4F–I) demonstrated more stable behavior over time than those binned by growth rate itself. We can only see significantly higher rates during 2005–2010 in the second (Figure 4G) and fourth quarter brackets (Figure 4I). Otherwise, no significant difference in the growth rate was detected when binned by city size.

Variance of the growth rates of the 32 cities changed over time as well (Figure 4J). Overall, the variance in the period of 2005–2010 was the smallest, significantly different from those in the periods of 1978–1990 and 1990–1995, respectively. The variance in the period of 1990–1995, being the largest among all time periods, was also significantly different from those in

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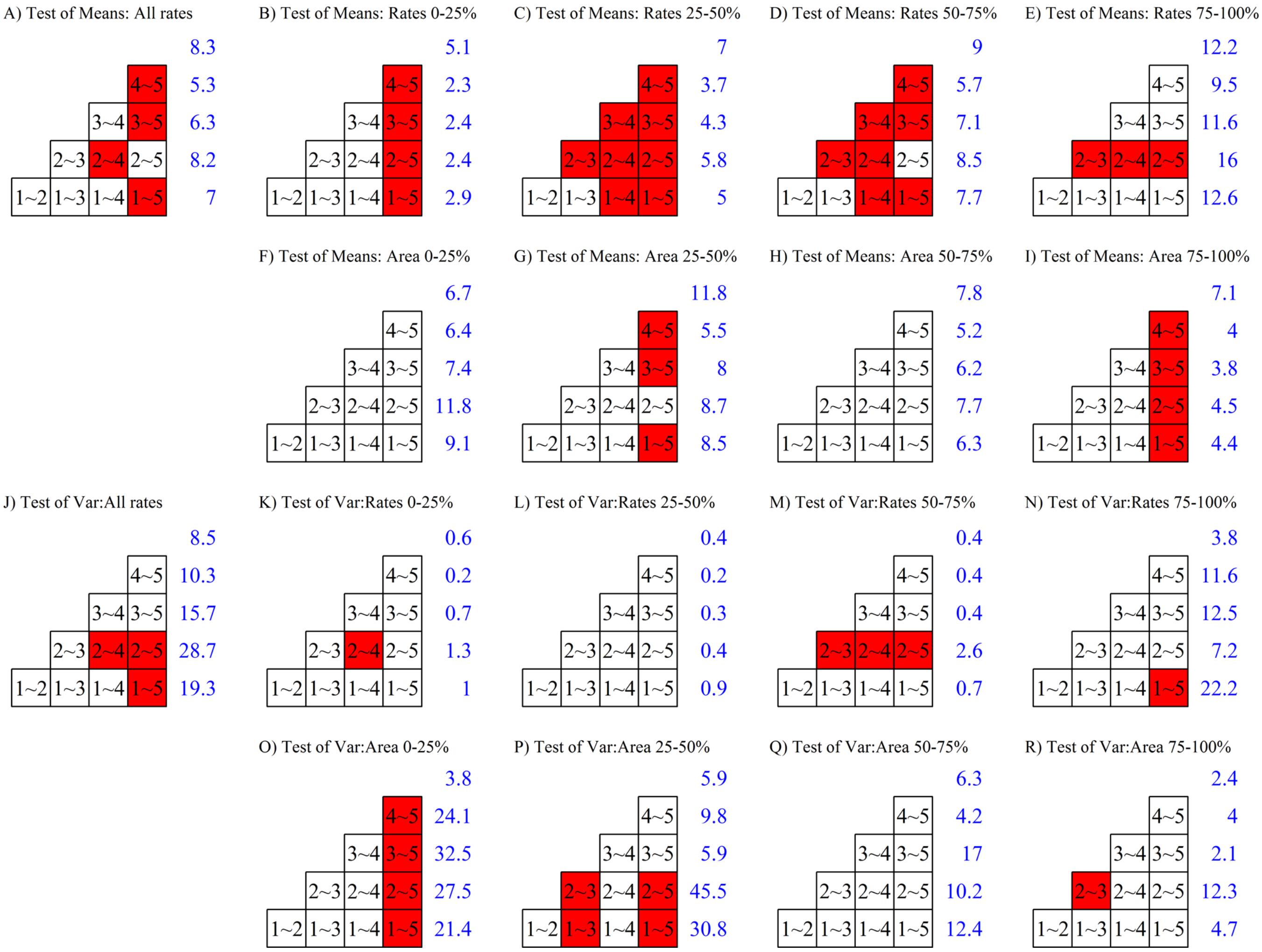

Figure 4. Comparison of the means and variances of growth rates during different time periods. The numbers in the squares denote the following time periods, respectively: 1 (1978−1990), 2 (1990−1995), 3 (1995−2000), 4 (2000−2005), and 5 (2005−2010). The pair of numbers in each square represents a pairwise comparison of means or variances between two time periods as the number indicated. Several comparisons were performed: growth rates for all 32 cities, cities grouped according to rate percentiles, and cities grouped according to size of urban area. The means or variances of the growth rates for time periods are shown in blue (%) on its right side from 1978−1990 to 2005−2010 upward, respectively. Boxes in red indicate significant difference between the two periods.

the periods of 2000−2005 and 2005−2010. When examining the variance change across rate quarters (Figure 4K−N), we see that the highest variance of growth was found in the fourth quarter (i.e., the 75−100% bracket). However, the variances presented a tendency to decrease from the first to the fourth area bin (Figure 4O−R). In fact, the results reflect one phenomenon: small cities grew faster on average than did larger ones (Figure 4F−I) but had higher intercity variability. The most noticeable change in variance was the significant decrease in the smallest cities (0−25% percentile) during the period of 2005−2010 (Figure 4O) and significant increase during 1990−1995 in the third rate bin (Figure 4M).

The average city sizes in the Western region was significantly lower than those in the Eastern and Central regions, and the latter two were not significantly different for all time periods (Table 1). No significant differences were observed among the city growth rates in the Eastern, Central, and Western regions for all time periods (Table 1). Nevertheless, this similarity in growth rates led to the increasing differences in mean urban size across regions because the exponential growth patterns enlarge differences in area.

Table 1. Averaged AGR and Urban Area of Cities in the Eastern, Central, and Western Regions for All Time Periods[a]

	time	East (n = 13)	Central (n = 9)	West (n = 10)
part I: urban area (km^2)	1978	279.1[a]	250.4[a]	48.5[b]
	1990	455.9[a]	469.2[a]	112.8[b]
	1995	606.7[a]	582.6[a]	166[b]
	2000	786.6[a]	718.3[a]	210.1[b]
	2005	1005.7[a]	853.9[a]	281.2[b]
	2010	1422.1[a]	1231.2[ab]	386.3[c]
part II: AGR (%)	1978−1990	7.11	8.23	5.92
	1990−1995	8.09	5.85	10.34
	1995−2000	6.83	6.1	5.96
	2000−2005	4.91	5.44	5.68
	2005−2010	8.4	9.25	7.45

[a]The means are significantly different if the regions, during the same period, are not labeled with the same letter.

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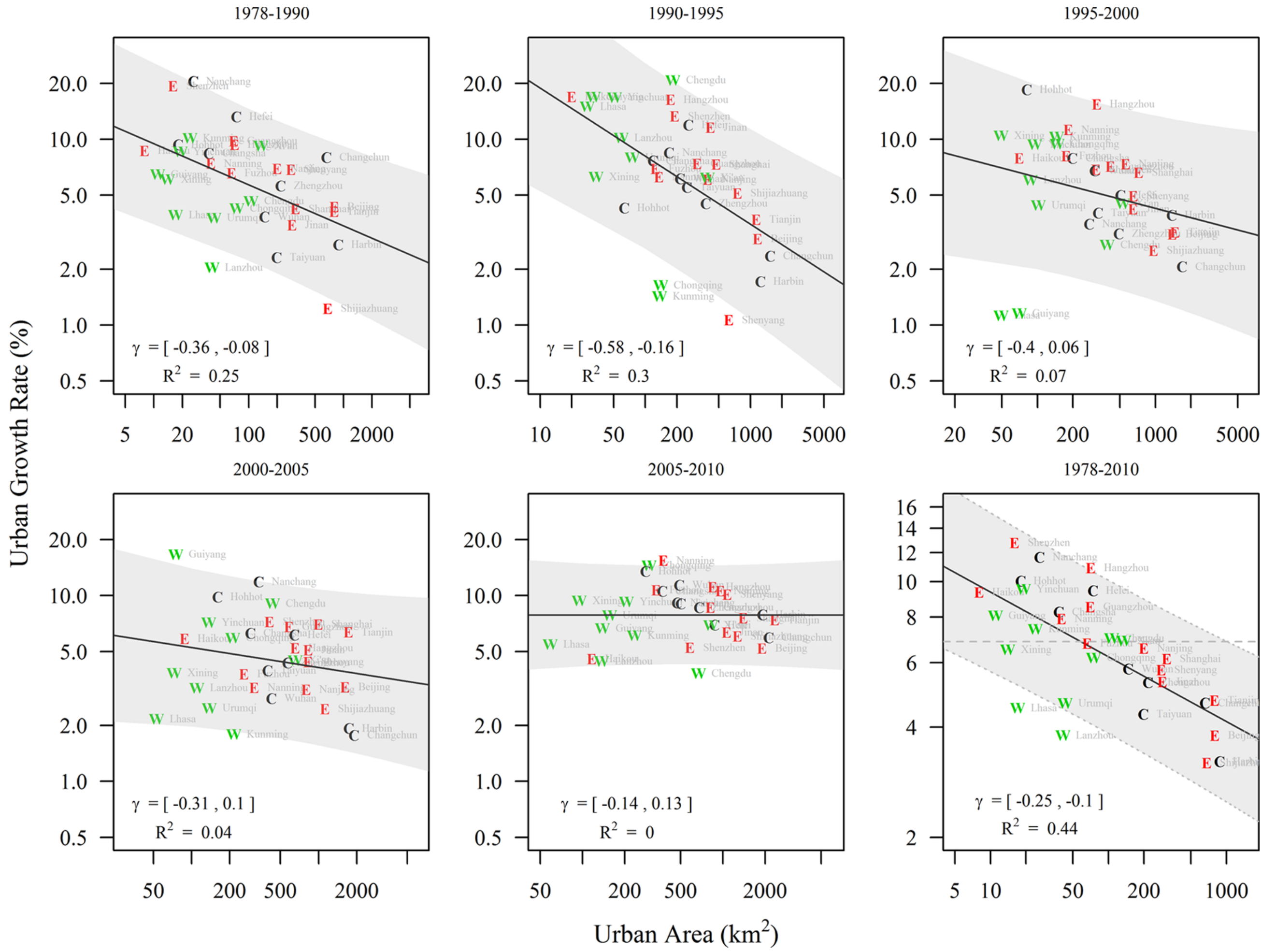

Figure 5. Temporal change of the relationship between growth rate and city size from 1978 to 2010. Letters E, C, and W represent the Eastern, Central, and Western regions, respectively. The black line and the shaded areas are the power regression line and its 95% confidence bounds, respectively. The values of γ and R^2 are the 95% confidence range of the exponent and the determination coefficient of the power regression.

Relationship between Growth Rate and City Size (Test of Gibrat's Law). The change of rates and variances over time and their regional differences described above can be seen broadly from Figure 5. More importantly, Figure 5 shows the temporal change of the relationship between growth rate and city size. According to the OLS regression analysis performed independently for each time period, a weak but significant power-law relationship was detected in the periods of 1978−1990 and 1990−1995 with the 95% confidence bounds for the coefficient being [-0.36, −0.08] and [-0.58, −0.16], respectively. This contradicts Gibrat's law, which requires that the coefficient not be significantly different from zero. However, the relationship became insignificant in the subsequent time periods, which suggests that city growth was proportionate and, therefore, Gibrat's law held. The power relationship between growth rate and the initial urban area was significant during the entire period from 1978 to 2010, and the 95% confidence limit of the coefficient was [-0.25, −0.10], contradicting Gibrat's law.

Other modeling approaches revealed results that are very similar to the OLS analysis. First, the effects or slopes of log(A) on log(rate) during the entire period (i.e., 1978−2010) estimated by different models were all significant regardless of the modeling approach (Table 2), suggesting the nonexistence of Gibrat's law. Second, the temporal change of the impacts of log10(area) across time periods as demonstrated by the variable coefficients time-fixed effects model (Table 3) also corroborated the findings from OLS.

Table 2. Means, Standard Errors, and the 95% Confidence Intervals of the Effects or Slopes of log(A) on log(rate) Estimated by Different Models for the Entire Period of 1978−2010

model	slope	standard errors	95% confidence interval
least squares dummy variable model	−0.192	0.041	[-0.274, −0.11]
fixed effects pooling model	−0.14	0.04	[-0.22, −0.06]
fixed effects within model	−0.119	0.051	[-0.221, −0.017]
random effects model	−0.137	0.036	[-0.209, −0.065]
random effects Variable Coefficients model	−0.16	0.058	[-0.276, −0.044]

Table 4 lists the relationship between variance of growth rate and city size according to the area percentile for each time period from 1978−1990 to 2005−2010. Significant differences between certain pair of quartiles were found for the periods of 1978−1990, 1995−2000, 2000−2005, and the entire period, rejecting Gibrat's law regarding the independence of variance on city size. Gibrat's law held for the periods of 1990−1995 and 2005−2010, when the highest and lowest overall variance of

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Table 3. Means, Standard Errors, and the 95% Confidence Intervals of the Effects or Slopes of log(A) on log(rate) Estimated for Various Timer Periods Using a Variable-Coefficients Time-Fixed Effects Model[a]

time period	slope	standard errors	95% confidence interval of slope
1978−1990	−0.221	0.07	[-0.362, −0.08]
1990−1995	−0.367	0.103	[-0.572, −0.161]
1995−2000	−0.167	0.113	[-0.393, 0.059]
2000−2005	−0.107	0.099	[-0.305, 0.091]
2005−2010	−0.001	0.066	[-0.132, 0.13]
1978−2010	−0.16	0.058	[-0.276,-0.043]

[a]The coefficients for the entire period of 1978−2010 were estimated using a variable-coefficients random-effects model.

Table 4. Comparison of the Variance of Growth Rates According to Area Percentiles for Each Time Period from 1978−1990 to 2005−2010[a]

	0−25%	25−50%	50−75%	75−100%
1978−1990	21.4^{ab}	30.8^{a}	12.4^{ab}	4.7^{b}
1990−1995	27.5^{a}	45.5^{a}	10.2^{a}	12.3^{a}
1995−2000	32.5^{a}	5.9^{bc}	17^{ab}	2.1^{c}
2000−2005	24.1^{a}	9.8^{abc}	4.2^{bc}	4^{c}
2005−2010	3.8^{a}	5.9^{a}	6.3^{a}	2.4^{a}
1978−2010	6.25^{a}	7.5^{a}	2.26^{ab}	1.25^{b}

[a]An F-test was used to test the significance of the difference between variances. The variances are significantly different if percentiles during the same period are not labeled with the same letter.

growth rate were observed, respectively (Figure 4J), and characterized by a size-independent variance. It should be noted that there were discrepancies in testing whether Gibrat's law holds for Chinese cities when using mean or variance of growth rate.

The doubling time was in general loosely related to city size, with longer times for larger cities (Figure 6). We can also see that geography played an important role in determining the length of doubling time: the longer times were usually associated with cities in the west (e.g., Lhasa, Lanzhou, and Guiyang) or north (e.g., Changchun, Harbin, and Shijiazhuang). The mean doubling time dropped significantly from 2000−2005 (18 years) to 2005−2010 (9.7 years) period. In addition, the variance of the doubling times across cities in the period of 2005−2010 was significantly lower than the variance in any of the previous periods.

DISCUSSION

It has long been speculated that the size of a city and its growth rate are independent, following Gibrat's law of proportionate growth.[21,36−39] A few studies have found that the population growth of cities is not consistent with Gibrat's law, and that the mean population growth rates of cities follows a power law with the city size.[22,40,41] Previous urban studies on the testing of Gibrat's law were mostly regarding either the mean or the variance of the growth rate instead of both and were related to population growth.[21,23,42] Our results show a more complicated evolution in the dynamic expansion of Chinese cities regarding both the mean and the variance of growth rate based on urban area growth. The relationship between growth rate and city size sometimes follows a power law (i.e., 1978−1990, 1990−1995 and the entire period, and 1978−1990, 1995−2000, 2000−2005, and the entire period in terms of mean and variance of growth rate, respectively) and other times follows Gibrat's law (i.e., the 1995−2000, 2000−2005 and 2005−2010, and 1990−1995 and 2005−2010 time periods, respectively). Chinese urban expansion follows power law in the period of 1978−1990 and the entire period (i.e., 1978−2010) but Gibrat's law in the period of 2005−2010 regarding the relationships between both mean and variance of growth rate and city size. The transition of the relationship between the expansion rate and the city size from the power law to Gibrat's law is intriguing. More in-depth studies are needed to understand its social and economic causes and consequences. It might be related to the long-lasting and gradual impacts of the reform and open-up policy implemented in the late 1970s, a transition from a planned to a market economy, and the economic growth during this time period. The power law before 1995 implies that smaller cities had higher rates than did the larger ones in general in China. This

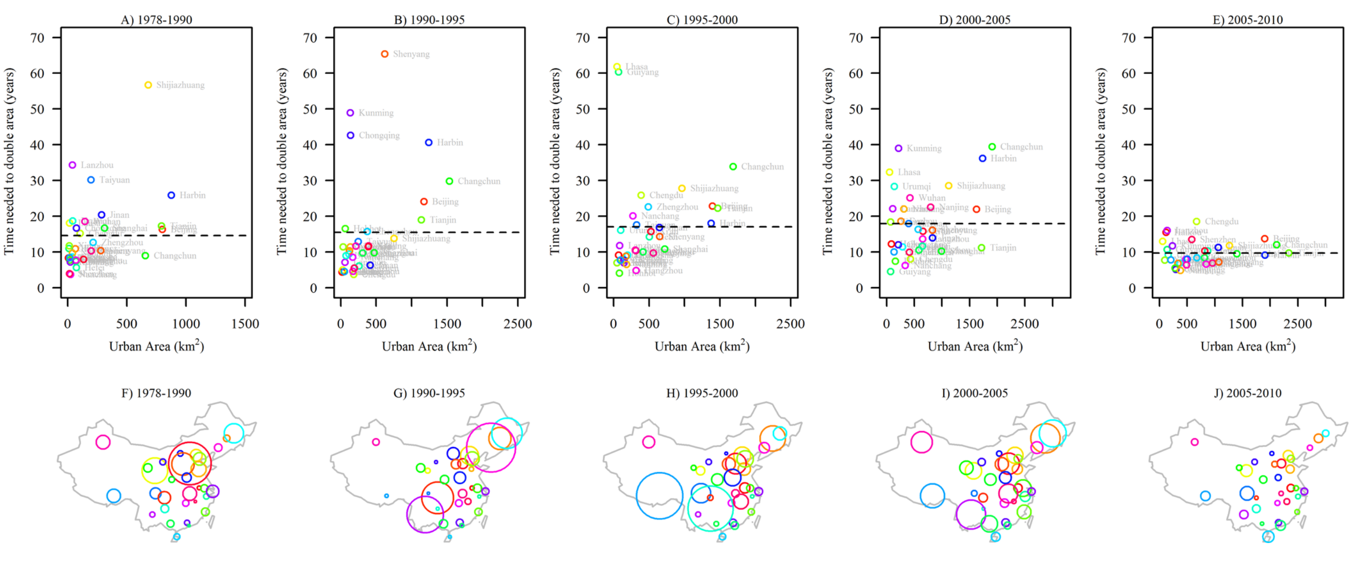

Figure 6. Time needed for doubling the size of each city by period, calculated according to its growth rate during different time periods from 1978 to 2010. Panels A through E show the relationship between the time needed to double the area and the urban area at the beginning period, and Panels F through J demonstrate the geographic distribution of time needed to double the area.

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pattern of city growth can probably explained by the diseconomies of scale such as higher property prices, technology, and traffic congestion in the early period of growth in large cities than smaller ones, similar to other observations.[43,44] It is interesting to note that the growth rates of small cities in Europe had slowed or even declined compared with larger ones since the 1960s,[45] which is different from what we have observed in China. Contrary to those in Europe, most small cities in China have experienced faster (but not significant) expansion rates than have larger ones, except during the most recent period (Figure 4F–I). Even in the most recent time period, the overall expansion rates of small cities were the same or faster than in previous periods, and the disappearance of differences in expansion rate between small and large cities were mainly caused by accelerated expansion in large cities, not the slowing of small ones. The transition from power law to Gibrat's law over time that was shown in our study signifies the temporal change of city development strategy from favoring small cities to favoring large ones. This might demonstrate that the organizational evolution of Chinese cities had gradually transitioned itself from diseconomies to economies of scale, directly supporting the new urban theory that larger cities are better positioned than smaller ones because of the economies of scale (i.e., more opportunities, infrastructure, and excitement available to firms and individuals in larger cities than in smaller ones).[46,47]

We have used various modeling approaches, including panel analysis, to examine the applicability of Gibrat's law in China. It is interesting to see that although there were minor differences in the coefficients among different modeling approaches, the inferences about the relationship between the urban expansion rate and city size were all the same. This robustness might suggest that violations of the assumptions about the cross-sectional and longitudinal correlations of the errors and the existence of heteroscedasticity did not lead to significant biases in inferences in our case. Nevertheless, it is prudent to use panel analysis techniques for cross-sectional time-series observations of city growth. This study focused on the relationship between urban expansion rate and city size and its change over time with reference to Gibrat's law. Future work should take advantage of the panel data analysis techniques by finding information from data panels that cannot be observed or measured (e.g., cultural factors or differences in business practices across cities) and from properties that change over time but not across cities (e.g., national policies). For example, our analysis on regional differences so far used a broad-brush approach, and a more detailed analysis on cross-sectional dependence in panels resulted from responses to common policy and economic shocks or spatial diffusion processes (such as the migration of people and policy from the East to the West in China) could shed light on the understanding of the driving forces of urban expansion in China.

Recent changes in urban expansion patterns, especially during the period 2005–2010, might reflect two major shifts, one planned and the other unintended, in China's political and economic policies. First, the implementation of the national "Western Development Strategy" policy, which was put in place by Chinese central government in the early 2000s, has effectively accelerated the pace of urbanization in the traditionally underdeveloped western inland of China.[12] For instance, propelled by this policy, the time needed to double the urban area of Lhasa had shortened from 35.4 to 12.5 years; Urumqi doubling time has gone from 29 to 9.1 years, and Kunming doubling time from 38.7 to 11.7 years, all in the western part of China. In fact, the expansion rates of some western cities (e.g., Nanning, Chongqing, Hohhot, Xining, and Yinchuan) were among the fastest in recent years. Second, the most recent time period had recorded accelerated urban expansion rates in large cities to megacities. For example, the time for doubling the size of Beijing, the fourth largest city in China in area, has shortened from 21.9 to 24.1 (from 1990 to 2005) to 13.7 years (from 2005 to 2010). Tianjin, the largest city in China in area, could be doubled in 9.7 years with the expansion rate witnessed in 2005–2010, which has shortened to more than half the rate observed in 1995–2000 (22.2 years). The convergence of urban expansion rates across all cities and the disappearance of the relationship between city size and growth rate during 2005–2010 might be unintended and alarming, particularly regarding the fast expansion of megacities. Our finding that urban expansion pattern has experienced drastic changes in China was consistent with Frolking et al. (2013),[16] who also observed a global macroscale change in urban structure from 1999 to 2009, particularly in Chinese cities. However, how much their results were influenced by the observations from China is not clear.

Fiscal and governance reforms on real estate have generated profound impacts on urban land expansion in China.[18,48,49] For example, the establishment of the urban land market in 1992 in Beijing has set up a brand new course that was sharply different from its past trends.[11] Urban land expansion has not been simply a passive outcome of urbanization but has been actively pursued by governments at different levels as a means of revenue generation to finance economic growth.[50–52] The income from land leases, which often means converting nonurban lands into built-ups, can account for 30–70% of a city's financial revenue.[53,54] It is expected the rates of urban land expansion will continue as the urban land prices exceeded agricultural land values considerably.[49]

Controlling urban expansion in a sustainable fashion is a huge challenge for humanity in general.[4,55] It is particularly so in China because of its huge population and the strong connection and positive feedback between urban expansion and economic development.[15] As the Chinese economy is somewhere between planned and market-driven, Chinese urbanization processes will inevitably face a series of practical and theoretical challenges that might be more complicated than what have seen from other countries. Our study revealed that the relationship between urban expansion rate and city size had changed over time in China, signifying fundamental changes in Chinese urbanization processes. However, the exact driving forces behind this observed transition is not clear. Is it connected to Chinese governmental policy and regional or city development plans, or is it purely a result of self-organization driven by many invisible factors, including the economies of scale? More large-scale interdisciplinary studies are needed to really understand the processes, driving forces, and consequences of urbanization in China.

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Notes

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