Does China's increasing coupling of 'urban population' and 'urban area' growth indicators reflect a growing social and economic sustainability?

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Abstract

Over the last four decades, China has experienced rapid parallel economic development and urbanization, leading to internal mass -migrations of its people from increasingly marginalized rural areas to urban centers where job opportunities and wealth are now concentrated. We compare the relative temporal growth trends in population-related and land-(i.e., area-) related urbanization systems to evaluate China's urbanization in the context of the 'New-Type' Urbanization Program (2014-2020). Based on coupling coordination models, we observed that the two systems were overall slightly decoupled since spatial urban expansion commonly outgrew urban population growth, but the degree of coordination between the two parameters was increasing. Employing exploratory spatial data analysis, we revealed that a high degree of coupling coordination has spread from Eastern to Western provinces. Urban planning and land policies have contributed to an increasing urban vegetation cover and the control of excessive urban land expansions. While China's urbanization appears to have become increasingly sustainable due to the increasing degree of coupling coordination between its subsystems, ongoing urban expansions require strong oversight to limit the environmental impacts of the country's sprawling mega-cities.
Keywords: 'New-type' urbanization; coupling coordination degree; urban planning; land policies; sustainability

1. Introduction

China's path to urbanization shows unique traits not only in the rapid movement of enormous numbers of people from rural to urban environments, but also with the additional implementation of household registration systems aimed at allowing social planning controls and rapid industrialization, while also leading to significant problems related to equity and efficiencies in the urbanization processes (Zhang, 2019). Over the last four decades, China's urbanization rate increased rapidly from ~18% in 1978 to ~60% in 2018. As a result, China's rural population has begun to decline strongly especially from 1995 and was overtaken by the urban population in 2011 for the very first time in China's history, heralding China's rapid transformation into a newly urbanized country (Yang, 2013).

China's urbanization has been described as the greatest human resettlement experiment in history (Kojima, 1995) that can be divided into three distinct phases (Ruibo and Linna, 2013): revival (1978-1996), transition (1996-2013) and 'new-type urbanization' (2013-present).

During the revival period, a Household Responsibility System (HRS) (Chen and Davis, 1998) and the introduction of foreign investment led to a dramatic expansion of many small and medium-sized cities. The HRS re-established individual households rather than collective communes as the basic unit of production and accounting in rural areas. This not only encouraged rural residents to optimize the productivity of their allocated agricultural land, but also provided towns with an increasing number of laborers. Further driven by the relaxation of migration restrictions formerly limiting movements to urban areas, rural laborers began to flock to 'Town and Village

Enterprises' (TVE) that strongly drove the expansion particularly of small-sized cities between the late 1980s and the early 1990s (Li et al., 2018). Apart from HRS, foreign investment pouring into China in the 1980s accelerated regional economic developments that in turn further expedited urbanization. These two factors laid the foundations for China's subsequent economic boom – and for substantial changes in the relationship between land and people.

The subsequent transition period was characterized by land-centered urbanization, focusing on the spatial expansion of urban areas and industries as a basis for increased economic output (Ye and Wu, 2016). While during the revival period, development was chiefly focused on small cities, cities at all levels grew rapidly in the transition period from 1995 onwards – again chiefly in response to changes in public policies (Li and Liu, 2018). At this period, large parts of China's rural population, rather than remaining in or moving to smaller towns, rushed into China's largest cities that experienced the most rapid economic growth (Chen et al., 2013). The resulting extreme inequality in income and access to jobs, social welfare and education further accelerated rural depopulation (Meng, 2014). With increasing city population sizes, urban land became a source of capital formation. In the absence of private land ownership in China, municipal governments took control of the capitalization of urban land, including expropriation, allocation, and conveyance of land. Facing increasing fiscal expenditures, municipal governments turned to land financing models that heavily relied on land leasing-based revenue. This revenue stream was used to finance urban development, including the expansion of public services and local infrastructure. The resulting rapid expansion of cities' populations was accompanied by strong links between the urban land area and urban population sizes (Ding, 2003; Theurillat, 2017).

These patterns led not only to an increasing expansion of China's main urban centers, but triggered a rapid loss of often highly productive agricultural land in the vicinity of China's cities. In response, the Chinese government released the 'National New-type Urbanization Plan (2014-2020)' (hereafter simply 'the Plan'). One major component of the Plan was the allocation of both, land and laborers, due to market mechanisms instead of top-down local government-led urban expansions (Yang et al., 2017). A notable parallel improvement from a social perspective was the principle of "people-oriented urbanization". This principle emphasizes that new urban residents emigrating from rural areas are immediately granted the same right to public services as held by established residents, therefore disregarding the established Hukou (household register) system previously heavily restricting such access for newcomers. Simultaneously, the Plan also aimed at a more sustainable urbanization model by changing ways of production and consumption with a focus on use efficiency and quality, and a switch from a land-urbanization mode mainly centered on land exploitation to a new urbanization mode that views coordinated urban-rural development as a priority (Luo et al., 2018; Taylor, 2015).

Previous studies have examined development modes (Yuan et al., 2018), driving factors (Tan et al., 2017), and societal impact of China's rapid urbanization (Xing et al., 2019). This urbanization was characterized by an unbalanced development between different regions (Du and Lin, 2019), hollowed cities (Long et al., 2018), and strong policy interventions (Bai et al., 2014). Rural-urban migration has chiefly determined urban population growth (Zhang and Shunfeng, 2003), while economic growth has strongly promoted the urban populations particularly in China's main urban centers . Urbanization most strongly impacted regions where people already achieved middle to high average incomes (Yang et al., 2017), arguably changing entire regional landscapes by the rapid expansions of built-up areas (Xu et al., 2015). Disparities in growth rates of the main urban populations and urban centers has furthermore recently resulted in a growing gap of regional development (Wang et al., 2019), resource scarcity (Liao et al., 2019), environmental degradation (Sun et al., 2019), and disparities in social welfare (Fei and Zhao, 2019).

Some studies have already focused on the strength and nature of relationships between urbanization and other factors (Cai et al., 2019; Li and de Jong, 2017) like the degree of coupling between land area and urban populations (Cai et al., 2019). However, most of these previous studies were conducted at the provincial level, and specific relationships between different elements characterizing the urbanization process have been rarely discussed. According to the *'New-Type' Urbanization Program (2014-2020)*, China's urbanization can be viewed through the lenses of a population-related urbanization and a land-related urbanization. The former focuses on the increase in urban populations and the promotion of their quality of life, while the latter focuses on the increase of the overall urban land area, but also for example on the increase of vegetation cover in urban areas and the speed of growth in built-up areas. To fill the aforementioned research gap, our paper investigates China's urbanization process with a focus on the relationship between population-related and land-related trends in urbanization, specifically testing the hypotheses that 1) while historically, massive urban sprawl has meant area-based urbanization systems changed massively faster than population-related systems, rapidly rising urban population numbers in combination with the improvements of the quality of urban life has begun to greatly increase the level of population-related urbanization systems, hence moving the systems to a much more closely coupled system – with this trend moving from Eastern to Western provinces, and 2) China's urbanization generally moves towards stronger coordination between urban population and area-based systems due to an increased emphasis on the quality of urbanization processes rather than an excessive expansion of urban land, reflecting a transition from land-centered to people-oriented urbanization.

2. Data and methods

2.1 Study areas and data

This paper explores China's urbanization at the national and provincial level. Based on the geographical location and regional economic development, we divided China into Eastern, Central and Western China (Fig.1).

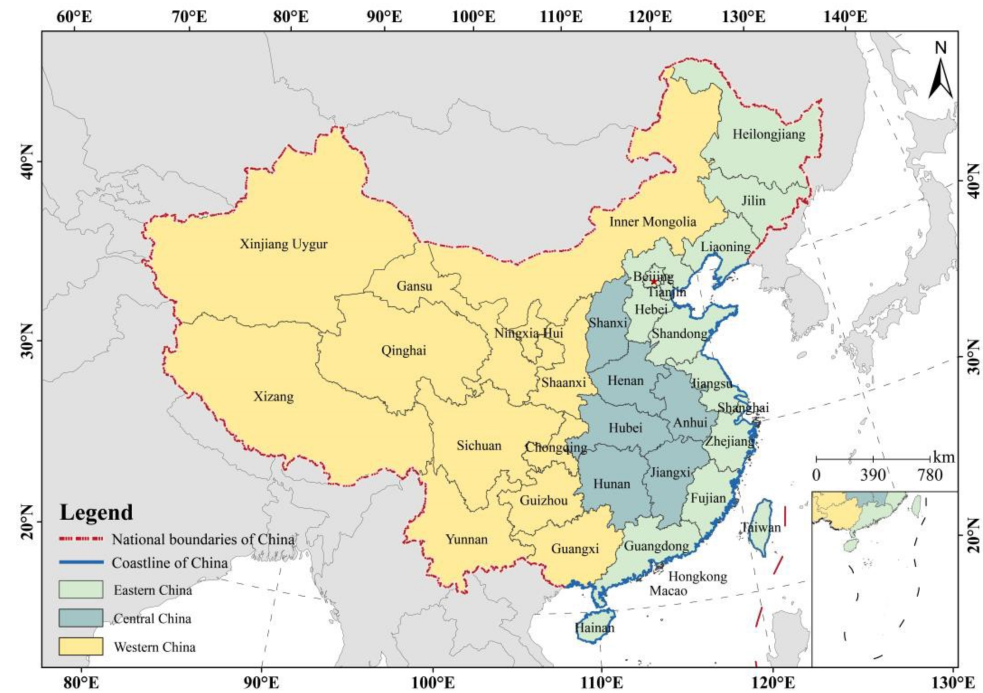

Fig.1. The subregions of China

In the context of the framework provided by the 'New-Type' Urbanization Program (2014-2020), we established indicators to investigate different aspects of China's urbanization, including the ratio of urban population to total population, per-capita disposal income of the urban population, percentage coverage of basic pension insurance, and GDP to characterize the population-related aspects of urbanization, and the percentage vegetation cover of urban areas, the overall size of the built-up area and the per-capita area of built-up land to characterize land-related aspects of urbanization (Table 1). The data of the first four population-related indicators were obtained from the *China Statistical Yearbook* (CSP, 2019), the data for overall built-up area and the per-capita value for this area were accessed from *China Urban Construction Statistical Yearbook* (MOHURD, 2018), and the data of the vegetation cover were collected from provincial statistic yearbooks.

Table 1

Indicators characterizing population-related and land-related aspects of China's urbanization

System	Indicator	Unit	Weight
	Ratio of urban population to total population	%	a_1

Population-related urbanization	Per-capita disposal income of the urban population	CNY/person	a_2
	Percentage coverage of basic pension insurance	%	a_3
	GDP	CNY	a_4
Land-related urbanization	The overall size of built-up areas	km^2	b_1
	Percentage vegetation cover of urban areas	%	b_2
	Per-capita area of built-up land	km^2/person	b_3

2.2 Methods

2.2.1 Data standardization

Differences in dimensions and magnitudes of the different indicator variables used in this study meant that it was necessary to standardize each variable, based on the raw data for the study period.

Indicators fall into two classes, i.e., positive indicators that show a subjective improvement in conditions like an increase in disposable income, pension insurance or vegetation cover in urban areas, and negative indicators which indicate negative trends in urbanization developments like the change in the overall built-up area and the per-capita area of built-up land. Positive indicators were used to designate the change in strength of the relative index value of an element similar to the change in the overall system, that is, the higher the value of an indicator, the higher the level of the system. Negative indicators in contrast designate the change in strength of the relative index value of an element opposite to the change in the overall system, that is, the higher the value of a negative indicator, the lower the overall level of the system(He et al., 2017).

For positive indicators, this was achieved with the equation

$$r_{ij} = \frac{x_{ij} - \min\{x_j\}}{\max\{x_j\} - \min\{x_j\}} \quad (1)$$

whereas for negative indicators, the respective equation was

$$r_{ij} = \frac{\max\{x_j\} - x_{ij}}{\max\{x_j\} - \min\{x_j\}} \quad (2)$$

where

x_{ij}: the value of indicator j in year i

$\max\{x_j\}$: the maximum value reached by indicator j across all years

$\min\{x_j\}$: the minimum value reached by indicator j across all years

2.2.2 The 'entropy method'

We then employed the entropy method to determine the weights of the seven indicators which were introduced above. The word *entropy* originates from studies of thermodynamics and can be interpreted as the uncertainty of an information source. The Entropy method employed here is based on information entropy and has been widely used in socio-economy and environmental science, as it can approximate the amount of 'useful' information of the data(Jiang et al., 2020). The degree of uncertainty is reduced when the indicator provides more useful information, resulting in low information entropy L. Therefore, entropy is a relatively objective method for weight determination. The steps for the calculation of weights were as follows(Dong and Li, 2021):

Proportion of indicator j in year i (p_{ij}):

$$p_{ij} = \frac{r_{ij}}{\sum_{i=1}^{n} r_{ij}} \quad (3)$$

where n refers to the numbers of all years, i refers to the year, j refers to the indicator.

Information entropy (e_j) of indicator j:

$$e_j = -\frac{1}{\ln n}\sum_{i=1}^{n} (p_{ij} \times \ln p_{ij})\left(0 \leq e_j \leq 1\right) \quad (4)$$

The weight (W_j) of indicator j:

$$W_j = \frac{1-e_j}{\sum(1-e_j)} \quad (5)$$

2.2.3 Modelling the coupling degree

Coupling refers to a phenomenon where two or more systems interact with each other. It originated from physics and gradually becomes an effective tool for the analysis of non-linear relationships between multiple factors (Li et al., 2012). Unlike concepts of correlation that initially referred chiefly to linear relationships (Lee Rodgers and Nicewander, 1988), the concept of coupling more generally describes the degree of interaction and influence amongst the elements of a system, or between different systems. The degree of coupling shows trends that range from randomness to order (Liu et al., 2005). In recent years, coupling degree models have been widely adopted in urban studies, particularly with regards to urbanization processes and environmental issues owing to rapid urbanization. The formula can be constructed as(Song et al., 2018):

$$C_n = \left\{\frac{m_1 \cdot m_2 \cdots\cdots m_n}{[\prod(m_i+m_j)]}\right\}^{\frac{1}{n}} \quad (6)$$

, where n: number of studied systems

C_n: coupling degree among all systems

m_i: contribution value of the i^{th} system

m_j: contribution value of the j^{th} system

However, the coupling degree cannot indicate synergies among the studied systems (Fan et al., 2019). Thus, we further employed a measure of the coupling coordination degree to assess whether there is a coordinated development of the systems through their interactions. The coupling coordination degree can be constructed as:

$$D_{ij} = \sqrt{C_{ij} \times T_{ij}}, \tag{7}$$

where $$T_{ij} = w_i m_i + w_j m_j$$

D_{ij}: degree of coupling coordination between the i^{th} and j^{th} system

C_{ij}: coupling degree between the i^{th} and j^{th} system

w_i and w_j: weights for the i^{th} and j^{th} system

The degree of coupling coordination can indicate four distinct states, that is, "seriously unbalanced development", "slightly unbalanced development", "slightly balanced development", and "superior balanced development" (Table 2). In this paper, $f(x)$ and $g(x)$ designate the population-related and the land-related urbanization systems, respectively. The difference value indicates a higher level of one system in comparison to the other system.

Table 2

Classification of coupling coordination degree

Coupling coordination degree	Classification	Difference	Secondary classification
0.7 < D≤1.0	Superior balanced development	g(x)-f(x) > 0.1	Lagging population-related urbanization
		f(x)-g(x) > 0.1	Lagging land-related urbanization
		-0.1 ≤ f(x)-g(x) ≤ 0.1	Parallel development of two subsystems
0.5 < D≤0.7	Slightly balanced development	g(x)-f(x) > 0.1	Lagging population-related urbanization
		f(x)-g(x) > 0.1	Lagging land-related urbanization
		-0.1 ≤ f(x)-g(x) ≤ 0.1	Parallel development of two subsystems
0.3 < D≤0.5		g(x)-f(x) > 0.1	Lagging population-related urbanization

	Slightly unbalanced development	f(x)-g(x) > 0.1	Lagging land-related urbanization
		-0.1 ≤ f(x)-g(x) ≤ 0.1	Parallel development of two subsystems
0 < D≤0.3	Seriously unbalanced development	g(x)-f(x) > 0.1	Lagging population-related urbanization
		f(x)-g(x) > 0.1	Lagging land-related urbanization
		-0.1 ≤ f(x)-g(x) ≤ 0.1	Parallel development of two subsystems

2.2.4 Exploratory spatial data analysis

We used an exploratory spatial data analysis, a powerful tool to establish the degree of spatial agglomeration effects at various scales (Xing et al., 2019), to identify any spatial clusters amongst Chinese provinces. This analysis has been widely used to examine whether sets of adjacent areas share or consistently diverge in certain characteristics. It uses global and local measures of spatial autocorrelation.

The global spatial autocorrelation, commonly referred to as Moran's I index, was used by us to test whether there is spatial autocorrelation at the national level. The index can be expressed as:

$$I = \frac{\sum_{i=1}^{n} \sum_{j=1}^{n} w_{ij}(z_i - \overline{z})(z_j - \overline{z})}{S^2 \sum_{i=1}^{n} \sum_{j=1}^{n} w_{ij}} \tag{8}$$

$$S^2 = \frac{1}{n}\sum_{i=1}^{n}(z_i - \overline{z}) \tag{9}$$

$$\overline{z} = \frac{1}{n}\sum_{i=1}^{n} z_i \tag{10}$$

Where n refers to total numbers of regions in the analysis, z_i and z_j refers to the attribute value of regions i and j, respectively, $\overline{z}$ refers to the average attribute value across all regions, S^2 refers to the variance, and w_{ij} refers to the space weight matrix that is calculated by the reciprocal of the shortest achievable distance between regions i and j.

We then also calculated the local spatial autocorrelation, referred to as Local Moran's I Spatial Autocorrelation (LISA), to identify local cluster effects. LISA can be calculated as:

$$LISA = \frac{(z_i - \overline{z})\sum_{i \neq j}^{n} w_{ij}(z_j - \overline{z})}{S^2} \tag{11}$$

3. Results and discussion

3.1 Links between changes in the 'urban population' and 'urban land' systems

3.1.1 National level-trends

Overall, the degree of coupling between changes in the urban population- and urban land-related systems increased steadily between 1996-2010 before briefly plateauing and showing a downward trend post-2011. In contrast, the degree of coordination, and the difference between these two systems, showed a consistent upward trend for the entire study period (Fig.2).

More specifically, the degree of coupling increased from around 0.6 in 1996 to 0.999 in 2011, indicating a system shift from weak to extremely strong coupling. In the coupling curve, a particularly strong increase occurred between 1999 and 2007, with a short break in this trend in the period 2004-2005. After 2011, the coupling curve dropped back slowly to 0.946 in 2016. This implies a very gradual de-coupling between the population-related and area-related urbanization systems.

The degree of coordination increased from 0.28 in 1996 to 0.60 in 2016, indicating that China's urbanization experienced a shift from seriously unbalanced to moderately balanced developments. During 1996-1998, the coordination degree remained below 0.3, implying a serious maladjustment in the relationship between population- and land-related urbanization factors. During 1999-2008, the coordination degree value increased gradually to values between 0.3 and 0.5, reflecting a slightly unbalanced relationship. In 2009, the coordination degree then began to exceed 0.5, indicating the relationship between systems combining population- and land-related urbanization factors, respectively, became slightly coordinated, with the degree of coordination steadily further increasing since that year.

Between 1996 and 2006, the difference of changes between the population-related urbanization system and the land-related urbanization system stayed below -0.1, implying that factors indicating changes in the urban population lagged behind factors describing changes in urban area. During 2007-2012, the difference ranged between -0.1 and 0.1, indicative of a near-parallel development of the two systems. From 2013 onwards, the difference remained above 0.1 with changes in factors indicative of developments in urban populations and quality of life exceeding the changes of the system describing land-related urbanization trends.

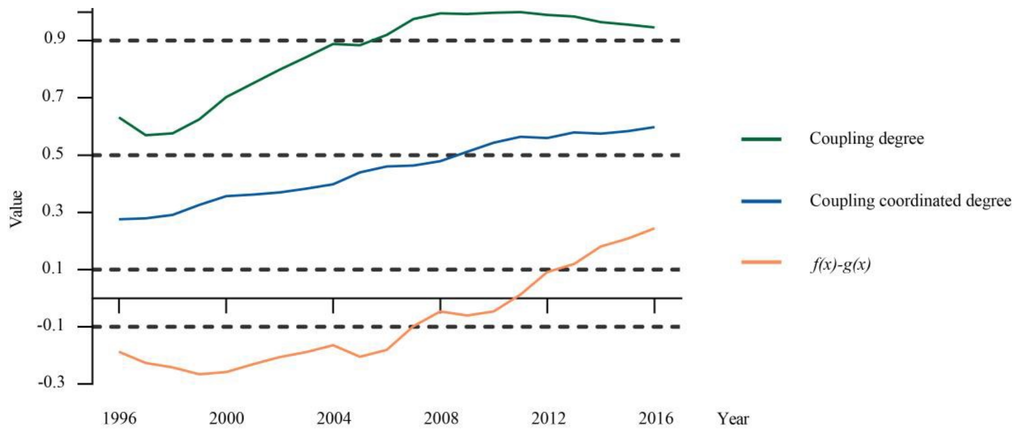

Fig.2. The coupling degree and coupling coordination degree at the national level between 1996 and 2016. The green line designates the degree of coupling, while the blue line designates the degree of coordination between the system changes in population- and land-related factor systems. f(x) and g(x) designate the population-related and land-related urbanization systems, respectively, with f(x)-g(x) referring to the difference in the speed of change between the two systems.

3.1.2 Provincial level-trends

In 2006, the degree of coupling between the two systems was >0.6 in all 31 provinces and autonomous regions (hereafter "provinces), with Guangdong Province achieving the minimum value of 0.67 (Fig.3). At this time, eastern and central provinces showed a smaller degree of coupling than northern and western provinces. In 2011, the degree of coupling in all provinces exceeded 0.95, indicating an extremely close relationship between changes in the population-related urbanization system and the land-related urbanization system. From 2011 to 2016, all provinces showed a downward trend in the degree of coupling, although, reflecting the picture at the national level, the rate of decrease was generally low. Some eastern provinces nonetheless were exceptions to this observation, showing a higher rate of change in the coupling than central and western provinces, with Liaoning Province reaching a minimum value of only 0.5 in 2016.

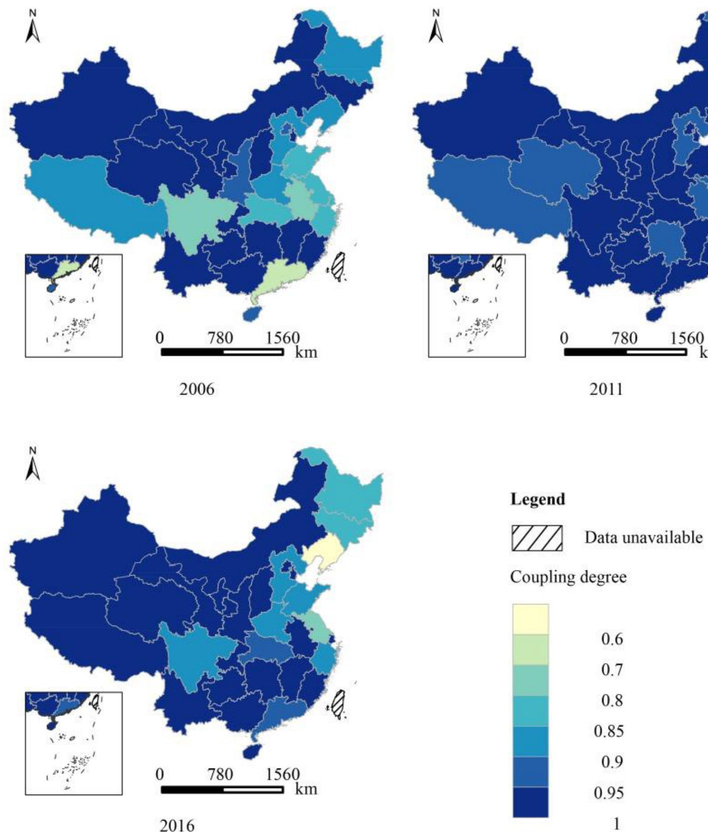

Fig.3. The degree of coupling between the population-related and land/area-related urbanization systems for 31 provinces of China in 2006, 2011 and 2016. (Data for Hong Kong Special Administrative Region, Macao Special Administrative Region and Taiwan are excluded)

The coordination degree changed significantly between 2006 and 2016, with changes particularly pronounced in western provinces (Fig.4). In 2006, the degree of coordination in the urban development systems of all 31 provinces was <0.5, with eastern provinces in general showing a higher degree of coordination compared to both central and western provinces. In contrast, the two systems showed a higher degree of coordination in most of the western provinces than in China’s central and eastern provinces by 2011. Post 2011 up to 2016, the western provinces also showed the greatest additional growth in the degree of coordination between the changes in the population-related and land-related urbanization systems, followed by the central provinces and eastern provinces, respectively. However, the degree of coordination decreased in China’s most north-eastern regions, namely in Liaoning, Jilin, and Heilongjiang Provinces, with Liaoning Province experiencing a shift from a moderately balanced to a slightly unbalanced state, with the coordination degree dropping sharply from 0.53 to 0.34.

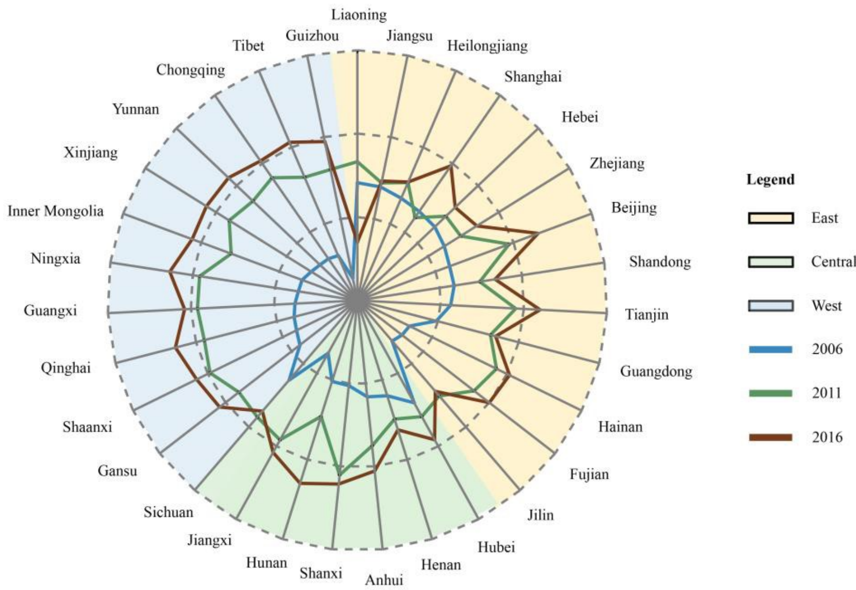

Fig.4. The degree of coordination between the systems describing population-related and land-related changes in urbanization at 31 Chinese provinces – provinces in each geographic region are presented in order of highest-lowest degree of coordination in 2006.

3.2 Inherent spatial patterns in the degree of coupling coordination between the two study systems

3.2.1 Global trends

The Global Moran's I index showed that the degree of coupling coordination in the population-related and land-related urbanization systems showed a positive spatial autocorrelation (Fig.5a). Global Moran's I value was >0, and Monte Carlo permutations showed that trends were statistically significant in all three core study years (p_{2006}=0.021, p_{2011}=0.041, p_{2016}=0.023). This indicates that provinces with a high degree of coordination tended to be located close to other provinces also showing a high degree of coordination, leading to spatial clusters of provinces showing similar trends, with the strength of this clustering decreasing from 2006 to 2011, but increasing again in 2016.

The scatter plots reflecting these relationships (Fig.5a) can be split into 4 quadrants: a high-high (HH) region, a low-low (LL) region, a high-low (HL) region and a low-high (LH) region. The HH region contains provinces with a high degree of coupling coordination surrounded by provinces also showing a high degree of coupling coordination. The LL region contains provinces with a low degree of coupling coordination surrounded by provinces also having a low degree of coupling coordination. In the HL and LH regions, we find provinces with a high degree of coupling coordination surrounded adjacent provinces with a low degree of coupling coordination (HL) and vice versa (LH). Most provinces fell into the HH and LL regions in all three target years (2006, 2011, 2016), affirming the aforementioned clustering of provinces with similar degrees of coordination.

3.2.2 Local trends

An analysis of Local Moran's I Spatial Autocorrelation (LISA) can provide further insights into the evolution of the degree of coordination in the 31 study provinces (Fig.5b). In this context, HH regions were denoted as "hotspot" areas (deep red areas) and LL regions as "cold-spot" areas (deep blue areas) (Fig.5b). During 2006-2016, the hotspot areas shifted from the east to the west. In 2006, hotspot areas included Shanghai as well as Hebei, Henan, Shandong, Jiangsu and Anhui Provinces, indicating a large cluster along China's Eastern shores of relatively high coordination degree. In contrast, Guangxi formed the center of the cold-spot area, indicating that this province and its neighbors were characterized by a low degree of coordination between the two urbanization systems. Sichuan Province finally represents a significant HL scenario, implying a province with highly coordinated systems surrounded by its neighboring western provinces showing consistently low degrees of coordination. In 2011, Gansu Province became the center of a hotspot area, indicating that the degree of coordination had increased in many western provinces. In contrast, Shanghai now became the center of a cold-spot areas, implying that the degree of coordination was not increasing any more in many eastern provinces. Anhui Province now replaced Sichuan as representing an HL area. By 2016, Gansu Province had remained the center of a hotspot area, while Sichuan Province had become an LH region, indicating a high degree of coordination in its neighboring Western provinces. Jilin Province was now in the center of a cold-spot area, reflecting its sharp decrease in the degree of coordination, and the similar, albeit not as pronounced, trend in its neighboring Northeastern Provinces.

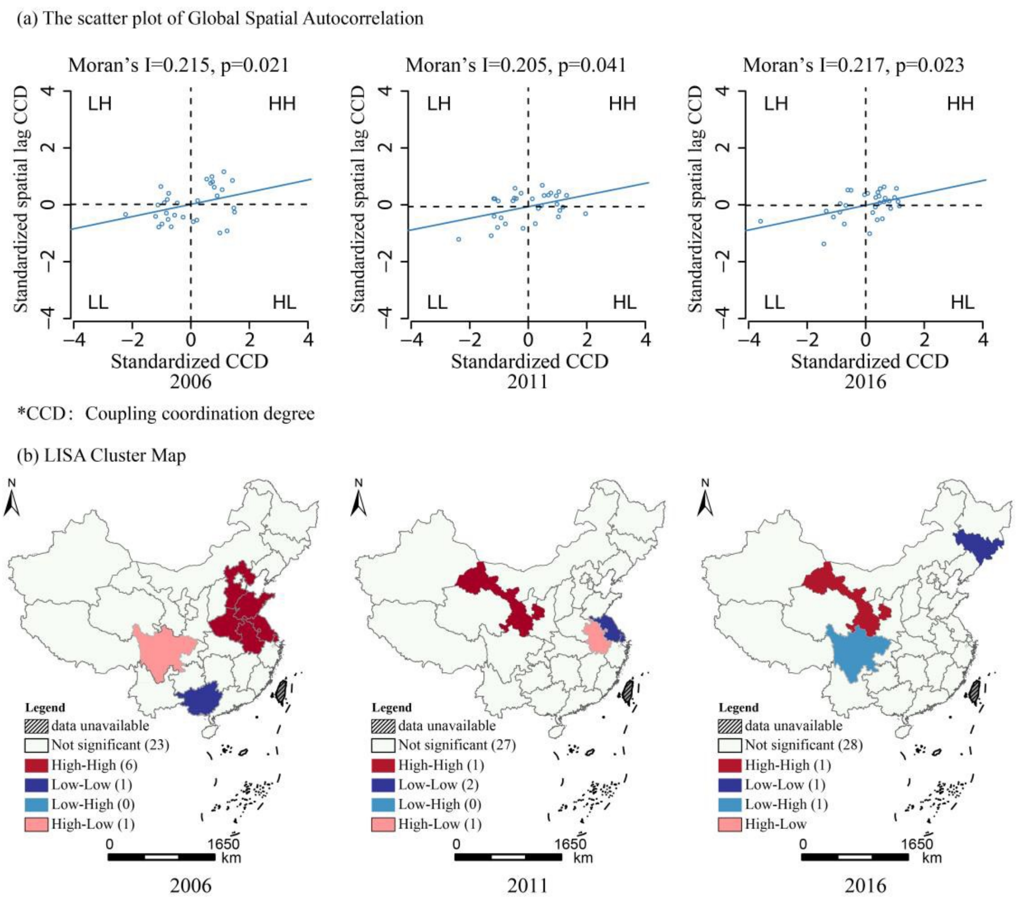

Fig.5. Spatial statistic measurement of the degree of coupling coordination between the two urbanization systems: (a) scatter plot of Global Spatial Autocorrelation. (b) LISA Cluster Map.

4. Discussion

In line with the first hypothesis, population-related urbanization and land-related urbanization have shown a tendency to decouple from 2011 onwards, although the overall degree of coupling remained very high when compared to the early years of our study period in the mid- late 1990s.

After the implementation of the Tax-Sharing Reform in 1994, tax revenue transferred from local government to the central government increased, with a widening gap between revenue and expenditure for local governments. Due to this trend, municipal governments turned to 'land financing' to obtain revenue. Specifically, local governments used profits from transferring land use-right to balance their budgets (Xu, 2019). This led to a very rapid expansion of urban areas lasting for more than a decade and severely impacted the level of change in the land-related urbanization system. The Western Development Strategy in 2001, aimed at reducing regional disparities between eastern and western regions of China, then introduced a great number of industrial enterprises in Western provinces that in turn attracted a large workforce to earn a living within the urban centers of this region (Yang et al., 2018). The resulting rural-urban migration was accompanied by a very rapid transformation of land into urban areas. This rapid transformation even outpaced population trends and hence hindered a stronger coordination in the changes experienced by the two urbanization systems. Furthermore, an increasing number of people chose to have a second house or large apartment in urban fringe areas where property values commonly remain distinctly lower than in urban centers. This trend represented a great investment opportunity for property developers, further fueling rapid urban land expansions. However, in 2004, the central government issued the 'Linking the Increase in Land Used for Urban Construction with the Decrease in Land Used for Rural Construction' policy (hereinafter simply 'Linking Policy') stipulating that the size of urban land expansion shall be linked to land reclamations in rural areas (Ma et al., 2019). This was the first time that land financing became somewhat restricted (Mo, 2018). In 2007, the announcement of the 'Regulation of The Land Bank System' was aimed to further hinder excessive development of land financing by strictly supervising the transfer of land-use right, rather than leaving this transfer to private negotiations (Huang and Chan, 2018). These measures were aimed at preventing urban land from excessively expanding, while simultaneously increasing vegetation coverage in built-up areas to offset some of the negative impacts of the previous excessive urban land expansion on urban environments (Cheng and Li, 2019). Overall, these legislative measures can in our view explain the strong overall increase in the degree of coupling coordination between the systems describing life quality of urban population and urban planning – arguably a sign that systems shifted more towards a higher degree of sustainability in urban expansions.

Overall, China's urbanization can be said to have experienced three distinct stages in urbanization that are reflected in the degree of coupling coordination between 1996 and 2016: a first phase of seriously unbalanced development (1996-1998), followed by slightly unbalanced development (1999-2008), and finally a slightly balanced development (2009-2016). As already briefly outlined above, China started to step into a 'land-centered' urbanization in 1996, with the pursuit of economic development as the primary, all-important goal for the nation. The surging land financing and disregard for the quality of life for its average citizen resulted in a heavy maladjustment between the population-related and land-related urbanization systems (Ruibo and Linna, 2013), causing the observed imbalance in China's urban development. During 1999-2007, the official GDP growth rate rose from 7.7% to a staggering 14.2% (CSP, 2020), accompanied by a rapidly increasing level of the urban populations, increasingly aligning the population-related measures of change with the measures reflecting the massive urban sprawl observed across the country. Throughout this time China's urbanization, measured by the alignment of the two systems, continued to become increasingly coordinated, with a coordination degree >0.5 since 2008, even when the country was faced with the global financial crisis 2008-2009 and an economic transformation towards high-quality production that replaced high-speed mass-production. The levels of the population-related urbanization system were chiefly increased due to an increase in both the overall urban population and the coverage of this population by basic pension insurance schemes. On the other hand, an increase in vegetation coverage within built-up urban areas has further contributed to the leveling between trends in the population and land-related urbanization systems.

The trend in an increased coordination development between population- and land-related urbanization revealed by our results is in line with the conclusions made by Lu and Ke (2018) (Lu and Ke, 2018). Similar to their observations, the smooth implementation of aforementioned land policies facilitated a sustainable urbanization via changing the pattern of economic growth that led to a rise in the social welfare. Moreover, Sun et al (2013) (Sun et al., 2013) also revealed that economic transition to development quality-oriented from development speed-oriented contributed to a continuously growing degree of coupling coordination of population- and land-related system, again conforming to what we have previously discussed -- people's life quality would impact positively on society's coordinated development.

The LISA-based results provide further important insights into the spatial differentiation of these developments across China. Provinces with high degrees of coupling coordination gradually shifted from East to West China in the study period, in line with the observations made by Zang and Su (2019) (Zang and Su, 2019), who held the opinion that economic strategies in various periods were the main reasons for that phenomenon. With an ideal coastal location for economic activities and preferential policies, the eastern provinces initially formed China's center of wealth accumulation, also reflected in a better city infrastructure, resulting in a greater degree of coupling coordination in urbanization trends over central and western provinces prior to 2010. Nevertheless, with the strengthening of the Western Development Strategy and the Rise in Central China Strategy, a vast amount of people, chiefly representing the majority Han population, flocked to China's central and western regions, where new urban areas were developed under the framework of the 'New-type' Urbanization Program promoted by the 12^{th} and 13^{th} Five-Year-Plans that set detailed targets for city infrastructure, resources and environments, and prohibited blind exploitation of land located at the urban fringes (Zang and Su, 2019). In combination, these policies and plans increased both changes in population-related and land-related urbanization systems. For the eastern provinces, on the one hand, sluggish urban population growth resulting from a tightening of the 'hukou' system caused a slow change in factors linked to the population-related urbanization system in subsequent years (Chen et al., 2018). On the other hand, the growth of vegetation cover in those regions did not keep up with the growth of newly-planned built-up areas (Liu et al., 2019), putting a drag on the levels of the land-related urbanization system. For the western provinces, the newly arriving sections of the population were allowed to easily obtain local urban hukou that granted them access to public services (Wu and Zhang, 2018), which in turn caused the growth in the levels of the population-related system in western provinces to exceed that in the eastern provinces. Moreover, since the 12^{th} Five-Year-Plan, some abandoned factories in western provinces have been turned into green production-oriented facilities, in turn avoiding the excessive land expansion by utilizing already established infrastructure (Hong et al., 2013), leading to an increasing level of land-related urbanization.

During the implementation of aforementioned national strategies, the central government also focused on the access to education of migrant children especially in western provinces, attracting more people to reside in those regions due to the increasing social equity (Chen et al., 2018). Besides, the surge in the establishment of hospital and medical institutes in central and western China provided residents with high-quality medical treatments (Liu et al., 2017), further enhancing the urbanization quality. Therefore, these measures eventually led to a high degree of coupling coordination in urbanization development in western provinces and narrowed the development gap among three subregions of China.

5. Conclusions

Our results reflect recent increases in aspects describing the quality of life for China's urban population – increasing per-capita disposable income, percentage cover of basic pension insurance schemes and the vegetation cover in urban areas. These changes are strongly reflected in the rapid increase in population-based urbanization system values we report. We therefore conclude that China's urbanization is becoming more sustainable than during previous 'revival' and 'transition' urbanization phases, reflecting the shift of focus from an excessive expansion of urban land (Supplementary information, Fig. S1) to urbanization quality, linked to the implementation of land policies and national strategies aiming at a more balanced development across the provinces of eastern, central and western China. Moreover, western provinces are experiencing a higher sustainable urbanization than eastern provinces, with a greener urban planning and a great promotion in social welfare including infrastructure, education, medical treatment, etc.

While it appears from our analysis that China's urbanization is indeed becoming more sustainable in that urban sprawl is slowing and cities are slowly greening, coupled with the aforementioned increase in measures for the urban quality of life, there are still massive challenges to this process that we were unable to also consider in our analysis. Urban centers are often characterized by particularly high levels of local pollution due to the immense local urban traffic volumes, while the reliable access to fresh water and basic medical insurance schemes are also key parts of the urban quality of life where we believe substantial work remains. Nonetheless, we show that some aspects of urban life are clearly improving, and that the rapid past expansions of China's urban center appear to be slowing. Particularly in the already extremely densely populated areas of Eastern China that also contain large areas of valuable agricultural land, this tendency is extremely welcome and requires strong future nurturing.

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